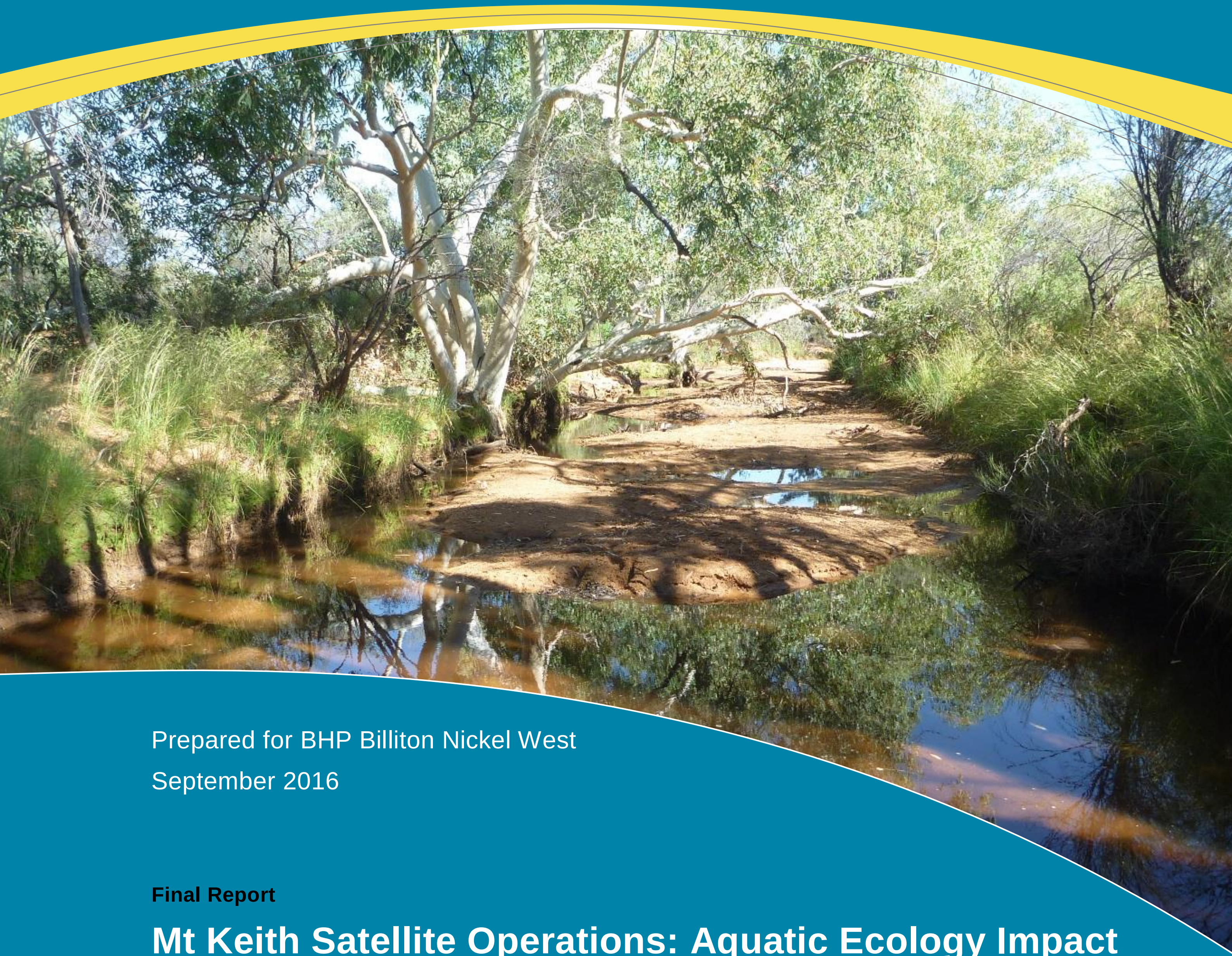
MWH

BUILDING A BETTER WORLD



Prepared for BHP Billiton Nickel West

September 2016

Final Report

Mt Keith Satellite Operations: Aquatic Ecology Impact Assessment

QUALITY STATEMENT

PROJECT MANAGER

Brooke Hay

PROJECT TECHNICAL LEAD

Dr Fiona Taukulis

PREPARED BY

Dr Fiona Taukulis

CHECKED BY

Dr Fiona Taukulis

REVIEWED BY

Kylie McKay (BHP Billiton Nickel West)

Dr David Jasper

APPROVED FOR ISSUE BY

Dr David Jasper

PERTH
41 Bishop Street, Jolimont , WA 6014
TEL +61 (08) 9388 8799, FAX : +61 (08) 9388 8633

Revision Schedule

Rev No	Date	Description	Signature or Typed Name (documentation on file).			
			Prepared by	Checked by	Reviewed by	Approved by
v1.0	13/07/16	Draft Report	Dr Fiona Taukulis			
V2.0	20/07/16	Revised Draft	Dr Fiona Taukulis		Kylie McKay	
V3.0	22/09/16	Final Report	Dr Fiona Taukulis			Dr David Jasper

Executive Summary

BHP Billiton Nickel West (Nickel West) is proposing to develop the Mt Keith Satellite Operations (MKSO Project), located approximately 25 km south of Mt Keith, in the Northern Goldfields region of Western Australia. The MKSO Project will include two open pits, a waste landform, run of mine (ROM) pad and associated mining and transport infrastructure. MWH Australia Pty Ltd (formerly Outback Ecology) was commissioned to undertake an aquatic ecology impact assessment of Jones Creek and the associated southwest terminal claypans, in relation to the MKSO Project. The impact assessment comprised the following components;

- database searches, to identify the potential likelihood of conservation significant communities or species;
- a literature review of all existing aquatic surveys completed in the vicinity of the MKSO Project, including a summary of methodology, key findings, species recorded and conservation status;
- an aquatic baseline study (this study), completed on Jones Creek and the claypans in 2011 (Outback Ecology 2012), investigating the diversity of aquatic biota and ecological values; and
- an impact assessment, relating to the ecological values of Jones Creek and the claypans, which may be used to inform future environmental approvals for the MKSO Project.

Previous aquatic ecology studies of Jones Creek were completed in 1992 and 2005, focussing on the aquatic invertebrate assemblage from a limited number of sites. In 2011, Outback Ecology employed a more comprehensive two phase approach to the aquatic baseline study, with field surveys undertaken in March and April 2011, following a major flood event. A total of 10 sites were established; six in Jones Creek and four in the terminal claypans, from which a range of ecological components were assessed, including for the first time planktonic and periphytic algae (primary producers). A summary of the key habitat characteristics is provided in **Table E1**, and a summary of the aquatic biota recorded during this study is presented in **Table E2**.

Table E1: Summary of habitat characteristics of Jones Creek and the claypans.

Waterbody	Residence Time	Water Clarity	Substrate Type	Water Quality	Riparian Vegetation
Jones Creek	<2 months	Clear	Coarse sands and pebbles, highly permeable	Freshwater, circumneutral to alkaline, low nutrients and metals	Highly degraded, understorey of grasses and sedges, overstorey of *Eucalyptus*
Claypan	>2 months	Turbid	Fine clays, overlying impervious layer	Freshwater, circumneutral, elevated nutrients and some metals	Highly degraded, understorey of grasses and herbs, overstorey of *Melaleuca* and *Acacia*

Table E2: Summary of diversity of aquatic biota recorded from Jones Creek and the claypans.

Biota	Jones Creek	Claypan	Total Taxa	General Distribution	Reproductive Strategies
Phytoplankton	26	22	33	Cosmopolitan	Desiccation resistant spores
Diatoms	21	32	35	Cosmopolitan	Desiccation resistant spores
Aquatic Invertebrates	93	90	132	Western Australia or Australia-wide*	Mobile adult stages or desiccation resistant eggs
Frogs	4	2	4	Australia-wide	Mobile adult stages

** with the exception of new taxa.*

Jones Creek and the claypans provide an important freshwater refugia within an arid environment. The 2011 study showed that the abiotic environment was governed by hydrological, geomorphological and biogeochemical factors, which strongly influenced the aquatic biota. Planktonic algae were more abundant and diverse in the clear pools of the creek, while periphytic diatoms dominated the claypans, due to the high turbidity. Opportunistic, transient insect groups were a characteristic of the invertebrate fauna assemblage of Jones Creek, and were associated with habitat availability and the limited residence time of surface water pools. In contrast, resident crustacean fauna were a feature of the claypans, due to the longer hydroperiod. Vertebrate fauna were limited to frogs, with most species occurring along the length of the creekline and into the claypans. The majority of organisms identified during this study were found to have a broader, cosmopolitan distribution throughout Western Australian and Australian inland waters.

Several threatening processes and potential impacts to the aquatic ecology of Jones Creek and the claypans were identified, although the overall risk was predominantly classified as *minor* (**Table E4**). This was due to the nature of the potential impacts, considered unlikely to occur, or occurring on a localised and/or temporary scale, as well as the extensive and comparable aquatic habitat available throughout the area. There were no communities or species of conservation significance found during the database searches, of relevance to aquatic ecosystems. In addition, the MKSO Project poses a *negligible* risk to the two new, verified aquatic invertebrate taxa recorded in this and previous studies (the rotifer *Cephalodella* sp. nov. and the clam shrimp *Eocyzicus* sp. OES 1), as they are unlikely to have a restricted distribution (**Table E3**), or be impacted by mining operations. It is expected that appropriate management and monitoring protocols will be implemented during the construction and operational phases of the MKSO Project, to prevent and detect potential impacts on the aquatic ecology of Jones Creek and the claypans.

Table E3: Verified new aquatic invertebrate taxa recorded from Jones Creek and the claypans.

Taxon Group	New Taxa	Location and Site Records	Dist. Downstream of MKSO Project	Risk and Justification
Rotifera (rotifer)	**Cephalodella* sp. nov.	Jones Creek (1 site)	200m (adjacent to 6 Mile Well Pit)	**Negligible** - unlikely to be impacted or restricted to the creek, due to the extent and availability of comparable habitat
Spinicaudata (clam shrimp)	***Eocyzicus* sp. OES1	Claypans (4 sites)	15km	**Negligible** – unlikely to be impacted or restricted to the claypans, due to the extent and availability of comparable habitat.

** identified by Wetland Research and Management (2005).*
*** identified by Outback Ecology (2012).*
Negligible: No impact expected on taxon.

Table E4: Summary of threatening processes and potential impacts to Jones Creek and the claypans associated with the MKSO Project.

	Threatening Process	Habitat Affected	Likelihood of Occurrence	Potential Impacts	Management / Mitigation	Risk and Justification
Direct	Disturbance (from creek crossings)	Jones Creek	Certain	- temporary loss or shift in aquatic habitat	- appropriate engineering design, construction and operation protocols - monitoring to include abiotic and biotic components	**Minor** – localised temporary impact, extensive comparable habitat remaining in creek.
Direct	Light and Vibration (from mining operations)	Jones Creek	Certain	- none (no available studies on impacts)	- 100 m creek exclusion zone - monitoring to include abiotic and biotic components	**Negligible** – not expected to have any impacts on the creek, attributed to limited frequency of flood events.
Indirect	Sedimentation (from MKSO Project features and creek crossings)	Jones Creek and Claypans	Possible	- reduced water quality - smothering of benthic communities	- appropriate engineering design, construction and operation protocols - 100 m creek exclusion zone - monitoring to include abiotic and biotic components	**Minor** – most common creek flow event once a year, with only short sections of the creek crossings affected and extensive creek and claypan habitat available.
Indirect	Changes to Surface Hydrology (from mining pits and creek crossings)	Jones Creek and Claypans	Certain	- reduced water levels and hydroperiod in southwest claypan - shift in the composition of aquatic biota	- monitoring to include abiotic and biotic components	**Minor** – minor decrease in catchment yield, negated by increase in baseline flow from historic land use practices, as well as highly adaptable nature of aquatic biota.
Indirect	Contamination (from orebody mineralogy or hydrocarbon spills)	Jones Creek and Claypans	Unlikely	- reduced water and sediment quality - toxic (lethal or sublethal effects) on aquatic biota	- appropriate engineering design, construction and operation protocols - 100 m creek exclusion zone - dilution of contaminants following major rainfall events - monitoring to include abiotic and biotic components	**Minor** – concentrations of nickel sulphide ore are expected to be low, and metals are unlikely to impact on aquatic biota, related to hydrogeochemical processes.

Minor: impact on a localised and/or temporary scale, with no irreversible damage to the aquatic ecosystem expected.
Negligible: No impact expected to aquatic ecosystem.

BHP Billiton Nickel West

Mt Keith Satellite Operations: Aquatic Ecology Impact Assessment

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1 Introduction

1.1 MKSO Project Location and Description

BHP Billiton Nickel West (Nickel West) commissioned MWH Australia Pty Ltd (MWH; formerly Outback Ecology) to undertake an aquatic ecology impact assessment for the proposed Mt Keith Satellite Operations (MKSO Project). The MKSO Project is located approximately five kilometres (km) east of the Goldfields Highway, and 25 km south of the existing Mt Keith Nickel Operation in the Northern Goldfields region of Western Australia (WA) (**Figure 1-1**). The MKSO Project is situated on the Yakabindie and Mt Keith pastoral leases and is immediately west of the Wanjarri Nature Reserve.

The MKSO Project comprises two open cut pits; Six Mile Well and Goliath (satellite mines), a run of mine pad (ROM) and waste rock facility. There is also a transport corridor that extends approximately 20 km north from the MKSO Project to the Mt Keith Nickel Operation, where nickel ore will be processed. In addition, two creek crossings will be constructed across Jones Creek; one associated with the ROM and another that bisects the MKSO Project area (**Figure 1-2**).

Jones Creek is a temporary, freshwater system, the terminus of which is a large floodplain, characterised by several claypans (**Figure 1-3**), and located approximately 10 km southwest of the Goldfields Highway. Creeks and wetlands are recognised as important and diverse habitats, which potentially support restricted and/or conservation significant species, protected under state and federal legislation; *Wildlife Conservation Act 1950* and *Environmental Protection Act 1986* (WA) and *Environment Protection and Biodiversity Conservation Act 1999* (Cwth), respectively. Nickel West is committed to protecting the ecological values of Jones Creek and the southwest claypans.

For the purpose of the aquatic ecology impact assessment, two broad habitats (study area) have been evaluated (**Figure 1-3**);

- Jones Creek: comprising creek habitat extending downstream of the MKSO Project area; and
- Claypans: comprising the southwest terminal floodplain area and associated claypans.

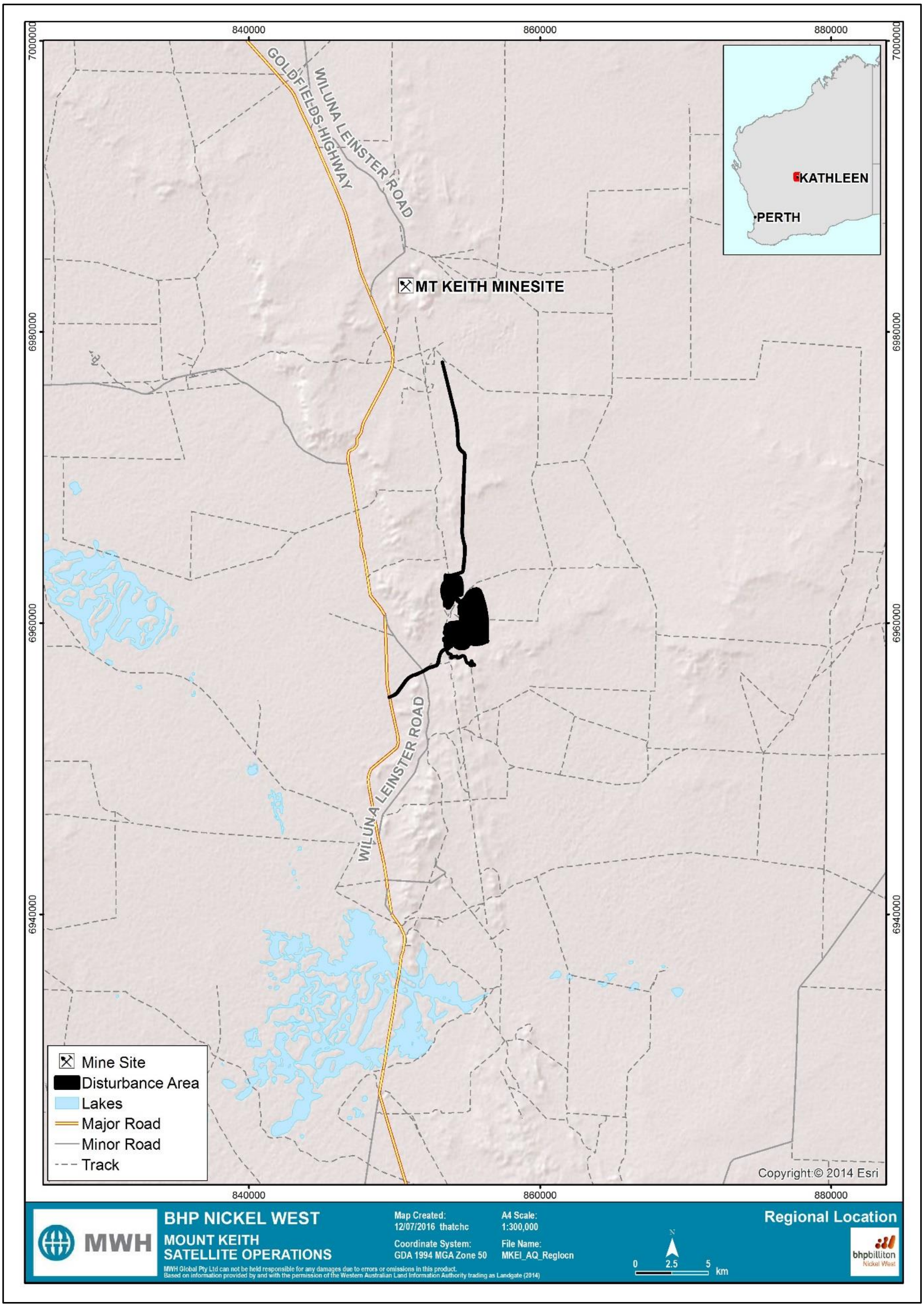


Figure 1-1: Regional location of the MKSO Project, in the Northern Goldfields of Western Australia.

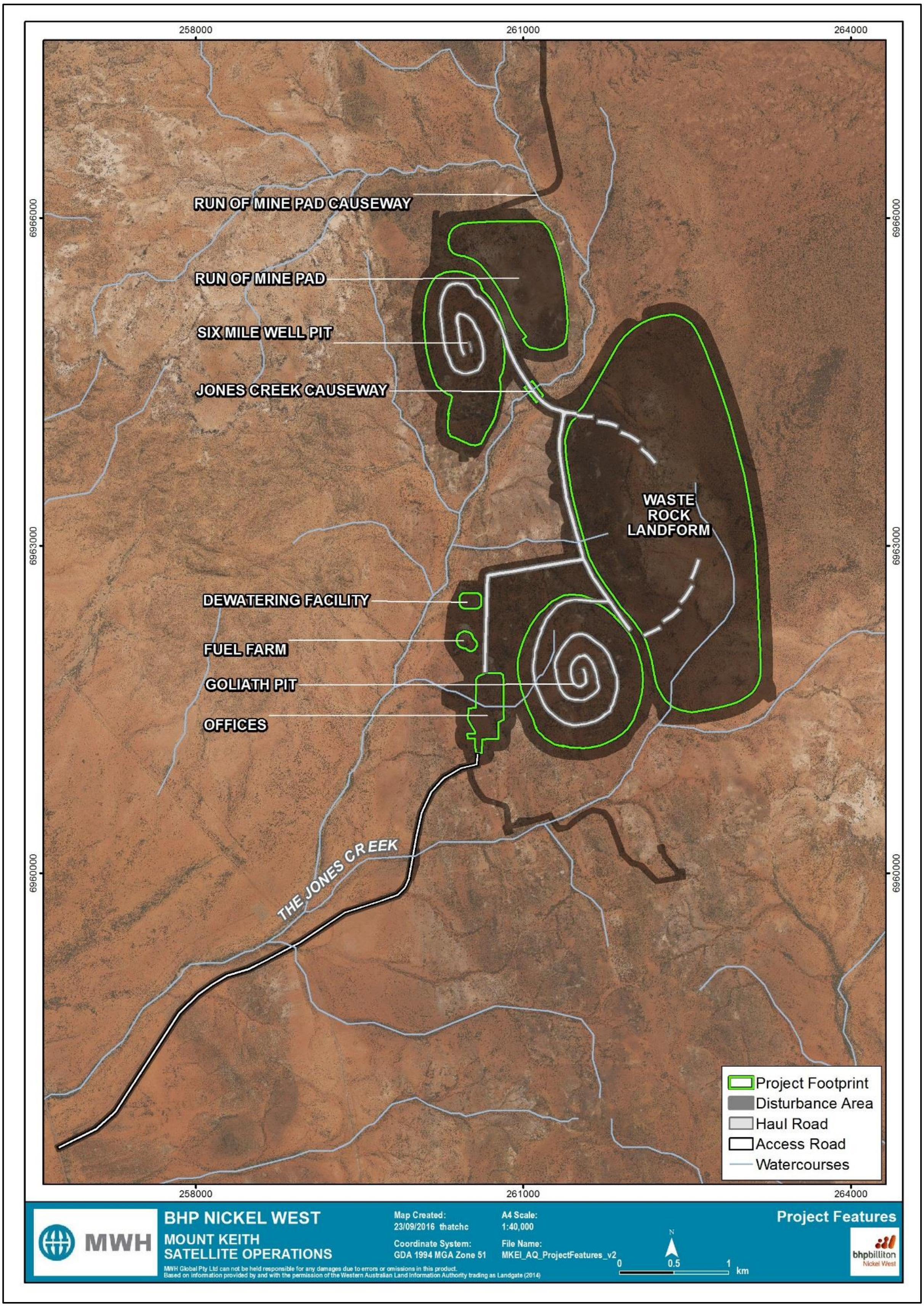


Figure 1-2: MKSO Project and associated features, in relation to Jones Creek.

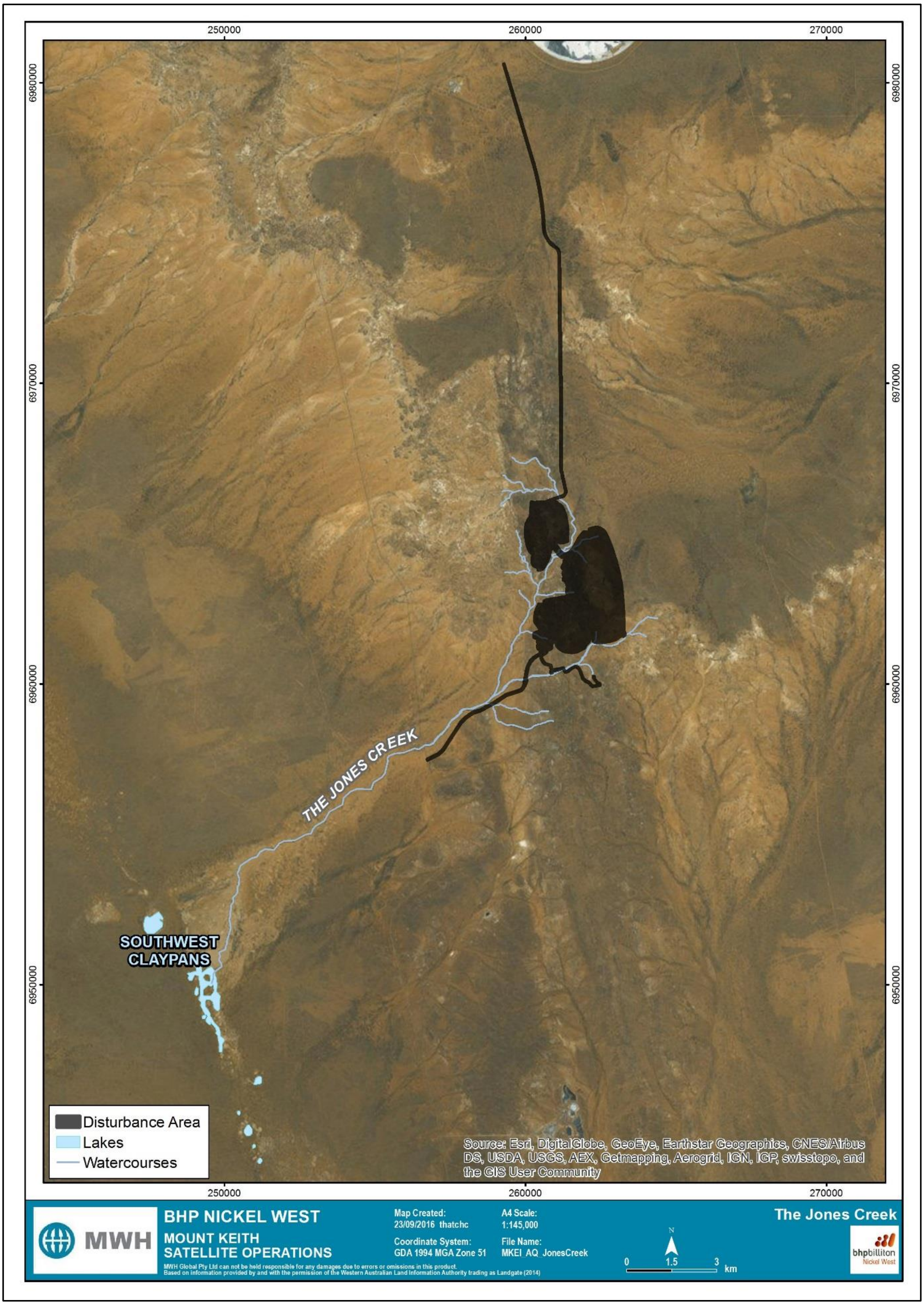


Figure 1-3: MKSO Project, indicating the extent of Jones Creek and claypans.

1.2 Assessment Scope and Objectives

The overarching objective was to undertake an aquatic ecology impact assessment of Jones Creek and the associated southwest terminal claypans, in relation to the MKSO Project. The assessment comprised the following components;

- database searches, to identify the potential likelihood of conservation significant communities or species;
- a literature review of all existing aquatic surveys completed in the vicinity of the MKSO Project, including a summary of methodology, key findings, species recorded and conservation status;
- an aquatic baseline study (this study[1]) completed on Jones Creek and the claypans in 2011 (Outback Ecology 2012), investigating the diversity of aquatic biota and ecological values, considered the most recent and relevant study; and
- an impact assessment, relating to the ecological values of Jones Creek and the claypans, which may be used to inform future environmental approvals for the MKSO Project.

The methods adopted for this aquatic ecology impact assessment have been aligned with relevant regulatory guidelines and information, to demonstrate that potential impacts on the environment are acceptable, in order to conserve biological diversity and protect ecological integrity and include:

- Environmental Protection Authority (EPA). Position Statement No. 4 (2004). *Environmental Protection of Wetlands*.
- Environmental Protection Authority (EPA). Guidance Statement No. 55 (2003). *Implementing Best Practice in Proposals Submitted to the Environmental Impact Assessment Process*.

[1] *Considered the most recent and relevant aquatic baseline study, and therefore the focus of the impact assessment.*

2 Existing Environment

2.1 Biogeographic Region and Land Use

The MKSO Project is located within the Eastern Murchison subregion of the Murchison Bioregion (Department of Sustainability Environment Water Population and Communities 2010), which covers an area of 7,847,996 ha (**Figure 2-1**). This subregion comprises extensive areas of elevated red/red-brown desert sand plains with minimal dune development, breakaway complexes, and internal drainage and salt lake systems associated with the occluded palaeodrainage system. Mulga woodlands dominate the subregion, as well as hummock grasslands, saltbush and samphire shrublands (Cowan 2001). Halophytic shrublands, mainly comprising samphires such as *Tecticornia*, occur adjacent to the salt lake systems (Pringle et al. 1994).

The dominant land use (85%) within the Eastern Murchison subregion is grazing by sheep and cattle (Australian Natural Resources Atlas 2010; Cowan 2001) (**Figure 2-2**). Other land uses include Unallocated Crown Land (UCL), Crown reserves, and mining (predominantly gold and nickel mines). In 2001, less than 2% of the Eastern Murchison subregion was classified as conservation estate (Cowan 2001), however since then, a comprehensive land acquisition program has increased this figure to 8% (Department of Environment and Conservation 2010).

There is one environmentally sensitive area that lies adjacent to the western edge of the MKSO Project; the Wanjarri Nature Reserve, classified as an A Class Nature Reserve. The reserve includes the northern catchment of Jones Creek (**Figure 2-2**), and its high conservation values are related to the terrestrial landforms and habitats represented, which support several conservation significant terrestrial fauna species. There are also several threatened ecological communities (TECs) in the vicinity of the MKSO Project (**Figure 2-2**), primarily associated with calcretes that support significant stygofauna communities.

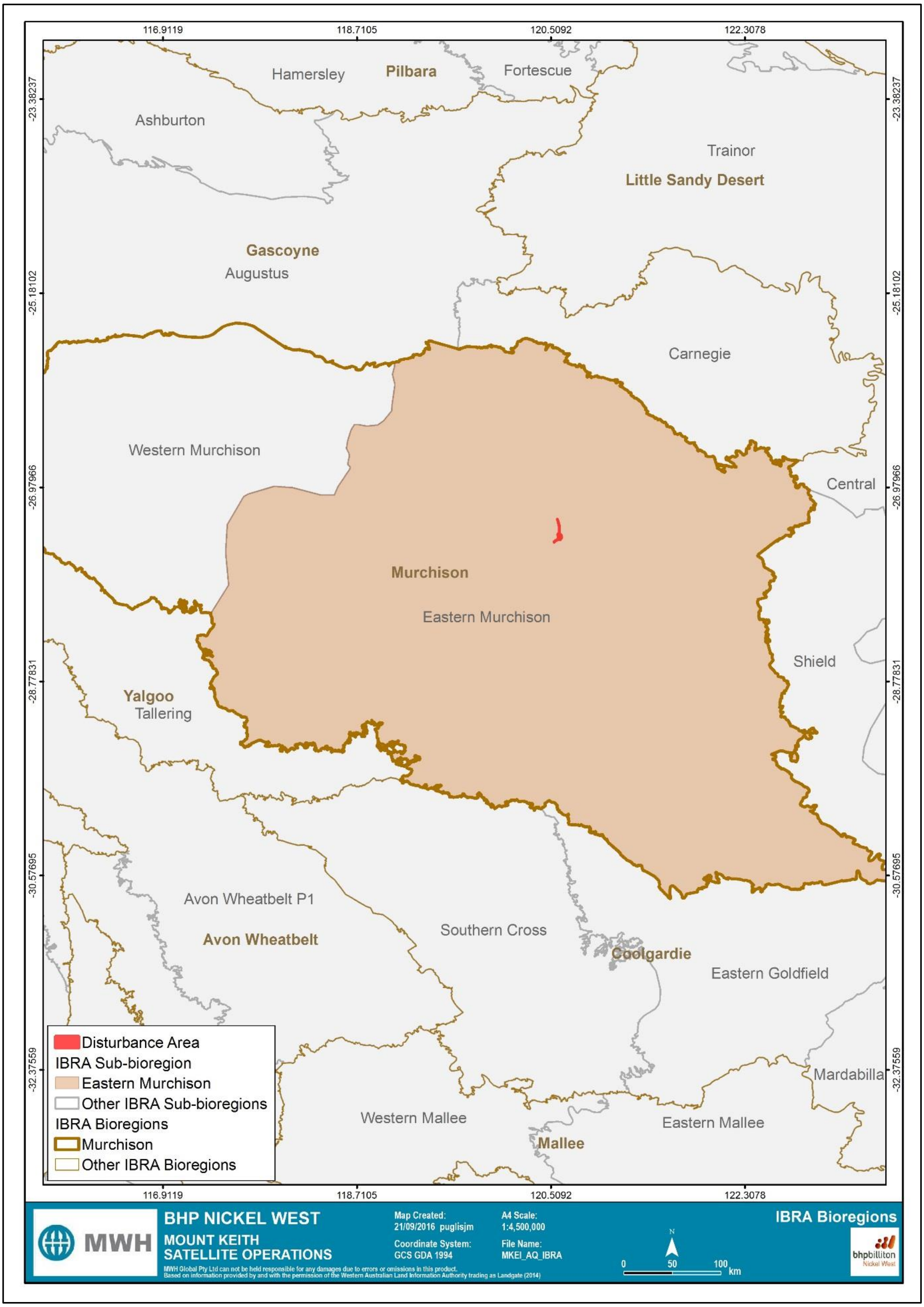


Figure 2-1: Location of the MKSO Project, in relation to the IBRA sub-bioregions.

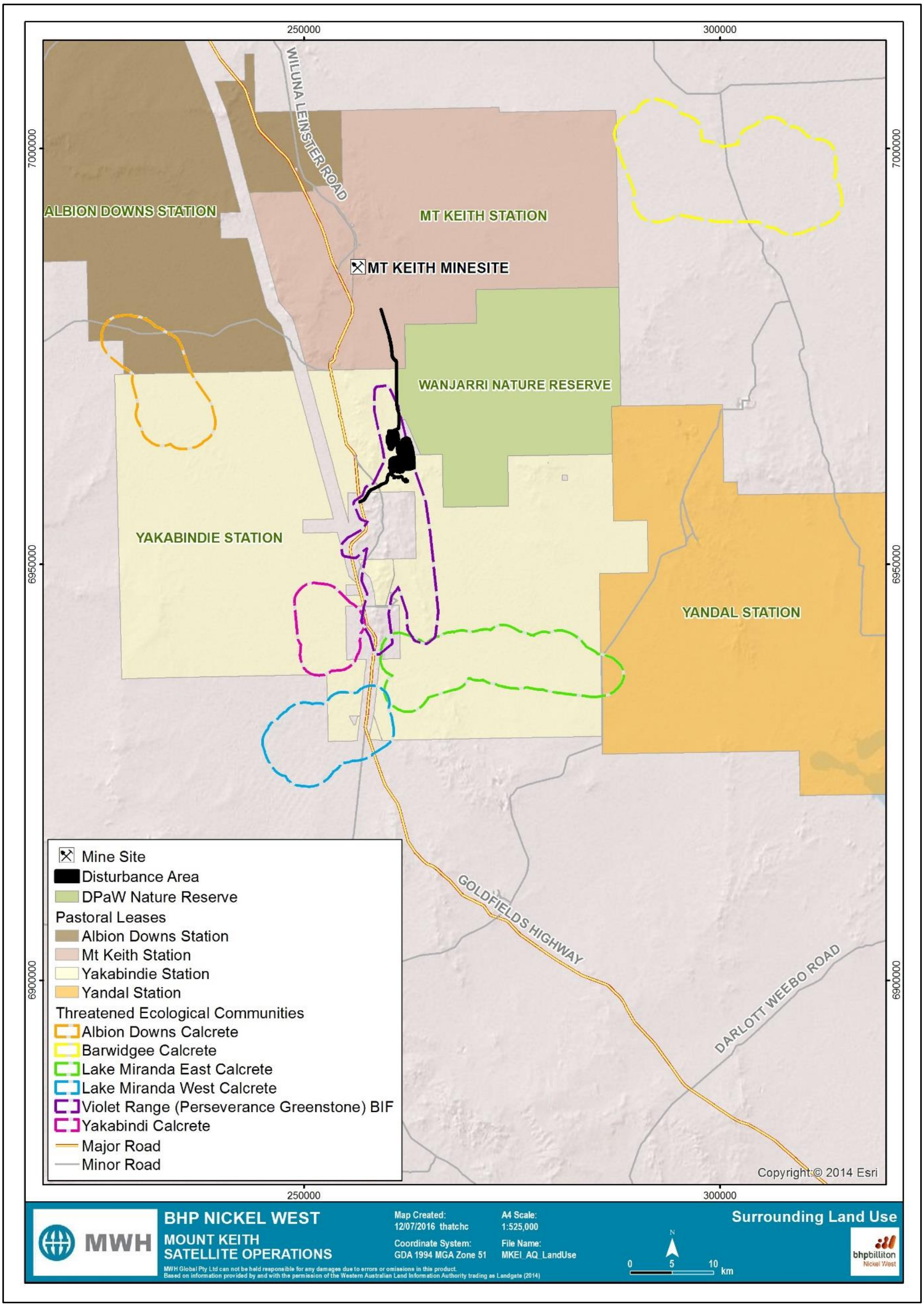


Figure 2-2: Land use in the vicinity of the MKSO Project, indicating nature reserves and threatened ecological communities (TECs).

2.2 Hydrology

Jones Creek is a lateral tributary system, incised into the Barr-Smith Range, where the majority of runoff is received from the upper catchment, which covers an area of 64.1 km^2. During large flood events water is rapidly shed from this part of the catchment into the creek, aided by the rocky nature of the terrain and sparse vegetative cover. The terminus for the creek is a large floodplain area to the southwest, containing a number of claypans (Berry 2011) (**Figure 2-3**). Beyond this, drainage becomes increasingly diffuse, before reaching Lake Miranda, located within the Carey Palaeodrainage System (Wetland Research and Management 2005).

Anecdotal evidence suggests that on average, Jones Creek flows once or twice a year, in response to moderate or high intensity rainfall of 25 mm or more. The morphology of the channel leads to high energy flows, with a velocity of up to 1.7 m per second. In the terminal claypans, depths of over two metres have been recorded following intensive rainfall. During large floods, the creek and associated claypans become connected, providing a mechanism for chemical and biological exchange (Berry 2011; Wetland Research and Management 2005).

Jones Creek is a freshwater system that, after flow events, rapidly dries to form a series of disconnected pools. Water is retained in the claypans for longer periods, supporting a predominantly freshwater ecosystem for several months or more (Berry 2011). The pools that form within Jones Creek, along with the claypans, provide an important refugia for aquatic biota within an arid landscape (Wetland Research and Management 2005).

2.3 Climate

The Murchison Bioregion is characterised as having an arid climate, with an annual rainfall of approximately 200 mm. Rainfall generally has a bimodal distribution, with low-pressure frontal systems originating from the south in winter, while summer rainfall is associated with local thunderstorms or tropical cyclone activity in the north (Beard 1990, Pringle et al. 1994). The limited rainfall received in the region coincides with high evaporation rates of approximately 2,400 mm per year (Beard 1976).

Yakabindie Station (station 12088) is the closest Bureau of Meteorology (BOM) rainfall station to the MKSO Project, and is located approximately 10 km south of the MKSO Project. Yakabindie has received a mean annual rainfall of 218 mm since 1961 (Bureau of Meteorology 2011). The nearest BOM station with temperature records is Yeelirrie Station (station 12090), situated 50 km northwest of the MKSO Project. Mean monthly temperatures recorded at Yeelirrie range from 19.3 °C in July to 38.0 °C in January (Bureau of Meteorology 2011). In the 12 months leading up to the 2011 aquatic baseline study, Yakabindie Station received more than twice the mean annual rainfall (440 mm), due predominantly to large, ex-tropical, low pressure systems, which moved through the area between December 2010 and February 2011 (**Figure 2-4**). Specifically in February 2011, the highest monthly rainfall total was recorded (>180 mm), which flooded Jones Creek and the claypans.

Figure 2-3: Surface hydrology features in the vicinity of the MKSO Project.

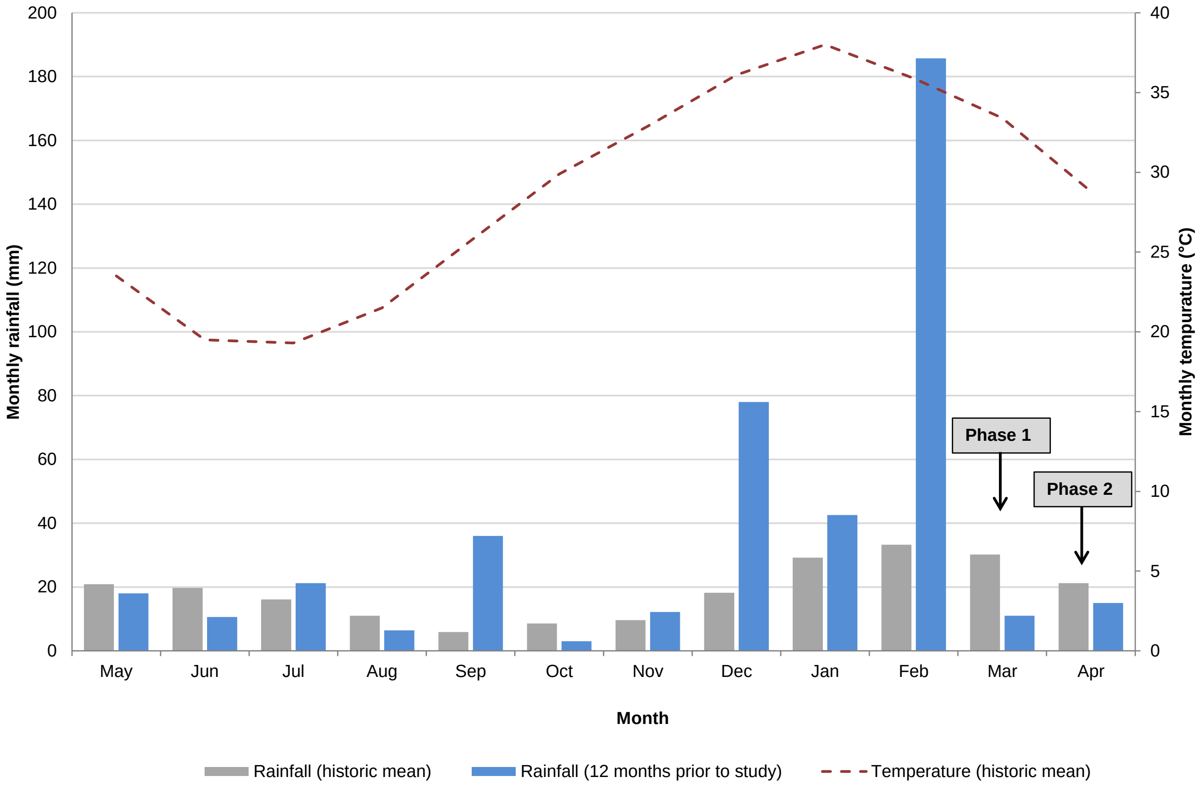


Figure 2-4: Historic mean monthly rainfall (Yakabindie Station) and temperature (Yeelirrie Station) compared to the 12 month period prior to the 2011 aquatic baseline study (phases 1 and 2 shown).

2.4 Ecology

There are few studies on the aquatic biota of ephemeral freshwaters in the vicinity of the MKSO Project or the broader region. The hydrological regime of rivers in the arid region determines the spatial and temporal availability of habitat. Aquatic biota will rapidly exploit newly-created waterbodies, which can be highly productive Organisms also employ a range of life histories and survival strategies, which strongly reflect their temporary environment (Young and Kingsford 2006). . During major flood events, the connectivity of aquatic systems also increases, allowing for the dispersal of propagules and the migration of species.

The biological activity of ephemeral waters is driven by the primary productivity of algae and macrophytes, which tend to be dynamic, and in turn support higher order consumers such as aquatic invertebrates, fish and waterbirds. Understanding the ecological values of these types of aquatic ecosystems, including Jones Creek and the claypans is vital, as they provide an important freshwater refugia in an otherwise arid landscape, and have the potential to be impacted by anthropogenic activities, including mining (Boulton *et al.* 2006; Brock *et al.* 2006; Bunn *et al.* 2006).

3 Methods

3.1 Database Searches and Literature Review

Database searches were undertaken, using a 100 km radius of the study area where possible, to identify restricted aquatic fauna communities, species or habitats of conservation significance, which may occur in the vicinity of Jones Creek (**Table 3-1**). Several databases were accessed from the following State and Commonwealth agencies; the Department of Parks and Wildlife (DPaW), the Western Australian Museum (WAM) and the Department of the Environment (DoE). Only search results relevant to this study have been presented in the report.

Table 3-1: Summary of database searches, including location and search area (GDA 94, UTM 51J).

Database	Reference	Coordinates	Search Area
NatureMap	(Department of Parks and Wildlife 2016a)	261433 6965254	Circular search area within a radius of 40 km*
Threatened and Priority Fauna Rankings	(Department of Parks and Wildlife 2016c)	261433 6965254	Circular search area within a radius of 100 km
Threatened and Priority Ecological Communities	(Department of Parks and Wildlife 2016b)	261433 6965254	Circular search area within a radius of 100 km
Western Australian Museum Invertebrates	(Western Australian Museum 2016a;b;c)	261433 6965254	Circular search area within a radius of 100 km
Protected Matters	(Department of the Environment 2016b)	261433 6965254	Circular search area within a radius of 50 km
Directory of Important Wetlands in Australia	(Department of the Environment 2016a)	261433 6965254	Circular search area within a radius of 100 km

** maximum allowable search area.*

The literature review was restricted to previous studies on Jones Creek and the claypans. The occurrence of conservation significant species within the vicinity of Jones Creek and the claypans was noted from the available literature. Key findings from the literature review were summarised and presented in the report.

3.2 Baseline Study

3.2.1 Design and Sampling Overview

An integrated sampling program was developed for Jones Creek and the claypans for the 2011 aquatic baseline study. Field work was undertaken by highly experienced aquatic ecologists (Richard De Lange, Dr Fiona Taukulis) and was conducted over two phases, at the end of March (phase 1), and three weeks later in mid-April 2011 (phase 2). The sampling regime was tailored to capture changes over the course of the hydroperiod, including the onset of flooding in Jones Creek, and the subsequent changes in aquatic biota as the creekline entered the drying phase. The study was executed under a Licence to Take Fauna for Scientific Purposes (Regulation 17); Fauna Licence Number SF008273, obtained from the Department of Parks and Wildlife (DPaW). On completion of this study, the results were submitted in electronic format, to DPaW, following appropriate protocols.

Ten sites were established during this study, comprising six sites within Jones Creek and four sites in the terminal floodplain area and claypans (**Plate 3-1A-D, Figure 3-1**); collectively referred to as claypans throughout the report. In the creek, sites were situated adjacent to the MKSO Project area, extending downstream for approximately 11 km. The claypan sites were situated approximately 15 km downstream of the MKSO Project area.

During both phases of this study, detailed habitat characterisations (**Appendix A**), including estimates of pool dimensions, were recorded and photo-monitoring provided a reference of each site. A range of ecological components were sampled at each site (**Table 3-2)**, broadly comprising:

- surface water (*in situ* and chemical analysis) and
- sediments (chemical analysis);
- phytoplankton (free-floating algae);
- diatoms (growing on substrates; periphyton);
- aquatic invertebrates (including micro and macroinvertebrates);
- resting stages (dormant biological propagules); and
- aquatic vertebrates (frogs and tadpoles).

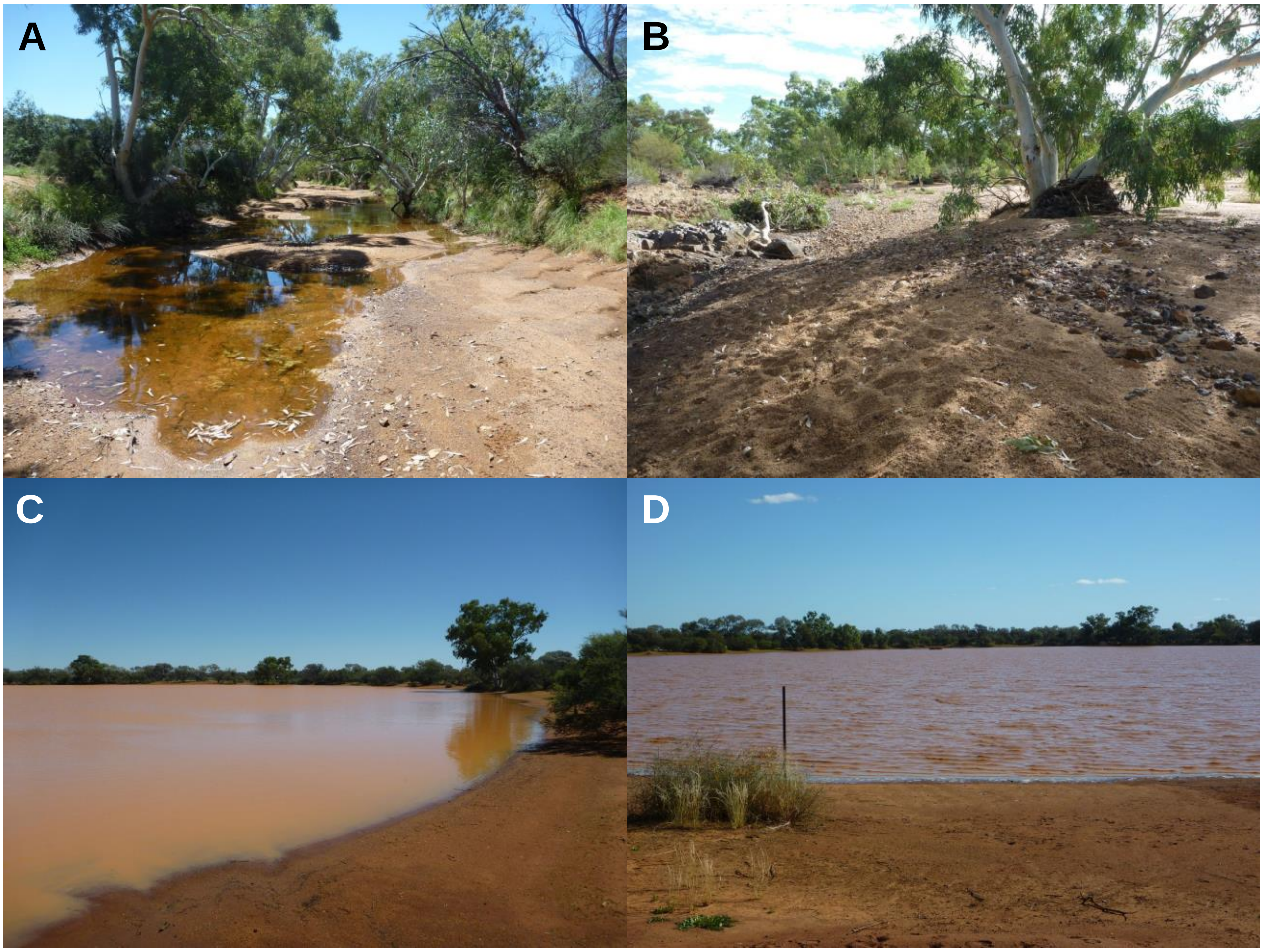


Plate 3-1: Examples of habitat sampled in Jones Creek (A-B), and the claypans (C-D), during the 2011 aquatic baseline study.

Figure 3-1: Jones Creek and claypan sites, sampled during the 2011 aquatic baseline study, in relation to the MKSO Project.

Table 3-2: Sampling sites and parameters measured at Jones Creek and the claypans, during the 2011 aquatic baseline study.

	Sites	Sample Date	Waterbody Type	GPS Coordinates (UTM 51J)	Elevation (m)	Brief description and Location	Habitat Charact.	Water Quality	Algae	Aquatic Invertebrates	Aquatic Vertebrates	Macrophytes / Riparian Veg	Resting Stages
Jones Creek	JC1	P1: 23/03/2011	Creekline	0261214 6956094	531	Northern-most creek site, adjacent to ROM pad and northern creek crossing.	•	•	•	•	•	•	
		P2: 11/04/2011 *DRY*					•			*DRY*			•
	JC2	P1: 23/03/2011	Creekline	0261409 6964545	529	Creek site, adjacent to ROM and southern creek crossing.	•	•	•	•	•	•	
		P2: 11/04/2011					•	•	•	•	•	•	•
	JC3	P1: 23/03/2011	Creekline	0260626 6963498	525	Creek site, adjacent to Six Mile Pit.	•	•	•	•	•	•	
		P2: 11/04/2011					•	•	•	•	•	•	•
	JC4	P1: 23/03/2011	Creekline	0259792 6961640	518	Creek site, 2.3km downstream of Six Mile Well Pit.	•	•	•	•	•	•	
		P2: 12/04/2011 *DRY*					•			*DRY*			•
	JC5	P1: 23/03/2011	Creekline	0258875 6959547	510	Creek site at former highway crossing, 4.5km downstream of Six Mile Well Pit.	•	•	•	•	•	•	
		P2: 12/04/2011					•	•	•	•	•	•	•
	JC6	P1: 24/03/2011	Creekline	0254133 6956365	495	Creekline site 9.8km downstream of Six Mile Pit and 3km southwest of the Goldfields Hwy.	•	•	•	•	•	•	
		P2: 12/04/2011					•	•	•	•	•	•	•
Claypans	JC7	P1: 24/03/2011	Claypan	0248040 6952116	471	Larger southwest terminal claypan, 17km downstream of Six Mile Pit and 10.4km southwest of Goldfields Hwy.	•	•	•	•	•	•	
		P2: 12/04/2011					•	•	•	•	•	•	•
	JC8	P1: 24/03/2011	Floodplain	0248068 6952655	474	Floodplain site, southwest of terminal claypan, 16.6km downstream of Six Mile Pit and 10.1km southwest of Goldfields Hwy.	•	•	•	•	•	•	
		P2: 12/04/2011					•	•	•	•	•	•	•
	JC9	P1: 24/03/2011	Floodplain	0250724 6945708	462	Southern-most floodplain site, 20.5km downstream of Six Mile Pit and 13.7km southsouthwest of Goldfields Hwy.	•	•	•	•	•	•	
		P2: 12/04/2011					•	•	•	•	•	•	•
	JC10	24/03/2011	Claypan	0251236 6946896	468	Smaller southern claypan, 19.2km downstream of Six Mile Pit and 12.3km southsouthwest of Goldfields Hwy.	•	•	•	•	•	•	
		12/04/2011					•	•	•	•	•	•	•

3.2.2 Water Quality

Water samples were collected from all sites apart from JC1 and JC4, which were dry in phase 2. Samples were collected using sterilised bottles provided by the NATA-accredited Australian Laboratory Group (ALS), containing preservative where required. Bottles were completely filled with water and sealed, excluding air from the samples (following instructions provided by ALS). Samples collected for the analysis of dissolved metals were field filtered through 45 µm cellulose acetate membrane filter paper using a Millipore portable filtering device. Samples were then couriered to ALS (Malaga) for analysis (**Table 3-3**). Dissolved metals were analysed by ICP-MS (inductively coupled plasma mass spectrometry). Holding times were met for most parameters, with the exception of pH, turbidity, NO_2, PO_4, S and Chl *a*, and these results should be considered indicative only.

Water quality was compared to the Australian and New Zealand Conservation Council (ANZECC) guideline trigger values for the protection of 80% of aquatic species in freshwaters (representative of highly disturbed ecosystems) (ANZECC 2000b). These trigger values were applied in the absence of comprehensive site-specific data, and should be considered reference values only. Basic water quality parameters were also measured *in situ* with a TPS 90FLMV hand-held meter, and included pH, salinity, electrical conductivity, dissolved oxygen, temperature and redox potential (**Appendix C**).

Table 3-3: Water quality parameters analysed from the surface waters of Jones Creek and the claypans, during the 2011 aquatic baseline study.

Basic Parameters and Nutrients	Anions and Cations	Dissolved Metals and Trace Elements	
pH	Chloride (Cl)	Aluminium (Al)	Lead (Pb)
Total Dissolved Solids (TDS)	Sulphate (SO_4)	Arsenic (As)	Mercury (Hg)
Electrical Conductivity (EC)	Bicarbonate (HCO_3)	Barium (Ba)	Nickel (Ni)
Turbidity	Carbonate (CO_3)	Cadmium (Cd)	Selenium (Se)
Total Nitrogen (TN)	Sodium (Na)	Chromium (Cr)	Silicon (Si)
Nitrite (NO_2) and Nitrate (NO_3)	Calcium (Ca)	Cobalt (Co)	Sulphur (S)
Total Kjeldahl Nitrogen (TKN)	Magnesium (Mg)	Copper (Cu)	Zinc (Zn)
Total Phosphorous (TP)	Potassium (K)	Iron (Fe)	**Other**
Chlorophyll *a*			Oil and Grease

3.2.3 Sediment Quality

At each site, the top two to three centimetres of shoreline sediments were collected to completely fill a sterilised glass container, which was then sealed and sent to ALS for analysis (Table 3-4). Samples were collected and stored using containers and instructions provided by ALS. The analysis of total metals in sediments was by ICP-AES (inductively coupled plasma-atomic emission spectrometry). Holding times were not met for pH, EC, Cl and SO_4, and these results should be considered indicative only.

Sediment quality data was compared to the ANZECC interim sediment quality guidelines (ISQG-High values) (Simpson *et al.* 2005). However, it is acknowledged that developing site-specific trigger values provides a more accurate indication of local conditions, instead of applying broad-scale guidelines (ANZECC 2000b), particularly in relation to temporary environments.

Table 3-4: Sediment quality parameters analysed in the surface sediments of Jones Creek and the claypans, during the 2011 aquatic baseline study.

Basic Parameters and Nutrients	Anions and Cations	Total Metals and Trace Elements	
pH	Chloride (Cl)	Aluminium (Al)	Lead (Pb)
Moisture content (MC)	Sulphate (SO_4)	Arsenic (As)	Mercury (Hg)
Electrical Conductivity (EC)	Sodium (Na)	Barium (Ba)	Nickel (Ni)
Total Suspended Salts (TSS)	Calcium (Ca)	Cadmium (Cd)	Selenium (Se)
Total Nitrogen (TN)	Magnesium (Mg)	Chromium (Cr)	Sulphur (S)
Nitrite (NO_2) and Nitrate (NO_3)	Potassium (K)	Cobalt (Co)	Zinc (Zn)
Total Kjeldahl Nitrogen (TKN)		Copper (Cu)	
Total Phosphorous (TP)		Iron (Fe)	
Total Organic Carbon (TOC)			

3.2.4 Algae

3.2.4.1 Phytoplankton

Phytoplankton was collected with a 25 µm mesh net, with the sampling technique varying according to habitat type. At the creekline sites, a 50 m transect was sampled within the main pool (or pools), whereas in the claypan sites the net was towed in an L-shaped transect (25 + 25 m), 10 to 20 m from the shore. The net was thoroughly rinsed between sites to prevent cross-contamination. Phytoplankton samples were transferred into a 70 mL vial and two to three drops of Lugol's (potassium iodide) solution was added to preserve algal structure.

On return to the laboratory, three slides were prepared from each sample, and examined under a compound microscope (40X) to assess the abundance and diversity of taxa. Colonial forms were counted per colony, while all remaining taxa were counted per cell. The habit (form) of each taxon was also noted (including planktonic, periphytic, filamentous, or colonial). Taxa were identified to the level of genera by Richard de Lange and Dr Fiona Taukulis, based on appropriate literature.

3.2.4.2 Diatoms

At each site periphyton was collected, which was found growing on macrophytes, twigs, sediments, rocks or debris in shallow waters, or along the margins of the creek and claypans. The resulting samples were placed into 70 mL vials and kept cool (no preservative was added). On return to the laboratory, periphyton was treated in 70% nitric acid (to remove organic material) and permanent slides were prepared according to John (1983). Three replicate slides were made for each sample and enumeration was carried out at

1000X magnification under a compound microscope. A maximum of 100 diatoms were counted at each site to provide a representation of community structure, and the abundance and diversity of taxa were recorded. Taxa were identified to species level by Dr Fiona Taukulis, using relevant taxonomic guides.

3.2.5 Aquatic Invertebrates

Aquatic invertebrates, comprising of microinvertebrates and macroinvertebrates, were collected from Jones Creek and the claypans using various sampling nets, appropriate for specimen size and habitat preferences. Nets were vigorously rinsed between sites, to prevent cross-contamination.

3.2.5.1.1 Microinvertebrates

Microinvertebrates samples were collected with a 150 µm mesh net, towed through the water column (avoiding the benthos) of all pools in the creekline, or for the claypans an L-shaped transect was sampled (50 + 50 m), 10 to 20 m from the shoreline. The resulting microinvertebrate sample was transferred into a 250 mL polycarbonate vial and placed in 100% undenatured ethanol to preserve DNA for future analysis if required.

In the laboratory, microinvertebrate samples were examined under a stereomicroscope (10X magnification) and sorted into broad taxonomic groups. The abundance and diversity of taxa was recorded. Specimens were identified to the lowest possible taxonomic rank by Dr Conor Wilson, Dr Erin Thomas and Dr Jason Coughran using appropriate invertebrate keys. Further specialist identification was provided by Bennelongia Environmental for the microcrustaceans including rotifers, copepods and ostracods, as well as for the protozoans. The abundance of the rotifers and protozoans in the samples could only be estimated due to their high densities.

3.2.5.1.2 Macroinvertebrates

Macroinvertebrate samples were collected with a 250 µm mesh, D-frame, sweep net, targeting the benthic environment. At creek sites, as many different habitat types as possible were sampled including sediments, organic material and debris, macrophytes, and near rocks, submerged logs and branches. These habitats were vigorously disturbed (using a kicking action) and the net was used to collect the dispersed material, which was then transferred into a 1.5 L pail and preserved in 100 % undenatured ethanol. At claypan sites, where there was less habitat diversity, macroinvertebrates were sampled in an L-shaped transect (50 + 50 m), 10 to 20 m from the shoreline. Where present in the claypans, habitats associated with inundated vegetation was also sampled, and all material transferred into pails and preserved. The macroinvertebrate samples were returned to the laboratory for further analysis.

In the laboratory, each sample was emptied into a wide plastic tray and all macroinvertebrate specimens were removed and separated into microvials (containing ethanol) based on their broad taxonomic rank. Each group was examined under the stereo microscope (10X magnification) and identified to the lowest possible taxonomic level by Dr Conor Wilson, Dr Erin Thomas and Dr Jason Coughran, using relevant keys. The abundance and diversity of taxa was recorded, and where specimens were found in high numbers an estimate of the total abundance was made. Additional identification was sought for some of the dipteran larvae, and was provided by Bennelongia Environmental.

3.2.6 Resting Stages

Surface sediments were collected from each site during phase 2 of the study (allowing adequate time for resident aquatic invertebrates to reproduce and deposit eggs into the sediments), to identify the presence of algal spores and the dormant eggs of aquatic invertebrates (known as resting stages). From each site, a 25 x 25 cm scraping of the surface sediments (approximately 1 to 2 cm deep) was collected and placed into calico bags. The samples were oven dried at 40°C in the laboratory. From each sample, a 100 g sub-sample was passed through 500 µm and 106 µm stacked Endecott® brass sieves. A sample of material (1 g) retained in the 106 µm sieve was examined using a stereo microscope, and abundances were calculated per 100 g of sediment, to provide an indication of the density of propagules within the sediments. Resting stages were counted and identified by Richard de Lange, with reference to appropriate literature

3.2.7 Aquatic Vertebrate Fauna

There were no fish observed during the study. Frogs and tadpoles were opportunistically collected in both phases of the study. This included specimens collected as by-catch in the macroinvertebrate D-frame sweep net. Additional collection of frogs and tadpoles occurred when specimens were observed in the water column, or in shoreline habitat in the creek and claypans. All captured specimens were photographed and released where possible. The resulting photographs were used for identification to species level by Dr Blair Parsons and Mr David Steane.

3.2.8 Macrophytes and Riparian Vegetation

A broad, qualitative assessment was undertaken for macrophytes and riparian vegetation during the study. Where present, samples of macrophytes were collected from Jones Creek (none were present in the claypans). Samples of dominant riparian plants were also collected from the creekline and claypans. Identification of all specimens were completed in the laboratory by Dr Rick Davies, with verification sought from the Western Australian Herbarium in some instances. The Waters and Rivers Commission (WARC; now the Department of Water) riverine condition assessment was used to grade the health of the riparian zone (**Table 3-5**). Macrophytes and dominant riparian vegetation identified from the Jones Creek and the claypans were included in the detailed habitat characterisations for each site (**Appendix A**).

Table 3-5: Summary of the WARC riverine grading system.

Grading	Condition	Description
A	Pristine to slightly disturbed	relatively intact tree cover, emergent growth in appropriate zones
B	Degraded	reduced tree/emergent cover, erosion in marginal areas
C	Erosion prone to eroded	remnant trees, grasses dominant, bank subsidence, channel infilling
D	Ditch	isolated trees, absence of emergents, widespread erosion and infill

3.2.9 Statistical Analyses

3.2.9.1 Univariate Analysis

Univariate analysis is a statistical technique that is used for analysing a single parameter at a time, and was performed on water and sediment data from Jones Creek and the claypans in MINITAB (Version 14) (Minitab Incorporated 2013). Where values were below detection (the analytical reporting limit), a value equal to half the limit of reporting was substituted. This only applied to parameters where less than half of the values were below detection; otherwise parameters were removed from further analysis.

One-way analysis of variance (ANOVA) was used to compare the statistical means of water and sediment parameters between sites, according to site classification (creek or claypan) and the study phase (phases 1 and 2). ANOVA testing was also conducted on the species diversity of biota, to determine differences between sites and phases. A confidence level of 95% (p value of <0.05) was considered statistically significant.

3.2.9.2 Multivariate Analysis

Multivariate analysis involves the statistical analyses of more than one parameter at a time. The multivariate procedure principal components analysis (PCA) was used to assess abiotic parameters, and hierarchical classification (which produces a dendrogram) was applied to biotic communities. These techniques were performed in the statistical package PRIMER, Version 6.0.

PCA was applied to water and sediment data across both phases of the study. For values below detection, a value equal to half the limit of reporting was substituted (parameters with values mostly below detection were removed). Select parameters were transformed to reduce skewness (ensuring the data was normally distributed) and collinear variables (those with a linear relationship) were removed during pre-treatment of the data. The results of the PCA are shown in the form of a plot, on which sites that are similar are located closer together. Vectors radiate from the centre of the plot, representing the influence of each parameter. Higher concentrations tend to occur near the end point of the vector. The percentage variance is used to explain the strength of the PCA; presented over the first two axes of the plot. A value of more than 50% is considered a useful interpretation of the results (Clarke and Warwick 2001).

Hierarchical classification was performed on the biological data (phytoplankton, diatoms and aquatic invertebrates). This procedure calculates the similarity between sites using the Bray-Curtis coefficient (Bray and Curtis 1957). Classification was based on the group-average linking algorithm, a process that generates a dendrogram (link-tree), showing the similarity percentage between sites based on the community structure of biological groups. Sites with the highest percentage similarity have the most similar species composition.

4 Results and Discussion

4.1 Database Searches and Literature Review

There were no conservation significant communities or species in the vicinity of the MKSO Project that were relevant to aquatic ecosystems. The closest Wetland of National Significance; Lake Carnegie, is more than 200 km to the northeast of the MKSO Project (Department of the Environment 2016a).

In addition to the 2011 aquatic baseline study, there have been two previous aquatic studies undertaken on Jones Creek; in 1992 (Streamtec Ecological Consultants 1992) and 2005 (Wetland Research and Management 2005). An additional study in 2005 provided a sediment characterisation of Jones Creek and the claypans (Sinclair Knight Mertz 2005). The key attributes and findings of these studies have been summarised in **Table 4-1**. The aquatic studies generally comprised similar methodology, albeit with a primary focus on aquatic invertebrates. A greater number of sites were sampled in 2005, including one of the southwest claypans. There was also improved taxonomic resolution in the 2005 study, particularly for microinvertebrate groups (**Figure 4-1**).

The earlier aquatic studies provided useful baseline data on surface water and sediment quality, as well as aquatic biota. More than 120 aquatic invertebrate taxa were found to inhabit the creek and claypans, while several frog species were also common. No fish were identified from Jones Creek or the claypans (**Table 4-1**). The previous studies did not characterise algal flora (phytoplankton and periphytic diatoms). An additional difference with the most recent study by Outback Ecology (2012), was that a two-phase sampling regime was implemented, with greater downstream coverage of the claypans (**Figure 4-1**), to provide a more comprehensive understanding of the aquatic ecosystem (**Table 4-1**).

The 2005 study recorded one verified new rotifer species (*Cephalodella* sp. nov.) (Wetland Research and Management 2005) (**Table 4-1**), which while new to science, was deemed unlikely to be restricted in distribution, due to the highly connected habitat of Jones Creek. During the 2011 aquatic baseline study (Outback Ecology 2012), a new clam shrimp was identified; *Eocyzicus* sp. OES1 from the claypans, which also has a likely distribution range that extends beyond the claypans (**Table 4-1**). The findings of this study are presented in more detail in the following sections.

Table 4-1: Summary of the 2011 aquatic baseline study and previous studies on Jones Creek and the claypans, within the vicinity of the MKSO Project.

Reference	Survey Name / Company	Survey Sites / Waterbodies	Survey Components / Methods	Survey Timing	Key Findings	Conservation Significant / Restricted Fauna
Outback Ecology (2012)	Project: NSD1 Mine and Corridor Project. Aquatic baseline study of Jones Creek and the southwest claypans Company: BHP Billiton Nickel West	10 sites (6 creekline and 4 claypans)	Water (*in situ* and chemical analysis) and sediment quality (chemical analysis). Phytoplankton (20 µm sweep net) and diatoms (periphyton collection). Aquatic invertebrates (micro and macroinvertebrates using 53 µm and 250 µm mesh nets, respectively) and resting stages (sediment collection). Aquatic vertebrate fauna (direct observation and net by-catch). Macrophytes (direct observation) and riparian habitat condition (based on WRC assessment grading).	March and April 2011 – wet conditions	Freshwaters throughout, clear water creek and turbid claypans. Circumneutral to alkaline pH. Varying ionic composition. Claypans had higher nutrients and some metals. A total of 33 phytoplankton, dominated by green algae and diatoms recorded. A total of 35 diatom taxa recorded in periphyton, dominated by freshwater genera. A total of 132 aquatic invertebrate taxa, with the creek dominated by insects and the claypans dominated by crustaceans. Three frog species recorded. No fish recorded. Degraded riparian habitat throughout. The creek and claypans provide important freshwater refugia for aquatic biota.	1 new clam shrimp; *Eocyzicus* sp. OES1
Wetland Research and Management (2005)	Project: Yakabindie Nickel Project. Baseline study of Jones Creek, including the southwest claypan area Company: BHP Billiton Nickel West	8 sites (7 creekline and 1 claypan)	Water quality (*in situ* and chemical analysis), aquatic invertebrates (micro and macroinvertebrates using 53 µm and 250 µm mesh nets, respectively), aquatic vertebrate fauna (direct observation, net by-catch and baited box traps), riparian habitat condition (based on WRC assessment grading).	May 2005 – wet conditions	Creek channel highly modified (erosion). Freshwaters throughout creek (clear water) and claypan (turbid), although ionic composition varied. Slightly acidic to circumneutral pH. High nutrients and some metals elevated (particularly in the claypan). A total of 124 aquatic invertebrate taxa recorded, dominated by insects, rotifers and crustaceans. Difference invertebrate assemblage in the creek and claypan. Most invertebrate taxa widespread. Two frog species recorded. No fish recorded. Degraded riparian habitat throughout, remaining large eucalypts of importance.	1 new rotifer; *Cephalodella* sp. nov.
Sinclair Knight Merz (2005)	Project: Yakabindie Jones Creek stream sediment characterisation Company: WMC Resources	6 sites (4 creekline and 2 claypans)	Characterisation (*in situ* descriptions), surveying (*in situ* level measurements), sediment sampling (grain size and chemical analyses).	December 2004 – dry conditions	During high flow, coarse sand and gravel are mobilised within the channel as bedload. Finer silt and sand transported into the system from catchment, deposited at channel margins and in mid-channel bars. Finer suspended sediment also deposited in claypans. Limited changes in chemical characteristics of the creek, some elevated metals due to greenstone parent rock in catchment.	NA
Streamtec (1992)	Project: Yakabindie Nickel Project. Jones Creek baseline survey of aquatic fauna and water quality Company: Dominion Mining Ltd	6 sites (6 creekline)	Water quality (*in situ* and chemical analysis), aquatic invertebrates (micro and macroinvertebrates using 120 µm and 250 µm mesh nets, respectively) and aquatic vertebrate fauna (direct observation and net by-catch).	January 1992 – wet conditions	Freshwater creekline, high tannin content, some elevated metals. A total of 38 aquatic invertebrate taxa recorded, dominated by insects. Larger pools located further downstream supported higher invertebrate diversity. Three frog species recorded. No fish recorded. The creek provides a refuge for aquatic invertebrate and vertebrate fauna.	Unknown; final taxonomic verification unavailable

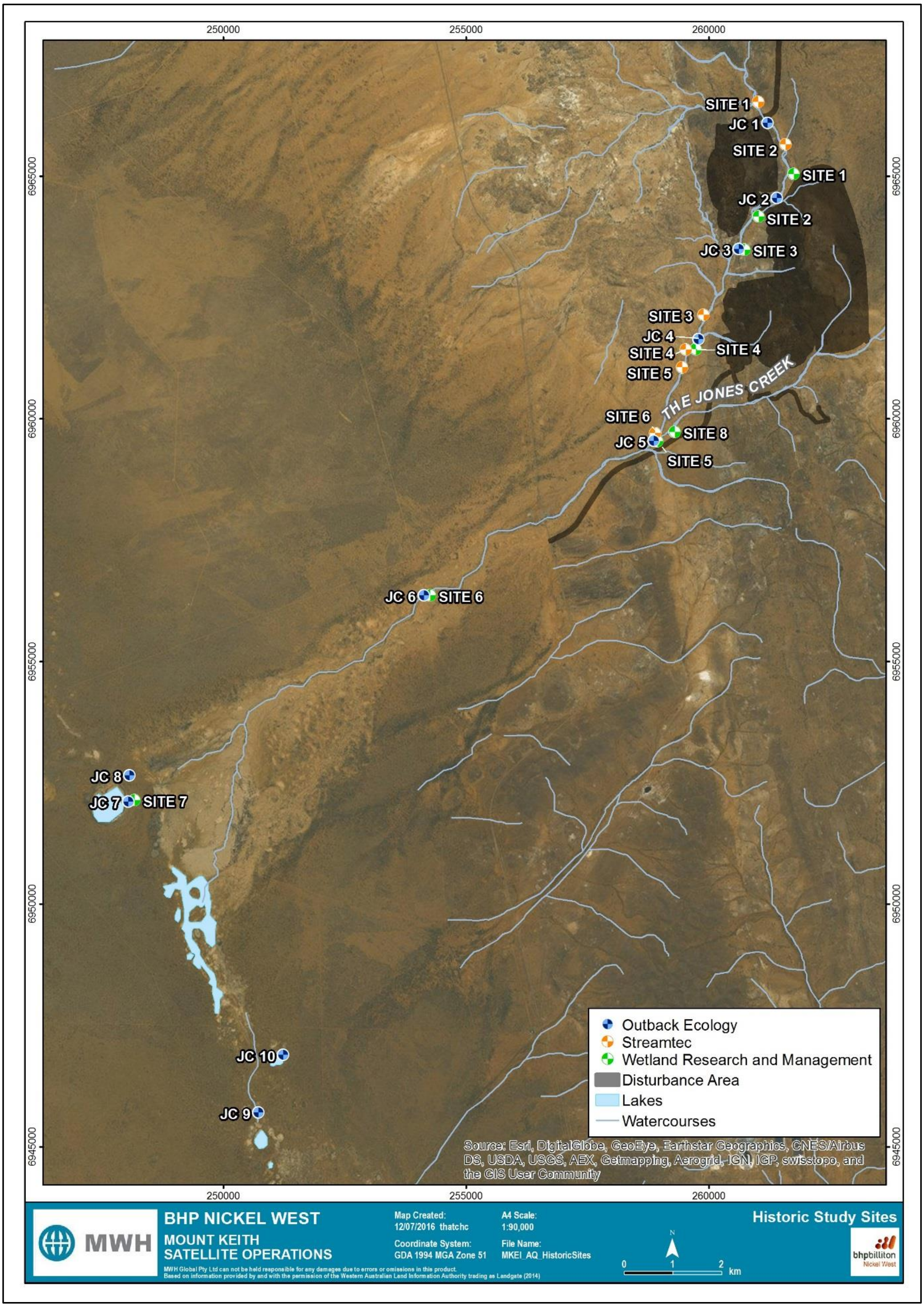


Figure 4-1: Jones Creek sites, sampled during the 1992, 2005 and 2011 aquatic ecology studies, in relation to the MKSO Project.

4.2 Baseline Study Findings

4.2.1 Habitat Characterisation

4.2.1.1 Jones Creek

During the 2011 aquatic baseline study, Jones Creek exhibited consistent characteristics along its length (**Plate 4-1A-F; Plate 4-2A-F**), although channel dimensions and pool sizes varied. The channel width of the creek ranged from 7.2 m to 15.5 m, gradually increasing downstream. Pools ranged in size and were up to 80 m long and 0.7 m deep at the time of sampling during phase 1 (**Appendix A**). All pools were substantially smaller in phase 2 sampling, three weeks later, with two of the creek sites completely dry. Given this rapid loss of surface water, it appears that the residence time of water in Jones Creek may be approximately two months following a major flood event.

Surface waters in the pools were mostly clear, and in some cases tannin-stained. Biological productivity was high, with filamentous green algae, aquatic invertebrates, and tadpoles or frogs noted at most sites. There was a high abundance of organic material throughout the creek, with high velocity flows transporting debris and vegetation from the catchment into the channel. Sediments comprised coarse sand, pebbles, and fine silt material, with a base of coffee rock exposed in some areas. There was also evidence of substantial mobilisation of sands along the creek bed. The banks were highly eroded, leading to active channel widening and terracing in parts of the creek.

The riparian vegetation had been heavily influenced by grazing, with a limited understorey of mostly native grasses and sedges, and an overstorey of *Eucalyptus camaldulensis* trees. A number of common native, macrophytes were found throughout the creek including the emergent sedges *Cyperus centralis* and *Schoenoplectus lateriflorus*, along with the aquatic plant *Marsilea hirsuta*, which can grow over land and water. A number of bryophytes were also observed along the banks. Based on the WARC riverine grading system, the creek habitat was a category ‘C’, classified as eroded, or prone to erosion, with few trees, a dominance of grasses and evidence of channel subsidence and filling.

Plate 4-1: Jones Creek sites; JC1 (A) phase 1, (B) phase 2; JC2 (C) phase 1 (D) phase 2; JC3 (E) phase 1, (F) phase 2.

Plate 4-2: Jones Creek sites; JC4 (A) phase 1, (B) phase 2; JC5 (C) phase 1 (D) phase 2; JC6 (E) phase 1, (F) phase 2.

4.2.1.2 Claypans

During phase 1 of sampling, surface waters in the claypans and associated floodplain area were highly connected (**Plate 4-3A-G**), with anecdotal evidence suggesting the claypans hold water for at least several months following heavy rainfall. Water depth generally ranged from 0.4 to 0.6 m in phase 1, decreasing by approximately 0.1 m at the time of sampling during phase 2 (**Appendix A**). In addition, water levels receded by up to 6 m across the shoreline between phases, a reflection of the low topographical relief in the area.

Surface water within the claypans was highly turbid throughout this study, due to the suspension of fine sediments. The bed surface comprised soft clay sediments, which were underlain by a hard base. Due to the high turbidity, there was limited planktonic algae in the claypans, although aquatic invertebrates and frogs were noted at most sites, albeit to a lesser extent than Jones Creek.

The riparian vegetation was dominated by larger native trees including *Melaleuca interioris* and *Acacia tetragonophylla* and the smaller shrub *Muehlenbeckia florulenta*, with an understorey of grazed native and exotic grasses and herbs. Many of the *Melaleuca* trees were inundated, reflecting their tolerance to periodic flooding. As with Jones Creek, the claypans had been heavily impacted by livestock, resulting in substantial degradation of the riparian habitat, which was classified as a category 'C', according to the riverine grading system (Water and Rivers Commission 1999).

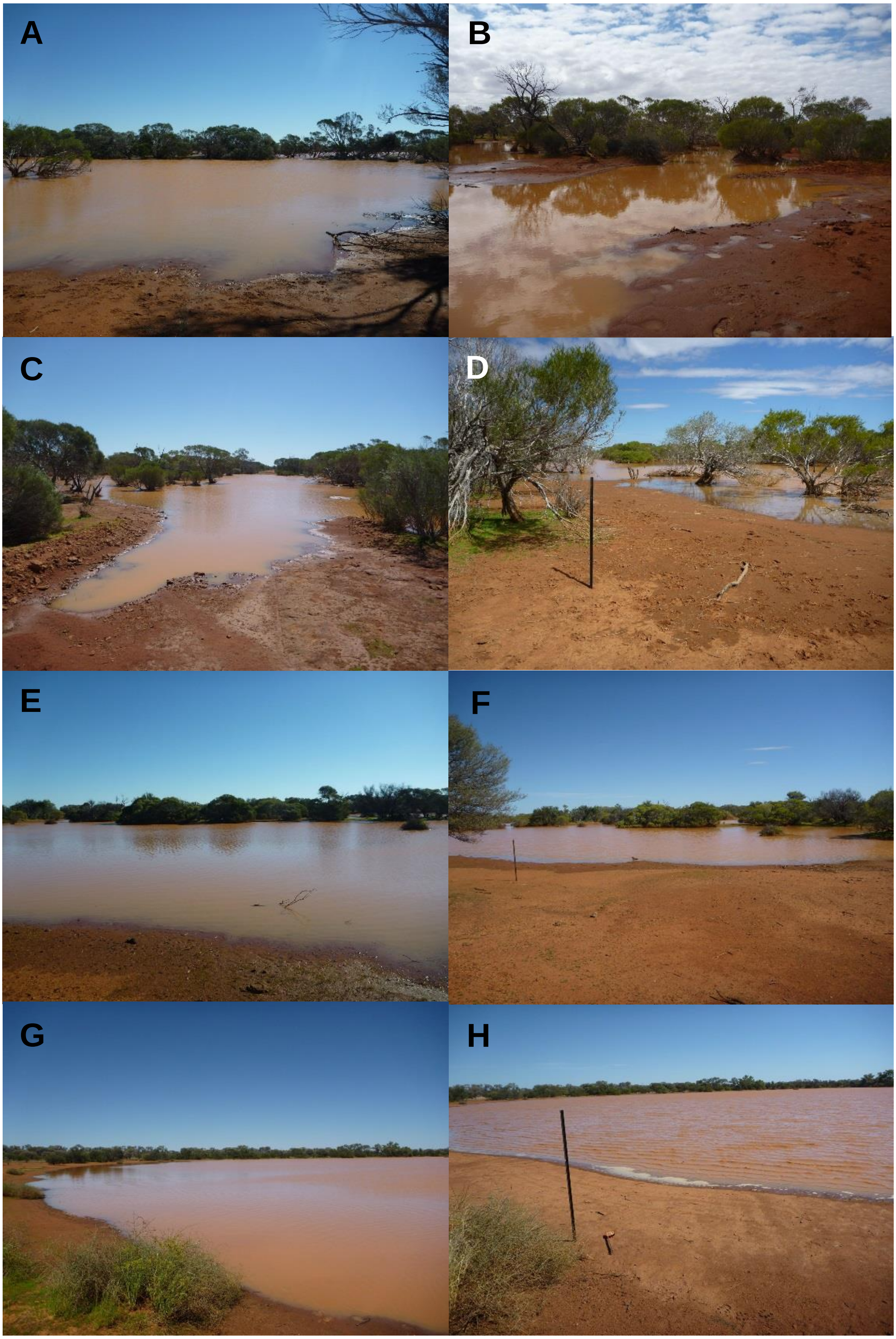


Plate 4-3: Claypan and floodplain sites; JC7 (A) phase 1, (B) phase 2; JC8 (C) phase 1 (D) phase 2; JC9 (E) phase 1, (F) phase 2; JC10 (G) phase 1, (H) phase 2.

4.2.2 Water Quality

During the 2011 aquatic baseline study (**Table 4-2**), water quality parameters were strongly influenced by local geomorphological and biological processes (Kingsford and Thompson 2006). The pH of all sites was classified as circumneutral to alkaline, *sensu* Foged (1978). A greater range of values was recorded in Jones Creek (6.77 to 8.71) (**Figure 4-2A**), compared to the claypans (7.26 to 7.56). During phase 2, the pH had increased at three of the four Jones Creek sites, while in the claypans there was negligible change. Differences may be related to increased evapoconcentration of surface waters in the creek between phases. Surface water pH is also strongly influenced by algal productivity (Reddy and DeLaune 2008), and associated photosynthesis and respiration shows strong diurnal variation (Boulton and Brock 1999). Jones Creek was associated with greater algal growth than the claypans during both phases of the study.

The maximum turbidity value recorded from Jones Creek during the 2011 study was 6.2 NTU (JC6, phase 1), while at the claypans was 1,000 NTU (JC10, phase 1). The increased turbidity of the claypans (**Table 4-2**) was also reflected by significantly higher TDS values ($p<0.001$) (**Appendix D**). The fine clay material suspended in the water column at the claypan sites was also noted in the 2005 aquatic study (Wetland Research and Management 2005), and is characteristic of many inland waterbodies after flooding (Bunn *et al.* 2006). Finer sediments also have a greater ability to adsorb contaminants (Sinclair Knight Mertz 2005).

The creek and claypans were classified as freshwater, being well within the upper salinity limit for inland freshwater environments (<5,000 µS/cm), *sensu* Hammer ((1986). This was consistent for all sites in both phases. The maximum recorded salinity (EC) was 281 µS/cm in the creekline pools, and 138 µS/cm in the claypans (**Figure 4-2B**). The Jones Creek sites had a significantly higher salinity (mean=180 µS/cm) than the claypans (mean=68 µS/cm) during both phases. As water persists for much longer in the claypans, it is likely that evapoconcentration will lead to increased salinities in this area as water levels recede (Berry 2011).

The dominant ion in surface waters was HCO_3, across all sites in both phases of this study (**Table 4-2**). The anion pattern was consistent in Jones Creek and the claypans (HCO_3>Cl> SO_4), while there was some variation in cations. In the creekline generally Ca>Na>Mg≈K, while the claypans followed Na<>K>Ca>Mg. Previous studies have found similar trends (Wetland Research and Management 2005), with ionic differences associated with local geology and the solubility of minerals within the catchment (Boulton and Brock 1999; Hart and McKelvie 1986).

Table 4-2: Water quality data recorded from Jones Creek and the claypans during the 2011 aquatic baseline study, in comparison to the ANZECC trigger values for the protection of 80% of species in freshwaters (units presented in mg/L unless stated). Values exceeding triggers are bolded.

Water Quality Parameters		Jones Creek												Claypans								ANZECC Trigger Values
		JC1		JC2		JC3		JC4		JC5		JC6		JC7		JC8		JC9		JC10		
		P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	
Basic and Nutrients	pH (unit)	7.42		6.77	7.74	7.72	8.71	7.36		7.65	7.96	8.05	7.91	7.28	7.26	7.35	7.27	7.56	7.54	7.54	7.56	
	EC (µS/cm)	117		121	211	154	281	147		122	175	220	256	40	50	46	50	55	64	97	138	
	TDS	97		105	152	133	169	109		105	141	111	164	196	268	252	314	426	544	838	1320	
	Turbidity	6.0		3.6	4.0	2.4	3.9	3.8		2.9	3.5	6.2	3.6	376.0	338.0	505.0	454.0	817.0	470.0	1000.0	871.0	
	TN	2.0		1.6	0.8	1.0	2.1	1.4		0.6	1.2	0.9	0.9	1.3	1.0	1.2	1.3	1.4	1.2	1.8	1.9	
	NO_2 and NO_3	0.01		0.01	<0.01	<0.01	0.04	0.06		0.02	0.01	<0.10	<0.01	0.27	0.34	0.23	0.30	0.05	0.08	0.50	0.08	
	TKN	2.0		1.6	0.8	1.0	2.1	1.3		0.6	1.2	0.9	0.9	1.0	0.7	1.0	1.0	1.4	1.1	1.3	1.8	
	TP	0.10		0.10	0.03	<0.01	0.06	0.06		0.03	0.06	0.04	0.04	0.19	0.17	0.22	0.25	0.33	0.30	0.58	0.78	
	Chl *a*	8		22	2	2	96	12		3	14	1	4	<1	6	<1	14	3	11	<1	18	
Anions and Cations	Cl	13.0		18.0	26.0	18.0	34.0	14.0		12.0	14.0	12.0	12.0	2.0	2.0	3.0	2.0	4.0	5.0	12.0	18.0	
	SO_4	1.0		2.0	2.0	3.0	<1	1.0		2.0	<1	<1	<1	<1	<1	<1	<1	<1	2.0	3.0	6.0	
	HCO_3	23.0		23.0	58.0	39.0	76.0	41.0		32.0	66.0	82.0	104.0	14.0	16.0	12.0	16.0	20.0	32.0	26.0	41.0	
	CO_3	<1		<1	<1	<1	8.0	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
	Ca	7.0		8.0	14.0	14.0	25.0	13.0		10.0	15.0	18.0	21.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	
	Mg	3.0		4.0	6.0	4.0	8.0	5.0		4.0	7.0	9.0	11.0	<1	<1	1.0	<1	1.0	<1	<1	1.0	
	Na	8		8	9	9	12	8		7	9	7	11	3	3	3	3	7	9	18	24	
	K	4.0	DRY	4.0	6.0	5.0	9.0	4.0	DRY	4.0	6.0	5.0	8.0	4.0	4.0	4.0	5.0	6.0	6.0	7.0	10.0	
Metals, Trace Elements and Other	Al	0.25		0.07	0.08	0.09	**0.20**	0.04		0.02	0.02	<0.01	0.03	**1.63**	**1.13**	**1.71**	**1.17**	**1.74**	**1.33**	**1.96**	**1.75**	0.15
	As	<0.001		<0.001	<0.001	<0.001	0.001	<0.001		<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.14
	Ba	0.053		0.070	0.092	0.051	0.027	0.058		0.060	0.060	0.110	0.118	0.016	0.016	0.019	0.025	0.017	0.019	0.030	0.047	
	Cd	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0008
	Co	<0.001		<0.001	0.002	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	0.002	0.002	0.002	0.002	0.004	
	Cr	0.001		<0.001	0.001	<0.001	0.001	<0.001		<0.001	<0.001	<0.001	<0.001	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.005	0.04
	Cu	**0.015**		**0.003**	**0.013**	**0.004**	**0.007**	0.002		0.002	**0.003**	0.001	**0.006**	0.002	**0.004**	0.002	**0.006**	**0.003**	**0.006**	**0.004**	**0.010**	0.0025
	Fe	0.53		0.40	1.36	0.19	0.52	<0.05		0.08	0.12	0.16	0.83	0.99	0.94	0.95	0.93	0.87	0.83	0.92	1.04	
	Hg	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0054
	Ni	0.003		0.003	0.005	0.002	0.005	0.004		0.003	0.005	0.004	0.007	0.005	0.005	0.004	0.006	0.004	0.005	0.005	0.010	0.017
	Pb	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.004	0.0094
	S	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
	Se	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.034
	Si	12.7		15.1	14.7	13.2	11.9	14.8		13.8	13.0	16.1	15.0	7.0	11.6	9.7	11.7	20.0	25.2	12.8	44.0	
	Zn	0.005		0.005	0.020	<0.005	0.006	<0.005		<0.005	<0.005	<0.005	0.013	0.008	<0.005	0.011	0.008	0.008	0.005	0.009	0.011	0.031
	Oil and Grease	<5		<5	<5	<5	<5	<5		<5	<5	<5	<5	NA	<5	NA	<5	NA	<5	NA	<5	

Concentrations of total nitrogen (TN) ranged from (0.6 mg/L to 2.1 mg/L) (**Figure 4-3A**), which was consistent with the 2005 aquatic study (Wetland Research and Management 2005). Total phosphorus (TP) however, was significantly higher ($p<0.001$) (**Appendix D**) in the claypan sites (mean=0.35 mg/L), compared to Jones Creek (mean=0.05 mg/L) (**Figure 4-3B**). The concentration of nitrogenous compounds (NO_2 and NO_3) also tended to be higher in the claypans (**Table 4-2**). These differences may be attributed to an accumulation of organic matter which has been transported downstream through the creek and deposited into the terminal claypans. Subsequent microbial activity in the sediments releases nutrients into the overlying waters (Boulton and Brock 1999). A comparison of the nutrients recorded during this study, with that of lakes in the nearby Carey Palaeochannel, including Lake Miranda and Lake Carey, indicated concentrations were either below or within the typical range for the region (Gregory 2008).

There was a distinction between the creek and claypan sites for metal concentrations (**Figure 4-4A-B**; **Figure 4-5A-B**). Concentrations of Al were significantly higher in the claypans ($p<0.001$) (**Appendix D**), while Ba was significantly greater in Jones Creek ($p<0.001$) (**Appendix D**). For Fe and Zn general trends also indicated that these metals were higher in the claypan sites (**Table 4-2**). This can be attributed to differences in mineralogy between the creek and claypans, as well downstream cumulative effects. The pH of surface waters and the rate of biological activity can also have a strong influence on the mobility of metals in freshwater systems (Connell 2005).

Concentrations of Al exceeded the ANZECC trigger value for the protection of 80% of species in freshwaters (0.15 mg/L) (**Figure 4-4A**). This mainly occurred within the claypans, with concentrations more than ten times the trigger value at JC10 in phase 1 (1.96 mg/L), indicating downstream accumulation. Concentrations of Cu exceeded the ANZECC trigger value at most sites in phases 1 and 2 of the study (**Table 4-2**). The highest concentration of Cu was recorded from JC1 during phase 1 (0.015 mg/L), and was more than six times greater than the ANZECC trigger value (0.0025 mg/L). This suggests a natural source of Cu within the catchment, and is supported by the 2005 aquatic study (Wetland Research and Management 2005). There were also significantly higher concentrations of Cu ($p=0.014$) and Ni ($p=0.001$) present during phase 2 (**Appendix D**), a reflection of evapoconcentration for these metals. The remaining metals and metalloids including As, Cd, Co, Hg, Pb, and Se were mostly below detection in both phases of this study.

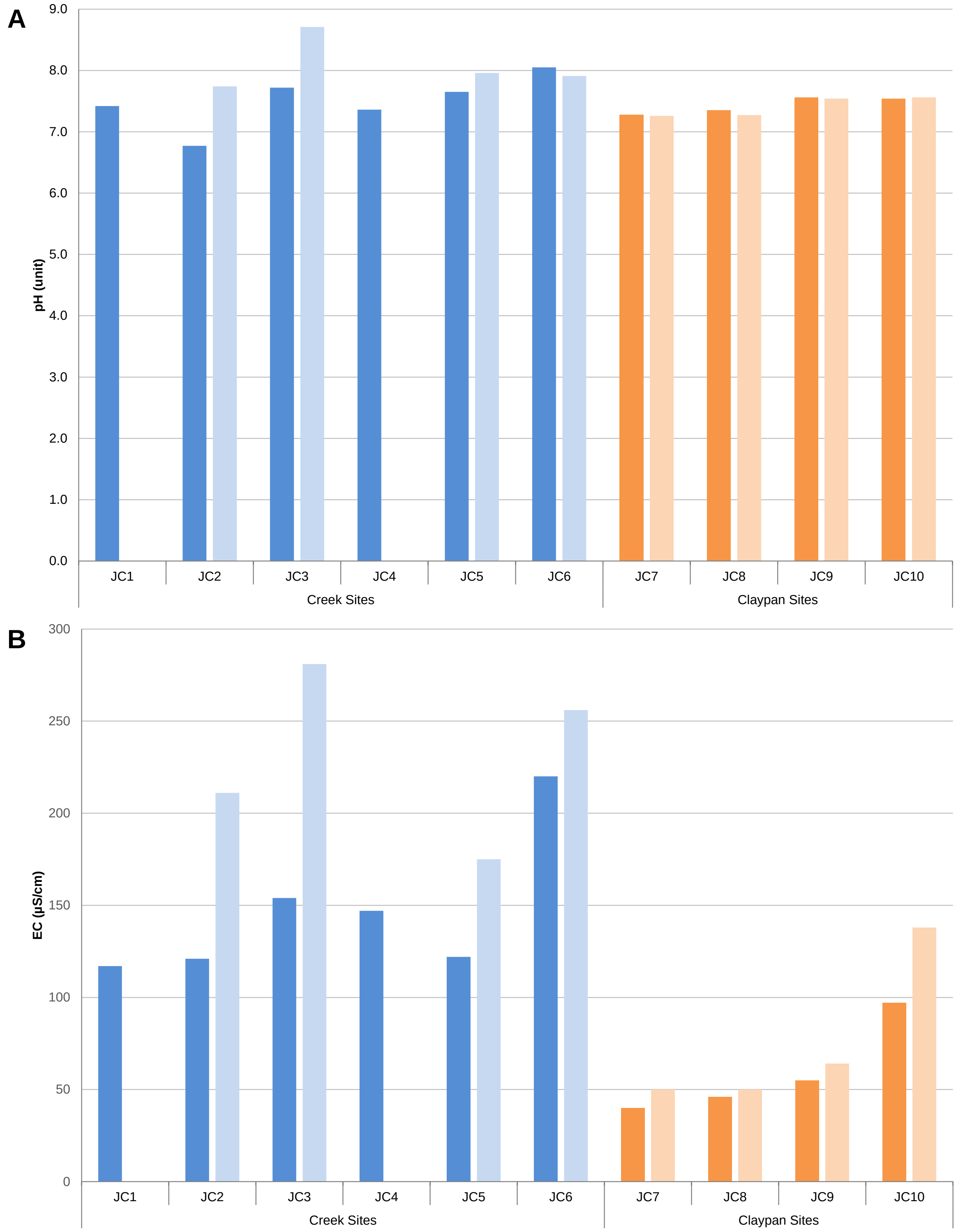


Figure 4-2: Changes in (A) pH and (B) salinity (EC) in the surface waters of Jones Creek (■= phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study.

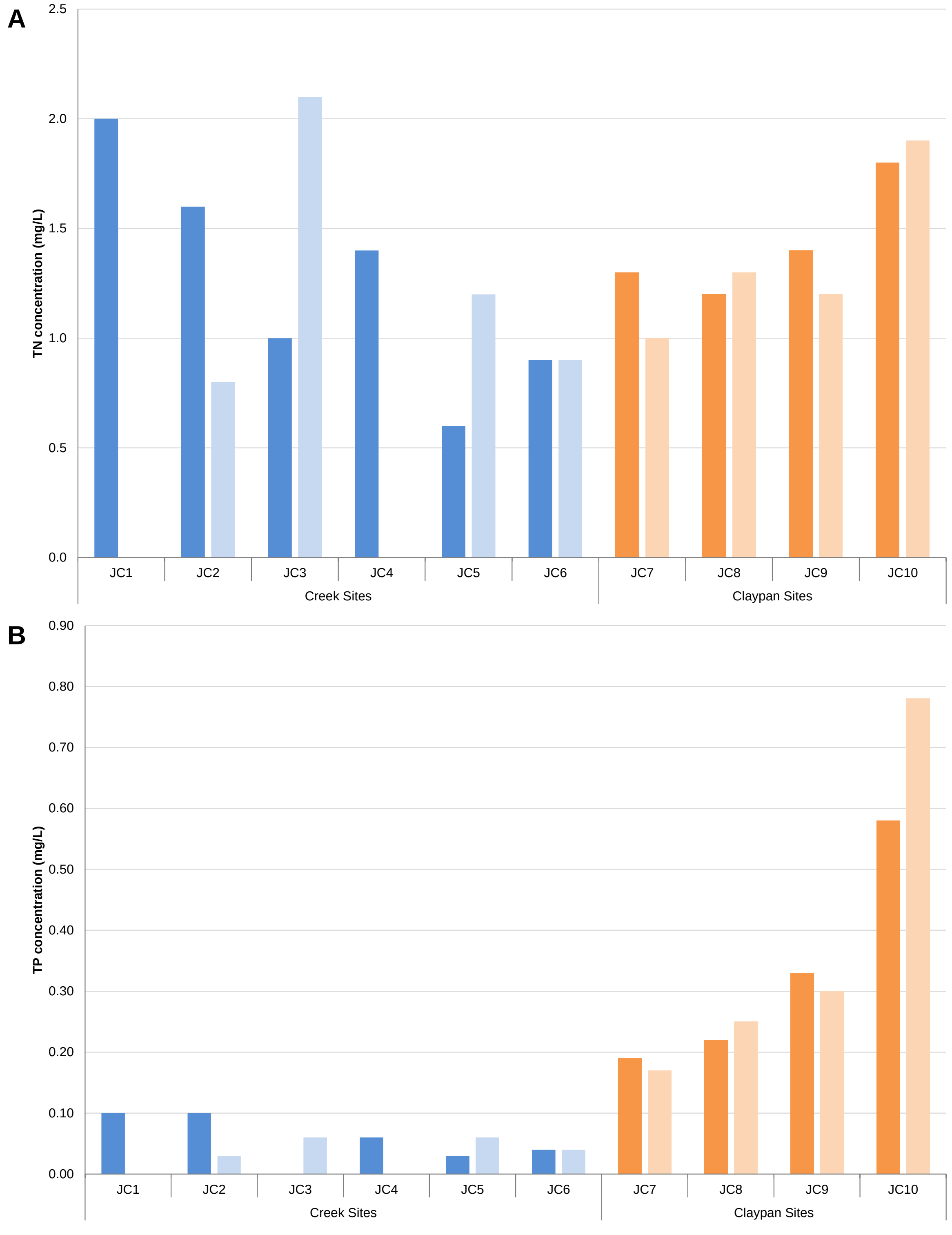


Figure 4-3: Changes in concentrations of (A) TN and (B) TP in the surface waters of Jones Creek (■= phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study.

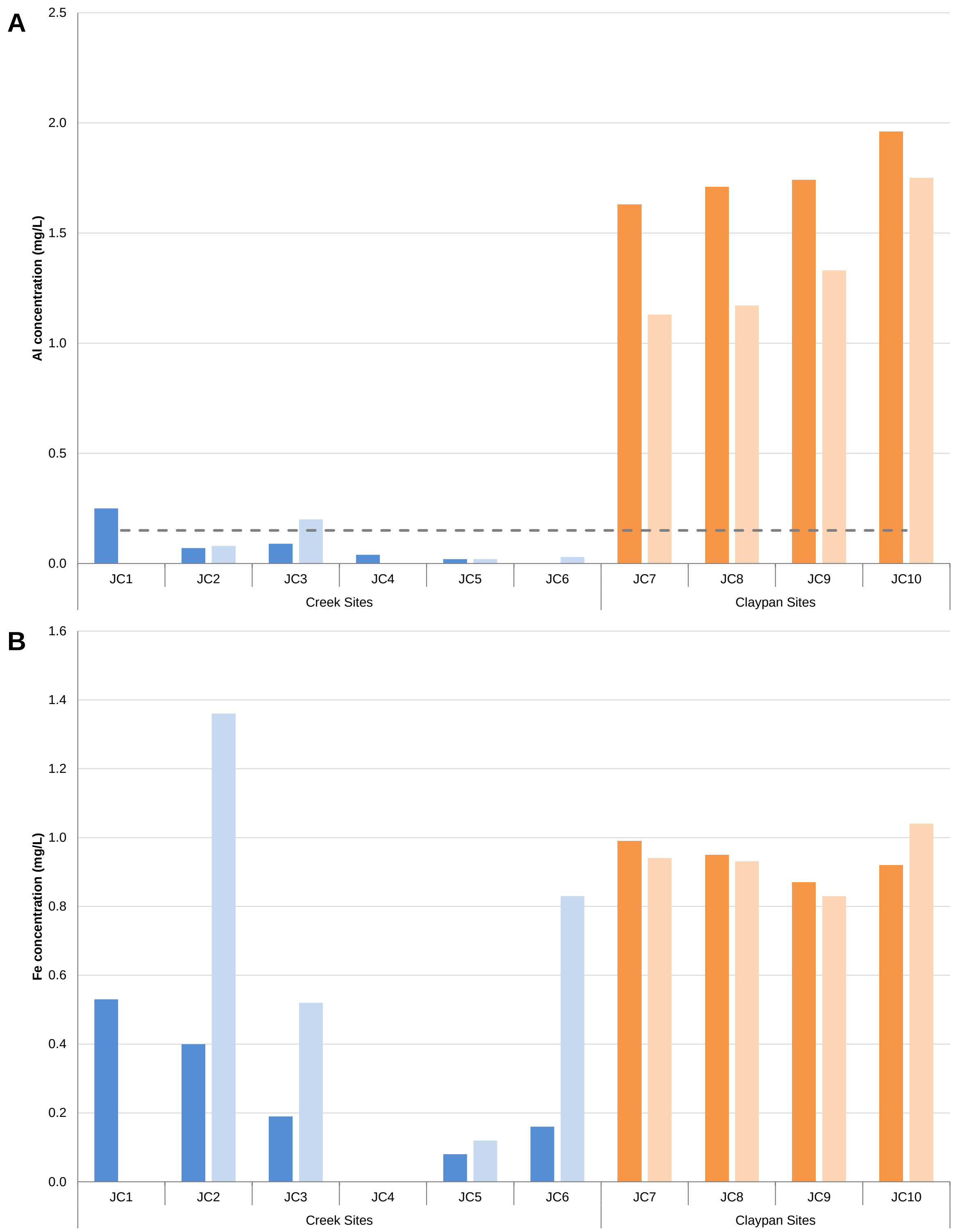


Figure 4-4: Changes in concentrations of (A) Al and (B) Fe in the surface waters of Jones Creek (■= phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study. The ANZECC ISQG-High value (grey dotted line) is also indicated. Note values below detection not shown.

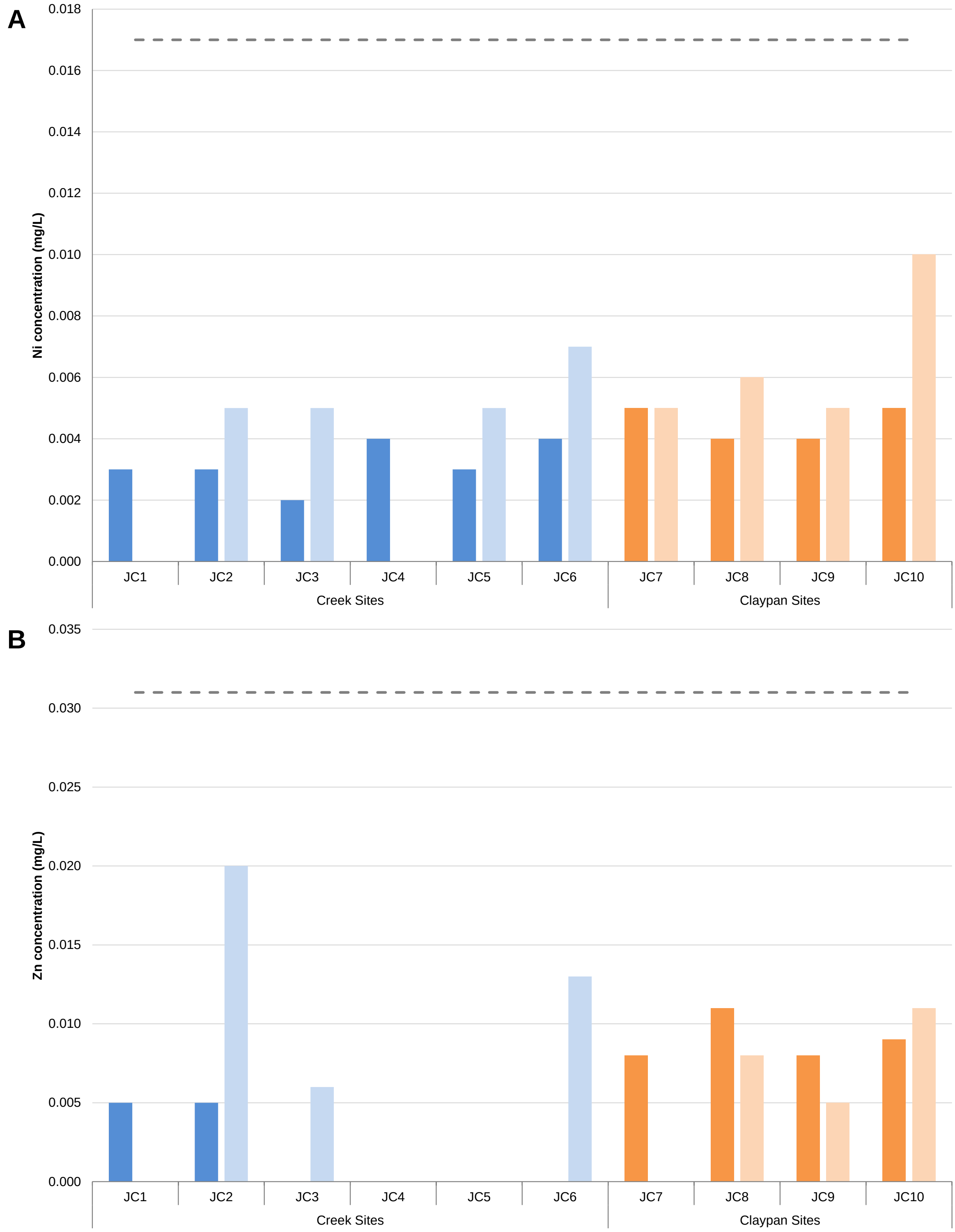


Figure 4-5: Changes in concentrations of (A) Ni and (B) Zn in the surface waters of Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study. The ANZECC ISQG-High value (grey dotted line) is also indicated. Note values below detection not shown.

Statistical analysis confirmed the differences in water quality, separating the Jones Creek and claypan sites, based on the PCA. This was related to factors including salinity (EC), TDS, nutrients (mainly TP) and metals (Ba, Cu, Fe and Ni) (**Figure 4-6**). However, apart from changes in Cu and Ni concentrations over the two phases, there was limited temporal variation in water quality during this study (**Figure 4-6**).

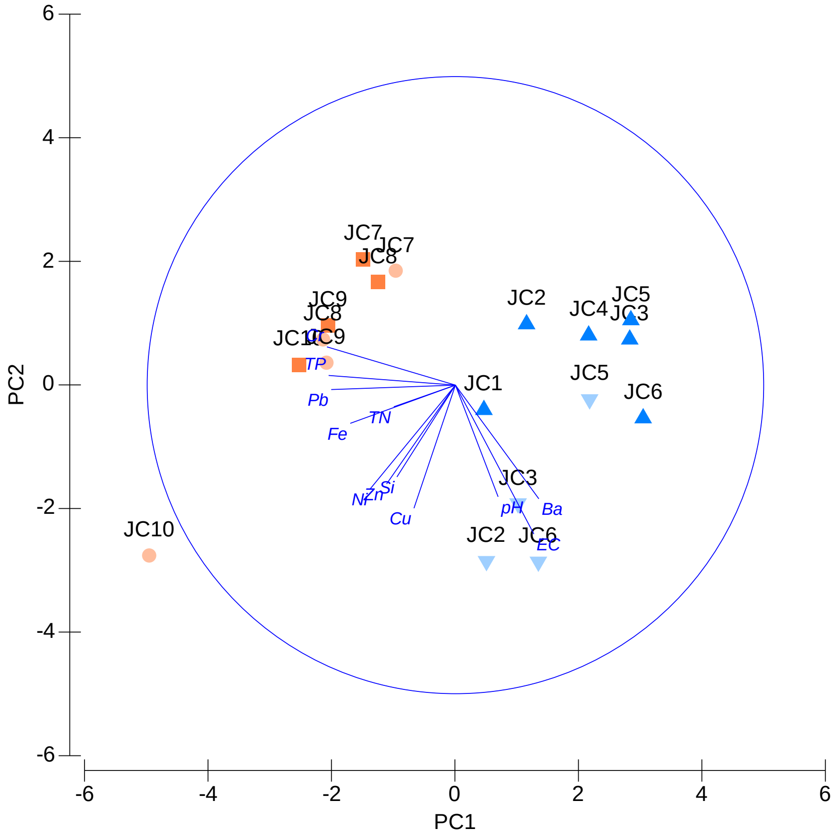


Figure 4-6: PCA plot of surface water quality data for Jones Creek (▲ = phase 1; ▼ = phase 2) and the claypans (■ = phase 1; ● = phase 2) during the 2011 aquatic baseline study. A total of 64.5% of the variation was explained by the first two axes.

4.2.3 Sediment Quality

Sediment quality for Jones Creek and the claypans during the 2011 aquatic baseline study showed a number of similarities (**Table 4-3**). Sediment pH was relatively consistent across all sites (**Figure 4-7A**), ranging from 6.5 to 7.4, regarded as neutral (Hazelton and Murphy 2007). During flood events, connectivity between rivers, tributaries and wetlands increases, leading to more homogenous conditions (Young and Kingsford 2006). Sediment pH had also increased significantly during phase 2 ($p<0.05$) (**Appendix D**), likely a reflection of receding water levels and associated changes in biogeochemical reactions within the sediments (Pulford and Flowers 2006; Reddy and DeLaune 2008).

Salinity (EC) was considered low in the sediments of Jones Creek and the claypans (**Figure 4-7B**), *sensu* Hazelton and Murphy (2007), reflecting freshwater input following heavy rainfall. Concentrations in the sediments were below 45 µS/cm, with the exception of site JC2 during phase 1 of this study, which recorded a substantially higher value (1,610 µS/cm). Given the magnitude of difference in comparison to the other sites it is likely this result is a laboratory error, supported by the concentrations of major anions and cations, which were mostly below detection (**Table 4-3**).

Concentrations of TN, TP (**Figure 4-8A-B**), and TOC were significantly higher ($p<0.05$) (**Appendix D**) in the sediments of the claypan sites than in Jones Creek. The maximum TN and TP concentrations recorded in the creekline were 290 mg/kg and 83 mg/kg respectively, compared to 280 mg/kg and 220 mg/kg in the claypans. This can be attributed to the downstream accumulation of organic material following the initial flow event. However, compared to Lake Miranda, a salt lake within the same drainage system to the south-west, nutrient concentrations were comparatively low in the sediments (Gregory 2008). Nutrient exchange in Australian wetlands is essential to ecological function, and nutrients are generally sourced from the surrounding floodplain and tributaries, transported as organic matter into the system (Boulton and Brock 1999). However the sparse vegetative cover associated with river systems in the arid zone is considered a key factor influencing the allochthonous sources of carbon and nutrients (Bunn *et al.* 2006).

The concentrations of all metals were well below the ANZECC ISQG-High values for sediments (where available), with the levels of As, Cd, Hg and Se also below the limit of analytical detection (**Table 4-3**). Similar to water quality, concentrations of Al were significantly higher ($p<0.01$) (**Appendix D**) in the claypans than the creekline (**Figure 4-9A**), with means of 2,188 mg/kg and 1,192 mg/kg respectively (**Appendix D**), likely a reflection of the higher clay content in the former. The concentrations of Fe, while tending to be higher in the surface waters of the claypans, showed no distinct differences in sediments across the sites (**Figure 4-9B**). .

Table 4-3: Sediment quality data recorded from Jones Creek and the claypans during the 2011 aquatic baseline study, in comparison to the ANZECC ISQG-High trigger values (all units presented in mg/kg unless stated).

Sediment Quality Parameters		Jones Creek												Claypans								ANZECC ISQG-High
		JC1		JC2		JC3		JC4		JC5		JC6		JC7		JC8		JC9		JC10		
		P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	
Basic and Nutrients	pH (unit)	7.1	7.4	6.7	7.5	7.0	7.4	7.0	6.6	6.9	7.3	6.7	7.0	6.7	6.5	6.5	7.4	6.8	7.2	7.1	7.3	
	MC (%)	16.4	3.1	19	17.1	9.6	8	7.1	14.6	17.9	17.5	19.6	10.2	14	13.8	17.6	17.2	17	13.5	12.4	13.3	
	EC (µS/cm)	19	39	1610	27	11	31	36	42	15	25	25	16	20	9	17	20	40	14	19	22	
	TSS	62	127	5230	88	36	101	117	136	49	81	81	52	65	29	55	65	130	46	62	72	
	TN	40	120	40	40	30	120	40	290	20	50	90	40	280	160	160	80	180	120	100	180	
	NO_2 and NO_3	<0.1	0.7	<0.1	<0.1	<0.1	0.4	0.1	<0.1	<0.1	0.2	<0.1	<0.1	0.5	<0.1	0.3	<0.1	0.3	<0.1	0.4	0.4	
	TKN	40	120	40	40	30	120	40	290	20	50	90	40	280	160	160	80	180	120	100	180	
	TP	38	62	32	28	37	67	52	83	39	37	30	55	171	139	159	82	82	126	155	220	
	TOC	0.06	0.08	0.04	0.05	0.04	0.1	0.07	0.06	0.05	0.06	0.07	0.05	0.23	0.29	0.15	0.03	0.37	0.23	0.06	0.16	
Anions and Cations	Cl	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	SO_4	<10	<10	<10	<10	<10	<10	20	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Ca	<10	<10	<10	<10	<10	10	<10	10	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Mg	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
	Na	10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	10	10	10	20	
	K	<10	10	<10	<10	<10	10	<10	<10	<10	<10	<10	<10	20	<10	20	10	20	<10	10	20	
Metals and Trace Elements	Al	1,260	1,310	750	1,190	1,380	1,750	770	1,610	800	1,370	1,440	680	2,090	2,010	2,920	1,100	1,800	1,910	1,950	3,720	
	As	<5	<5	<5	<5	<5	<5	<5	<5	6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	70
	Ba	10	20	10	<10	10	10	<10	20	90	10	30	20	10	<10	20	<10	<10	<10	310	120	
	Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	10
	Co	<2	<2	<2	<2	2	2	8	3	4	3	2	4	<2	<2	4	<2	3	2	18	11	
	Cr	81	62	32	93	136	150	59	210	30	89	65	26	60	48	89	41	59	65	58	67	370
	Cu	<5	<5	<5	<5	5	12	6	10	<5	9	<5	<5	<5	<5	8	<5	6	5	8	12	270
	Fe	17,600	18,000	9,800	20,600	28,400	27,400	18,500	35,400	7,500	18,500	11,200	10,600	9,680	9,380	16,300	5,900	11,400	13,400	15,500	21,000	
	Hg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1
	Ni	10	8	4	5	13	8	36	24	15	26	11	18	10	9	13	4	9	9	18	22	52
	Pb	6	<5	<5	<5	6	6	<5	<5	16	<5	<5	<5	<5	<5	5	<5	<5	<5	6	7	220
	S	n/a	<0.01	n/a	0.02	n/a	0.02	n/a	0.01	n/a	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	
	Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
	Zn	<5	<5	<5	<5	5	6	11	6	<5	7	5	5	8	12	8	<5	6	<5	8	12	410

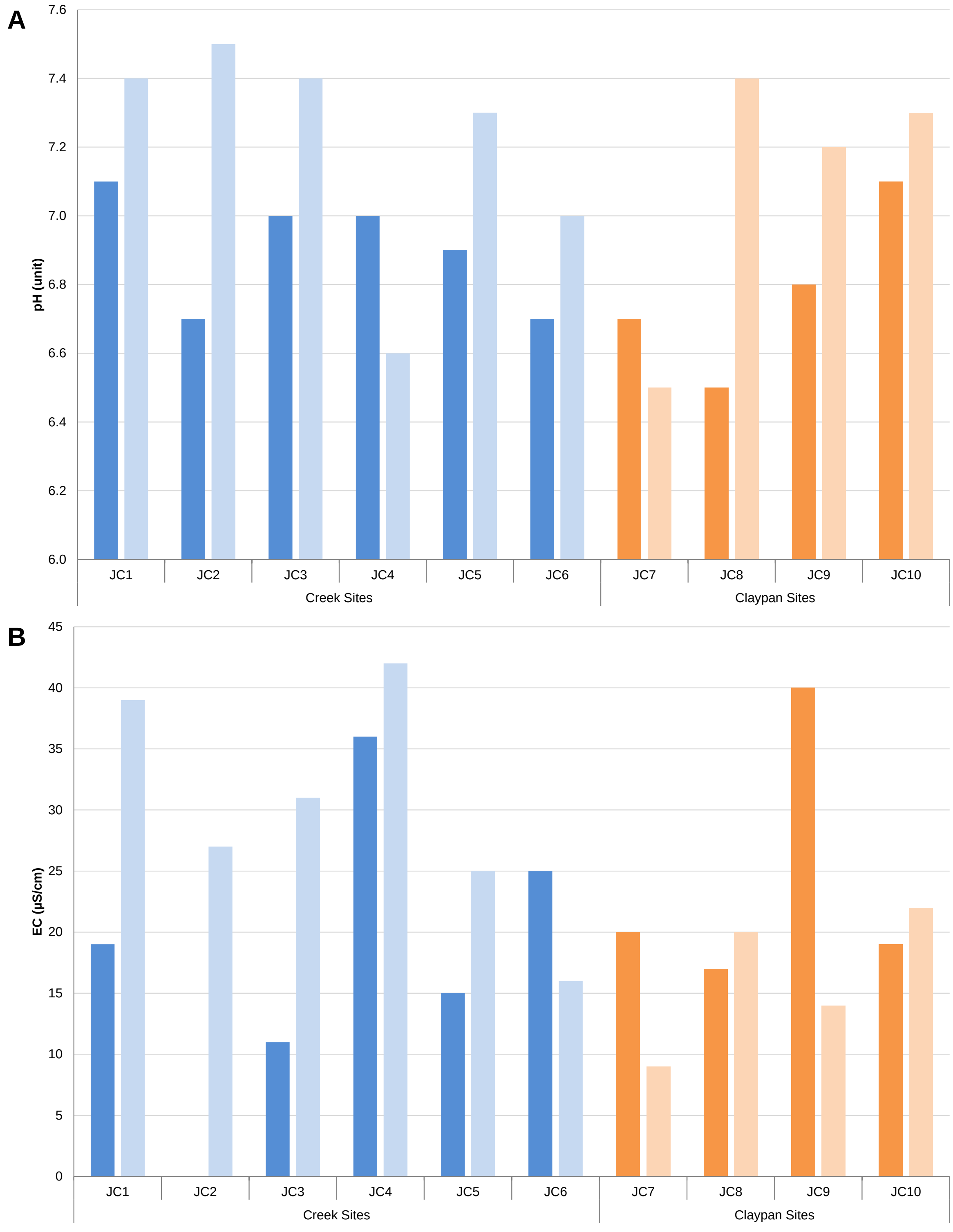


Figure 4-7: Changes in (A) pH and (B) salinity (EC) in the sediments of Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study. Note the outlier for JC2, phase 1 was excluded due to erroneous laboratory result.

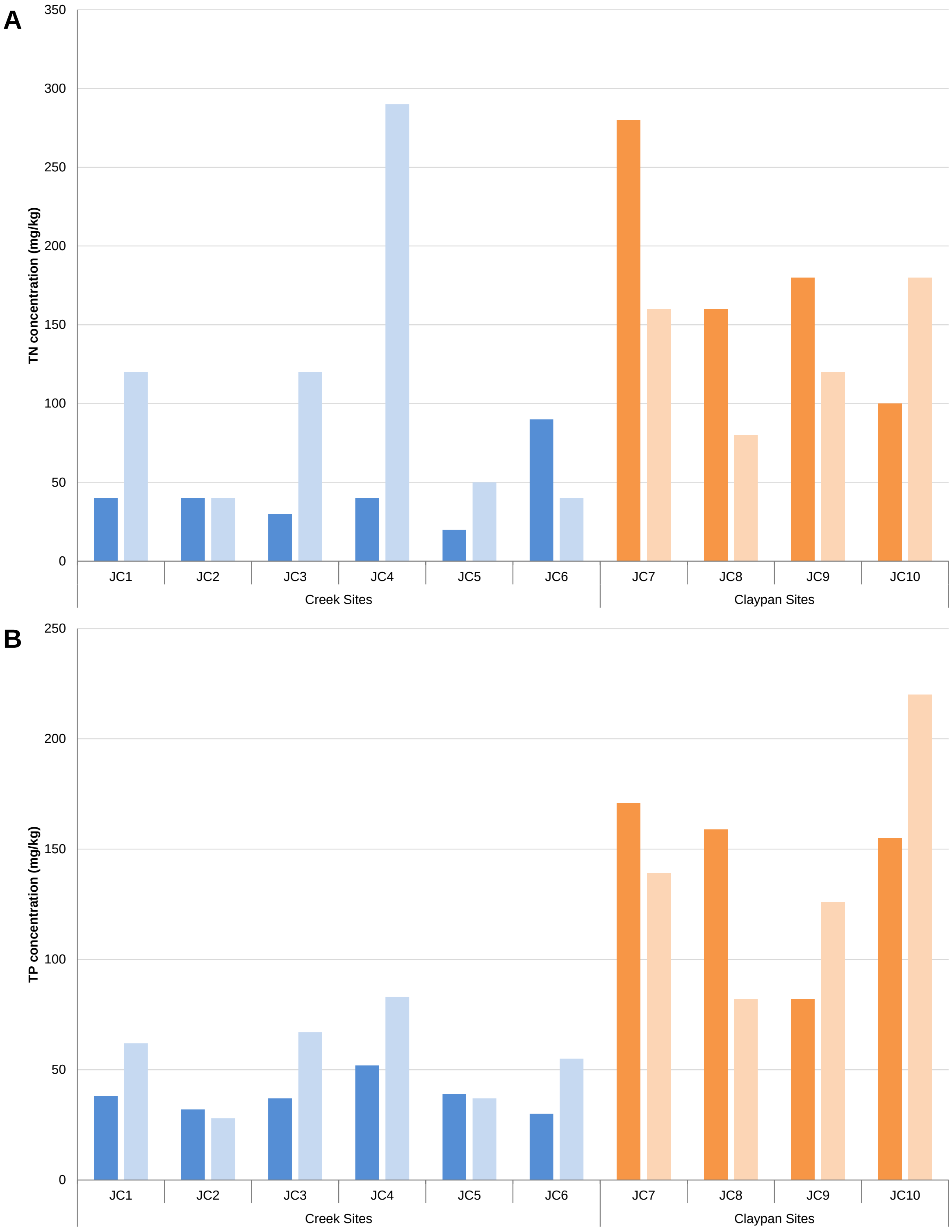


Figure 4-8: Changes in concentrations of (A) TN and (B) TP in the sediments of Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study.

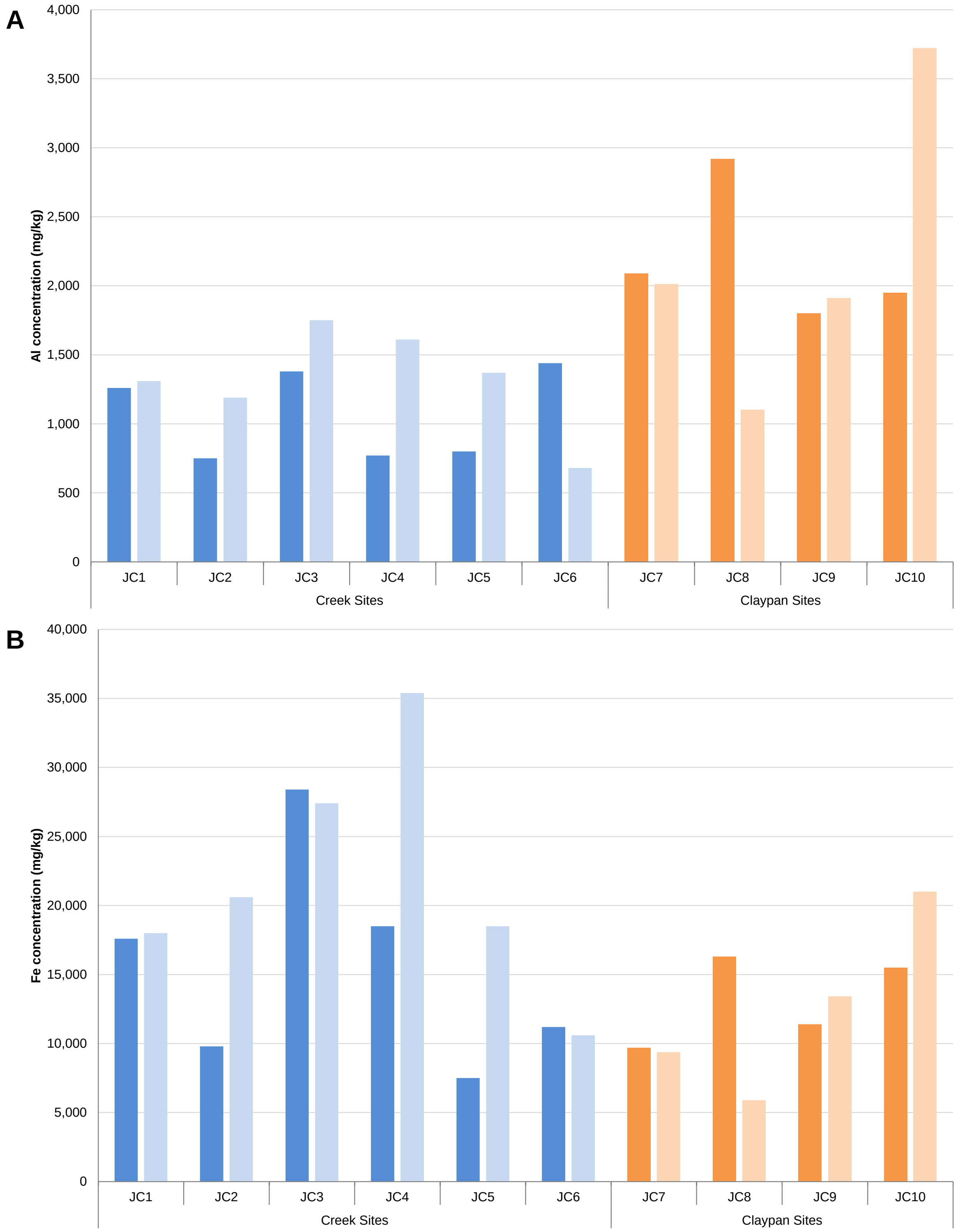


Figure 4-9: Changes in concentrations of (A) Al and (B) Fe in the sediments of Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2) during the 2011 aquatic baseline study.

The PCA of sediment quality from the 2011 aquatic baseline study (**Figure 4-10**) showed that there were differences between Jones Creek and the claypans due to nutrients (TN, TP and TOC) and the concentrations of Al. However, similarities were observed for parameters such as pH and salinity (EC), and metals including Cr, Fe and Ni. This is a function of the hydrological characteristics of the system (Kingsford and Thompson 2006), as well as the complex biological and chemical processes that occur, which cause changes in pH, ionic composition and metal concentrations over the duration of the hydroperiod (Howard 1998; Pulford and Flowers 2006). As with water quality, there were few differences observed between the two phases of this study.

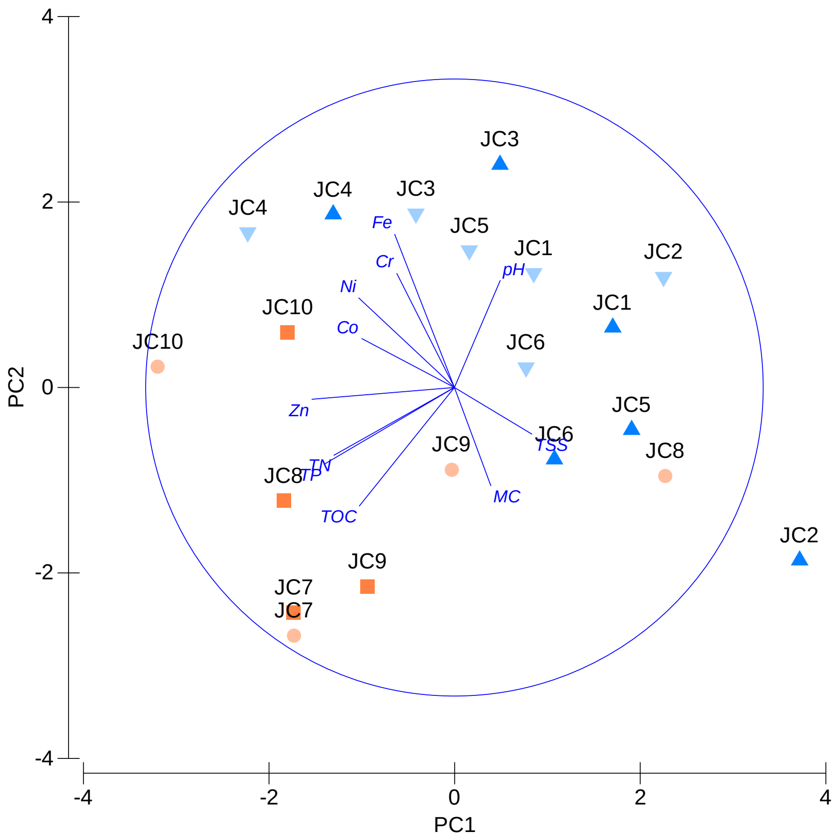


Figure 4-10: PCA plot of sediment quality data for Jones Creek (▲ = phase 1; ▼ = phase 2) and the claypans (■ = phase 1; ● = phase 2) during the 2011 aquatic baseline study (P1=phase 1, P2=phase 2). A total of 53.0 % of the variation was explained by the first two axes.

4.2.4 Algae

4.2.4.1 Phytoplankton

A total of 33 algal taxa, belonging to five phyla, were recorded from the Jones Creek and claypan phytoplankton samples, during both phases of the 2011 aquatic baseline study (**Table 4-4**). Previous studies on Australian inland riverine environments have found up to 34 taxa, occurring within a range of ephemeral river systems and water holes (McGregor *et al.* 2006). During this study, the most diverse phyla comprised Chlorophyta (green algae) and Bacillariophyta (diatoms) with 21 and nine taxa, respectively (**Figure 4-11A**). Cyanophyta (blue-green algae), Dinophyta (dinoflagellates) and Euglenophyta (euglenoids) were represented to a lesser extent, with one taxon each. All algae recorded were considered widespread, cosmopolitan genera, associated with freshwaters throughout Australia and overseas (Bowling 2009; Entwisle *et al.* 1997; Reynolds 1993).

In Jones Creek, up to 26 taxa were recorded, dominated by chlorophytes (**Figure 4-11C**), compared to 22 taxa in the claypans, which had a higher diversity of diatoms (**Figure 4-11B**). The mean species diversity in Jones Creek was also significantly higher (p=0.001) than the claypans (**Appendix E**), with more than 15 taxa recorded from JC4 and JC5 in phase 1 (**Figure 4-12**). However there was no significant difference in diversity between the two phases, although water analysis showed that Chl *a* (an indication of phytoplankton productivity) was significantly higher in phase 2 (p=0.025). This was attributed to an increase in planktonic and colonial algal growth at Jones Creek sites JC2 and JC3, and the claypan site JC10.

The most abundant taxa recorded from the creekline across both phases were *Mougeotia* sp. and *Spirogyra* sp. (**Table 4-4**); filamentous chlorophytes associated with slow-moving streams and freshwater lakes throughout Australia (Entwisle *et al.* 1997; John 2002). They are often found in association with other filamentous forms including *Oedogonium* and *Zygnema* (John 2002), also recorded from Jones Creek in this study. The widespread chlorophytes *Pseudosphaerocystis* sp. and *Cosmarium* sp. (Entwisle *et al.* 1997), were also common in most of the creek sites (JC2 to JC6). Chlorophytes are generally most prominent in freshwater lakes in cooler conditions over autumn and winter, with numbers strongly correlated with phosphorus levels (Gordon *et al.* 1981), and are also related to productive, freshwater ecosystems (Bowling 2009).

Periphytic diatoms (Bacillariophyta), such as *Nitzschia* sp., were frequently recorded from the phytoplankton samples, in both Jones Creek and the claypans (**Table 4-4**). This genus is prevalent in freshwater streams and lakes throughout Australia and the world (John 2000). In the claypans, the diversity and abundance of true planktonic algae was much lower than Jones Creek (**Appendix E**), a reflection of higher turbidity, with suspended particulates limiting light for photosynthesis (Rissik *et al.* 2009). However at JC10 in phase 2, there was a high abundance of the green alga *Kirchneriella* sp., a genus commonly associated with freshwater blooms in Australia and overseas (Entwisle *et al.* 1997; Soylu and Gonulo 2010). Blooms of certain algal taxa are known to occur in highly turbid waters, with some species able to harvest different wavelengths of light for growth and development (Rissik *et al.* 2009).

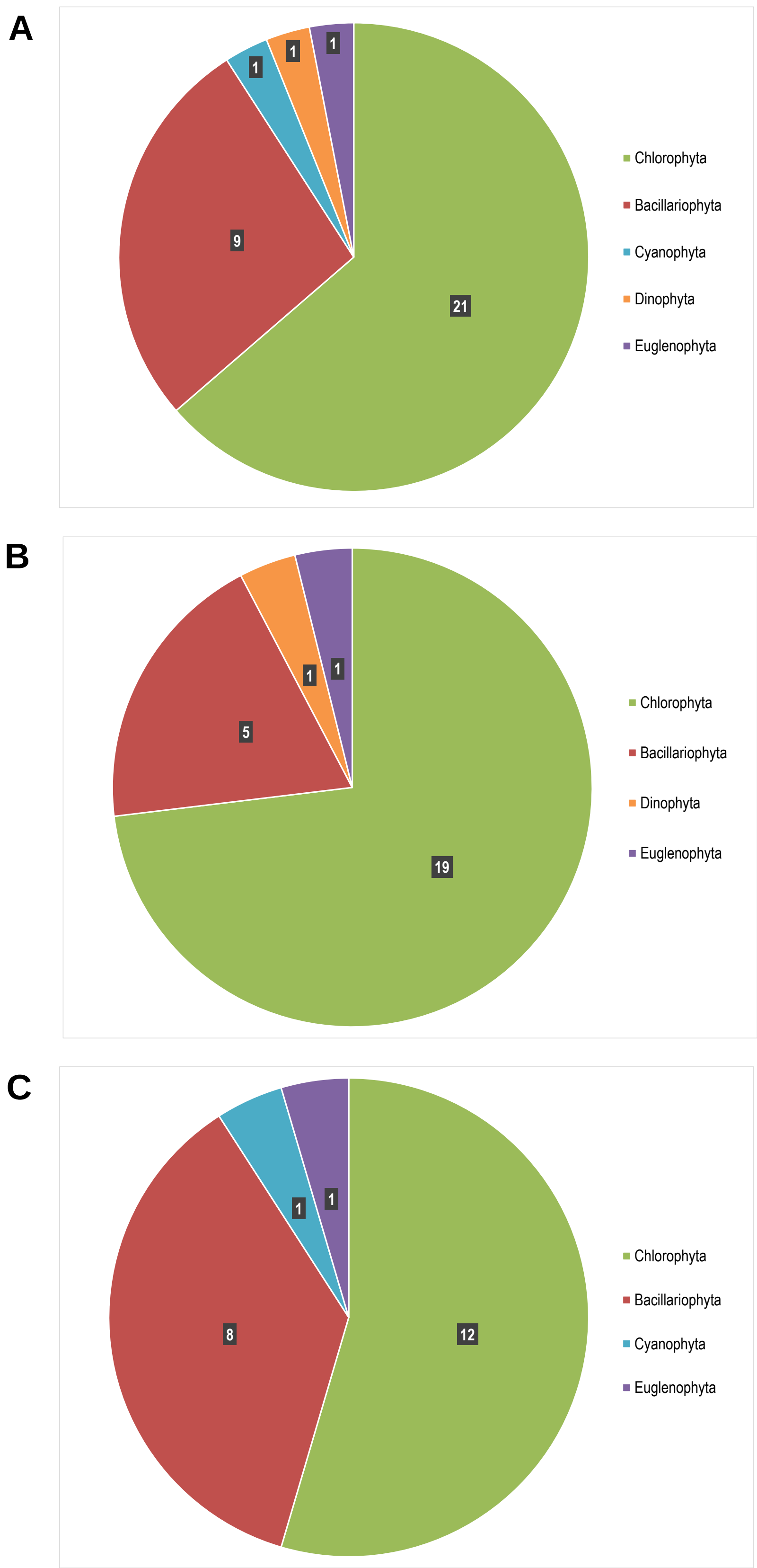


Figure 4-11: Diversity of phytoplankton taxa (per phyla) recorded in both phases of the 2011 aquatic baseline study; (A) Jones Creek and claypans, (B) Jones Creek and (C) claypans.

Table 4-4: Algal diversity and abundance recorded from Jones Creek and the claypans during the 2011 aquatic baseline study.

Phytoplankton Taxa	Jones Creek												Claypans							
	JC1		JC2		JC3		JC4		JC5		JC6		JC7		JC8		JC9		JC10	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Bacillariophyta																				
Achnanthidium sp.[PE]																				311
Cyclotella sp.[PL/PE]	12		2		3		3		26		1				2					
Encyonema sp.[PE]				5						9		29				2		12		
Gomphonema sp.[PE]			1		19		17		24		23				1					
Gyrosigma sp.[PE]																		2		1
Hantzschia sp.[PE]																		1		
Navicula sp.[PE]																2		2		
Nitzschia sp.[PE]				4		3	8		17	7		24		7	2	7		5		
Pinnularia sp.[PE]					1		2		6		3									
Chlorophyta																				
Ankistrodesmus sp.[C]				1		1														
Dictyosphaerium sp.[C]																			7	3
Kirchneriella sp.[C]										1		1								20
Pseudosphaerocystis sp.[C]			9	6	13		21		7	4	14	4							1	3
Pediastrum sp.[C]					5		4				1	4								
Bulbochaete sp.[F]						2									20					
Cladophora sp.[F]							9		11	2	1	8								
Mougetia sp.[F]	2		22	33	18	90	19		27	89	21	4						1		
Oedogonium sp.[F]		DRY	22	11	37	20	152	DRY	60		16								3	
Rhizoclonium sp.[F]									1											
Spirogyra sp.[F]			3	59		283	7		5	32	47	17	2		76	20				
Stigeoclonium sp.[F]												1								
Ulothrix sp.[F]									7		26									
Zygnema sp.[F]					5		46		23	5	38	1							1	
Chlamydomonas sp.[PL]															750					
Closterium sp.[PL]				1								2			1					
Cosmarium sp.[PL]				3	7	2	8		23	20	8	41			1	3				1
Oocystis sp.[PL]				2			10		4	1	2	31								
Micrasterias sp.[PL]				5			1													1
Scenedesmus sp.[PL]				20	5	56	4		2	5		15								
Staurastrum sp.[PL]				2			10		11	1	8	6								
Cyanophyta																				
Anabaena sp.[PL]																2				
Dinophyta																				
Peridinium sp.[PL]			8	1						1										
Euglenophyta																				
Euglena sp.[PL]	1				3		1		4						1					
Abundance	**15**		**67**	**153**	**116**	**457**	**322**		**258**	**177**	**209**	**188**	**2**	**7**	**854**	**36**	**0**	**23**	**12**	**340**
Diversity	**3**		**7**	**14**	**11**	**8**	**17**		**17**	**13**	**14**	**15**	**1**	**1**	**9**	**6**	**0**	**6**	**4**	**7**

Taxa found in low abundance during 2011 aquatic baseline study belonged to representatives from Cyanophyta, Dinophyta (*Peridinium* sp.) and Euglenophyta (*Euglena* sp.) (**Table 4-4**), ubiquitous genera that occur throughout Australian waters, and are often known to form blooms in nutrient rich lakes (Entwisle *et al.* 1997). A single cyanobacterium; *Anabaena* sp., was recorded from JC8 in phase 2, and while potentially toxic (Bowling 2009), was not considered to be harmful due to its limited abundance. Previous studies have found that low light availability (corresponding with high turbidity and TDS in the claypans) precludes blue-green algal growth (Geddes 1984).

Differences in the composition of algae between Jones Creek and the claypans was reflected in the hierarchical classification (**Figure 4-13**), attributed to habitat characteristics. While the creekline comprised clear pools dominated by filamentous chlorophytes, the claypans generally had limited planktonic algae and a higher abundance of periphytic diatoms, associated with the high turbidity. The Jones Creek sites also had a higher degree of species similarity (up to 85%), in comparison to the claypan sites (up to 45%). There was minor temporal differentiation between the phases ($p>0.05$), due to the relatively consistent water and sediment quality (**Appendix E**).

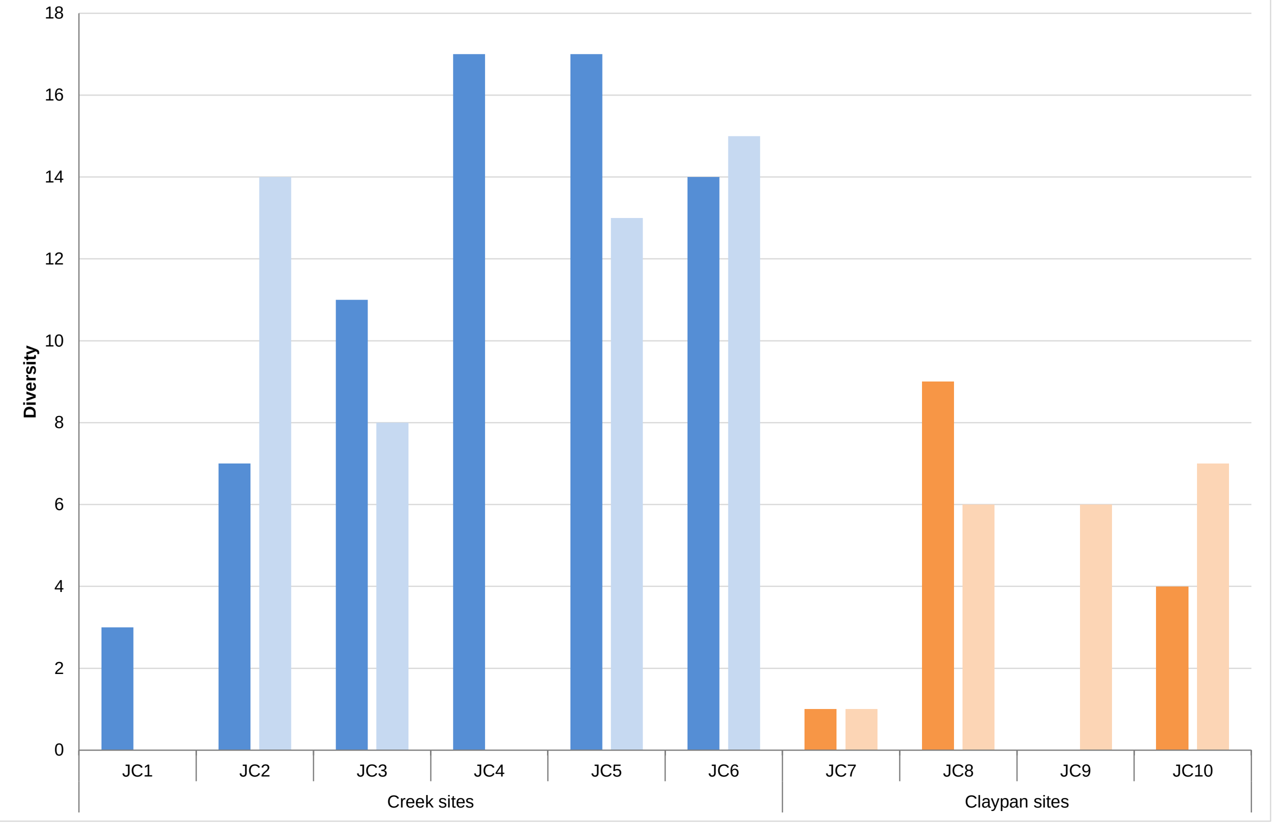


Figure 4-12: Diversity of algal taxa recorded from Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2), during the 2011 aquatic baseline study.

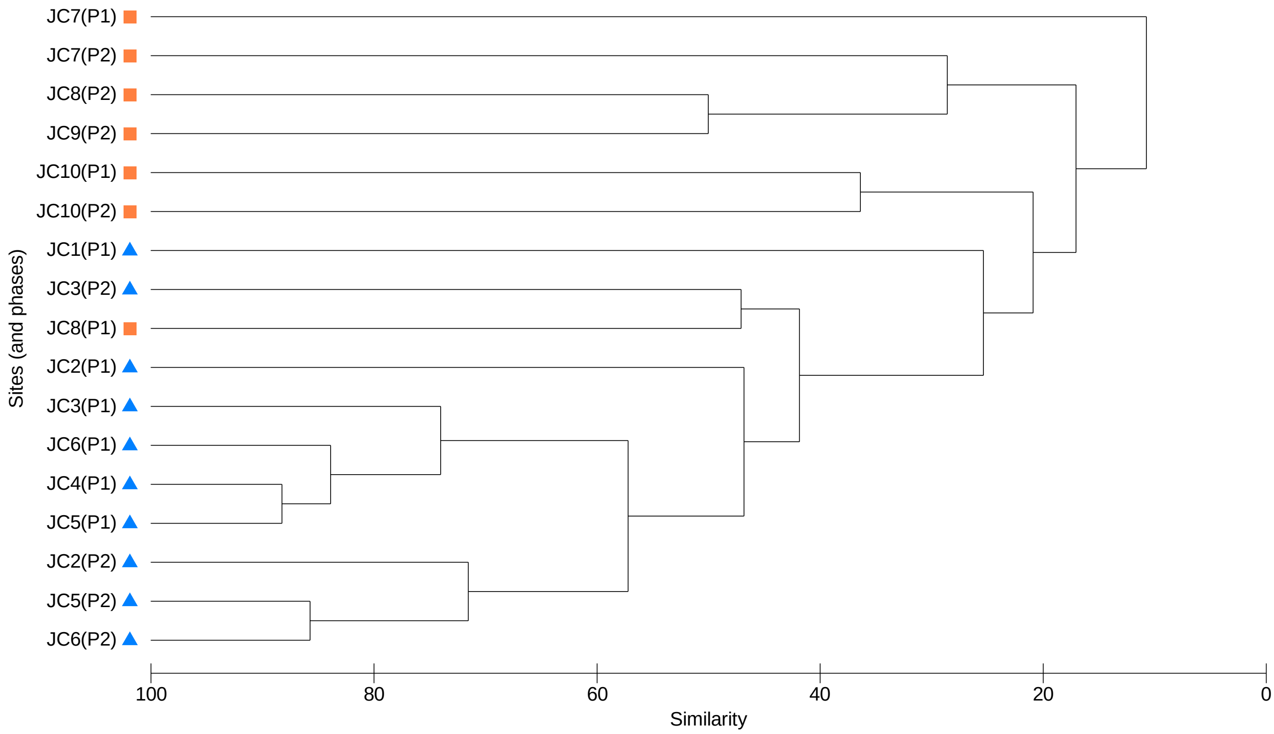


Figure 4-13: Dendrogram showing similarity in species composition of algal taxa recorded from Jones Creek (▲) and the claypans (■) during the 2011 aquatic baseline study.

4.2.4.2 Diatoms

Thirty five diatom taxa were recorded in the periphyton samples from Jones Creek and the claypans during the 2011 aquatic baseline study (**Table 4-5; Figure 4-14A**). This is typical of freshwater habitats in the wheatbelt region of Western Australia and eastern parts of Australia, where more than 30 species have been identified from salinities <5,000 µS/cm (Blinn *et al.* 2004; Taukulis 2007). In this study, the taxa belonged to fourteen different genera, with representatives including *Eunotia*, *Fragilaria*, *Gomphonema*, *Navicula, Pinnularia* and *Stauroneis* commonly associated with fresh and circumneutral waters globally (Camburn and Charles 2000; Foged 1978; John 2000). The most diverse genera belonged to Navicula and Pinnularia, with five taxa each (**Figure 4-14A**). Although species diversity was higher in the claypans compared to Jones Creek, with 32 and 21 taxa, respectively (**Figure 4-14B-C**), there were similarities in species composition.

The most frequently recorded taxa included *Encyonema minutum*, *Gomphonema auritum*, *Gomphonema parvulum*, *Nitzschia palea* and a number of *Pinnularia* species, which were widespread in the creek and claypans across both phases (**Table 4-5**). These are all considered discriminating taxa for freshwater and circumneutral environments in Australia (Foged 1978; John 2000; Taukulis 2007; Thomas 2007), and comparable waterbodies throughout the world (Camburn and Charles 2000; Czarnecki and Blinn 1978; Ehrlich 1995; Gasse 1986). In Jones Creek *Nitzschia palea* was the most abundant taxon, while in the claypans *Gomphonema parvulum* was the most dominant species (**Table 4-5**).

There were several diatom taxa recorded from Jones Creek and the claypans that are associated with broad salinity and pH ranges, including *Luticola mutica* and *Hantzschia amphioxys* (**Table 4-5**). Both taxa usually occur in more saline environments (Ehrlich 1995; Taukulis 2007), however are also known from freshwaters (Ehrlich 1995). They are commonly identified from eroded sediments (John 2000), and their presence during this study reflects the high velocity flow of surface waters during major flood events.

While species composition was similar throughout the system, the diversity was higher in the claypans, with a maxima of 21 taxa recorded from the claypan site JC7, compared to eleven taxa from the creekline site JC6 (**Figure 4-15**). Claypan sites supported a significantly higher ($p<0.001$) mean number of species than creekline sites, although there was no difference between phases (**Appendix E**). This may be attributed to higher nutrient levels (TN/TP) and silica concentrations (used for growth) in the claypans, supporting a more diverse diatom assemblage. While there are many factors that influence diatoms, a relatively small number are considered to be primary variables and these include nutrients, pH and salinity (Battarbee *et al.* 2001).

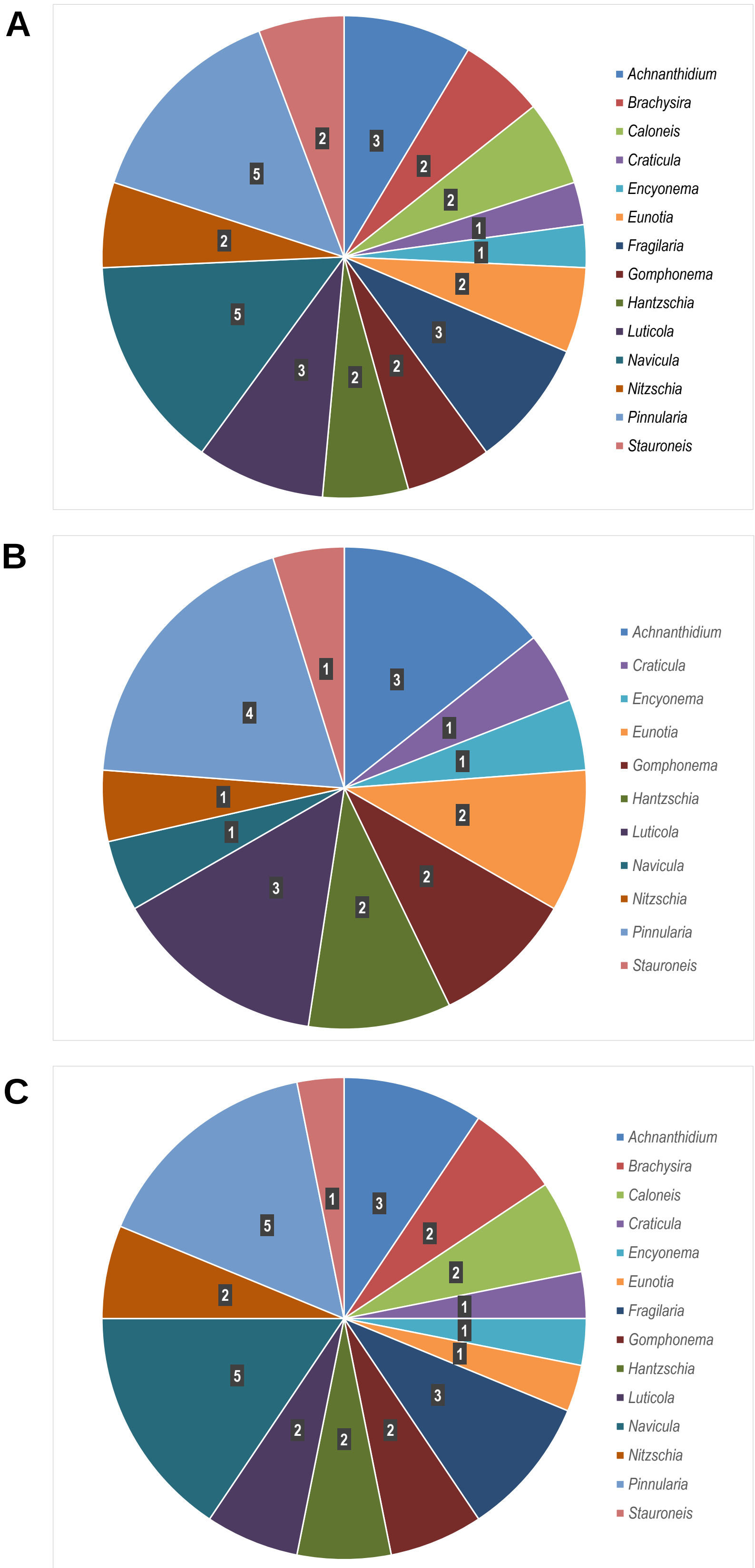


Figure 4-14: Diversity of diatom taxa (per genera) recorded in both phases of the 2011 aquatic baseline study; (A) Jones Creek and claypans, (B) Jones Creek and (C) claypans.

Table 4-5: Diatoms recorded from Jones Creek and the claypans during the 2011 aquatic baseline study.

Diatom Taxa	Jones Creek												Claypans							
	JC1		JC2		JC3		JC4		JC5		JC6		JC7		JC8		JC9		JC10	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Achnanthidium binodis		2	1	2						1	1		4	1			3			3
Achnanthidium exigua											1		1	1		4				
Achnanthidium oblongella													2	3	10	1		19	58	13
Brachysira brebissoni													1							1
Brachysira vitrea																5				
Caloneis bacillum													1							
Caloneis ventricosa													5			2				
Craticula cuspidata										2							2			
Encyonema minutum	15	17	7	34	23	38	24	56	29	45	30	62			5	5				
Eunotia sp. aff. *fallax*	3						4						8	6			2		4	
Eunotia pectinalis		1						1												
Fragilaria brevistriata																	1			
Fragilaria vaucheriae													13							
Fragilaria construens													3	3					1	1
Gomphonema auritum	3	5	4	19	19	9	8	9	3	4	4	12			6	1	8	4		
Gomphonema parvulum		4	2	27	11	7	4	2		4	2	7		8	59	43	7	4		
Hantzschia amphioxys	9		2		1	1		1	1	5	1		8	7		2	11	10	2	42
Hantzschia sp. 1 (JC2011)									1	3		6	3	4				1	5	7
Luticola cohnii							1													
Luticola mutica	4			1		1		1	3		1			1			4			
Luticola nivalis				2							1		1	1				1		
Navicula bicontracta													1		2				2	
Navicula cryptocephala													3	7	1	3			1	1
Navicula sp. aff. *tenelloides*													3	13	5	2		2	5	5
Navicula sp. aff. *festiva*		2			1								4	1			7			
Navicula halophila													5	8	3	1		11	1	6
Nitzschia palea	57	68	75	15	39	27	55	26	56	29	57	13	20	10	4	16	19	15	7	6
Nitzschia paleacea																	4			
Pinnularia borealis	2	1	3		2	8			1	1				1			8	5		3
Pinnularia gibba	3					3	2			6					1			13		2
Pinnularia appendiculata	3		3		3	2	1	1	4		1					8	4			
Pinnularia sp. aff. *divergens*	1		3			4		3	1				1			2				
Pinnularia subcapitata													12	24	4	5	17	15	14	10
Stauroneis anceps					1		1		1		1									
Stauroneis dubitalis													1	1			3			
Diversity	**10**	**8**	**9**	**7**	**9**	**10**	**9**	**9**	**10**	**10**	**11**	**5**	**21**	**18**	**11**	**15**	**15**	**12**	**11**	**13**

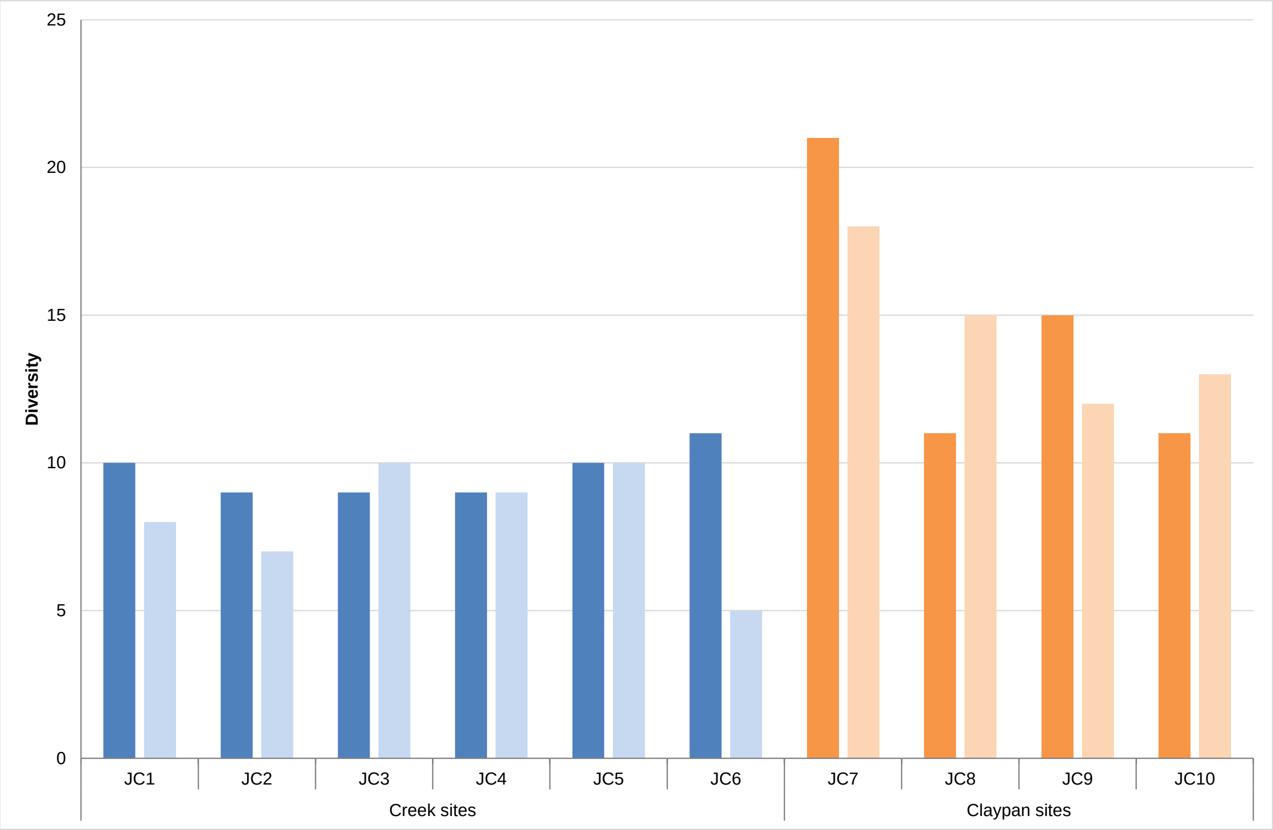


Figure 4-15: Diversity of diatom taxa recorded from Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2), during the 2011 aquatic baseline study.

There was at least 30% similarity in species composition across all sites during this study (**Figure 4-16**). Previous studies have also shown comparable assemblages in still and flowing waters throughout Western Australian waters (Blinn and Bailey 2001; Taukulis 2007), likely a reflection of the efficient dispersal mechanisms of diatoms (Blinn 1995). However there were still distinct assemblages associated with the creek and claypan sites. The creek sites had the most consistent diatom community structure, with more than 60% similarity in both phases (**Figure 4-16**). In contrast, the claypan sites were more variable, reflecting the higher diversity of diatoms identified from these sites (**Figure 4-15**).

The phytoplankton and diatom studies undertaken as part of the 2011 aquatic baseline aquatic study will substantially increase knowledge on the algal flora of the region. Few studies have been published on the algal communities of Australian riverine systems and on the composition of planktonic and periphytic communities (McGregor *et al.* 2006). In particular, this study provides important baseline information on the microalgae inhabiting an ephemeral creek in the Northern Goldfields region.

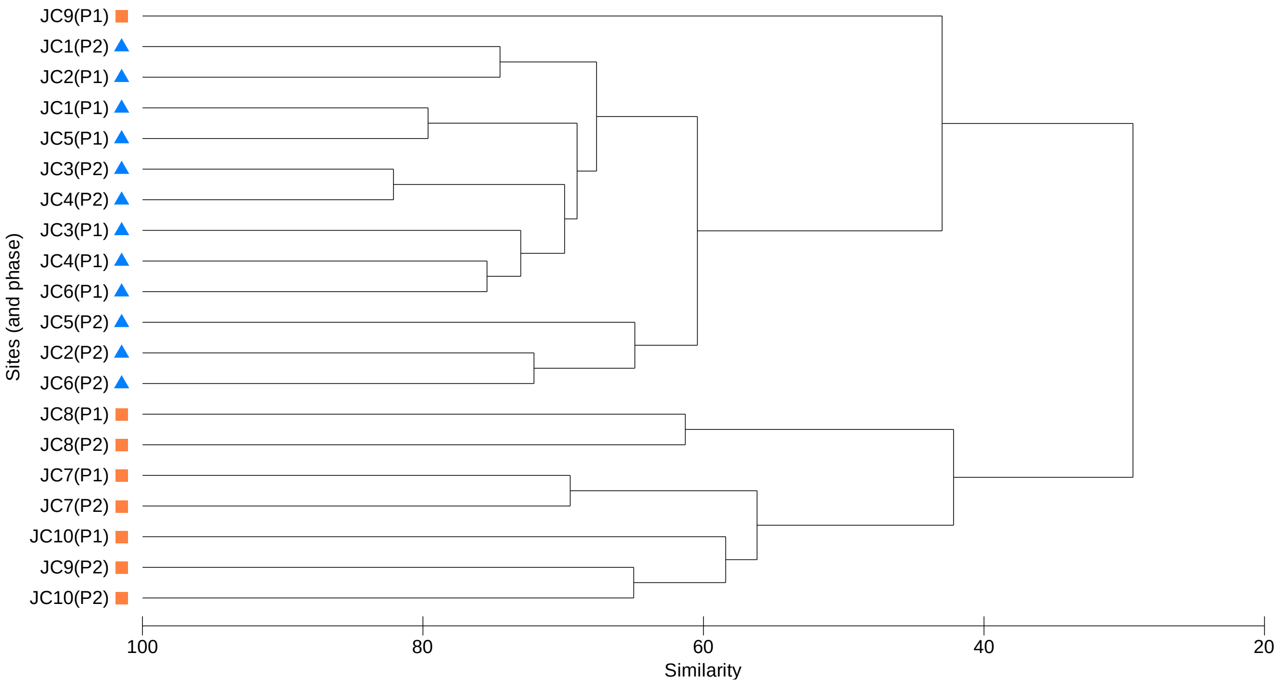


Figure 4-16: Dendrogram showing similarity in species composition of diatom taxa recorded from Jones Creek (▲) and the claypans (■) during the 2011 aquatic baseline study.

4.2.5 Aquatic Invertebrates

In total, 132 aquatic invertebrate taxa (including microinvertebrates and macroinvertebrates) were recorded from Jones Creek and the claypans in 2011 aquatic baseline study, representing five main groups (**Appendix F**). This was comparable to the 2005 aquatic study, in which 124 taxa were identified (Wetland Research and Management 2005). The groups in this study comprised taxa belonging to Rotifera, Amoebozoa, Gastrotricha, Insecta and Crustacea (**Figure 4-17A**), also consistent with the aquatic studies undertaken in 1992 and 2005 (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005), reflecting the resilience of aquatic invertebrates inhabiting temporary waters. Species diversity was relatively consistent between the creek and claypans (93 and 90 taxa, respectively) (**Figure 4-18**), however the composition of taxa (**Figure 4-17B-C**), and abundance of specimens showed substantial variation (**Figure 4-18**).

The majority of invertebrate abundance during this study was attributed to rotifers (**Appendix F**), representing a typically ubiquitous microfaunal element within Australian freshwaters (Ingram *et al.* 1997; Williams 1980). They are considered resident taxa, producing desiccation-resistant stages that enable them to persist during extended dry periods (Ingram *et al.* 1997; Wetland Research and Management 2005). The diversity of rotifers was also high (49 taxa) (**Figure 4-17A**), characterised by *Keratella procurva* in Jones Creek, which accounted for the majority of invertebrates recorded in both phases (**Figure 4-18**). In the 2005 aquatic study, this taxon was common in the creek (Wetland Research and Management 2005) and future sampling is likely to find additional rotifer taxa, which often dominate the microinvertebrate community of inland rivers (Boulton *et al.* 2006).

The remaining invertebrate groups that were prevalent in this study comprised insects (**Plate 4-4A-F**) and crustaceans (**Plate 4-5A-F**), with 46 and 31 taxa, respectively (**Figure 4-17A**). These two groups represent differing levels of dependence on aquatic habitats. The insect fauna, which dominated Jones Creek (**Figure 4-17B**), can be considered transient or opportunistic species, with mobile adult stages that do not require surface water (Gooderham and Tsyrlin 2002). They are unlikely to be restricted to the creek or claypans, and would utilise a range of surface water habitats in the broader area following major rainfall events. Jones Creek had nearly twice the number of insect taxa as claypan sites (**Figure 4-17B-C**), particularly of Coleoptera (beetles) and Diptera (fly larvae), groups that are common throughout Australian inland waters (Williams 1980). The greater number of insect taxa also contributed to a typically higher diversity of taxa recorded from the creek sites (**Figure 4-19**).

Some of the most dominant insect taxa in the creek comprised *Eretes australis* (Coleoptera; water beetle), *Anisops stali* (Hemiptera; backswimmer) and *Hemianax papuensis* (Odonata; dragonfly larvae), which occurred in at least four of the six sites during the 2011 study (**Appendix F**). All are widespread throughout Western Australia, the Northern Territory and eastern Australia (Department of Environment Water Heritage and the Arts 2011; Humphrey *et al.* 2008), and have highly mobile adult stages, which enables rapid colonisation of newly inundated wetlands (Gooderham and Tsyrlin 2002).

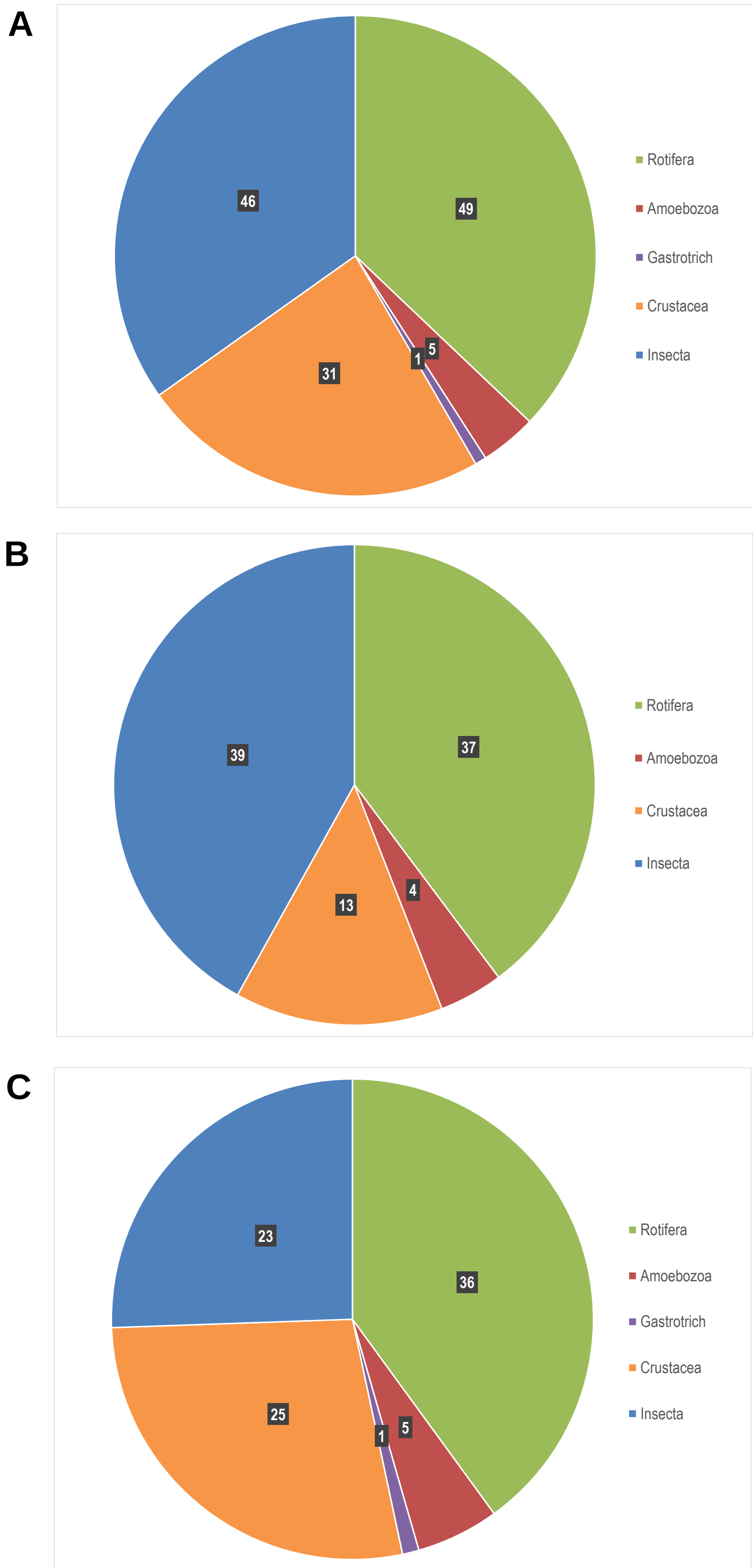


Figure 4-17: Diversity of aquatic invertebrate taxa (per group) recorded in both phases of the 2011 aquatic baseline study; (A) Jones Creek and claypans, (B) Jones Creek and (C) claypans.

Crustaceans were more diverse in the claypans than the creek (**Figure 4-17B-C**), and are considered permanent aquatic inhabitants. This was typified by groups including Copepoda (copepods), Ostracoda (ostracods or seed shrimp) and Branchiopoda (fairy shrimp), which all produce desiccation-resistant eggs (resting stages) that allow them to persist in the sediments during dry periods (Williams 1980;1985). The resting stages of two crustacean species were also identified in the sediments of the claypan site JC10 during the 2011 study (**Appendix G**). These likely belonging to the two fairy shrimp species recorded from the surface waters of the claypans; *Branchinella halsei* and *Branchinella occidentalis*. *Branchinella halsei* has been previously found in the north-west (Carnarvon) and wheatbelt region (Newdegate) of Western Australia, while *Branchinella occidentalis* is characteristic of turbid claypans, occurring from the northern coast through to the Goldfields Region of Western Australia (Timms 2002).

Most of the crustacean taxa in the claypans also occur more widely (Timms 2008;2009; Timms *et al.* 2006). For example, the notostracan shield shrimp *Triops australiensis* is common in ephemeral creeks throughout Australia (Jones and Morgan 2002; Williams 1980). In addition, there are several yet to be described taxa found in this study likely to occur elsewhere. For example, the conchostracan clam shrimp *Caenestheriella* sp. (**Appendix F**) belongs to a group of currently undescribed taxa (related to *Caenestheriella packardi*), recorded from various waterbodies in the arid zone (B. Timms pers. comm. 2011). One crustacean taxon however, was only identified from the claypans; the conchostracan *Eocyzicus* sp. OES1 (**Appendix F**), which almost certainly represents a new species of clam shrimp (B. Timms pers. comm. 2011). While it is likely that the distribution range of this taxon extends beyond the claypans and floodplain area, further investigation would be required to verify this.

The difference in invertebrate assemblages between Jones Creek and the claypans is a reflection of the hydrology (water quality and retention time) and habitat availability. The creekline is characterised by clear water (with short retention times), coarse, sandy sediments and abundant microhabitats in the form of woody and leafy debris, particularly suitable for aquatic insects and their larvae (Gooderham and Tsyrlin 2002). Taxa such as *Austrolestes analis* (Odonata; damselfly larvae), *Kiefferulus intertinctus* (Diptera; chironomid larvae) and *Dineutus australis* (Coleoptera; whirligig beetle), were generally restricted to the creek sites, and are known to require large amounts of vegetation or debris during some stage of their life cycle (Gooderham and Tsyrlin 2002; Hawking and Smith 1997; Ingram *et al.* 1997).

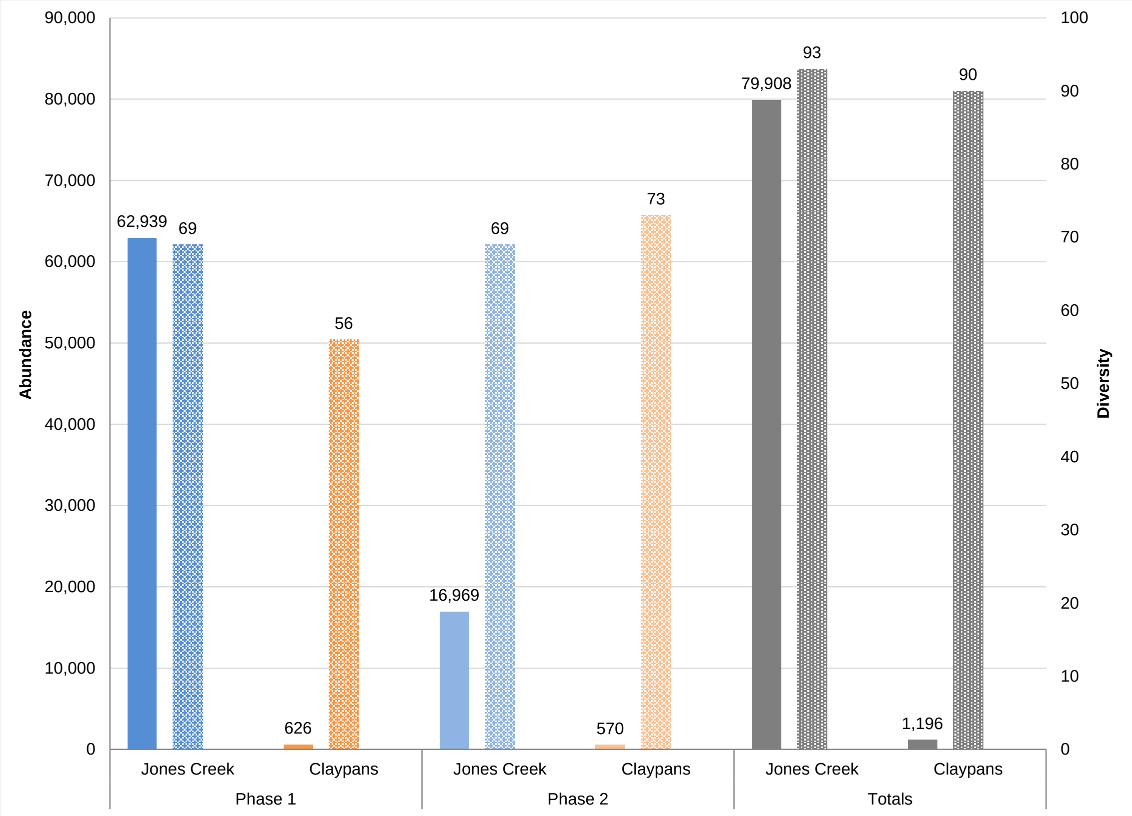


Figure 4-18: Summary of diversity (solid fill) and abundance (patterned fill) of aquatic invertebrates recorded during the 2011 aquatic baseline study.

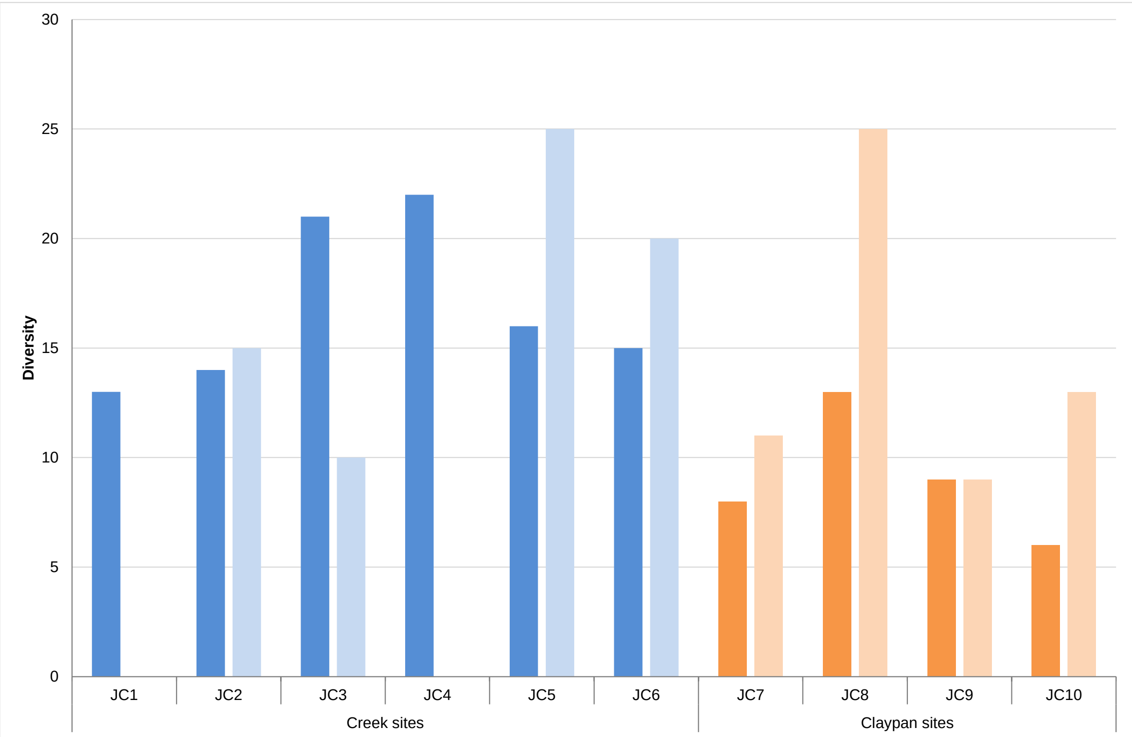


Figure 4-19: Diversity of aquatic invertebrate taxa recorded from Jones Creek (■ = phase 1; ■ = phase 2) and the claypans (■ = phase 1; ■ = phase 2), during the 2011 aquatic baseline study.

The increased turbidity and longer hydroperiod of the claypans is more suitable for crustaceans, which are well documented from inland waters with high suspended solids (Timms *et al.* 2006). The increased turbidity, lack of physical habitat within the water column (restricting refugia) (Boulton *et al.* 2006), and more exposed environment is also likely to account for the limited number of insect taxa in the claypans. Reduced insect diversity may also be influenced by predation from the carnivorous notostracan shield shrimps, which are known to have a strong effect on invertebrate faunal composition (MacDonald *et al.* 2011).

While there was no significant difference ($p>0.05$) in species diversity between the creek and claypans, or between the two phases of the study (**Appendix E**), differences in species assemblages were shown in the hierarchical classification (**Figure 4-20**). Overall there was close to 30% similarity in species composition across both habitats. However within Jones Creek the aquatic invertebrate assemblage was up to 70% similar, with more variation in the claypans, where up to 55% similarity was indicated, attributed to the dominance of the insect and crustacean groups in their respective areas.

The limited successional change in aquatic invertebrate fauna between phases was also evident in the hierarchical classification (**Figure 4-20**), related to water retention times. With water persisting in the claypans for longer (Berry 2011), it is likely changes in the assemblage of aquatic invertebrates will occur towards the end of the hydroperiod (Wetland Research and Management 2005). Further investigation of the resident fauna in the claypans would provide information on successional change within this part of the system.

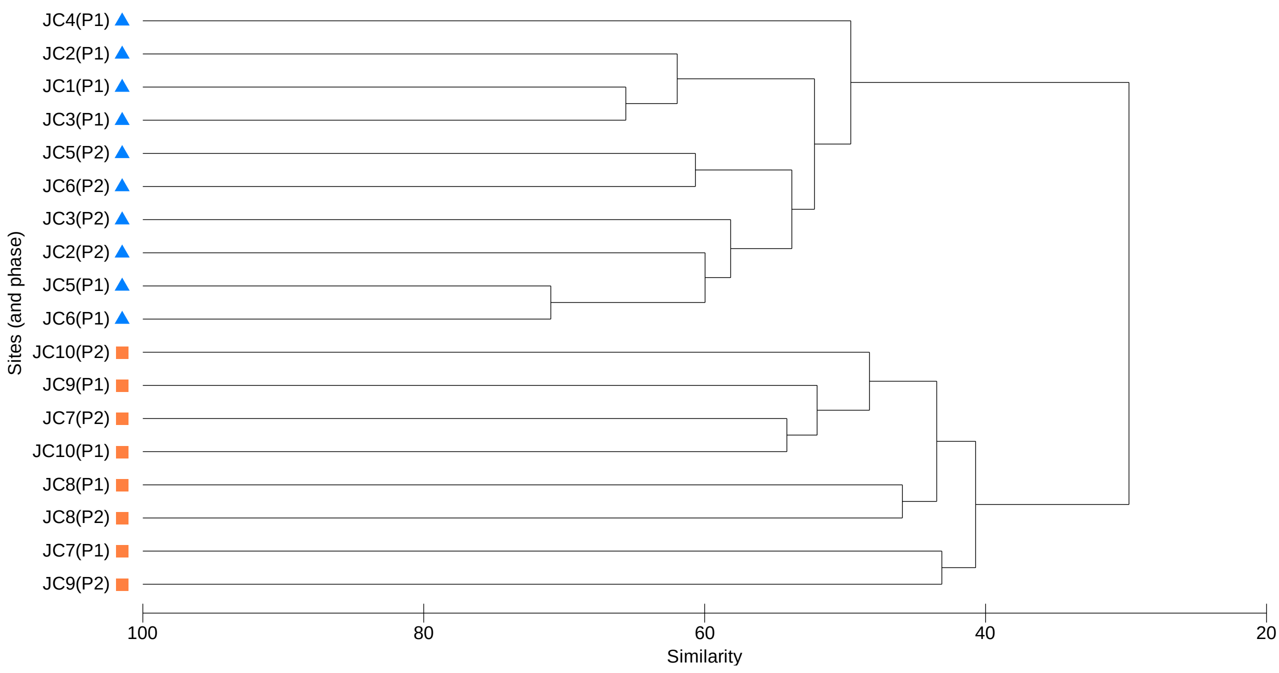


Figure 4-20: Dendrogram showing relative similarity in species composition of aquatic invertebrate taxa recorded from Jones Creek (▲) and the claypans (■) during the 2011 aquatic baseline study.

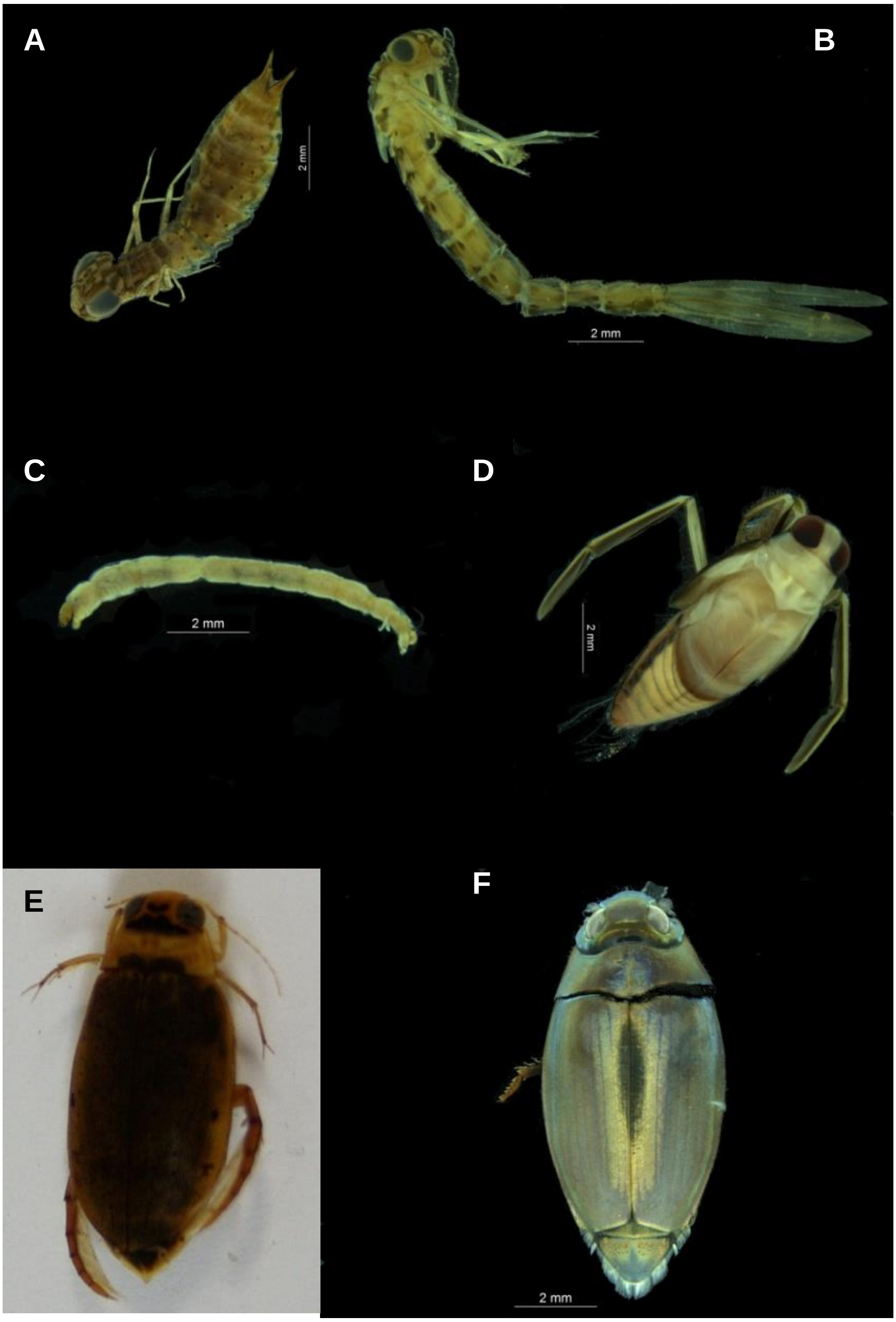


Plate 4-4: Aquatic invertebrates recorded from Jones Creek during the 2011 aquatic baseline study. (A) *Heminiax papuensis*, (B) *Austrolestes analis*, (C) *Kiefferulus intertinctus*, (D) *Anisops stali*, (E) *Eretes australis* (length=1.7 cm) and (F) *Dineutus australis*.

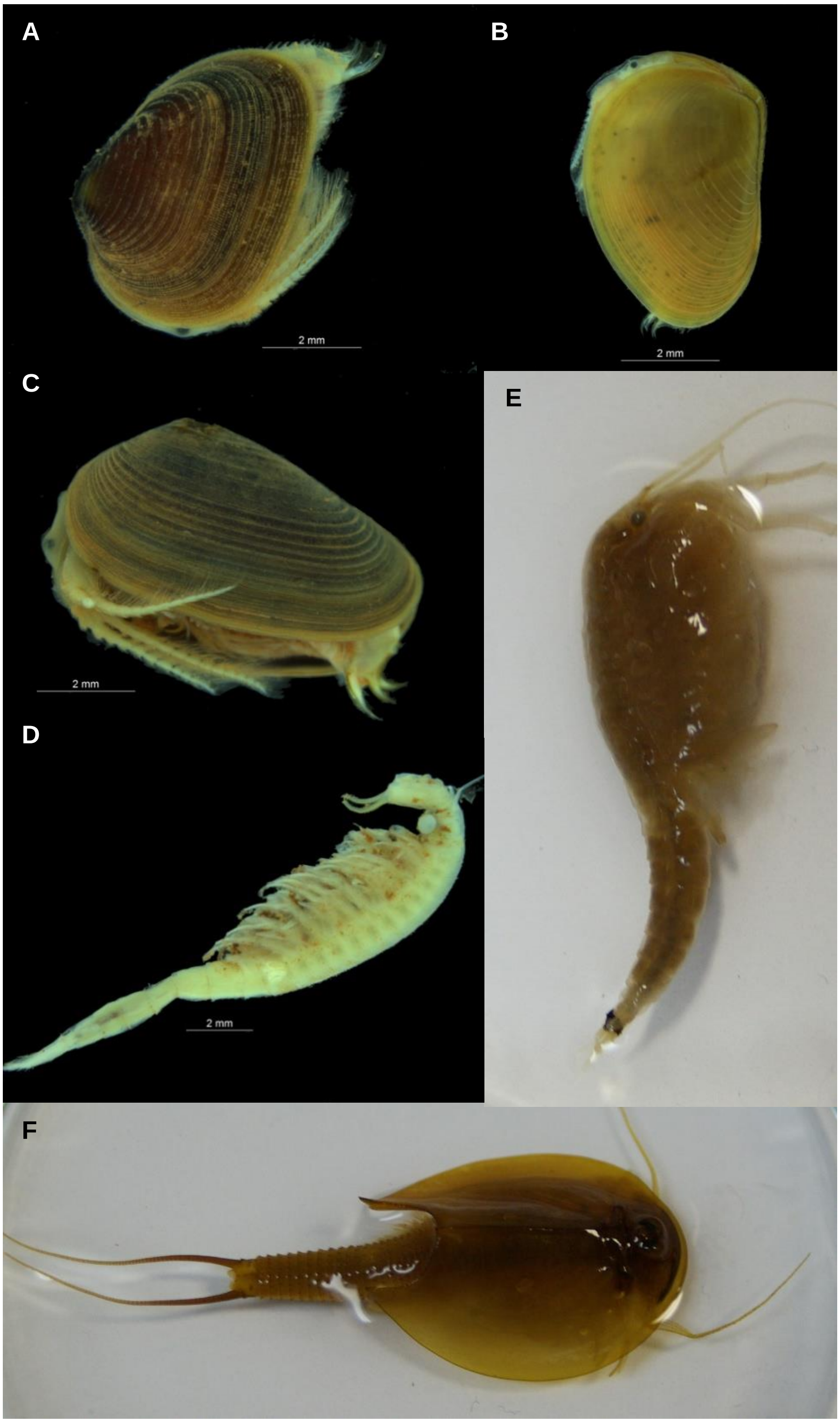


Plate 4-5: Aquatic invertebrates recorded from the claypans during the 2011 aquatic baseline study. (A) *Caenestheriella* sp., (B) *Eocyzicus* sp. OES1, (C) *Caenestheria* sp., (D) *Branchinella halsei*, (E) *Branchinella occidentalis* (length=3.1 cm) and (F) *Triops australiensis* (length=4.1 cm).

4.2.6 Vertebrate Fauna

Frogs were common during the 2011 aquatic baseline study (**Table 4-6**), with three adult species identified; *Cyclorana maini*, *Cyclorana platycephala* and *Litoria rubella* (**Plate 4-6A-E**). A fourth species belonging to immature tadpoles was also recorded from the creek (likely from the genus *Neobatrachus* (**Table 4-6, Plate 4-6F**). Jones Creek supported a higher diversity of species in comparison to the claypans (four and two taxa, respectively), likely reflecting the broader range of habitats available. All four taxa are considered widespread, and are associated with inland rivers throughout Western Australia, as well as having rapid breeding cycles to cope with their temporary environments (Anstis 2002; Cronin 2009; Robinson 1998).

Table 4-6: Frog taxa recorded from Jones Creek and the claypans during the 2011 aquatic baseline study (shaded circle indicates presence).

Frog Taxa	Jones Creek						Claypans			
	JC1	JC2	JC3	JC4	JC5	JC6	JC7	JC8	JC9	JC10
Main's Frog *Cyclorana maini*					●	●	●	●	●	
Water-holding Frog *Cyclorana platycephala*	●	●	●	●	●	●	●			
Desert Tree Frog *Litoria rubella*		●	●		●	●				
Unidentified taxon* (tadpoles only)						●				

** likely to belong to Neobatrachus (a broadly distributed genus).*

Water-holding Frogs (*Cyclorana platycephala*) were recorded from all of the Jones Creek sites, and one of the claypan sites, occurring in the upper and middle reaches (JC1 to JC7) (**Table 4-6**). This species is an arid specialist capable of surviving several years below ground, and is usually only seen after heavy rains (Cronin 2009; Robinson 1998). It is found in association with temporary ponds, ditches, swamps and claypan habitats throughout central parts of Australia (Anstis 2002; Robinson 1998).

Main's Frog, *Cyclorana maini*, is another arid species that is widely distributed across the central region of Western Australia, emerging after heavy rains to breed (Tyler and Doughty 2010). Although not recorded from Jones Creek previously (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005), in this study they occurred in five sites (**Table 4-6**), including the creek and claypans.

Although not found in previous studies (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005) the Desert Tree Frog, *Litoria rubella*, is one of Australia's most widespread frogs, occurring across the northern parts of the continent (Cronin 2009). In arid areas they are usually found near permanent water, taking shelter in rocky crevices, damp soils and tree hollows during dry periods (Cronin 2009). During this study, they were only recorded from Jones Creek (**Table 4-6**), although it is likely this species would occurred more widely throughout the area.

Plate 4-6: Frogs and tadpoles recorded from Jones Creek and the claypans during the 2011 aquatic baseline study. (A-B) *Cyclorana platycephala*, (C-D) *Cyclorana maini*, (E) *Litoria rubella* and (F) an unidentified tadpole.

5 Summary of Ecological Values

5.1 Abiotic Component

Ephemeral rivers situated in the arid zone fluctuate between being highly fragmented and strongly connected, a feature that contributes to their natural habitat variability, and allows them to support a diverse range of aquatic biota (Kingsford and Thompson 2006; McGregor *et al.* 2006). These systems are driven by hydrological and geomorphological processes (Kingsford and Thompson 2006), observed during this and previous studies of Jones Creek and the claypans (Wetland Research and Management 2005).

Following heavy rainfall, Jones Creek serves as a flow-through system, rapidly draining runoff from the surrounding catchment. As water moves through the creek, coarse sands and gravels are mobilised and deposited at the channel margins or in mid-channel bars (Sinclair Knight Mertz 2005). After a limited period (with continuous flow for between 48 and 72hrs and having a frequency of approximately 1:100 years) (MWES Consulting 2016), only remnant pools of clear water remain, which continue to recede over the course of several weeks (**Table 5-1**).

The claypans serve as the terminus point for Jones Creek and the adjacent floodplain. They have a greater water retention time (typically several months), associated with their geomorphology and relatively impervious base (**Table 5-1**). They are characterised by fine clay sediments, which are easily suspended after flooding, and water remains turbid throughout the hydroperiod. Riparian vegetation along the margins of the creek and claypans is degraded, contributing to the potential for erosion during high velocity flows (**Table 5-1**).

Table 5-1: Summary of key habitat characteristics of Jones Creek and the claypans, based on the 2011 aquatic baseline study.

Waterbody	Residence Time	Water Clarity	Substrate Type	Water Quality	Riparian Vegetation
Jones Creek	<2 months	Clear	Coarse sands and pebbles, highly permeable	Freshwater, circumneutral to alkaline, low nutrients and metals	Highly degraded, understorey of grasses and sedges, overstorey of *Eucalyptus*
Claypan	>2 months	Turbid	Fine clays, overlying impervious layer	Freshwater, circumneutral, elevated nutrients and some metals	Highly degraded, understorey of grasses and herbs, overstorey of *Melaleuca* and *Acacia*

During this study both the creek and claypans were classified as freshwater, with circumneutral to alkaline pH (**Table 5-1**). The persistence of water in the claypans also indicates that salinities may increase slightly in surface waters over time, due to evapoconcentration (Berry 2011). While metal concentrations appeared typically low, this and previous studies have shown that elevated metals in water and sediments are not uncommon (WRM 2005; OES 2012; SKM 2005). Aluminium and copper concentrations have exceeded the ANZECC trigger values for the protection of 80% of freshwater in the creek and claypans (WRM 2005; OES 2102), while nickel has exceeded the ANZECC ISQG-High values in the claypans

(Sinclair Knight Mertz 2005). The concentrations of metals and nutrients is also higher in the surface waters and sediments of the terminal claypans (**Table 5-1**), related to their geomorphology and biogeochemistry (Reddy and DeLaune 2008; Young and Kingsford 2006). It is unlikely that this or previous studies (Sinclair Knight Mertz 2005; Wetland Research and Management 2005) have adequately captured the natural range of fluctuations in the abiotic environment of Jones Creek and the claypans, with high spatial and temporal variability a characteristic of ephemeral inland waters (Gregory 2007; John 2001; Smith *et al.* 2004).

5.2 Biotic Component

During major flood events, river systems in the arid zone become highly productive, with an influx of freshwater and nutrients initiating the 'boom' cycle, leading to the rapid emergence of primary producers, aquatic invertebrates and vertebrate fauna (Young and Kingsford 2006). There is also increased connectivity between habitats, providing an opportunity for the dispersal of aquatic biota and their propagules. In a region dominated by salt lakes, and which experiences an irregular flooding regime, Jones Creek and the claypans are considered an important freshwater refugia for aquatic biota. During this and previous studies, there has been an immediate response to major flood events, with a diverse array of organisms colonising newly created aquatic habitat. The total number of taxa recorded during the 2011 aquatic baseline study comprised 33 phytoplankton, 35 diatoms, 132 aquatic invertebrates and four vertebrate fauna (frogs), all of which are likely to have a distribution range that extends beyond Jones Creek and the claypans (**Table 5-2**).

Table 5-2: Summary of aquatic biota recorded from Jones Creek and the claypans during the 2011 aquatic baseline study, indicating general distribution and key reproductive strategies.

Biota	Jones Creek	Claypan	Total Taxa	General Distribution	Reproductive Strategies
Phytoplankton	26	22	33	Cosmopolitan	Desiccation resistant spores
Diatoms	21	32	35	Cosmopolitan	Desiccation resistant spores
Aquatic Invertebrates	93	90	132	Western Australia or Australia-wide*	Mobile adult stages or desiccation resistant eggs
Frogs	4	2	4	Australia-wide	Mobile adult stages

** with the exception of new taxa.*

The algal flora of Jones Creek and the claypans were typically freshwater taxa, with a cosmopolitan distribution around the world (although species-level identification may show a degree of endemism) (**Table 5-2**). However, composition was strongly influenced by water clarity and movement, two key factors responsible for influencing algal growth in ephemeral waters of the arid zone (Bunn *et al.* 2006). Planktonic and filamentous green algae were more abundant and diverse in the clear, still pools of Jones Creek (26 taxa compared to 22 taxa in the claypans) (**Table 5-2**). In contrast, the turbid claypans generally supported limited true planktonic algae, and instead were characterised by periphytic diatoms (32 taxa compared to 21 taxa in Jones Creek). In the absence of submerged macrophytes, algae are the main source of primary productivity in Jones creek and the claypans, and survive by producing desiccation resistant spores, which remain viable in the sediments during extended dry periods (Maggs and Callow 2002).

The diversity of aquatic invertebrates (**Table 5-2**) was comparable between the creek (93 taxa) and claypans (90 taxa), however the assemblage differed, attributed to water quality and habitat availability. While Jones Creek was dominated by opportunistic, transient insect fauna, resident crustaceans were abundant in the claypans, a trend also observed in previous studies (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005). These groups employ various reproductive and dispersal mechanisms to cope in their temporary environments, with adult insects being typically mobile (Gooderham and Tsyrlin 2002), and resident crustaceans capable of producing desiccation-resistant eggs (Williams 1985). The majority of aquatic invertebrates recorded during this and previous studies (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005) are known to be widespread throughout inland Western Australian or Australian waters (**Table 5-2**). They also provide an important role in ephemeral waters, mediating functional processes, as well as providing a food source for larger vertebrate fauna, such as frogs (Boulton *et al.* 2006), which were common in the creek and claypans during this study.

While spatial differences were evident in the aquatic biota between Jones Creek and the claypans, temporal changes were limited, due to the relatively homogenous conditions, a feature of ephemeral waterbodies during major flood events (Young and Kingsford 2006). The temporary nature of the environment, particularly in Jones Creek, also limits organisms to those taxa with short life cycles; usually less than three weeks (Boulton *et al.* 2006; Bunn *et al.* 2006; Kingsford *et al.* 2006). As surface water habitats diminish, the 'bust' cycle begins, although by this stage aquatic biota are likely to have matured and reproduced (Young and Kingsford 2006). In the claypans, the longer hydroperiod may also allow for a successional change in aquatic biota (Wetland Research and Management 2005).

6 Impact Assessment

Based on the findings of the database searches, previous studies and the 2011 aquatic baseline study of Jones Creek and the claypans, the following aquatic ecology impact assessment has been developed. The impact assessment provides a description of the relevant threatening processes associated with the MKSO Project and the likelihood of the impact of these threatening processes on the aquatic ecosystem of the creek and claypans. Potentially conservation significant taxa are also considered in relation to potential impacts.

6.1 Threatening Processes and Impacts to Aquatic Ecology

Threatening processes associated with the MKSO Project can be categorised as either direct or indirect impacts. Direct impacts are those that occur through direct interaction with an environmental component, while indirect impacts are generated from a complex impact pathway and are often referred to as secondary impacts. Threatening processes, potential impacts and management and mitigation measures are discussed in more detail below, and are summarised in **Table 6-1**, in the context of a preliminary risk framework.

6.1.1 Direct Impacts

6.1.1.1 Disturbance

The construction of two creek crossings across Jones Creek, to facilitate the transport of waste to the waste landform, and to transport nickel ore to Mt Keith for processing, is considered a direct impact from the MKSO Project. Their construction (to the north and south of the ROM pad), will cause a direct disturbance, affecting habitat and hydrology (flow regime) in a localised area of the creek, with approximately 0.034 km^2 affected. The crossings are expected to be constructed at bed height, and of comparable bed material, allowing for their integration into the creek during a flow event, after which they will be re-constructed as required (likely to occur on average once a year) (MWES Consulting 2016).

The creek crossings will result in a minor loss of aquatic habitat within Jones Creek, as well as a potential change in the flow regime within the immediate area, resulting in a reduction or shift in the available habitat of aquatic biota. However, given the extent of the creek and similarities in the biological assemblage observed along its length, there should be adequate comparable habitat providing refugia during flooding. Appropriate engineering design of the creek crossings, and management during construction, should aim to limit impacts to the creek and riparian zone. A suitable monitoring program comprising abiotic and biotic components should also be implemented for the creek following construction. Once mining is complete the creek crossings should be removed. Overall, the disturbance associated with the creek crossings is considered temporary, and the risk to Jones Creek is classified as *minor* (**Table 6-1**).

Direct impacts associated with light or vibration from proposed mining operations are not expected to impact on the aquatic biota of Jones Creek, due to the limited frequency of flooding and the 100 m exclusion zone surrounding the creekline, posing a *negligible* risk (**Table 6-1**). However there are limited studies available on the effects of these processes on ephemeral aquatic ecosystems.

6.1.2 Indirect Impacts

6.1.2.1 Sedimentation

Increased sedimentation may be considered an indirect impact, with the potential for sediment mobilisation and runoff into Jones Creek from the creek crossings, mining pits and waste landform, as well as areas that have been cleared for the MKSO Project. Of these, sedimentation is most likely to occur from the runoff of stockpiled material associated with the ROM pad (oxidised waste rock with the potential to undergo further weathering), and the erosion of road material and banks from the creek (MWES Consulting 2016). Higher sediment loads in the creek may also cause sedimentation downstream, dependent on particle size, with coarse sands deposited along the creekline, and finer clay material transported through the system, and ultimately deposited in the terminal claypans (Sinclair Knight Mertz 2005). However, major rainfall events are infrequent, and the more common, lesser flows (likely to occur once a year after approximately 30 mm of rainfall), will only affect short sections of the crossings (MWES Consulting 2016), reducing the area over which sediments may be mobilised.

Sedimentation can result in a general decline in water quality and can potentially smother benthic communities (Boulton and Brock 1999). It is expected that appropriate engineering design and construction of the creek crossings, mining pits and waste landform will be undertaken to minimise sediment mobilisation, and that ongoing operations will be suitably managed. Specific mitigation measures include rock armouring of the crossings, the use of suitably graded material during construction and maintenance, and best operational vehicular practices (MWES Consulting 2016). In addition, a series of bunds, silt traps and clean stormwater diversion drains are proposed to be installed at strategic locations throughout the MKSO Project area, and together with the 100 m exclusion zone should minimise the potential for sedimentation in the creek (MWES Consulting 2016). However, in order to detect potential impacts, a suitable monitoring program should be implemented for the creek and claypans. Based on the expected management and monitoring measures, as well as the extent of aquatic habitat available throughout Jones Creek and the claypans, the overall risk associated with sedimentation has been classified as *minor* (**Table 6-1**).

6.1.2.2 Changes to Surface Hydrology

Changes to the surface hydrology of Jones Creek and the claypans is considered an indirect impact associated with the MKSO Project. The development of the two mining pits (6 Mile Well and Goliath), are expected to result in minor reduction in the upper catchment area (from 64.1 km^2 to 56.9 km^2). However hydrological modelling predicts that flows will continue to occur every second year on average, with no substantial effect on flooding frequency, and a change of only 1% in probable fill depths for both the creek and southwest claypan (MWES Consulting 2016). It is predicted that the change in catchment yield (with a reduction in median total flow of approximately 12%), may be most obvious in the southwest claypan, during the more common flooding events (1 in 2 year, or 1 in 5 year events on average). The resulting decrease in water levels and duration of the hydroperiod may potentially cause a shift in the composition of aquatic biota.

However, the claypans already receive more water than their current storage capacity (MWES Consulting 2016); in some instances more than double their volume (Berry 2011). Anecdotal evidence also suggests that in recent years, the hydroperiod of the claypans has been extended, following major rainfall events (D. Brownlie, pers. comm. 2011). This is attributed to past catchment clearing and pastoralism in the region, which have led to the degradation and reduction of riparian vegetation, increasing runoff from the surrounding catchment (Wetland Research and Management 2005).. Therefore, a decrease in catchment yield from the MKSO Project would only partially negate the higher flow rates and volumes associated with historic land use practices and their influence on the surface water hydrology. Therefore any potential hydrological impacts from the Project on the aquatic habitat of Jones Creek and the claypans, have been classified as a *minor* risk (**Table 6-1**), due to the substantial changes that have already occurred, and the highly adaptable nature of biota inhabiting ephemeral waters.

6.1.2.3 Contamination

Contamination may be another indirect impact of the MKSO Project, and specifically, elevated concentrations of nickel has the potential to enter the creek and claypans via mining operations from dust particulates, or runoff from the pits, ROM pad and waste rock landform during heavy rainfall. However mineralogy comprises low grade nickel sulphide ore (MWES Consulting 2016), with prevailing alkaline and low salinity conditions, as well as a low solubility of minor elements during weathering (Berry 2011). Therefore, appropriate operational procedures (including the 100 m creek exclusion zone) should ensure that potential for contamination is minimised. In addition, as contamination in runoff is most likely to occur following major rainfall events (with pit stability studies also being undertaken to prevent mobilisation of soils), dilution will reduce the potential for ecotoxicity impacts on aquatic biota.

Hydrogeochemical processes affect the solubility of metals such as nickel, including adsorption on fine clays and complexation with dissolved ions or other metals, reducing their bioavailability and toxicity (ANZECC 2000a; National Pollutant Inventory 2012). While contamination of aquatic ecosystems can alter the natural structure and function of aquatic ecosystems, with lethal or sub-lethal effects on biota (Boulton and Brock 1999), it is expected that these hydrogeochemical processes would reduce any ecotoxicity risk. However previous studies on Jones Creek have found slightly acidic pH (ranging from pH 5 to 6) within the pools (Streamtec Ecological Consultants 1992; Wetland Research and Management 2005), indicating there is the potential for the mobilisation of metals (ANZECC 2000a). The implementation of a monitoring program, comprising abiotic and biotic components, would aid in identifying potential contaminants and assess their movement downstream, with the overall risk classified as *minor* (**Table 6-1**).

General mining operations also have the potential to cause contamination of the creek, with point sources associated with hydrocarbon spills from the use of heavy machinery, as well as litter or rubbish from the mine workforce. However, it is expected that potential point sources of contamination will be minimised through appropriate protocols and management, as well as being aided by the 100 m exclusion surrounding Jones Creek, with the risk classified as *minor* (**Table 6-1**).

Table 6-1: Summary of threatening processes and potential impacts to Jones Creek and the claypans associated with the MKSO Project, within a preliminary risk framework (incorporating management and mitigation measures).

	Threatening Process	Habitat Affected	Likelihood of Occurrence	Potential Impacts	Management / Mitigation	Risk and Justification
Direct	Disturbance (from creek crossings)	Jones Creek	Certain	- localised change in flow regime - temporary loss or shift in aquatic habitat	- appropriate engineering design, construction and operation protocols - monitoring to include abiotic and biotic components	**Minor** – localised temporary impact, extensive comparable habitat remaining in creek.
Direct	Light and Vibration (from mining operations)	Jones Creek	Certain	- none (no available studies on impacts)	- 100 m creek exclusion zone - monitoring to include abiotic and biotic components	**Negligible** – not expected to have any impacts on the creek, attributed to limited frequency of flood events.
Indirect	Sedimentation (from MKSO Project features and creek crossings)	Jones Creek and Claypans	Possible	- reduced water quality - smothering of benthic communities	- appropriate engineering design, construction and operation protocols - 100 m creek exclusion zone - monitoring to include abiotic and biotic components	**Minor** – most common creek flow event once a year, with only short sections of the creek crossings affected and extensive creek and claypan habitat available.
Indirect	Changes to Surface Hydrology (from mining pits and creek crossings)	Jones Creek and Claypans	Certain	- reduced water levels and hydroperiod in southwest claypan - shift in the composition of aquatic biota	- monitoring to include abiotic and biotic components	**Minor** – minor decrease in catchment yield, negated by increase in baseline flow from historic land use practices, as well as highly adaptable nature of aquatic biota.
Indirect	Contamination (from orebody mineralogy or hydrocarbon spills)	Jones Creek and Claypans	Unlikely	- reduced water and sediment quality - toxic (lethal or sublethal effects) on aquatic biota	- appropriate engineering design, construction and operation protocols - 100 m creek exclusion zone - dilution of contaminants following major rainfall events - monitoring to include abiotic and biotic components	**Minor** – concentrations of nickel sulphide ore are expected to be low, and metals are unlikely to impact on aquatic biota, related to hydrogeochemical processes.

Minor: impact on a localised and/or temporary scale, with no irreversible damage to the aquatic ecosystem expected.
Negligible: No impact expected to aquatic ecosystem.

6.2 Conservation Significant Species

Based on the findings of the database searches, there are no conservation significant communities or species in the vicinity of the MKSO Project area relevant to aquatic ecosystems. However, this and previous studies of Jones Creek and the claypans have identified two invertebrate taxa, verified as new to science; the rotifer (Rotifera) *Cephalodella* sp. nov. and the clam shrimp (Spinicaudata) *Eocyzicus* sp. OES 1. These taxa have been recorded from the creek and claypans, respectively (**Figure 6-1**), and while new and currently undescribed, both are unlikely to have a restricted distribution, or be impacted by the MKSO Project (**Table 6-2**).

Cephalodella sp. nov., was deemed unlikely to be restricted due to the highly connected habitat of Jones Creek during flooding, and its occurrence at a single location (**Figure 6-1**) during the 2005 study was deemed an apparent artefact of sampling (Wetland Research and Management 2005). It is also likely that increased sampling of freshwater environments in the broader area would find a range extension for *Eocyzicus* sp. OES 1 (B. Timms pers. comm. 2011), which was recorded from four locations (claypans and adjacent floodplain) during this study (**Figure 6-1**). There were also several potentially new invertebrate taxa have been identified in both the 2005 and the 2011 studies, however these were not verified, due to the current state of taxonomy. Since the 2011 study, there have been no taxonomic nomenclature updates, and a number of the invertebrates recorded in Jones Creek and the claypans belong to groups or genera that require substantial taxonomic review (B. Timms, pers. comm. 2011).

Overall, the risk of the MKSO Project on the new, verified invertebrate taxa is classified as *negligible* (**Table 6-2**), attributed to the extent and availability of comparable habitat throughout the creek and claypans. The high connectivity of aquatic habitat during major flood events has also likely contributed to the dispersal of these taxa more widely throughout the area (although further sampling would be required to confirm this). However, it is recommended that appropriate management of threatening processes is undertaken during mine construction and operation, and that an ongoing monitoring program is implemented as the MKSO Project progresses, to ensure that the ecological integrity of Jones Creek and the claypans is maintained.

Table 6-2: Verified new aquatic invertebrate taxa recorded from Jones Creek and the claypans in this and previous studies (note distance is an approximate from 6 Mile Well Pit).

Taxon Group	New Taxa	Location and Site Records	Dist. Downstream of MKSO Project	Risk and Justification
Rotifera (rotifer)	**Cephalodella* sp. nov.	Jones Creek (1 site)	200m (adjacent to 6 Mile Well Pit)	**Negligible** - unlikely to be impacted or restricted to the creek, due to the extent and availability of comparable habitat
Spinicaudata (clam shrimp)	***Eocyzicus* sp. OES1	Claypans (4 sites)	15km	**Negligible** – unlikely to be impacted or restricted to the claypans, due to the extent and availability of comparable habitat.

** identified by Wetland Research and Management (2005).*
*** identified by Outback Ecology (2012).*
Negligible: No impact expected on taxon.

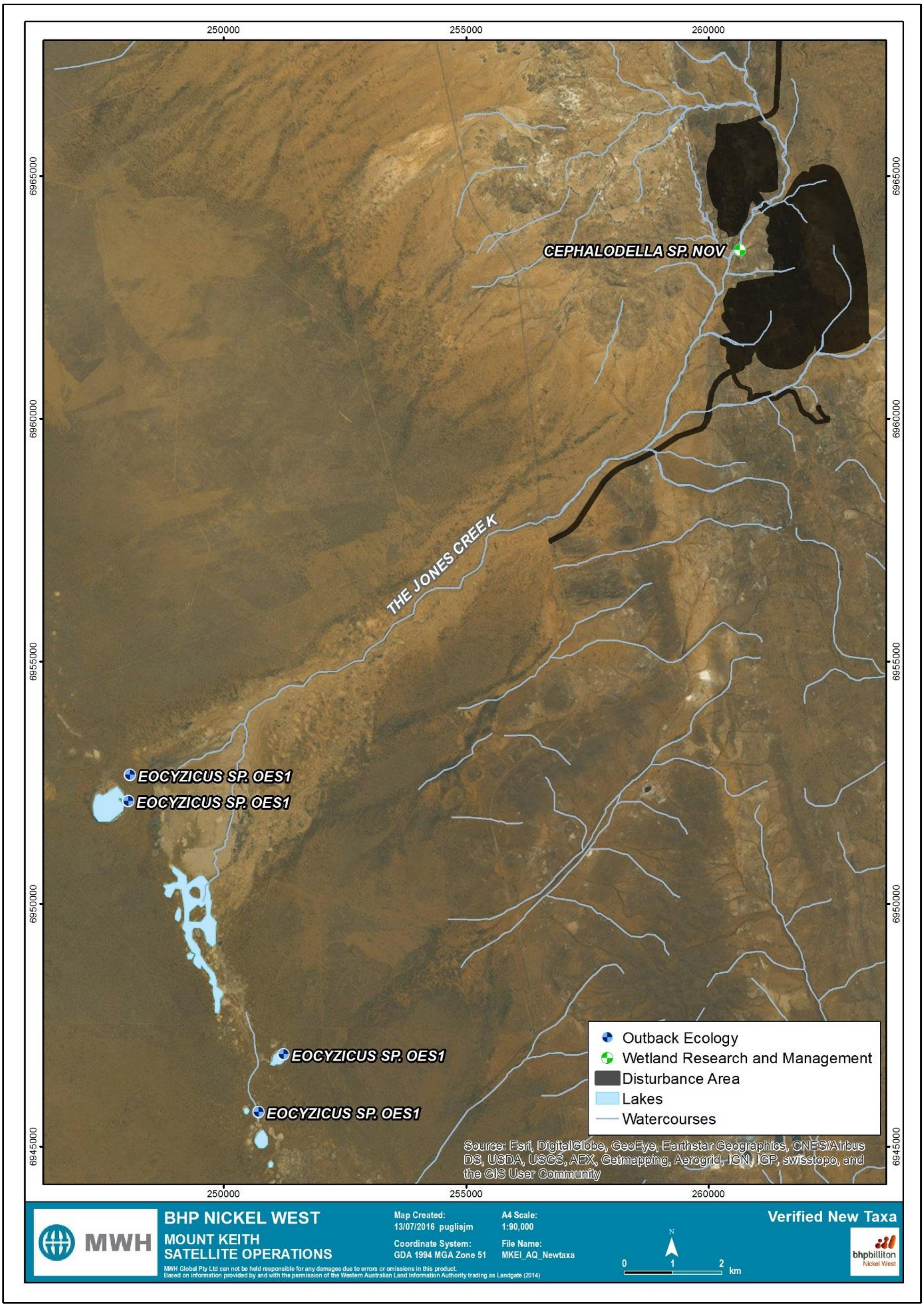


Figure 6-1: Aquatic invertebrate taxa verified as new, based on Wetland Research and Management (2005) and Outback Ecology (2012) studies, in relation to the MKSO Project.

7 Conclusions

Jones Creek and the claypans provide an important freshwater refugia within an arid environment. The 2011 aquatic baseline study showed that the abiotic environment was governed by hydrological, geomorphological and biogeochemical factors, which strongly influenced the aquatic biota. Planktonic algae were more abundant and diverse in the clear pools of the creek, while periphytic diatoms dominated the claypans, due to the high turbidity. Opportunistic, transient insect groups were a characteristic of the invertebrate fauna assemblage of Jones Creek, and were associated with habitat availability and the limited residence time of surface water pools. In contrast, resident crustacean fauna were a feature of the claypans, due to the longer hydroperiod. Vertebrate fauna were limited to frogs, with most species occurring along the length of the creekline and into the claypans. The majority of organisms identified during this study were found to have a broader, cosmopolitan distribution throughout Western Australian and Australian inland waters.

Several threatening processes and potential impacts to the aquatic ecology of Jones Creek and the claypans were identified, although the overall risk was predominantly classified as *minor*. This was due to the nature of the potential impacts, considered unlikely to occur, or occurring on a localised and/or temporary scale, as well as the extensive and comparable aquatic habitat available throughout the area. There were no communities or species of conservation significance found during the database searches, of relevance to aquatic ecosystems. In addition, the MKSO Project poses a *negligible* risk to the two new, verified aquatic invertebrate taxa recorded in this and previous studies (the rotifer *Cephalodella* sp. nov. and the clam shrimp *Eocyzicus* sp. OES 1), as they are unlikely to have a restricted distribution, or be impacted by mining operations. It is expected that appropriate management and monitoring protocols will be implemented during the construction and operational phases of the MKSO Project, to prevent and detect potential impacts on the aquatic ecology of Jones Creek and the claypans.

8 References

Anstis, M. (2002). Tadpoles of South-eastern Australia. New Holland Publishers, Sydney.

ANZECC. (2000a). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1, Aquatic Ecosystems (Chapter 3). Environment Australia, Paper 4, Canberra.

ANZECC. (2000b). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2, Aquatic Ecosystems - Rationale and Background Information (Chapter 8). Environment Australia, Paper 4, Canberra.

Australian Natural Resources Atlas. (2010). Biodiversity Assessment - Murchison. Available online at http://www.anra.gov.au/topics/vegetation/assessment/wa/ibra-murchison.html. Accessed on 6/10/2011.

Battarbee, R. W., Jones, V. J., Flower, R. J., Cameron, N. G., Bennion, H., Carvalho, L. and Juggins, S. (2001). Diatoms. In: J. P. Smol, H. J. B. Birks and W. M. Last (eds) Tracking Environmental Change Using Lake Sediments Volume 3. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 155-202.

Berry, K. (2011). NDS1 impacts on hydrology of Jones Creek and terminal claypan. Internal memorandum prepared for BHP Nickel West, Perth, Western Australia.

Blinn, D. W. (1995). Diatom community structure along salinity gradients in Australian lakes: biogeographic comparisons with other continents. In: J. P. Kociolek and M. J. Sullivan (eds) A Century of Diatom Research in North America: A Tribute to the Distinguished Careers of Charles W. Reimer and Ruth Patrick. Koeltz Scientific Books, Illinois, USA.

Blinn, D. W. and Bailey, P. C. E. (2001). Land-use influence on stream water quality and diatom communities in Victoria, Australia: A response to secondary salinisation. *Hydrobiologia* 466: 231-244.

Blinn, D. W., Halse, S. A., Pinder, A. M., Shiel, R. J. and McRae, J. M. (2004). Diatom and micro-invertebrate communities and environmental determinants in the Western Australian Wheatbelt: a response to salinization. *Hydrobiologia* 528: 229-248.

Boulton, A. J. and Brock, M. A. (1999). Australian Freshwater Ecology: processes and management. Cooperative Research Centre for Freshwater Ecology, Adelaide, South Australia.

Boulton, A. J., Sheldon, F. and Jenkins, K. M. (2006). Natural disturbance and aquatic invertebrates in desert rivers. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 133-153.

Bowling, L. (2009). Freshwater phytoplankton: diversity and biology. In: I. M. Suthers and D. Rissik (eds) Plankton: A Guide to their Ecology and Monitoring for Water Quality. CSIRO Publishing, Collingwood, Victoria, pp 115-140.

Bray, J. R. and Curtis, J. T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* 27: 325-349.

Brock, M. A., Capon, S. J. and Porter, J. L. (2006). Disturbance of plant communities dependent on desert rivers. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, New York, pp 100-132.

Bunn, S. E., Balcombe, S. R., Davies, P. M., Fellows, C. S. and McKenzie-Smith, F. J. (2006). Aquatic productivity and food webs of desert river ecosystems. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 76-99

Bureau of Meteorology. (2011). Climate Data Online. Monthly Statistics. Bureau of Meteorology. Australian Government. Available online at http://www.bom.gov.au/. Accessed on October 2011.

Camburn, K. E. and Charles, D. F. (2000). Diatoms of Low-Alkalinity Lakes in the Northeastern United States. Scientific Publications, Philadelphia, USA.

Clarke, K. R. and Warwick, R. M. (2001). Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E, Plymouth.

Connell, D. W. (2005). Basic Concepts of Environmental Chemistry. CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Cowan, M. (2001). Coolgardie 3 (COO3 - Eastern Goldfields Subregion). Department of Conservation and Land Management.

Cronin, L. (2009). Australian Reptiles and Frogs. Allen & Unwin, Crows Nest, NSW.

Czarnecki, D. B. and Blinn, D. W. (1978). Diatoms of the Colorado River. *Bibliotheca Phycologica* Band 38: 1-181.

Department of Environment and Conservation. (2010). DEC Managed Lands and Waters within Western Australia. . Prepared by the Department of Environment and Conservation, Information Management Branch, Perth, Western Australia.

Department of Environment Water Heritage and the Arts. (2011). Australian Faunal Directory. Commonwealth of Australia. Available online at http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/home. Accessed on October 2011.

Department of Parks and Wildlife. (2015). NatureMap: Mapping Western Australia's Biodiversity. Available online at http://naturemap.dec.wa.gov.au./default.aspx. Accessed on December 2015.

Department of Parks and Wildlife (2016a). NatureMap Species Report. Available online at https://naturemap.dpaw.wa.gov.au/.

Department of Parks and Wildlife. (2016b). Threatened and Priority Ecological Communities Database Search 13-0416EC. 13-0416EC.

Department of Parks and Wildlife. (2016c). Threatened and Priority Fauna Database Search 2016/00030 #5201. 2016/00030 #5201.

Department of the Environment. (2016a). Directory of Important Wetlands in Australia Search Tool. Available online at http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=670. Accessed on May 2016.

Department of the Environment. (2016b). Protected Matters Search Tool. Available online at http://www.environment.gov.au/epbc/protected-matters-search-tool. Accessed on July 2016.

Ehrlich, A. (1995). Atlas of the inland-water diatom flora of Israel, Flora Palestina. Publications of the Israel Academy of Science ad Humanities, Israel.

Entwisle, T. J., Sonneman, J. A. and Lewis, S. H. (1997). Freshwater algae in Australia - a guide to the conspicuous genera. Sainty and Associates, Potts Point.

Foged, N. (1978). Diatoms in Eastern Australia. *Bibliotheca Phycologica* 41: 1-242.

Gasse, F. (1986). East African diatoms, taxonomy, ecological distribution. *Bibliotheca Diatomologica* 11: 201 - 245.

Geddes, M. C. (1984). Limnology of Lake Alexandrina, River Murray, South Australia, and the effects of nutrients and light on phytoplankton. *Australian Journal of Marine and Freshwater Research* 35: 399-415.

Gooderham, J. and Tsyrlin, E. (2002). The Waterbug Book. A Guide to the Freshwater Macroinvertebrates of Temperate Australia. CSIRO Publishing, Victoria, Australia.

Gordon, D. M., Finlayson, C. M. and McComb, A. J. (1981). Nutrients and phytoplankton in three shallow, freshwater lakes of different trophic status in Western Australia. *Australian Journal of Marine and Freshwater Research* 32: 541-553.

Gregory, S. J. (2007). The classification of inland salt lakes in Western Australia. Masters Thesis. Curtin University of Technology.

Gregory, S. J. (2008). The classification of inland salt lakes in Western Australia. Minerals and Energy Research Institute of Western Australia, Perth, Western Australia.

Hammer, U. T. (1986). Saline Lake Ecosystems of the World. Dr. W. Junk Publishers, Dordrecht.

Hart, B. T. and McKelvie, I. D. (1986). Chemical limnology in Australia. In: P. W. De Dekker, W. D. (ed) Limnology in Australia, vol IV. Australian Society for Limnology, CSIRO, pp 3-32.

Hawking, J. H. and Smith, F. J. (1997). Colour guide to invertebrates of Australian inland waters. Identification guide No. 8 Co-operative Research Centre for Freshwater Ecology, Albury.

Hazelton, P. and Murphy, B. (2007). Interpreting Soil Test Results. What do all the numbers mean. CSIRO Publishing, Collingwood, Victoria.

Howard, A. G. (1998). Aquatic Environmental Chemistry. Oxford University Press Publications, United States, New York.

Humphrey, C., Hanley, J. and Camilleri, C. (2008). A compendium of ecological information on Australia's northern tropical rivers. Sub-project 1 of Australia's tropical rivers - an integrated data assessment and analysis (DET18). A report to Land & Water Australia, National Centre for Tropical Wetland Research, Townsville, Queensland.

Ingram, B. A., Hawking, J. H. and Shiel, R. J. (1997). Aquatic Life in Freshwater Ponds: A Guide to the Identification and Ecology of Life in Aquaculture Ponds and Farm Dams in South Eastern Australia. Co-operative Research Centre for Freshwater Ecology, Albury, NSW.

John, J. (1983). The diatom flora of the Swan River Estuary, Western Australia. J. Cramer, Germany.

John, J. (2000). A guide to diatoms as indicators of urban stream health. National River Health Program, Urban Sub Program, Report No. 7. LWRRDC Occasional Paper 14/99. Land and Water Resources and Development Corporation, Canberra.

John, J. (2001). Water quality and bioassessment of inland salt lakes. In Salt Lake Workshop. Bentley Technology Park. Centre for Land Rehabilitation, UWA, Perth.

John, J. (2002). Introduction to the freshwater algae. Wetland Research Group, Department of Environmental Biology, Curtin University of Technology, Perth, Western Australia.

Jones, D. and Morgan, G. (2002). A Field Guide to Crustaceans of Australian Waters. New Holland Publishers, Sydney.

Kingsford, R. T., Georges, A. and Unmack, P. J. (2006). Vertebrates of desert rivers: meeting the challenges of temporal and spatial unpredictability. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 154-200.

Kingsford, R. T. and Thompson, J. R. (2006). Desert or dryland rivers of the world: an introduction. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 3-10

MacDonald, K. S., Sallenave, R. and Cowley, D. E. (2011). Morphologic and genetic variation in *Triops* (Branchiopoda: Notostraca) from ephemeral waters of the northern Chihuahuan Desert of North America. *Journal of Crustacean Biology* 31(3): 468-484.

Maggs, C. A. and Callow, M. E. (2002). Algal Spores. *Encyclopedia of Life Sciences*: 1-6.

McGregor, G. B., Marshall, J. C. and Thoms, M. C. (2006). Spatial and temporal variation in algal-assemblage structure in isolated dryland river waterholes, Cooper Creek and Warrengo River, Australia. *Marine and Freshwater Research* 57: 453-466.

Minitab Incorporated (2013). MINITAB statistical software, release 17 for Windows. State College. Available online at http://www.minitab.com.

MWES Consulting. (2016). Mt Keith Satellite Operations, water aspects and impacts. Internal report for BHP Billiton Nickel West, Perth, Western Australia.

National Pollutant Inventory. (2012). Substance fact sheets. Department of Sustainability, Environment, Water, Populations and Communities. Available online at http://www.npi.gov.au/substances/factsheets.html. Accessed on October 2012.

Outback Ecology. (2012). Aquatic baseline study of Jones Creek and the south-west claypans. Internal report for BHP Billiton Nickel West, Perth, Western Australia.

Pulford, I. and Flowers, H. (2006). Environmental Chemistry at a Glance. Blackwell Publishing, Oxford, United Kingdom.

Reddy, K. R. and DeLaune, R. D. (2008). Biogeochemistry of Wetlands. Science and Applications. CRC Press, Boca Raton, Florida.

Reynolds, C. S. (1993). The Ecology of Freshwater Phytoplankton. Cambridge University Press, New York, USA.

Rissik, D., van Senden, D., Doherty, M., Ingleton, T., Ajani, P., Bowling, L., Gibbs, M., Gladstone, M., Kobayashi, T., Suthers, I. and Froneman, W. (2009). Plankton-related water quality issues. In: I. Suthers and D. Rissik (eds) Plankton: A Guide to their Ecology and Monitoring for Water Quality. CSIRO Publishing, Collingwood, Victoria, pp 39-72.

Robinson, M. (1998). A Field Guide to Frogs of Australia. New Holland Publishers, Sydney.

Simpson, S. L., Batley, G. E., Chariton, A. A., Stauber, J. L., King, C. K., Chapman, J. C., Hyne, R. V., Gale, S. A., Roach, A. C. and Maher, W. A. (2005). Handbook for Sediment Quality Assessment CSIRO, Bangor, NSW.

Sinclair Knight Mertz. (2005). WMC Yakabindie - Jones Creek stream sediment characterisation. Report prepared for WMC Resources, Perth, Western Australia.

Smith, R., Jeffree, J., John, J. and Clayton, P. (2004). Review of methods for water quality assessment of temporary stream and lake systems. ACMER, Queensland.

Soylu, E. N. and Gonulo, A. (2010). Seasonal succession and diversity of phytoplankton in a eutrophic lagoon (Liman Lake). *Journal of Environmental Biology* 31(5): 629-636.

Streamtec Ecological Consultants. (1992). Jones Creek baseline survey of aquatic fauna and water quality. Report prepared for Dominion Mining Limited, Perth, Western Australia.

Taukulis, F. E. (2007). Diatom communities in lakes and streams of varying salinity from south-west Western Australia: distribution and predictability. Doctoral Thesis. Curtin University of Technology.

Thomas, E. (2007). Diatoms and invertebrates as indicators of pH in wetlands of the south-west of Western Australia. Doctoral Thesis. Curtin University of Technology.

Timms, B. V. (2002). The fairy shrimp genus *Branchinella* Sayce (Crustacea: Anostraca: Thamnocephalidae) in Western Australia, including a description of four new species. *Hydrobiologia* 486: 71-89.

Timms, B. V. (2008). The ecology of episodic saline lakes of inland eastern australia, as exemplified by a ten year study of the Rockwell-Wombah Lakes of the Paroo. *Proceedings of the Linnean Society of New South Wales* 129: 1-16.

Timms, B. V. (2009). Biodiversity of large branchiopods of Australian saline lakes. *Current Science* 96(1): 74-80.

Timms, B. V., Datson, B. and Coleman, M. (2006). The wetlands of the Lake Carey catchment, northeast Goldfields of Western Australia, with special reference to large branchiopods. *Journal of the Royal Society of Western Australia* 89: 175-183.

Tyler, M. J. and Doughty, P. (2010). Field Guide to Frogs of Western Australia. Fourth Edition. Western Australian Museum, Perth, Western Australia.

Water and Rivers Commission. (1999). Planning and Management: Foreshore condition assessment in farming areas of south-west Western Australia. Waters and Rivers Commission River Restoration Report No. RR3, Perth, Western Australia.

Western Australian Museum. (2016a). Arachnida and Myriapoda Database Search. WAMDB108.

Western Australian Museum (2016b). Arachnida and Myriapoda Database Search. WAMDB108.

Western Australian Museum. (2016c). Crustacea Database Search. WAMDB108.

Wetland Research and Management. (2005). Baseline aquatic biology and water quality study of Jones Creek, including south-west claypan area. Report prepared for Nickel West, BHP Billiton, Perth, Western Australia.

Williams, W. D. (1980). Australian Freshwater Life: The invertebrates of Australian inland waters. Macmillan Educational Australia, Pty Ltd, Melbourne.

Williams, W. D. (1985). Biotic adaptations in temporary lentic waters, with special reference to those in semi-arid and arid regions. *Hydrobiologia* 125: 85-110.

Young, W. J. and Kingsford, R. T. (2006). Flow variability in large unregulated dryland rivers. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 11-46.

Appendix A Site Habitat Characteristics

Table A1: Habitat characteristics of Jones Creek and claypans during the 2011 aquatic baseline study (NA = not applicable).

	Site	Habitat type	Sediment Characteristics	Organics	WARC Riparian Grading	Channel Width (m)	Water Depth Range (m)	Site Description
Jones Creek	JC1	Creekline pools	Sand/gravel/pebbles/quartz	Abundant organics and woody debris	C	7.8	Dry - 0.4	Northern most creekline site within the upper catchment area. Main channel separated into a number of pools in phase 1 (water tannin stained), which had dried by phase 2. Eroded banks and incised channel. Channel bed highly mobile, comprised mainly of course sand, interspersed with larger pebbles. An abundance of invertebrates, tadpoles and frogs observed in the water column. Green filamentous algae growing in the shallows. Riparian vegetation comprising *Cyperus centralis* and native grasses, with larger *Eucalyptus camaldulensis* providing overstorey cover. Area heavily impacted by pastoralism.
	JC2	Creekline pools	Sand/gravel/pebbles/quartz	Abundant woody debris and larger logs	C	7.2	0.1 - 0.4	Located downstream from JC1 in the upper catchment. Two main pools present in phase 1, although water receded greatly by phase 2. Water clear relatively clear, some tannin staining evident. Eroded banks and incised channel. Channel bed highly mobile, comprised mainly of course sand, interspersed with larger pebbles. Banks elevated with exposed coffee rock and terracing. An abundance of invertebrates, tadpoles and frogs observed in the water column. *Marsilea hirsuta* growing along the banks together with bryophytes, *Cyperus centralis*, native grasses and larger *Eucalyptus camaldulensis* trees. Area heavily impacted by pastoralism.
	JC3	Creekline pools	Sand/gravel/pebbles/quartz/ coffee rock	Abundant debris, logs, branches and leaves	C	9.3	0.07 - 0.6	Downstream from JC2 in the upper catchment. Two main pools present in phase 1, along with a number of smaller pools (both clear and tannin stained), which receded to only one pool by phase 2. Located at a bend in the channel, which becomes wider, leading to sediment accumulation (mainly sand), having occurred in past flow. Eroded banks and incised channel. An abundance of invertebrates, tadpoles and frogs observed in the water column, with filamentous green algae present along the shore and amongst the benthos. *Marsilea hirsuta* growing along the surface water, and the banks together with bryophytes. *Cyperus centralis*, native grasses and larger *Eucalyptus camaldulensis* trees also present. Area heavily impacted by pastoralism.
	JC4	Creekline pools	Sand/gravel/pebbles/quartz/ coffee rock	Reduced, with only leaves and debris	C	11.5	Dry - 0.4	Located downstream from JC3. One elongated pool of water present during phase 1 (clear water), subsequently dry in phase 2. Eroded banks and incised channel, becoming wider as the creek progresses downstream. Bed sands highly mobile (with sediment loading in places), and some exposed coffee rock. Highly productive, with an abundance of invertebrates, tadpoles and frogs, and a high density of filamentous green algae present along the shore and amongst the benthos. Vegetation typical of the area including *Marsilea hirsuta, Cyperus centralis*, native grasses and larger *Eucalyptus camaldulensis* trees. Area heavily impacted by pastoralism.
	JC5	Creekline pools	Sand/gravel/pebbles/quartz	Reduced, with only leaves and debris	C	15.5	0.3 to 0.7	Downstream from JC4, situated at the former highway crossing. Two main pools, upstream and downstream of the former highway crossing (creates artificial embayment to substantial depth). Numerous smaller pools present in phase 1, with only remnant pools found in phase 2. Water relatively clear (some tannin staining). Highly mobile sands present. Eroded banks and incised channel (becoming wider), with highly mobile sand bed. South of the highway channel becomes braided. Highly productive, with an abundance of invertebrates, tadpoles and frogs, and a high density of filamentous green algae present. Vegetation includes *Marsilea hirsuta,* and bryophytes, as well as *Cyperus centralis*, native grasses and larger *Eucalyptus camaldulensis* trees. Area heavily impacted by pastoralism.
	JC6	Creekline pools	Sand/gravel/pebbles/quartz/ coffee rock	Abundant woody debris, leaves, branches and logs	C	15.5	0.2 to 0.3	Located across the Goldfields Highway at an historic telegraph line crossing (southern-most creekline site). Two main pools and numerous smaller pools present in phase 1, reduced to one small pool in phase 2 (clear water). Wider section of channel with mobile sands and incised eroded banks (exhibiting terracing), with some exposed coffee rock. Abundance of invertebrates, tadpoles and frogs. Filamentous green algae also present along shore and growing on debris. Aquatic vegetation comprises *Marsilea hirsuta*, *Cyperus centralis*, and *Schoenoplectus laterifforus*. Riparian communities include larger *Eucalyptus camaldulensis* trees along with native grasses. Area heavily impacted by pastoralism.
Claypans and floodplain	JC7	Claypan	Clay, underlain by hardpan	Inundated riparian vegetation	C	NA	0.37 to 0.50	Widely flooded claypan, at terminus of Jones Creek (to the south-west). Water levels receded by phase 2. Clay sediment with a hard base below. Turbid water due to suspension of fine sediment material. Some erosion evident on the shoreline. Aquatic invertebrates, tadpoles and frogs observed in the water column. Limited green algal growth along parts of the shore. Riparian vegetation mainly *Melaleuca interioris*, with many of the trees inundated. Little to no understorey (grazed grasses, and small patches of *Muehlenbeckia florulenta*), due to intensive pastoralism.
	JC8	Floodplain	Clay, underlain by hardpan	Inundated riparian vegetation	C	NA	0.41 - 0.58	Floodplain north of JC7, intersects main pastoral track (terminus of Jones Creek). Clay sediment with a hard base below. Turbid water due to suspension of fine sediment material, water levels receded by phase 2. Erosion gullies evident along shoreline. Aquatic invertebrates, tadpoles and frogs observed in the water column, with limited green algal growth in patches in the shallows. *Melaleuca interioris* wetland, with many of the trees inundated. Little to no understorey (some grasses), as area subject to intensive pastoralism.
	JC9	Floodplain	Clay, underlain by hardpan	Inundated riparian vegetation	C	NA	0.18 - 0.31	Terminal floodplain for Jones Creek and southern most of all sites. Clay sediment with a hard base below. Turbid water due to suspension of fine sediment material, water levels receded by phase 2. Erosion gullies present around the shoreline. Aquatic invertebrates and tadpoles noted in the water column, no algal growth observed. Riparian vegetation comprised *Melaleuca interioris* and *Acacia tetragonophylla*, with an understorey of *Muehlenbeckia florulenta* and grazed grasses. Evidence of heavy stock usage, causing extensive degradation.
	JC10	Claypan	Clay, underlain by hardpan	Inundated riparian vegetation	C	NA	0.29 - 0.38	Sma+A1:I11ll rounded claypan, terminus for Jones Creek (north of JC9). Clay sediment with a hard base below. Turbid water due to suspension of fine sediment material, water levels receded by phase 2. Erosion gullies evident along the shoreline. Aquatic invertebrates and tadpoles noted in the water column, no algal benthic growth observed. During phase 2, planktonic green algal bloom observed in the water column. Larger remnant trees surrounding claypan comprised Melaleuca interioris, Eucalyptus camaldulensis and Acacia tetragonophylla. Patchy understorey of Muehlenbeckia florulenta and grazed grasses. Area heavily degraded due to intensive pastoralism.

Appendix B Water Level Changes

Table B1: Changes in water level between phases at Jones Creek and the claypans.

Sites		Max. Dim. (m)	Pool 1		Pool 2	
			Phase 1	Phase 2	Phase 1	Phase 2
Jones Creek	JC1	Length	33.0	DRY	19.5	DRY
		Width	7.8		5.1	
		Depth	0.4		0.3	
	JC2	Length	45.0	9.7	28.5	3.6
		Width	7.2	4.6	3.3	1.7
		Depth	0.4	0.2	0.4	0.1
	JC3	Length	48.0	6.1	29.0	6.1
		Width	9.3	2.1	4.2	2.1
		Depth	0.50	0.07	0.60	0.10
	JC4	Length	40.5	DRY	NA	NA
		Width	3.8			
		Depth	0.4			
	JC5	Length	80.0	23.4	NA	NA
		Width	9.5	5.2		
		Depth	0.70	0.30		
	JC6	Length	41.0	4.9	32.0	DRY
		Width	15.5	1.9	5.0	
		Depth	0.30	0.20	0.20	
Claypans	JC7	Depth	0.50	0.37	NA	NA
	JC8	Depth	0.58	0.41	NA	NA
	JC9	Depth	0.31	0.18	NA	NA
	JC10	Depth	0.38	0.29	NA	NA

Appendix C Field Water Quality

Table B1: Field water quality recorded from Jones Creek and the claypans in phase 1.

	Sites	pH (units)	Conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (ppm)	Temperature (°C)	Depth (cm)	Anoxic layer (cm)	Redox (mV)
Jones Creek	JC1	6.5	165.9	58.9	5.03	24.2	39	0	128
	JC2	5.5	151.6	55.3	4.2	29	42	0	134
	JC3	5.5	173.3	63.8	2.53	28.1	55	0	97
	JC4	5.5	152.8	56.1	4.9	29.4	43	0	120
	JC5	5.1	136.1	50.1	2.57	27.6	67	0	166
	JC6	5.6	214.2	80.0	4.81	20.7	49	0	155
Claypans	JC7	7.1	37.1	12.4	4.43	24.9	51	0	260
	JC8	7.5	41.4	14.2	5.34	25.7	58	0	211
	JC9	6.2	60.9	21.5	5.42	26.1	31	0	272
	JC10	7.8	94.9	33.9	5.23	24.1	38	0	162

Table B2: Field water quality recorded from Jones Creek and the claypans in phase 2.

	Sites	pH (units)	Conductivity (µS/cm)	Salinity (ppm)	Dissolved oxygen (ppm)	Temperature (°C)	Depth (cm)	Anoxic layer (cm)	Redox (mV)
Jones Creek	JC1	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	JC2	7.5	233.7	85.3	10.48	14.2	20	0	247
	JC3	10.3	272	100.0	18.18	9.3	7	0	113
	JC4	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	JC5	8.1	166.3	62.3	6.68	17.6	31	0	197
	JC6	7.4	252	96.0	5.02	20.5	19	0	136
Claypans	JC7	7.9	40.9	14.4	8.55	23.7	37	0	101
	JC8	7.6	75.8	27.6	7.83	21.9	41	0	128
	JC9	8.7	93.3	34.2	10.24	24.6	18	0	124
	JC10	8.0	143	53.0	9.71	23.9	29	0	143

Appendix D ANOVA Results: Water and Sediment

Table D1: ANOVA results for water quality between Jones Creek and the claypans.

Parameters		ANOVA results		Mean values	
		Significance	p-value	Jones Creek	Claypan
Basic and Nutrients	pH	NS	0.115	7.7	7.4
	EC	*	0.000	180.4	67.5
	TDS	*	0.000	128.6	519.8
	TUR	not normally distributed			
	TN	NS	0.515	1.3	1.4
	TP	*	0.000	0.053	0.353
	Chl *a*	NS	0.306	16.4	6.7
Metals and Trace Elements	Al	*	0.000	0.085	1.553
	Ba	*	0.000	0.070	0.024
	Cr	not normally distributed			
	Cu	NS	0.949	0.006	0.005
	Fe	not normally distributed			
	Ni	NS	0.071	0.004	0.006
	Pb	not normally distributed			
	Si	NS	0.646	14.0	17.7
	Zn	not normally distributed			

Table D2: ANOVA results for water quality between study phases.

Parameters		ANOVA results		Mean values	
		Significance	p-value	Phase 1	Phase 2
Basic and Nutrients	pH	NS	0.167	7.5	7.7
	EC	NS	0.259	111.9	153.1
	TDS	NS	0.259	237.2	384.0
	TUR	not normally distributed			
	TN	NS	0.925	1.3	1.3
	TP	NS	0.621	0.166	0.211
	Chl *a*	*	0.025	5.3	20.6
Metals and Trace Elements	Al	NS	0.757	0.756	0.714
	Ba	NS	0.895	0.048	0.051
	Cr	not normally distributed			
	Cu	*	0.014	0.004	0.007
	Fe	not normally distributed			
	Ni	*	0.001	0.004	0.006
	Pb	not normally distributed			
	Si	NS	0.537	13.5	18.4
	Zn	not normally distributed			

Table D3: ANOVA results for sediment quality between Jones Creek and the claypans.

Parameters		ANOVA results		Mean values	
		Significance	p-value	Jones Creek	Claypan
Basic and Nutrients	pH	NS	0.457	7.1	6.9
	TSS	NS	0.81	513.3	65.5
	MC	NS	0.47	13.3	14.9
	TN	*	0.018	76.7	157.5
	TP	*	0.000	46.7	141.8
	TOC	*	0.019	0.061	0.190
Metals and Trace Elements	Al	*	0.001	1193	2188
	Ba	Not normally distributed			
	Co	Not normally distributed			
	Cr	NS	0.384	86.1	60.9
	Fe	NS	0.095	18625	12820
	Ni	NS	0.586	14.8	11.8
	Zn	Not normally distributed			

Table D4: ANOVA results for sediment quality between study phases.

Parameters		ANOVA results		Mean values	
		Significance	p-value	Phase 1	Phase 2
Basic and Nutrients	pH	*	0.026	6.9	7.2
	TSS	NS	0.878	588.7	79.7
	MC	NS	0.271	15.1	12.8
	TN	NS	0.335	98.0	120.0
	TP	NS	0.589	79.5	89.9
	TOC	NS	0.960	0.114	0.111
Metals and Trace Elements	Al	NS	0.667	1516.0	1665.0
	Ba	Not normally distributed			
	Co	Not normally distributed			
	Cr	NS	0.555	66.9	85.1
	Fe	NS	0.327	14588.0	18018.0
	Ni	NS	0.749	13.9	13.3
	Zn	Not normally distributed			

Appendix E ANOVA Results: Aquatic Biota

Table E1: ANOVA results for diversity of aquatic biota between Jones Creek and the claypans.

Biota	ANOVA results		Mean values	
	Significance	p-value	Jones Creek	Claypan
Phytoplankton Diversity	*	0.0010	12	4
Diatom Diversity	*	0.0000	9	14
Invertebrate Diversity	NS	0.180	33	28

Table E1: ANOVA results for diversity of aquatic biota between study phases.

Biota	ANOVA results		Mean values	
	Significance	p-value	Phase 1	Phase 2
Phytoplankton Diversity	NS	0.871	8	9
Diatom Diversity	NS	0.499	12	11
Invertebrate Diversity	NS	0.405	29	33

Appendix F Aquatic Invertebrate Data

Table F1: Aquatic Invertebrate data recorded during the 2011 aquatic baseline study. NB: An estimate of amoebozoan, gastrotrich and rotifer numbers are provided. Estimates were also made for some of the remaining taxa where they occurred in high densities.

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
INSECTA																				
Coleoptera																				
Dytiscidae																				
Cybister tripunctatus										1										
Eretes australis	4		5				2		1	3			11	10	5	45	13	4	16	14
Hydaticus sp.							1				1									
Hyphydrus sp.										1		2								
Necterosoma sp.										2		6								
Paroster sp.				3																
Sternopriscus sp.										3							1			
Gyridae																				
Dineutus australis	2		3		2		2			1				1						
Dineutus sp.				6			1			8	11	23								
Hydrophilidae																				
Berosus sp.													1							
Diptera																				
Ceratopogonidae																				
Leptoconops sp.												1								
Nilobezzia sp.										1								1		
Chironomidae																				
Ablabesmyia sp.							20										4			
Ablabesmyia hilli										2										
Ablabesmyia notabilis	1				1	1				2			1						2	1
Chironomus sp. aff. *alternans*	2																			
Coelopynia pruinosa																				1

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Diptera (continued)																				
Cryptochironomus griseidorsum															1			2		
Kiefferulus intertinctus	1		2		1				7	1	1									
Parachironomus 'K2'			1																	
Paratanytarsus sp.																	4			
Polypedilum nubifer					1				1		2									
Procladius paludicola			2		1								1					4		
Tanytarsus fuscithorax			1									2		1						
Culicidae																				
Anopheles annulipes												4								
Culex annulirostris			3								1	1								
Culex palpalis			1																	
Culex sp.							15													
Culex starkae						2														
Tipulidae																				
(unidentified)										1		3								
Hemiptera																				
Corixidae																				
Agraptocorixa sp.	5				2									1	40		6	10	10	
Corixidae juveniles													40				4			
Notonectidae																				
Anisops sp.			2		1		2													
Ansipos stali	30		37	7	25	6			1	125		24		63		6		31	1	1
Micronecta robusta													3							
Notonectidae juveniles					42	2	21		35	14	25			33	3	12	23		70	40
Lepidoptera																				
Noctuoidea larva			1																	

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Odonata																				
Austrolestes analis	9		15		1	2			1							3				
Austrolestes aridus	5				1										1				1	
Austrolestes sp.	2						3		13		9	12		2			3			
Diplacodes sp.												2								
Hemicordulia tau	1		6		1	2				13	4				6					
Heminiax papuensis	17		39	4	39	20	6		30	17	3	1	1	4			1	1		
Pantala flavescens	3		1							1		1								
Trichoptera																				
Economus sp.										1										
Triplectides australis (?)																		1		
BRANCHIOPODA																				
Cyzicidae																				
Caenestheria sp.													2	19		1	12	4	9	
Caenestheriella sp.													58	9	48	26	5	20	7	8
Eocyzicus sp. OES1														5	14	18	5	23	6	
Thamnocephalidae																				
Branchinella halsei													100	103	100	100	17	1	200	108
Branchinella occidentalis													26		6	3				
Triopsidae																				
Triops australiensis													22	7	9	2	1			
CLADOCERA																				
Daphnia angulata													1							
Daphnia projecta													1			2			1	
Daphniopsis queenslandensis															2					
Diaphanosoma unguiculatum													49	1	50	9			11	1
Macrothrix breviseta									1	2	1	6				7				

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
CLADOCERA (continued)																				
Moina micrura			1	50		1			1	37	7	30					16	19	28	20
COPEPODA																				
Centropagidae																				
Boeckella triarticulata																		5		1
Calamoecia baylyi													50	7	50	50	38	5	51	40
Cyclopidae																				
Mesocyclops brooksi				1	50		20		10	20	10	15				1	6			3
Metacyclops pilanus																3				
Microcyclops varicans				5						10	10					3				
Thermocyclops sp. B2 (nr incisus)	50		50	1		3	20		30		20	15								
OSTRACODA																				
Cyprididae																				
Bennelongia australis																2				
Bennelongia nimala						1					2	1								
Bennelongia sp. 563 (SAP)							1						4	1						
Cypretta aff. *baylyi* (KIM-UWA)																		5		
Cypretta sp. BOS249	7			6		3	1		28	15	10	5			1					
Cypretta sp. BOS252							1							1		6				
Cypretta sp. PSW57 (PSW)																1				
Cypricercus sp. 253																		1		
Heterocypris tatei						13	1		5											
Ilyocypris australiensis																6				
Isocypris williamsi	7					1														
Strandesia sp. BOS248												5								
Zonocypris sp. 466 (CB)											4	10								

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
GASTROTRICHA																				
Gastrotricha																1				
AMOEBOZOA																				
Arcellinida																				
Arcella sp.	1		10	1000	10		100		10	100	20	100		5	50				10	
Centropyxis sp.			2		50		100		100	1	100				10					
Difflugia sp.	2			50	10	10			10000	100	20	2000		10		1	10		1	1
Euglyphida																				
Euglypha sp.				100	1		1			100	2	10	1	2		1		1	10	1
Trinema sp.																			1	
ROTIFERA																				
Bdelloidea																				
Bdelloidea sp. 2:2			2	50	10	100	100		100	100	100	1000		2		20				10
Bdelloidea sp. 3:3							1													
Flosculariacea																				
Conochilus dossuarius													100							
Conochilus natans							1					1								1
Hexarthra mira						1							2				1	2		
Testudinalla amphora																30				
Testudinalla cf. *parva*														2		10		100		
Testudinalla patina			2	10	1	1	1			10	1	50		5			2			1
Monogononta																				
Notommata cf. *pachyura*					1		30			1					1					1
Ploimida																				
Anuraeopsis navicula	20		50		1		10		1											
Asplanchna cf. *brightwelli*							1													5
Brachionus angularis										1							10			

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Ploimida (continued)																				
Brachionus cf. *lyratus*										1							200			
Brachionus quadridentatus	50		100	10	20	3	50		5	10	20	20				20		5		
Brachionus urceolaris													10	2		50				
Cephalodella gibba					1				1	10	1	1								
Colurella coluris					1															
Colurella uncinata bicuspidata	2		2	1000	6	20	1		2	100		2	1	2						20
Dicranophorus grandis																1				
Euchlanis cf. *meneta*	2			20	2		50			2		20				20				
Euchlanis dilatata									5			10		1	2	20				1
Keratella australis																	1			1
Keratella procurva	10000		10000	20	10000	1	10000		10000	10000	1000	50	1		100	1	1	20	10	
Lecane aculeata																				
Lecane batillifer							1													
Lecane bulla	10		20	100	100	2	100		20	100	100	100			10	30	1		2	
Lecane cf. *halicylsta*										1										
Lecane cf. *pertica*																		1		
Lecane cf. *stichaea*										1						1				
Lecane crepida							1		10	100	20	100								
Lecane curvicornis												1			2					
Lecane furcata				1						2										
Lecane hamata	71		1		1					1		1								
Lecane ludwigii															5	20				
Lecane luna											1					20				
Lecane signifera	20		10	10	10	1			10	100	10	100	1		2	30		1		
Lepadella cf. *triptera*	1		2	5	4					1		2								
Lepadella patella	1			2	2		5		5	1					1					1

Invertebrate Taxa	Jones Creek												Claypans							
	JC1	JC1	JC2	JC2	JC3	JC3	JC4	JC4	JC5	JC5	JC6	JC6	JC7	JC7	JC8	JC8	JC9	JC9	JC10	JC10
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Ploimida (continued)																				
Macrochaetus altamirai					1															
Notommata cf. *tripus*			1				5					1				1				
Polyarthra dolichoptera	50		2				10		2	10	1			2	5	10	1	20		10
Proales cf. *daphnicola*																1				
Scaridium longicaudum							30			2		20				10				
Trichocerca bidens																		1		
Trichocerca cf. weberi																				
Trichocerca iernis																1				
Trichocerca rattus				3	4	5	1		2		1				1	2				1
Trichocerca similis													10	10	50	20				
Wolga spinifer																1				

Appendix G Resting Stages Data

Table G1: Resting stages recorded during phase 2 of the 2011 aquatic baseline study, where abundance data is presented per 100 g of sieved sediment.

Taxa	Jones Creek						Claypans			
	JC1	JC2	JC3	JC4	JC5	JC6	JC7	JC8	JC9	JC10
Algae (Macrophytes)										
Lamprothamnium sp.						1				
Nitella sp.							79		35	
Aquatic Invertebrates										
Branchinella sp.										148
Unknown branchiopod										25
Abundance	**0**	**0**	**0**	**0**	**0**	**1**	**79**	**0**	**35**	**173**
Diversity	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**2**