OVERARCHING WATER MANAGEMENT STRATEGY

Kemerton Strategic Industrial Area





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Disclaimer

SUMMARY

The Kemerton Strategic Industrial Area (KSIA) has been established by the state as an area for strategic and heavy industry in the south-west region of Western Australia.

The KSIA Local Structure Plan includes a substantial 7,508 hectares (ha) which comprises the following areas:

- 2,024 ha of Strategic Industry Zone (core)
- 284 ha of Ancillary Industry Zone (support industry area)
- 4,771 ha as Industry Buffer Zone (buffer)
- 234 ha as Public Purposes
- 195 ha as Regional Open Space.

The Better Urban Water Management (BUWM) framework (WAPC October 2008) established the requirement for a Local Water Management Strategy (LWMS) to be prepared to support a Structure Plan application. The KSIA water management framework is intended to meet the overall objectives of BUWM; however, it is also intended to meet the unique planning and environmental assessment context of the KSIA planning process.

This Overarching Water Management Strategy (OWMS) has been developed in the context of the KSIA statutory planning framework to not only address the objectives of BUWM and demonstrate that the area is capable of supporting future development with respect to water related constraints, but also to inform the water management detail required by each proponent at subdivision stage. The report identifies the planning and environment context of the subject site, and outlines the key water servicing, drainage and environmental management considerations to be progressed in support of subsequent design development and planning approval phases. Further consideration of relevant government policies and advice may be warranted as subdivision occurs incrementally over a long term timeframe.

An inventory of the key elements for inclusion in the OWMS, together with a cross-reference to the relevant section in this document is presented in Table 1.

Table 1: Inventory of Key OWMS Elements

Key OWMS Elements	Compliance to Objectives
Proposed LSP (Section 1.2)	▪ The KSIA encompasses a total area of 7,508 hectares (ha) of which 4,771 ha consists of an Industry Buffer Zone (buffer), a 2,024 ha Strategic Industry Zone (core) and a 284 ha Ancillary Industry Zone (support industry area). The remainder of the LSP is set aside for Public Purpose and Regional Open Space. ▪ The KSIA buffer is to remain under the management of its owner agency, currently being the Department of Park and Wildlife (DPaW).
Location and Existing Land Use (Section 2.1)	▪ The KSIA comprises a mix of semi-cleared grazing land and properties, plantation forestry, areas of native vegetation, wetlands and existing heavy industry. ▪ Existing heavy industries including Kemerton Silica Sands, Simcoa Operations, Cristal (Millennium Inorganic Chemicals), Nufarm Coogee Pty Ltd, BOC Limited, Transfield and Tesla. ▪ Other landowners within the KSIA include the DPaW, Western Power and private landownership currently used for rural and semi-rural pursuits.
Topography (Section 2.2)	▪ The KSIA core generally slopes from west to east. The western border is characterised by a ridge that ranges from 50 m AHD in the north to 15 m AHD in the south.
Geology (Section 2.3)	▪ Bassendean Sands are the predominant soil type at the KSIA. The Guildford Formation, consisting of peaty sand and clay, and sands derived from the Tamala Limestone are present towards the west of the site, within the Kemerton Industrial Core. ▪ Soil sampling was completed on site in July 2011 in order to establish the Phosphorus Retention Index (PRI) of the soils. The PRI of the soils within the site ranged from 0.1 to 37.2. With the exception of the high PRI of 37.2 at one site, the remaining samples indicate that the site contains soils that have a weak capacity to adsorb phosphorus. ▪ A Preliminary Geotechnical Investigation was completed for the KSIA core and KSIA support industry area by Douglas Partners in April 2011. The report recommends a minimum fill level above the Average Annual Maximum Groundwater Level (AAMGL) of 1.5 m. Results of permeability testing suggest a design permeability of 1×10^{-4} m/s (8.6 m/d)
Groundwater (Section 3.0)	▪ The groundwater in the Kemerton subareas is divided into four distinct groundwater resources – Superficial aquifer, Leederville aquifer, Yarragadee aquifer and the Cattamarra Coal Measures. ▪ Groundwater level and quality data collected at the site to date has been included in this OWMS. ▪ The groundwater mapping of the AAMGLs indicates the groundwater level is at 6 m AHD to 14 m AHD, which represents groundwater generally being 40 m below ground level (bgl) at the western ridge and 0 to 5 m bgl through the central to east of the site. ▪ Initial pre-development water quality is generally poor, with nutrient levels above the Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guideline for wetlands.

Key OWMS Elements	**Compliance to Objectives**
Surface Water (Section 4.0)	▪ The main surface drainage feature around the KSIA is the Wellesley River located outside the eastern and south-eastern boundaries of the KSIA. The river flows in a south-westerly direction into the Brunswick River that then merges with the Collie River prior to discharging into the Leschenault Inlet to the south-west. ▪ Due to its low topography and deep, well-drained sands, there is limited natural surface water drainage within the KSIA. A number of artificial drains have been constructed to drain the Multiple Use wetlands and inundated palusplain areas. These drains generally flow to the east and south discharging to the Wellesley River. ▪ 84 geomorphic wetlands (or part thereof) are located within the KSIA core. Twenty two are classified as Conservation Category wetlands, seven are former EPP Lakes, 14 are Resource Enhancement wetlands and 39 are Multiple Use wetlands and two are not assessed. ▪ The northern extent of the Leschenault Estuary is located approximately 1 km west of the Industry Buffer Zone.
Water Supply (Section 5.0)	▪ The existing industries at the KSIA abstract water for process and potable requirements from the unconfined and confined groundwater aquifers and the Harvey Irrigation Scheme. ▪ A total allocation of 9.787 GL is currently available from the groundwater management areas at the KSIA ▪ It has been estimated that if a number of high-demand industries locate to the KSIA such as an aluminium smelter and a power station (Transfield), the water demand for the KSIA could reach a total of 40 GL/year. ▪ An application was lodged with the Department of Water (DoW) in 2011 to secure a groundwater allocation from the Cattamarra Coal Measures aquifer of the Kemerton North and South groundwater sub-areas for industrial processing within the KSIA. ▪ The DoW advised that a staged development plan would be required and that the maximum permitted licence term for large staged developments with a water entitlement exceeding 500 ML/yr is five years. In 2011, a staged development plan was not available and the time frames for development of the KSIA were uncertain. In addition, the DoW requested that a H3 Hydrogeological Assessment report and successful drilling of the aquifer be completed prior to the DoW issuing a 5C licence to take water. ▪ Future applications to secure a groundwater licence will be supplied to the DoW following approval of the KSIA Structure Plan and the required information being available. ▪ Future water supply options at the KSIA include – Integrated Water Supply Scheme (Potable) – Wellington Dam (Potable and Process) – Groundwater Abstraction (Potable and Process) – Brine Diversion from Collie Water Recovery Project (Process) – Recycled water from the Kemerton Wastewater Treatment Plant (Process) – Recycling water within the KSIA at the lot scale and between industries.

Key OWMS Elements	**Compliance to Objectives**
Wastewater Treatment (Section 6.0)	▪ The following are the preferred options to manage industrial wastewater at the KSIA – Industry to treat effluent to predetermined acceptance criteria and recycled on site or to a neighbouring industry. – Industrial wastewater to be collected centrally and recycling opportunities sought or disposal considered. – If a critical mass of industry is reached, a combined application for a common outfall could be made whereby wastewater is treated to an acceptable standard on site or centrally within the KSIA prior to disposal (subject to required environmental approvals). ▪ There will be no reticulated wastewater collection provided by Water Corporation to treat wastewater generated from toilets, bathrooms and kitchens within each lot. ▪ Aerobic Treatment Units (ATUs) and/or septic tanks and leach drains are the proposed treatment options for commercial wastewater.
Surface Water Management (Section 7.0)	▪ Rainfall up to the 1:10 year ARI event will be retained and infiltrated within lot boundaries using vegetated swales / detention areas. Lot run-off in excess of 1 in 10-year ARI event shall discharge to roadside swales. ▪ Roadside conveyance swales shall be sized to convey the critical 10-year ARI storm event from road run-off. ▪ Large rainfall events (>10 year) up to the 1:100 year ARI event will be conveyed by the roads and road side swales where possible to drainage basins located in designated drainage reserves, the location of which will be determined at lot scale WMP stage, with due consideration to environmental factors such as groundwater clearance and wetland impacts. ▪ Stormwater storage areas have been sized to accommodate the 1:100 year ARI event within Catchments 1 to 7. Catchments 8 to 10 are sized to cater for the 1:100 year ARI event with restricted overflow to Wellesley River. ▪ Best management practices and treatment measures shall be put in place to retain the quality of stormwater at Kemerton
Groundwater Management (Section 8.0)	▪ The use of soil amendment in the drainage basin(s) in order to increase the retention of nutrients, prior to infiltrating to groundwater. ▪ Industry operators within the site will be encouraged to implement Industrial BMPs for their industry with regard to protection of water resources. These may include oil and water separators or bunding of vehicle wash-down areas and limitations on the quantity and period of time hazardous materials can be held on site. ▪ The use of vegetated swales in lieu of a piped drainage network where possible to remove sediment and contaminants prior to infiltration. ▪ The use of a soil amendment beneath drainage areas or beneath building envelopes to minimise the leaching of contaminants to groundwater. ▪ A post-development groundwater monitoring program will be completed to compare to pre-development conditions. ▪ At this stage of planning, a clearance of 1.5 m from AAMGL to finish lot levels is proposed, however details of groundwater control will be undertaken at subdivision stage, with due consideration to *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013a). ▪ Stormwater storage areas and swales are proposed to have 0.3 m clearance from the base of the swale to maximum groundwater levels (MGLs) to ensure that water is infiltrated within suitable timeframes, however details of water control will be undertaken at subdivision stage in accordance with DoW (2013a).

Key OWMS Elements	Compliance to Objectives
Wetland Management (Section 9.0)	▪ The KSIA Structure Plan has been developed to ensure that a majority of the high value Conservation category and Resource Enhancement wetlands are contained within the KSIA buffer and Regional Open Space. ▪ A wetland risk analysis has been undertaken by RPS in consultation with DPaW to provide a qualitative risk assessment and management strategy for wetlands at the site. The wetland risk analysis report provides recommendations for future site specific assessments and management measures. ▪ The appropriate site-specific management plans will be prepared prior to subdivision, which will address specific management measures for any wetlands potentially impacted by development proposals.
Post-development Monitoring and Reporting (Sections 10.0)	▪ Post-development groundwater monitoring will occur over a period of three years (quarterly for quality, monthly for levels). Post-development monitoring requirements will be determined so as not to duplicate any DER monitoring requirements imposed on industry proponents. ▪ Opportunistic surface water monitoring of the drainage areas will occur for water quality once every year during the first winter flush for a period of three years ▪ Trigger values for the site will be calculated by adding 20% to the median value calculated from predevelopment monitoring for groundwater or by comparison to ANZECC water quality guidelines for surface water. These values will be outlined in the subdivision scale Water Management Plan(s) and they will determine when contingency measures will be used. ▪ Contingency measures will be implemented in the event of trigger values being exceeded in two consecutive monitoring events. ▪ The post-development results of the monitoring program will be reported annually to the Shire of Harvey (SoH) and DoW and will be reviewed annually in conjunction with the SoH and DoW
Future Areas to be Investigated after OWMS (Section 11.0)	▪ Areas to be investigated after OWMS are identified. Works include completing the detailed earthworks and engineering design, as well as confirming the future water supplies for industrial uses.

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1.0 INTRODUCTION

1.1 Planning Framework

1.1.1 Overview

LandCorp, on behalf of the Department of State Development (DSD) are seeking Structure Planning approval for the Kemerton Strategic Industrial Area (KSIA).

The KSIA will provide an area for strategic and heavy industry in the south-west region of Western Australia. Development of the KSIA is expected to occur over a long-term time frame, which will be influenced by the demand for strategic and heavy industrial sites. A range of lot sizes will be available for subdivision by prospective buyers who will have the opportunity to purchase or lease land to suit their individual industry requirements.

1.1.2 Proposed Local Structure Plan

The KSIA extends across the suburbs of Parkfield and Wellesley, both of which are located within the Shire of Harvey. The KSIA encompasses a total area of 7,508 hectares (ha) (Figure 1). A comprehensive Structure Plan (Figure 2) has been developed in collaboration with DSD and LandCorp by TPG town planning and urban design consultants. The site environmental constraints and existing service corridors have led to the development of a Structure Plan, which incorporates the following:

- a Strategic Industrial Zone (core) comprised of approximately 2,024 ha
- an Ancillary Industry Zone (support industry area) of 284 ha which is likely to comprise of supporting industrial uses
- an Industry Buffer Zone (buffer) of 4,771 ha
- 234 ha as Public Purposes
- 195 ha as Regional Open Space.
- service corridors that provide links to the major transit corridors and rail linkages.

The Structure Plan provides zones for various industry types categorised by risk to both air and noise pollution. The risk categories aim to locate suitably industry types within the core industrial area. Industries that are considered high risk are located in the centre of the industrial area to increase the buffer from these industries to the surrounding environment and other industries.

1.1.3 Planning Background

In 1985, The KSIA was established as an area for heavy industry. The proposed KSIA is the largest industrial area in the south-west of Western Australia and is one of the state's designated "strategic industrial" areas. It is envisaged that the KSIA will provide a leading industrial area to enable efficient, internationally competitive and environmentally responsible processing of the south-west's resources. In addition, The KSIA will provide alternatives to the Kwinana and Rockingham industrial centres and will ideally place new industrial centres closer to the source of primary resources as well as promoting regional economic development and employment.

1.1.4 Bunbury-Wellington Region Plan

The Bunbury Wellington Region Plan (1995) was adopted by the Western Australian Planning Commission (WAPC) as the Regional Plan to guide statutory planning decision-making in the Bunbury-Wellington region. Recommendations of this plan relating to the KSIA include:

- installing the Kemerton rail spur adjacent to Marriott Road
- supporting new industries such as the production of tonnage glass, special ferrous metals, rare earths and peculiar metals from heavy minerals and processes related to chlor-alkalis
- identify and protect buffer zones around industrial areas from encroachment by incompatible land uses such as residential
- provide the community with adequate information about proposed industrial developments at an early stage
- the Region Plan incorporates the Greater Bunbury Structure Plan (1995) which identified the KSIA core, KSIA support industry area and KSIA buffer
- Kemerton specifically provides for development to proceed in accordance with the approved Kemerton Industrial Park Plan.

1.1.5 Industry 2030 – Greater Bunbury Industrial Land and Port Access

This report referred to as "Industry 2030" was adopted by the WAPC and the State Government in 2000 as the planning response to the industrial land and port access needs of the Greater Bunbury region over the next 30 years and beyond. The Final Industry 2030 report released in April 2000 recommended the expansion of the Industrial Core to 2,106 ha and the buffer area (including inter-industry buffer and support industry area) to 5,437 ha.

1.1.6 Greater Bunbury Region Scheme

A draft Greater Bunbury Region Scheme (GBRS) (WAPC 2000) was released for public comment in August 2000 by the WAPC. A formal environmental assessment was carried out with the EPA's report and recommendations on the GBRS (Bulletin 1108) released in September 2003. The Minister for the Environment issued the environmental conditions (Statement No. 697) on 31 October 2005. The GBRS was tabled in Parliament on 17 October 2007 and it came into effect in November 2007.

Planning controls for the KSIA are reflected in the GBRS in the following manner:

- The KSIA core is zoned "Industrial".
- The KSIA buffer is zoned "Rural" with a "Special Control Area No. 2 (SCA No. 2)" designation applied over it. Under the GBRS, "SCA No. 2" will ensure that development within the special control area does not prejudice the use of the Kemerton core for industrial purposes, and local government in considering development applications within the area will be required to have due regard to the purpose of the "SCA No. 2".

The following uses are not permitted in SCA No. 2:

- residential accommodation including single residential dwellings and grouped dwellings
- hospitals
- schools
- institutional or other uses involving residential accommodation, including temporary, short stay or holiday accommodation
- general, noxious, hazardous and light industry uses as defined in State Planning Policy No. 4.1: State Industrial Buffer Policy.

Within the Buffer Areas, changes in land use will be considered by the WAPC if they are compatible with continued development and protection of the Industry Core.

A ministerial condition placed on the GBRS, required a Drainage, Nutrient and Water Management Plan (DNWMP) to be completed.

1.1.7 Shire of Harvey District Planning Scheme No. 1

The KSIA is located within the Shire of Harvey District Planning Scheme No. 1 (DPS 1), a gazetted planning scheme with statutory land use classifications and provisions.

With respect to the KSIA, DPS 1 details the following:

- development and zoning standards for the KSIA core, the KSIA support industry area, and the KSIA buffer
- KSIA and Buffer Statement of Policy
- Schedule 18 KSIA Area Strategy Plan
- building line setbacks on roads declared by the Shire of Harvey as having scenic value.

This setback applies to Wellesley Road, which has a building line setback of 80 m on both sides of the road within the Shire. Following approval of the GBRS, planning legislation provides that, where inconsistencies between the GBRS and DPS 1 exist, the provisions of the region scheme prevail.

1.2 Water Management Framework

1.2.1 Greater Bunbury Region Scheme Water Management Condition

A ministerial condition placed on the GBRS, required a DNWMP to be completed. Following conditional endorsement of the GBRS amendment however, the Better Urban Water Management guidelines (BUWM) (WAPC 2008) were released which states that a Local Water Management Strategy (LWMS) is to be completed to support a Structure Plan. A LWMS would generally supersede the DNWMP as the report content is similar. However in the case of the KSIA planning framework, the ministerial condition will be met by the completion of an Overarching Water Management Strategy (OWMS), with the rationale provided in the following sections.

1.2.2 BUWM Framework

The Better Urban Water Management (BUWM) framework (WAPC 2008) establishes a requirement for a District Water Management Strategy (DWMS) to be prepared in support of a region scheme amendment or district structure plan. The objective of the DWMS is to demonstrate that the area is capable of supporting future development in terms of water supply planning, flood mitigation, drainage manage and water quality protection. A Local Water Management Strategy (LWMS) is typically undertaken at Local Structure Plan (LSP) stage; its purpose is to support and facilitate approval of the LSP. The LWMS details the integrated water management strategies that will be implemented, and demonstrates that the land is capable of facilitating urban development whilst achieving sustainable, water and environmental outcomes. An Urban Water Management Plan (UWMP) is typically required at subdivision stage, its purpose being to support subdivision approval. The UWMP provides the detail to the design proposed in the LSP.

1.2.3 KSIA Water Management Planning Framework

This KSIA OWMS has been developed in the context of the KSIA statutory planning framework to not only address the objectives of BUWM and demonstrate that the area is capable of supporting future development with respect to water related constraints, but also to inform the water management detail required by each proponent at subdivision stage. The OWMS identifies the planning and environmental context of the subject site, and outlines the key water servicing, drainage and environmental management considerations to be progressed in support of subsequent design development and planning approval phases. Further consideration of relevant government policies and advice may be warranted as subdivision occurs incrementally over a long term timeframe.

Section 1.9 of the KSIA Structure Plan refers to an overarching environmental management plan (EMP) (Eco Logical 2015). The OWMS falls under this overarching EMP, as water is a Deferred Factor under Ministerial Statement 697. Section 1.9 of the Structure Plan includes the following:

> 1.9.1. The overarching Environmental Management Plan (EMP) establishes the deferred environmental factors, to be addressed by a proponent through a proposal specific EMP at the Subdivision or Development Application stages.
>
> 1.9.2 A proposal specific EMP will only be required as a condition at either the Subdivision or Development Application stages if the proposal will have an impact on the deferred environmental factors.
>
> 1.9.3 Any conditions in a proposal specific EMP must be capable of being complied with during the execution of the proposal and not create ongoing obligation beyond the completion of the proposal.

As described in the EMP, proponents will be required to complete site-specific environmental management documents to develop the site in the future, that are cognisant of the requirements of the over-arching documents. The over-arching documents are intended to broadly address the conditions of Ministerial Statement 697, however the lot scale future management documents will be required to address all of the conditions to an acceptable level of detail. All future proponents will be responsible for obtaining their own State and Commonwealth approvals associated with their lots; it is noted there are a number of State and Commonwealth environmental values throughout areas zoned for development however this does not necessarily mean that disturbance is allowed in these areas.

On the basis of the KSIA planning framework, it is appropriate to refer to this report as an Overarching Water Management Strategy (OWMS), rather than an LWMS which is typically required for structure planning under BUWM, to recognise that the same level of detail typically required in an LWMS under the BUWM framework is not intended for this OWMS. The intention of the OWMS is to address the regional water related issues so the proponent is aware of detailed investigation that may be required at subdivision stage, under a lot scale Water Management Plan (WMP). The benefit of this approach is that the OWMS identifies broad water management issues while deferring certain investigation and design costs until such time as a specific proponent is present, and a better understanding of actual land requirements in terms of size, configuration, location, co-location, flood immunity and servicing requirements is known.

The Department of State Development (DSD) is the Lead Agency for the KSIA and LandCorp is the KSIA estate manager, landowner and lessor. When considering Business Case submissions from future heavy industry proponents seeking to establish within the KSIA, DSD and LandCorp will consider the proposal in the context of the Structure Plan, and the supporting technical reports and operational requirements of the KSIA. This is to ensure the KSIA is developed to its full potential, namely to establish resource processing industries and associated support activity in order to fulfil its designated role as a SIA in the south-west region. This process occurs well before the lodgement of a Development Application with the Shire of Harvey and / or Western Australian Planning Commission.

As proponents' development requirements can vary considerably based on the type of industry, associated operational requirements and footprint, and site-specific characteristics, the imposition of conventional information requirements (and subsequent subdivision / development conditions) is not always appropriate as it does not reflect the long term, proponent-driven development nature of the SIA. Information requirements (and subsequent subdivision / development conditions) should be considered on a case-by-case basis. In the heavy industrial areas, proponents will be required to investigate, fund and implement the specific infrastructure and services they need to support their developments on their sites (i.e. power, water, telecoms, and wastewater solutions).

Development of the KSIA is intended to occur over a long-term timeframe, depending upon the demand for individual sites within the heavy industrial areas. Due to the uncertain nature and timing of the demand for sites, the specific needs of each proponent and subsequent servicing requirements, development of sites is intended only when required by a future proponent. Proponents may have large or no servicing requirements depending on the nature of their proposal or may elect to self-service within their own sites. Where proponents require services to be extended to their sites, this is expected to be undertaken in a coordinated way with the rest of the KSIA. Of note is that responsibility may not 100% rest with the proponent in instances where there is shared infrastructure such as road or drainage basins (which may require LandCorp input).

1.3 OWMS Objectives

This OWMS supports the use of the Kemerton SIA for general and heavy industrial uses by demonstrating that the area is capable of supporting future development in terms of water supply planning, flood mitigation, drainage management and water quality protection.

The report has been developed in accordance with and in consideration of the following guidance documents:

- Water Quality Protection Note 52: Stormwater Management at Industrial Sites (DoW 2010a)
- Shire of Harvey Information Sheet No. 3 Development Standards – Industrial Area
- Better Urban Water Management (WAPC 2008)
- Western Australian State Water Plan (Government of Western Australia 2007)
- Kemerton Groundwater Subareas Water Management Plan (DoW 2007)
- State Planning Policy 2.9: Water Resources (WAPC 2006)
- Local Area Management Plan for the Groundwater Resources of the Kemerton Subareas (DoW 2005)
- Stormwater Management Manual for Western Australia (DoW 2004–2007)
- Industry 2030 – Greater Bunbury Industrial Land and Port Access (WAPC 2000).

This OWMS aims to achieve integrated water management through the following design objectives:

- Effectively manage the risk to human life, damage to property and environmental degradation from water contamination, flooding and waterlogging.
- Maintain and if possible improve water quality (surface and groundwater) within the development in relation to pre-development water quality.
- Reduce potable water consumption within both public and private spaces using practical and cost-effective measures.
- Promote infiltration of surface water close to source to minimise the risk of water quality degradation and to mimic the dominant pre-development hydrological process of rainfall infiltration.

- Implement best management practices in regards to industrial stormwater management.
- Incorporate where possible, low maintenance, cost-effective landscaping and stormwater treatment systems.

As discussed above, the development time frames of the KSIA are long-term and dependent on the demand for strategic and heavy industrial sites. This OWMS details the integrated water management strategies to facilitate future water management planning that are consistent with current government policies and advise. Due to the long development time frames however, consideration of relevant government policies and advice may be warranted as subdivision occurs in a staged process with time.

1.4 Previous Studies

1.4.1 Water Studies

There have been numerous technical investigations and reports completed for the KSIA during the past decade. The most significant to the OWMS are the Phase 1 and 2 Kemerton Water Studies.

The Kemerton Technical Working Group, comprising LandCorp, Department of Mineral and Petroleum Resources and the then Water and Rivers Commission, organised for a Phase 1 Water Study to be completed by Bowman Bishaw Gorham (BBG) in 1999. The objectives of this study were to:

- Collate and review available data, identify deficiencies and specify additional work required to collect the necessary data.
- Assess at a desktop level the potential impacts of development (including water supply and drainage) on the groundwater, wetlands, groundwater dependent vegetation and surface catchments of the KSIA and surrounds.
- Propose management measures to avoid or mitigate adverse impacts and allow development to proceed.

Following the Phase 1 investigations, a specialist water resource and management company, Aquaterra, was commissioned to carry out the recommendations provided in the Phase 1 Water Study and complete additional monitoring and modelling. The main objectives of the Phase 2 Water Study included:

- the acquisition of additional hydrogeological data (complete on site monitoring) and assessment with existing information to address a range of water related environmental objectives

- to develop an understanding of the interactions between the surface water, groundwater and groundwater dependent ecosystems. This was largely achieved through the development of a multi-layered groundwater model

- the development of a refined Water Management Strategy that identifies inter-relationships between water and environmental values and issues to allow the environmentally sustainable development and operation of the KSIA.

At the time the Water Study was completed (Aquaterra 2002), there was no government based water framework requiring the completion of a District Water Management Strategy (DWMS) (or equivalent) to support a Region Scheme Amendment, however the Study was completed to establish the current hydrological conditions at the KSIA in order to develop a suitable Structure Plan for the site.

The Phase 2 Water Study was therefore not formally endorsed by the then Water and Rivers Commission (now Department of Water (DoW)), however was developed in collaboration with the parties discussed above (including the Water and Rivers Commission) and it has provided critical information for inclusion in this OWMS. An electronic copy of the Water Study (Aquaterra 2002) is provided on CD at the rear of this report in Appendix 1 for reference. Further details of the report conclusion and recommendations are discussed throughout the OWMS.

1.4.2 Water Related Technical Investigations

The following is a list of studies previously undertaken which are related to water management at the KSIA:

- Hydrological Monitoring at Kemerton Industrial Park (Cardno 2010a)

- Wellington Dam and Upper Collie Water Supply and Demand Project (Marsden Jacobs Associates 2010)

- Kemerton Industrial Park Strategy Plan (DSD et al. 2009)

- Kemerton Industrial Park Environmental Overview for the KSIA Strategy Plan (Coffey 2007)

- Kemerton Water Study Phase 2 (Aquaterra 2002)

- Kemerton Water Study Phase 1 (BBG 1999).

1.5 Current Studies

Eco Logical (2015) has prepared an Environmental Management Plan (EMP) document to support the KSIA Structure Plan. The EMP document has outlined a future process for state and federal environmental approvals, which is essentially going to require future proponents to seek their own environmental approvals at the subdivision stage of development. Section 1.2.3 provides further detail.

A detailed water management document will be required by each proponent at subdivision stage, referred to as Water Management Plans (WMPs). Details of relevant investigations that are yet to be finalised, which may affect the management of water at the KSIA will be discussed in the future lot scale WMPs, which are likely to be completed as a condition of subdivision.

2.0 EXISTING ENVIRONMENT

2.1 Location and Existing Land Use

The KSIA is located in the Shire of Harvey (SoH) in the south-west region of Western Australia, approximately 160 km south of Perth and 17 km north-east of Bunbury (Figure 1). The site is bound to the east and south-east by the Wellesley River and to the west and south-west by Old Coast Road.

A majority of the land within the KSIA Industrial Core is owned by LandCorp, with the southern area (south of Marriott Road) containing most of the existing heavy industries including, Simcoa Operations, Cristal (Millennium Inorganic Chemicals), Nufarm Coogee Pty Ltd, BOC Limited, and Tesla. Kemerton Silica Sands is located to the north-east of the KSIA core and Transfield is located in the north-east of the KSIA core. Other landowners within the KSIA include the Department of Parks and Wildlife (DPaW), Western Power and private landownership currently used for rural and semi-rural pursuits.

The KSIA core comprises a mix of cleared former grazing land, plantation forestry, areas of native vegetation and wetlands. Sand extraction mines occur within the KSIA core and KSIA buffer.

The KSIA buffer is managed by DPaW; in addition to the sand extraction operations the buffer comprises remnant vegetation and wetlands. Two landfill sites are located at Stanley Road in the southern end of the buffer zone. An abattoir and a piggery are located on the western side of the KSIA core. A Water Corporation wastewater treatment plan (WWTP) with an existing capacity of three mega litres (ML) is located in the Public Purposes area on the western side of the KSIA core. A number of grazing, agriculture and rural uses presently exist on private and public landholdings within the buffer area also. Figure 3 illustrates the existing land uses at the site. Plate 1 shows the site entrance.

Plate 1: Entrance to the Kemerton Strategic Industrial Area

2.2 Topography

The Industrial Core generally slopes from west to east, towards the Wellesley River. The western margin is characterised by a ridge that ranges from 50 m AHD in the north to 15 m AHD in the south. This ridge slopes down to the eastern margin of the site, which is low-lying, and gently sloping with an elevation of approximately 10 m AHD. The topography of the site is presented in Figure 4.

2.3 Geology

2.3.1 Soil Types

The 1:250 00 Australian Geological Series Sheet SF 5004 (third edition 2006) identifies the following surface geology at the site (Figure 5).

Qts – Sand derived from Tamala Limestone: typically consists of yellow/orange medium-grained quartz sand. It occurs towards the west near the coastline and has a maximum thickness of approximately 90 m.

Qpb – Bassendean Sand: consists of white to pale grey (occasionally brown) moderately sorted, fine to medium grained quartz sand. It unconformably overlies the Guildford Formation across large areas of the site (Qpb/Qpa), and may reach a maximum thickness of about 30 m. The Bassendean Sand outcrops as low dunes in the eastern and central parts of the Kemerton area.

Qpa – Guildford Formation: can be divided into a clay member to the east and a sand member in the west. The clay member consists of brown or grey clay and sandy clay. The sand member consists predominantly of grey, poorly sorted, fine to very coarse-grained quartz sand with minor beds of brown or grey clay. This unit has a maximum thickness of about 35 m. The Guildford Formation outcrops east of the Kemerton area.

Qrw – Swamp and lacustrine deposits: consisting of peat, peaty sand and clay, associated with the presence of waterbodies and wetlands.

2.3.2 Geotechnical Investigation

A Preliminary Geotechnical Investigation was completed for the Industrial Core and Support Area by Douglas Partners (Douglas Partners 2011). The field work was undertaken on 17 February 2011.

The Geotechnical Investigation comprised a desktop review of available geological information, a walk over survey and the drilling and testing of 25 boreholes to provide preliminary geotechnical comments on earthworks requirements, suitable fill levels above AAMGL, suitability for on-site stormwater disposal using soakwells and sumps and included an assessment of soil permeability.

The boreholes were generally undertaken across the range of geological units within the site to confirm the soil types and thus verify the published mapping. The ground conditions encountered at the boreholes generally comprised of topsoil overlying sand. Some exceptions were encountered and they included silty sand, peaty sand, clayey sand and coffee rock.

No free groundwater was observed within any of the boreholes drilled to depths of up to 2.0 m below ground level (mbgl), albeit the investigation was undertaken when groundwater levels are expected to be at the annual low (17 February 2011). A groundwater monitoring well located on the west side of Wellesley Road, approximately 1.3 km north of the intersection with Treasure Road, was dipped and it recorded a groundwater level of 3.2 mbgl (11.96 m AHD).

The report recommends a minimum fill level above Average Annual Maximum Groundwater Level (AMMGL) of 1.5 m. Douglas Partners considers that this level is suitable to meet the geotechnical requirements of the area.

Results of the analysis indicate that ground conditions beneath the site generally comprise sand, and that on site stormwater disposal using soak wells and sumps is feasible. A permeability of between 2×10^{-4} and 3×10^{-4} m/s (17 to 26 m/d) for the sand encountered at the site is suitable, however, a design permeability of 1×10^{-4} m/s (8.6 m/d) is suggested given the sand encountered at the borehole locations is generally loose to medium dense.

2.3.3 Phosphorus Retention Index

To determine the ability of the soils within the site to retain phosphate, the Phosphorus Retention Index (PRI) of the soils on site was analysed. Lower PRI values indicate a lower ability of soils to adsorb phosphorus and leaching occurs more readily.

Soil samples were obtained from seven sites to a maximum depth of 1 mbgl. Sample locations were chosen to obtain a sample from all the various soil types on site, and samples were taken from the soil profile where a change in soil characteristics was observed. Figure 6 illustrates the PRI sample locations and the results of the laboratory analysis are attached in Appendix 2.

The results of the PRI analysis of the soil on site are provided below in Table 2

Table 2: PRI Results

Location	Depth (m)	Average PRI
KM 1-1	0–0.15	1.7
KM 1-2	0.15–1.0	1.5
KM 2-1	0–0.5	0.2
KM 2-2	0.5 1.0	0.5
KM 3-1	0–0.2	0.8

Location	Depth (m)	Average PRI
KM 3-2	0.2–1.0	0.8
KM 4-1	0–0.15	0.2
KM 4-2	0.15–0.4	0.1
KM 4-3	0.4–1.0	0.5
KM 5-1	0–0.1	0.8
KM 5-2	0.1–1.0	1.1
KM 6-1	0–0.4	1.1
KM 6-2	0.4–1.0	1.5
KM 7-1	0–0.90	1.4
KM7-2	0.90–1.0	37.2

Table 3 below describes the ranges of PRI results and the ability of the soil to adsorb phosphorus. Based on the results above, a majority of the soils on site have a weakly adsorbing ability to retain applied phosphorus.

Site KM7-2 recorded a higher value of 37.2 at depth. This site is located in the Guildford Formation and is representative of the clay content found in this soil profile. Soils of the Guildford Formation are commonly found to have a moderate to strong adsorption ability.

Table 3: PRI Fixation Properties

PRI	Description
negative	desorbing
0–2	weakly adsorbing
2–20	moderately adsorbing
20–100	strongly adsorbing
>100	very strongly adsorbing

2.3.4 Acid Sulfate Soils

The Department of Environment Regulation (DER) Acid Sulphate Soils (ASS) Risk Mapping indicates that a majority of the site is mapped as having a "moderate to low risk" of ASS occurring with isolated pockets of "high to moderate risk" generally associated with the wetlands on site. A majority of the western extent of the Industrial Core has "no known risk" of ASS occurrence.

Consistent with the WAPC Planning Bulletin no. 64: Acid Sulfate Soils (WAPC 2003), site investigations to determine whether ASS are present and their extent and severity, will be undertaken prior to subdivision. If the site is found to contain ASS that may be disturbed by the development, an ASS Management Plan will be submitted for approval by the Department of Environment Regulation (DER) prior to subdivision. All site works will be carried out in accordance with the provisions of the approved ASS Management Plan to the satisfaction of the DER. Further details will be provided in future lot scale WMPs.

3.0 GROUNDWATER

3.1 Groundwater Aquifers

The groundwater in the Kemerton subareas is divided into four distinct groundwater resources based on the hydrogeology of the:

- Superficial aquifer, with a saturated thickness of approximately 20 – 40 m
- Leederville aquifer, with a top elevation at approximately -15 m AHD
- Yarragadee aquifer, with a top elevation at approximately -120 to -220 m AHD
- Cattamarra Coal Measures aquifer, with a top elevation at approximately -150 to -300 m AHD.

The results of the hydrogeological investigations and modelling completed for the Kemerton Phase 2 Water Study (Aquaterra 2002) have been referenced to provide much of the detail discussed below. The Kemerton Phase 2 Water Study is provided in Appendix 1 (on CD) for reference.

3.1.1 Superficial Aquifer

The Superficial aquifer consists of clay and sand in the east and sand and limestone in the west, and has a saturated thickness of around 20–40 m. Topography, drainage and surface geology influence the hydrological regime of the Superficial formations, potentially giving rise to groundwater mounding in areas of high groundwater.

Rainfall recharges the aquifer but a large proportion of the infiltration is lost due to evapotranspiration from areas where there is limited separation to groundwater.

Groundwater flow is generally westwards from the Darling Scarp, and seasonal variations in the water table are in the order of 1 to 2 m. Variations in water level can usually be correlated with variations in rainfall. Groundwater discharges locally to watercourses, swamps and wetlands (including Myalup Swamp), the Wellesley River and Leschenault Inlet. There is also leakage to the underlying Leederville aquifer and discharge to the Indian Ocean. Inflow into the Superficial aquifer may also occur from the Leederville aquifer and from the Harvey River Diversion Drain.

Groundwater, west of the Wellesley River, is generally fresh to marginal (250 to 1,500 mg/L Total Dissolved Solids (TDS)) and is generally brackish to the east. In local discharge areas west of the Wellesley River, the salinity can be as high as 20,000 mg/L TDS. Fresh groundwater (< 500 mg/L TDS) is generally more extensive at the water table than at the base of the aquifer. The groundwater salinity generally increases in the direction of groundwater flow but there are significant local variations due to differences in permeability, irrigation, evapotranspiration and leakage from clays. A saline interface is present along the western boundary of the aquifer (Aquaterra 2002).

3.1.2 Leederville Aquifer System

The Leederville Aquifer is a confined aquifer system and is recharged mainly by downward leakage from the overlying Superficial aquifer in the southern part of the estate (Aquaterra 2002). Upwards leakage from the Yarragadee Formation to the Leederville may also occur in some areas. The main recharge area around Kemerton for the Leederville aquifer is between the Wellesley River and Myalup Swamp, where there is a downward vertical gradient and the overlying Superficial formation is predominantly sand (Aquaterra 2002).

Groundwater within the Leederville aquifer flows westerly and discharges to the Indian Ocean. Groundwater is freshest (850 to 1,500 mg/L TDS) between the main recharge area and the saline interface near the coast. The remainder of the aquifer is brackish to saline (1,500 to 19,000 mg/L TDS).

3.1.3 Yarragadee Aquifer

Underlying the Leederville aquifer is the Yarragadee aquifer, which consists mainly of sandstone. The Yarragadee aquifer is only present in the southern part of the Kemerton subareas. The Yarragadee Formation and the Cattamarra Coal Measures form a single flow system. Recharge to the aquifer along the Picton Line occurs in the south or southeast and groundwater flows east to west, discharging out to sea. The salinity of the aquifer is between 300 and 8,000 mg/L TDS. Groundwater is freshest in the upper part of the flow system, and is brackish to saline in the lower part (Aquaterra 2002).

3.1.4 Cattamarra Coal Measures Aquifer

The Cattamarra Coal Measures aquifer is a confined multi-layered aquifer composed of siltstone and shale interbedded with sandstone. Monitoring of the groundwater area suggests that this aquifer is not likely to be recharged from downward leakage within the Kemerton area. Natural variation in the water levels is around 0.5 m.

The salinity of the groundwater ranges between 2,510 and 26,100 mg/L TDS and generally, the groundwater salinity is lower in the south than in the north. The fresher quality groundwater in the southern part of the aquifer is likely to be attributed to the throughflow from the Yarragadee aquifer. The Cattamarra Coal Measures aquifer is divided locally into two parts separated by a shale layer with an upper sequence containing fresher quality groundwater and a lower sequence containing brackish groundwater. The active flow system in the west contains brackish groundwater (2,500 to 7,000 mg/L TDS) and the remainder of the aquifer is saline. The salinity levels are probably a reflection of the distance from recharge and the low permeability of the sediments. In the area of the KSIA, the salinity is mostly brackish (< 3,000 mg/L) (Aquaterra 2002).

3.2 Groundwater Levels

3.2.1 On site Monitoring Data

A network of groundwater monitoring bores has been established on site to monitor the groundwater levels and quality. There were 68 monitoring bores identified in the Phase 1 Water Study in the Kemerton area, a number of these have regular monitoring carried out including;

- WRC Network – number of bores which make up the south-west coastal, Harvey shallow and Kemerton monitoring networks.
- MIC – monitoring bores KM1 to KM17 and MB01 to MB03 (located across the plant site) with data regularly reported to the DoW.
- Simcoa Operations – monitoring bores Sim1 to Sim3 (shallow and deep monitoring bore at each location) with data regularly reported to the DoW.
- Kemerton Silica Sands – monitoring bores KMB1 to KMB13 (situated across the plant site) with data regularly reported to the DoW.

The Phase 1 Water Study completed by BBG in 1999 assessed the available data and identified the need for additional monitoring bores in the northern extension of the Industrial core and service areas. As a result, an additional 17 monitoring bores were installed in the north at 12 sites in January 2001 to complement the existing shallow groundwater monitoring network within the core and buffer areas. In April 2001, Aquaterra carried out one round of groundwater monitoring on the new and existing bores.

Cardno was commissioned to undertake groundwater level and quality monitoring throughout the study area for a period of three months. Groundwater levels were measured in October 2009, November 2009 and January 2010 at 55 monitoring bores located within the study area. Cardno found that groundwater levels were generally less than 5 m below ground level in October 2009 (which generally represents the annual high). Parsons Brinckerhoff undertook a one off groundwater monitoring event in October 2010 with monthly monitoring of levels commencing in January 2011 until October 2011. Appendix 3 contains the collated monitoring data from Cardno and Parsons Brinckerhoff.

3.2.2 Superficial Groundwater Mapping

Aquaterra calculated the AAMGL using data from the WRC, Simcoa and MIC monitoring networks. Data was obtained from the various bores that had a monitoring period of at least two years, and had at least one record during the winter period. Not all the time frames for monitoring were the same due to the fragmented ownership of the bores within the site. The AAMGL contours are therefore not based on a set of bores monitored continuously over a defined, long-term period, nor do the bores cover the entire KSIA.

The AAMGLs calculated by Aquaterra were revised by RPS to include the winter data from the monitoring carried out by Cardno and Parsons Brinckerhoff. Please refer to Appendix 3 for the tabulated AAMGL data. Any additional on-site monitoring data collected in the future will be used to update the groundwater mapping and included in subsequent WMPs. The AAMGL and MGL are presented on Figures 7 and 8.

The downstream boundaries of the Indian Ocean, Leschenault Inlet and the Wellesley River were important factors in mapping the groundwater levels (AAMGL and MGL) due to the site's proximity to these waterbodies. It was presumed that the level of the Ocean and Inlet was 0 m AHD and the water level in the Wellesley River was estimated by creating Lidar cross-sections of the river and using the level of the river bank to be the maximum water level.

Although an average Ocean and Inlet elevation of 0 m AHD was applied to the AAMGL and MGL mapping, it should be noted that the groundwater level in the Superficial aquifer adjacent to the coast may be slightly higher than this at limited times of the year due to the tidal influence.

A groundwater mound trending north to south is clearly evident under the central and eastern parts of the KSIA. East of the ridge, groundwater is less than 5 mbgl over most of the area, with areas having less than 2 m groundwater clearance associated with the wetlands in this area.

The groundwater mapping indicates the AAMGL ranges between approximately 6 m AHD to 14 m AHD, which represents groundwater generally being 40 m below ground level (mbgl) at the ridge and 0 to 5 mbgl through the central to eastern areas of the site.

The depths to AAMGL and MGL (pre-development) are shown on Figures 9 and 10 and have implications for proponents to ensure development affords infrastructure protection in areas with low clearance via engineering controls such as subsoil drainage. Further monitoring and analysis is likely to be required at the next planning stage based on the level of risk and in accordance with *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013a). Specific details of required groundwater controls (such as levels and system design) would be agreed between DoW and the proponent at subdivision stage to ensure protection of groundwater dependent ecosystems.

3.3 Groundwater Quality

A desktop assessment of available water quality data for the 68 Superficial monitoring bores was undertaken during the Phase 1 study of the KSIA, which concluded that the bores contained high suspended solids, and should be re-developed in order to be used for water quality monitoring.

All existing bores that could be located were redeveloped and purged by Aquaterra during the Phase 2 investigations and monitored for water levels, pH, EC, major cations and major anions between 22 January and 7 February 2001.

Twelve of these bores and two wetlands were also monitored for nutrients, which concluded that concentrations of total nitrogen ranged between 0.2 and 9.9 mg/L and total phosphorus ranged between 0.0 and 0.9 mg/L. It was presumed that the high concentration in some of the groundwater bores and wetlands is likely to be a direct result of infiltration from run-off from cleared farmland in the area.

Following the Phase 2 Water Study (Aquaterra 2002), Cardno performed groundwater sampling of 41 bores in January 2010 for physical parameters (pH, temperature, salinity, dissolved oxygen, electrical conductivity, redox) and fractional components of nitrogen and phosphorus. Nutrient concentrations were found to vary considerably across the site with higher levels associated with the agricultural areas with lower clearance from groundwater. Concentrations across the site were generally moderate but higher than the reference values outlined in Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) for wetland ecosystem protection.

Parsons Brinckerhoff was commissioned in January 2011 to undertake quarterly groundwater and surface water sampling events. Groundwater samples were collected at 56 groundwater bores installed as part of previous site investigations undertaken across the site by Aquaterra and Cardno. Surface water samples were taken from three locations across the KSIA and buffer area. To date, two quarterly groundwater sampling events have been undertaken. During the first monitoring event 37 bores out of the 56 were sampled for the nutrient parameters (NH_4, NOx, TKN, TN, TP, FRP). Concentrations across the site were commonly higher than the reference values outlined in ANZECC (2000) for wetland ecosystem protection. Refer to Appendix 3 for details.

The existing prescribed industrial sites located in the KSIA are required to provide Annual Environmental Reports, which amongst other topics includes a discussion of the on-site monitoring data. The 2010 Cristal (Millennium Inorganic Chemicals) Annual Environmental Report shows through a series of hydrographs that the groundwater levels beneath the plant have been declining since 1994, which is attributed to the low rainfall and recharge occurring in the south-west region.

3.4 Groundwater Management Areas and Allocations

The KSIA extends across two DoW Groundwater Management Areas, being the South West Coastal in the north and the Bunbury Groundwater Management Area in the South. Groundwater in the Kemerton area is currently used for industry, agriculture and public water supply.

The Kemerton Groundwater Subareas Water Management Plan, released in July 2007 by the DoW identified at that time that there was an available water allocation of 29 GL per year, 18 GL of which was allocated. Of the 11 GL available, 2 GL was contained in the Superficial aquifer. The dispersed nature of the Superficial aquifer makes extraction of the water for industrial use difficult. In addition, water from the Cattamarra Coal Measures in Kemerton North is relatively deep (> ~ 150 mbgl) with high salinity. Therefore, only 3 GL of water contained in the Cattamarra Coal Measures in Kemerton South might be considered readily accessible by industry which may not require high quality water (MJA 2011). An extract of DoW (July 2007) that illustrates the groundwater management areas is provided in Appendix 4.

A recent (July 2016) Groundwater Allocation Report was obtained from the DoW to confirm the volumes of water currently available for allocation across the two management areas. This report, also provided in Appendix 4, indicates that there is currently 3GL available in the Cattamarra Coal Measures in the Bunbury Groundwater Area and 6GL available in the Cattamarra Coal Measures in the South West Coastal Groundwater Area. In addition, there is 0.337GL available in the Superficial Swan in the South West Coastal Groundwater Area.

Further investigations into the required quality of water for industrial use and possible treatment options need to be investigated, along with drilling of the aquifers in order to accurately confirm the availability and quality of groundwater in each aquifer.

4.0 SURFACE WATER

4.1 Wellesley River

The main surface water feature in the vicinity of the KSIA is the Wellesley River located outside the eastern and south-eastern boundaries of the KSIA. The river flows in a south-westerly direction into the Brunswick River that then merges with the Collie River prior to discharging into the Leschenault Estuary to the south-west.

Due to its low topography and deep, well drained sands, there is limited natural surface water drainage within the KSIA. A number of artificial drains have been constructed to drain the Multiple Use wetlands and inundated palusplain areas. These drains generally flow to the east and south, discharging to the Wellesley River.

Figure 11 provides indicative foreshore mapping, with the foreshore defined as the greater of the 100 year ARI floodplain extent (as provided by DoW Flood Protection Branch) or extent of riparian vegetation. Any further detail in waterways and foreshore mapping that may be required will be undertaken at the lot scale WMP stage.

4.2 Wetlands

Eighty four geomorphic wetlands (or part thereof) are located at the site. Twenty two are classified as Conservation Category wetlands (CCW), 14 are Resource Enhancement wetlands (REW), 39 are Multiple Use wetlands (MUW), seven are former EPP[1] Lakes and two have not been assessed. Figure 12 shows the wetland mapping across the site.

A majority of the wetlands within the KSIA are groundwater-dependent ecosystems, many of which are maintained by perched water tables and supported by surface run-off and direct rainfall (Coffey 2007). Drainage within the KSIA occurs at regional and local scales. Regionally, surface water drains towards the Wellesley River on the KSIA's eastern boundary, and locally, due to its low topography and relatively high water tables, surface water within the KSIA drains into the ephemeral wetlands.

Department of Parks and Wildlife (DPaW) and DoW have been consulted with respect to establishing appropriate wetland buffers at this stage of investigation. The primary outcomes of the consultation involved the completion of mapping that showed the depth to AAMGL at the wetland, with shallower depths generally considered to present a higher potential risk of impact. Figure 12 shows the depth to AAMGL and wetland mapping. This information was in turn included in a qualitative Wetland Risk Analysis (RPS 2016), which is provided in Appendix 5.

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[1] Reference to EPP lakes in the figures is by name only; the Environmental Protection (Swan Coastal Plain Lakes) Policy 1992 was revoked in late 2015, and some of the geomorphic classifications need to be reviewed where the EPP protection has been removed

The wetland analysis provides general management strategies for development and proposes that specific management strategies for individual wetlands are undertaken on a case by case basis with the individual lot proponent and regulator at subdivision stage, guided by the information provided in the Wetland Risk Analysis report (RPS 2016). As recommended in the EPA's advice when the EPP Lakes Policy was revoked, a comprehensive update of the geomorphic wetland dataset should be undertaken for wetlands identified in this report, at subdivision stage. It should also be noted that a number of wetland classifications warrant review with field surveys and assessments, and this may raise the conservation status of some wetlands. Assessment required at subdivision stage should cover all wetlands and include:

1. Monitoring of current groundwater regimes and quality.

2. Review of wetland classification.

3. Biophysical assessment of buffer requirements.

4. Review of proposed landuse change and risks presented by:

    a. Groundwater connectivity and grade.
    b. Surface water drainage management.
    c. Process water management.
    d. Process and site pollutants and their management.
    e. Transport corridors.
    f. Other relevant site details.

4.3 Other Relevant Site Details Leschenault Estuary

The Leschenault Estuary is located approximately 1 km west of the Kemerton Industry Buffer and approximately 2.5 km from the most western extent of the Strategic Industry Zone.

The Leschenault Estuary is a shallow, elongated water body lying roughly north to south and separated from the Indian Ocean by a sand dune peninsula. The estuary is approximately 13.5 km long, up to 2.5 km wide and has a surface area of approximately 25 km^2. The Leschenault water catchment encompasses the Wellesley, Brunswick, (lower) Collie, Ferguson and Preston river sub-catchments.

5.0 WATER SUPPLY

5.1 Existing Water Demand and Sources

5.1.1 Aquaterra (2002)

In the Phase 2 Water Study, Aquaterra (2002) summarised the abstraction bores which are used by existing industries at the KSIA to source process and potable water requirements from unconfined and confined aquifers:

- Simcoa Operations Pty Ltd (Kemerton Silica Smelter) operates two production bores, PB1 and PB2. Bore PB2 extracts water from the Yarragadee Formation and is the primary source of water. Bore PB1 has been used from time to time as a back-up and extracts water from the Superficial formation. The site operates a water treatment plant for water pumped from the production bores. The treated water is then pumped to a process water tank, which is used to meet potable and process water requirements. Problems have been encountered with treatment of groundwater extracted from the Superficial formation due to high TDS, dissolved organics and hydrogen sulfide. Wastewater is discharged via drainage channels or pumped to a polyethylene lined settling pond where, after solids have settled out, it is recycled for on-site use for dust suppression and irrigation purposes.

- Kemerton Silica Sands operate two production bores, KW7 and KW14, both extracting water from the Superficial formation. The process water supply is primarily made up of return water used in the process and supplemented by water from the production borefield. Water from the production borefield is also the source for on-site potable water requirements.

- Cristal (Millennium Inorganic Chemicals) operates three production bores, KW-1, KW-3 and KW-4. Bore KW-1 draws water from the Leederville formation and bores KW-3 and KW-4 from the Cattamarra Coal Measures. This water is treated prior to use in the process. All wastewaters, excluding stormwater, are directed to their wastewater treatment plant. The treatment plant currently discharges around 1 GL/yr to the ocean.

- Nufarm-Coogee – No production bores. All water requirements for the site are provided by MIC. All effluent produced from the process, and run-off from the salt slabs, is pumped to the wastewater treatment plant operated by MIC.

- Cockburn Cement – No production bores. All water requirements for the site are provided by MIC. All effluent produced from the process is pumped to the wastewater treatment plant operated by MIC.

- BOC Gases – As for Nufarm, process and potable water requirements for BOC Gases, located in the southern part of the Estate, is supplied by MIC. The water is treated on site for potable needs using side stream filters and water softeners through a cooling tower. The wastewater from the cooling tower is conveyed to a concrete lined pit, which is then pumped back to MIC to be treated in the wastewater treatment plant, and discharged to the ocean.

- Kemerton Power Station (Transfield Services) commenced operation in November 2005. In June 2008, a 40 MW upgrade was completed on Kemerton Power Station, increasing its capacity to 300 MW. Transfield Service has an agreement with Harvey Water to supply up to 5 GL per year of water from the Harvey Irrigation Scheme to the Transfield Worley power station as and when required. Wastewater generated at the Power Station is disposed of on-site using evaporation ponds.

5.1.2 Marsden Jacob Associates (2011)

Marsden Jacob Associates (MJA) was commissioned by the South West Development Commission to undertake an economic analysis of the likely demand for industrial water and potential supply options. A copy of this report is provided in Appendix 6.

MJA (2011) described the current or near future (i.e. new water usages that were in planning at the time of the MJA investigation) water usage and sources as follows for the KSIA (Table 4).

Table 4: Existing (or near-future) Water Demand

User	Source	Usage (GL)
Various[1]	Groundwater Abstraction	3.6
Transfield Services	Wellington Dam[2]	5
Bauxite Resources	Unconfirmed[3]	2-3
Total	**-**	**10.6 - 11.6**

[1] Major users include Simcoa, Cristal, Transfield Services and Goodchild Abattoir

[2] An existing agreement with Harvey Water if and when Kemerton Power Station is upgraded

[3] Potential sources include saline water from Binningup Desal plant or Verve ocean outfall pipeline

5.2 Future Water Demand and Sources

5.2.1 Aquaterra Water Study (2002)

An estimate of the type and number of industries that would locate to the KSIA and estimated future water demand were completed in the Phase 2 Water Study (Aquaterra 2002). It was estimated that the water demand at the KSIA is likely to range between 7 GL/yr and 23 GL/yr. Table 5 below provides an estimate of the predicted water demand required at the KSIA for various growth scenarios.

Table 5: Future Water Demand for the KSIA (Aquaterra 2002)

Scenario	Demand	Comments
Low Growth	7 GL/yr	Status quo with demand dictated by the expansion of Cristal and Simcoa operations. Included also is the possibility of titanium sponge production and a few small unspecified industries.
Medium Growth	10 GL/yr	Volume required is higher to meet the demands of a synthetic rutile plant, wool processing, iron briquetting plant and a pulp mill.
High Growth	14 to 18 GL/yr	High growth scenario view considering the full development of Kemerton with a wide range of industries including an aluminium smelter, power station and other industries.
Maximum	23 GL/yr	High growth demand plus the introduction of a "high water demand" industry.

Source: Aquaterra 2002 Table 3.2

5.2.2 Marsden Jacob Associates (2011)

The potential water demand of the KSIA was investigated as part of this study. Using other industrial parks in Australia as a benchmark, it was calculated that diversified industrial estates, similar to the KSIA, have a general water demand of 0.02 – 0.03 GL/ha/yr. Therefore, the benchmark forecast suggests that additional water demand could be in the order of 18 to 27 GL/year if all remaining industrial land at the KSIA was fully developed.
MJA (2011) concluded that the water demand for the KSIA could reach 40 GL/year in the event that a number of high demand industries (such as an aluminum smelter) locate to the KSIA.

In terms of available additional water sources for the KSIA, the study estimated that 9 GL per year of water can be provided from sources considered "easily accessible", including the Superficial, Leederville and Cattamarra South aquifers (Catamarra North is relatively deep (> ~ 150 mbgl) and has a high salinity) and Harvey Water's existing pipeline in the area. A further (more long-term) additional supply of 7 GL was estimated (from recycled wastewater from the Kemerton Water Treatment Plant and groundwater from the Cattamarra Coal measures) to give a total future water source of 26 GL.

The above forecasts of potential water demand and supply are summarised below in Table 6 for various scenarios.

Table 6: Summary of Supply and Demand Balance for Each Scenario (Marsden Jacobs 2011)

	Current Supply/ Demand (GL)	High Demand and Supply (GL)	High Demand, Low Supply (GL)
Kemerton Water Supply	19	26	19
Kemerton Water Demand	10	40	40
Shortfall	NA	14	21

Table 6 describes a potential water supply shortfall for the long-term, high-demand development scenarios. In this instance, additional alternate water supplies will be required to meet the water demands of possible high demand industries that may locate to the KSIA in the long term. Should capacity be reached in the long term (which is predicted to be in 20 to 30 years), further water provision options shall be sought from possible sources such as improved water recycling initiatives on site and from local industries. These two options mentioned above and additional water sources are discussed in further detail in the next section (Section 5.3).

5.3 Future Supply Options

The Marsden Jacob study assessed the feasibility of a wide range of possible water sources and uses. The key water sources identified by MJA (2011) for the KSIA are listed below. These potential sources are described in the following sections and a summary of their respective costs, reliability of access and water quality is provided at the end of this section.

- Integrated Water Supply Scheme (IWSS) (Potable)
- Groundwater Abstraction (Potable and Process)
- Wellington Dam (Potable and Process)
- Brine Diversion from Collie Water Recovery Project (Process)
- Recycled water from the Kemerton WWTP (Process).

An additional water supply option which is discussed below but was not investigated by the Marsden Jacob study, is the broad scale application of water recycling within the KSIA at the lot scale and between industries located within the KSIA.

5.3.1 Integrated Water Supply Scheme

Harvey is supplied by the Integrated Water Supply Scheme that services the Perth metropolitan area. The Water Corporation presumes the supply to KSIA would be limited to domestic and low usage industry only with major industrial water use sourced through other means such as groundwater or recycled water.

5.3.2 Groundwater Abstraction

The remaining allocation for the groundwater management areas the KSIA is located in is 11 GL/year, the majority of which is within the Cattamarra Coal Measures in the KSIA north and south sub-area.

As discussed in Section 3.4, 2 GL is contained in the Superficial aquifer in a dispersed nature making extraction of the water for industrial use difficult. In addition, the water from Cattamarra Coal Measures in Kemerton North is relatively deep (>~150 mbgl) with high salinity. Therefore, only 3 GL of water contained in the Cattamarra Coal Measures in Kemerton South might be considered readily accessible by industry (MJA 2011).

An application was lodged with the DoW in 2011 to secure a groundwater allocation of 9 GL/year from the Cattamarra Coal Measures aquifer of the Kemerton North and South groundwater sub-areas for the purpose of industrial processing within the KSIA.

The DoW advised that a staged development plan would be required and that the maximum permitted license term for large staged developments with a water entitlement exceeding 500 ML/yr is five years. In 2011, a staged development plan was not available and the time frames for development of the KSIA were also uncertain. In addition the DoW requested that a H3 Hydrogeological Assessment report and successful drilling of the aquifer be completed prior to the DoW issuing a 5C license to take water.

Future applications to secure a groundwater license for both potable and process water will be supplied to the DoW following approval of the KSIA Structure Plan and the required information being available.

5.3.3 Wellington Dam

Wellington Dam has an estimated annual yield of 86.2 GL and a storage capacity of 185 GL, however is under utilised due to high salinity levels. The total allocation available from the Wellington Dam is currently 85.1 GL, with water currently allocated or reserved for the following purposes (MJA 2011):

- Harvey Water irrigators currently use around 47.5 GL of the 86 GL per year entitlement (average since 1996–1997). Harvey Water has been in negotiations with a number of industrial customers to supply water to industry from the remaining allocation.

- To expand the potential for industrial supply, Harvey Water has constructed a pipeline that can, at present, transfer up to 6 GL of water from the Collie River catchment. Harvey Water has constructed a pipeline capable of supplying up to 5 GL per year of water to the Transfield Worley power station as and when required.

- The Collie Water Recovery Project has outlined an option to reduce salinity in the dam by diverting high saline flows from the Collie River (into disused mine voids for later desalination). Harvey Water has indicated that if salinity is reduced to the target levels and a Commonwealth funded initiative to pipe the Collie irrigation area is undertaken, Harvey Water would provide 11 GL of water to the Commonwealth Environmental Water Holder, 11 GL for industrial use and the remaining 46 GL for irrigation.

5.3.4 Brine Diversion from Collie Water Recovery Project

The Collie Water Recovery Project (discussed in Section 5.3.3) includes disposal of the desalination brine via the Verve Ocean outfall pipeline which is currently licensed for approximately 7 ML per day of discharge. Verve has indicated that the pipeline will be at full capacity if and when current negotiations with DoW are finalised. The Verve pipeline passes the KSIA and could potentially be used as a source of recycled water, although the quality of the wastewater may make recycling an expensive alternative (MJA 2010).

Correspondence with the Water Corporation has commenced to seek advice as to whether they would look favorably on diverting treated effluent to the KSIA for reuse. The Water Corporation has responded outlining that discharge of treated wastewater via the Verve Energy outfall does not preclude commercial reuse alternatives such as the KSIA. Refer to Appendix 7 for correspondence with the Water Corporation.

5.3.5 Recycled Water from Kemerton Domestic WWTP

The Water Corporation's Kemerton Wastewater Treatment Plant treats wastewater from the nearby towns of Australind and Eaton. The plant is currently capable of treating 3 ML per day (approximately 1 GL per year) of wastewater. The Water Corporation is currently examining alternatives to upgrade the plant to treat 7.2 ML per day (2.6 GL per year at full capacity). Harvey Water understands that the volume available for recycling could ultimately be increased to 8 GL per year; however, this could not be confirmed by MJA at the time of reporting. A portion of the treated water from the plant is used for irrigation of nearby tree farms at the KSIA. The Water Corporation is also in discussions with a potential industrial customer to supply the remaining capacity of the plant as recycled water (MJA 2011).

Correspondence with the Water Corporation has commenced to seek advice as to whether they would look favorably on diverting treated wastewater to the KSIA for reuse. The Corporation has supported the proposal to draw some or all of the treated wastewater from the Kemerton WWTP subject to availability and a commercial agreement. Refer to Appendix 7 for correspondence with the Water Corporation.

Since early discussions with the Water Corporation occurred regarding the recycling of wastewater from the Kemerton WWTP, it appears that Harvey Water are in negotiations to purchase the water from the Water Corporation to shandy with water from Harvey Water's dam supplies. The option of reusing water direct from the WWTP may not be an option; however purchasing the water from Harvey Water is a possibility.

5.3.6 KSIA Water Recycling

A potential source of water is the supply of recycled wastewater generated by the industries located within the KSIA. The strategy in the short term is for sites which generate industrial wastewater, to treat the water at the lot scale to a standard where it is suitable for disposal to a nearby facility or reuse on site or by a neighboring industry.

In the long term, once a sufficient mass of industry is located at the KSIA, alternate wastewater disposal options will be investigated, including the establishment of an on-site wastewater treatment and recycling plant to allow for the large scale collection and recycling of water within the KSIA.

Further details on this topic can be found in Section 6.1 Industrial Wastewater.

5.3.6.1 MIC Wastewater Treatment Plant

The existing Cristal (Millennium Inorganic Chemicals) wastewater treatment plant discharges approximately 1 GL/yr to the ocean, with an effluent water quality of around 30,000 mg/L Total Dissolved Solids (TDS). Nutrient concentrations are generally around 0.35 mg/L for nitrate and 0.05 mg/L for phosphorous. This treated water quality is not suitable for re-use by the existing industries, but it may be suitable for use by future industries, or for further treatment by any future wastewater treatment plants at Kemerton (Aquaterra 2002).

5.3.7 Summary of Potential Water Sources

Table 7 below is adapted from MJA (2011) and provides an assessment of costs, reliability of access and water quality for the various potential water sources discussed above.

Table 7: Water Supply Options Assessment

Source	Volume	Capital Exp.	Operating Exp.	Unit (kL) Cost	Reliability	Quality
IWSS[1]	Unlimited?	-	-	$1.87+	~100%	Potable
Groundwater Abstraction[2]	3GL?	-	-	$0.20-$0.50?	~100%	Non-potable <1200 TDS
Wellington Dam[3]	7GL	$3-6m	$0.63/kL	-	Agreement with Harvey Water	Non-potable <1200 TDS
Brine via Verve Outfall[4] (without Desalination)	5GL	$50m	$250k p.a.	$0.71	80-100%	Non-potable >1200TDS
Brine via Verve Outfall[5] (incl. Desalination)	5GL	$50m	$6m p.a.	$2.90?	80-100%	Potable

Source	Volume	Capital Exp.	Operating Exp.	Unit (kL) Cost	Reliability	Quality
Kemerton WWTP[6]	1GL+	-	-	\$0.40-\$1.50?	~100%	Non-potable <1200 TDS

[1] Additional costs associated with developer contribution for extending distribution system etc. Water Corporation does not support supply of potable water via IWSS for industrial purposes.

[2] Unit cost based on Kwinana Industrial abstraction and treatment costs.

[3] Information sourced from Harvey Water, provided commercial-in-confidence. Operating expenditure includes pumping costs and charge for water resource.

[4] Estimate from Harvey Water. Initial cost estimate approximately \$80m; net cost of \$50m assumes \$30m State and Commonwealth diversion grant available.

[5] Net capital cost assumes \$30m funding from State and Commonwealth government. Desalination costs estimated from project proposal.

[6] Current capacity is 1 GL p.a. Potentially as much as 8 GL p.a. at full capacity by 2030 (pers comm. Water Corporation, unconfirmed). Water recycling costs based on estimate for treatment and distribution provided by Water Corporation.

6.0 WASTEWATER TREATMENT

6.1 Industrial Wastewater

The Water Corporation does not support reticulated wastewater collection from industrial sites for treatment in conventional wastewater treatment plants. Industrial estates by nature of layout, discharge type and potential high flow rates are not readily compatible with domestic treatment processes. Industrial treatment, reuse and disposal are often better addressed on site or locally.

The Water Corporation has outlined the preferred options to manage industrial wastewater at the KSIA:

- Industry to treat effluent to predetermined acceptance criteria and recycled on site or to a neighbouring industry, (this currently occurs on site by some of the existing industries).

- Industrial wastewater to be collected centrally and recycling opportunities sought or disposal considered.

- If a critical mass of industry is reached, a combined application for a common outfall could be made whereby wastewater is treated to an acceptable standard on site or centrally within the KSIA prior to disposal (subject to required environmental approvals).

As the development timetable and occupancy rate of the KSIA is undefined at this stage in the planning process, the strategy in the short term is for sites which generate industrial wastewater to treat the water at the lot scale to a standard where it is suitable for disposal to a nearby facility or reuse on site or by a neighboring industry.

In the long term, once a sufficient mass of industry is located at the KSIA, alternate wastewater disposal options will be investigated, including the establishment of an on-site wastewater treatment and recycling plant.

6.2 Commercial Wastewater

The population of employees expected to work at the KSIA on a daily basis is not expected to warrant the demand and expense of the infrastructure to install reticulated wastewater collection sewers provided by the Water Corporation to dispose of wastewater generated from toilets, bathrooms and kitchens at the lot scale.

As an alternative, the KSIA will rely on the use of Aerobic Treatment Units (ATUs) and/or septic tanks and leach drains to collect, store and treat wastewater from the Lots. It is DoW's preference that ATUs are used, particularly where groundwater clearance is low, which is identified on Figure 9. The Shire of Harvey expressed their preference for the use of septic tanks and leach drains at a brief meeting held between the Shire of Harvey, RPS and Wood and Grieve Engineers on 11 July 2011. It was agreed at this meeting that the location, number and type of system would be confirmed in the WMPs, which are to be completed as a condition of subdivision and development applications submitted to the SoH for individual lots at time of construction. It is recommended that Figure 9 be referred to for designing the system in relation to depth to groundwater.

6.2.1 Aerobic Treatment Units

Aerobic Treatment Units (ATU) are self-contained electrical wastewater (sewage) treatment systems for use on properties that are not connected to mains sewerage.

The ATUs shall be designed and located in accordance with the Department of Health's (DoH) *Code of Practice for the Design, Manufacture, Installation of Aerobic Treatment Units (DoH 2001)* and the Department of Water, *Water Quality Protection Note 70 Water Treatment and Disposal – Domestic Systems* (DoW 2010b).

ATUs consist of a series of treatment chambers including an aeration chamber and a solids settling chamber where the effluent is discharged via an underground soakage system.

These systems normally reduce degradable organic matter, sediment, suspended solids and grease to concentrations significantly less than conventional septic tank treatment systems.

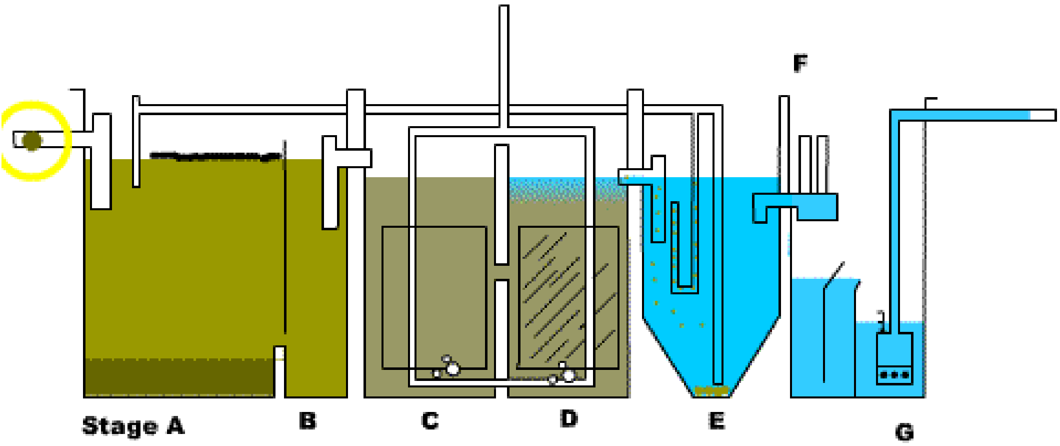


Figure A: Example ATU – DoH Approved Biomax Model C10

Figure A above illustrates that the ATU is divided into five principal chambers:

- Stage A – Anaerobic chamber – anaerobic treatment
- Stage B – Aerobic chamber – aerobic treatment
- Stage C/D –- Clarification chamber – sludge settlement and removal
- Stage E – Disinfection chamber – contact time with chlorine
- Stage F/G – Pumpout chamber – discharge to disposal system.

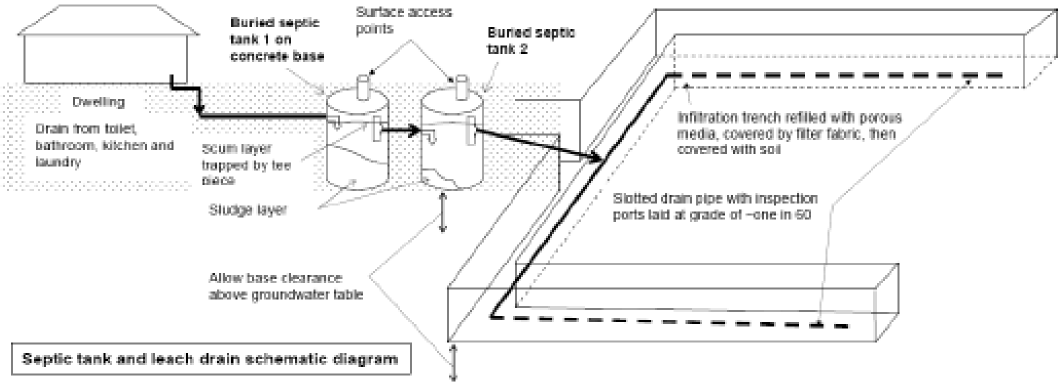
This system is approved for dripper irrigation. Other units that are DoH approved do not contain a disinfection chamber and effluent can be discharged to soakage wells or horizontal leach drains. Soakage through an approved amended soil mix (that retains phosphate on fine soil particles) in an effluent disposal area can achieve phosphorus removal. The amended soil has a finite operational life before becoming saturated with phosphate and will need replacing when phosphate breakthrough occurs.

The soil characteristics at the disposal site should allow effective soakage of treated wastewater in accordance with the Health (Treatment of sewage and disposal of effluent and liquid waste) Regulations 1974.

Under DoH legislation, ATUs are required to be serviced at least every three months. Servicing can only be carried out by a person who has approval from the Executive Director, Public Health to service ATUs.

6.2.2 Septic Tanks with Amended Soil Effluent Systems

A possible septic tank system for the KSIA consists of two conventional septic tanks in series, followed by leach drains surrounded by a permeable amended soil blend that removes phosphate (Figure B). One approved soil amendment material is a by-product of alumina processing known as red mud and red sand. This type of system reduces concentrations of biochemical oxygen demand, suspended solids, micro-organisms and phosphate in effluent.



(Source: DoW 2010b)

Figure B: Septic Tank System

6.2.3 Buffers to Wastewater Systems with Phosphorus Removal

Table 8 outlines the horizontal buffers recommended to wastewater treatment systems with phosphate removal near sensitive waterways or wetlands. These recommended buffers have been adopted from the DoW's water quality protection note no. 70 – Wastewater treatment and disposal – domestic systems (DoW 2016). Whilst it is noted that this note provides guidance for domestic rather than industrial systems, the minimum buffer distances are considered appropriate given that these systems will be used for disposing toilet, bathroom and kitchen wastewater only; industrial process wastewater will need to be treated and managed separately, as discussed in Section 6.1.

RPS understands that the above water quality protection note will be updated following a Department of Planning review of Government Sewerage Policy – Perth Metropolitan Region (DoH 1996) and Draft Country Sewerage Policy (DoH 2003) which is currently underway. The updated water quality protection note may provide additional guidance on suitable wastewater treatment measures to be considered at the WMP stage.

Table 8: Horizontal Buffers to Wastewater Systems with Phosphate Removal

Feature	Minimum Horizontal Buffer Distance	Comments
Wetlands	100 m	Buffer in accordance with the DPaW and Environmental Protection Authority policies on the minimum buffer required for any type of development near a wetland.
Waterways	100 m	Setbacks less than 100m may be considered on a case-by-case basis (i.e. in low risk situations such as small subdivision (less than 5 lots)) in consultation with the DoW.
	Outside the flooded area resulting from a 10 year (average recurrence interval) storm	

(Source: DoW 2016)

In addition to horizontal buffers, DoH (2012) recommends a minimum vertical buffer of 0.6 to 1.5 m to the highest known groundwater level. The distance is dependent on soil type, with the minimum distance appropriate for loams and clays and the maximum used for sands and gravels. The depth is measured from the base of the disposal/ irrigation system (i.e. trench bottom, bed base or dripper tube).

7.0 SURFACE WATER MANAGEMENT

7.1 Stormwater Management

The site will effectively manage stormwater through the implementation of Water Sensitive Urban Design (WSUD) principles and Best Management Practices (BMPs) to control water quality and quantity from both minor and major storm events.

To manage the increased run-off expected from development, the site has been divided into 10 sub-catchments to allow for a series of stormwater management measures to be implemented throughout the site, to manage stormwater close to source and to facilitate the infiltration of stormwater where possible.

In accordance with the Stormwater Management Manual for Western Australia (DoW 2004–2007) and the Department of Waters Water Quality Protection Note 52 "Stormwater Management at Industrial Sites" (May 2010), the drainage system will aim to achieve the following objectives:

- Maintain the existing hydrological regime by allowing the infiltration of uncontaminated water on site and limiting discharges from the KSIA to pre-development peak flows and volumes.
- Uncontaminated stormwater run-off from roofs for example will not be allowed to mix with process effluent and stored chemicals to allow for the infiltration of uncontaminated stormwater and recharge of the Superficial aquifer.
- Rainfall up to the 1:10 year ARI event will be retained and infiltrated within lot boundaries using vegetated swales and detention areas. Lot run-off in excess of 1 in 10-year ARI event shall discharge to roadside swales.
- Roadside conveyance swales shall be sized to convey the critical 10-year ARI storm events from the road reserves wherever possible to minimise the use of a piped drainage network.
- Large rainfall events (>10 year) up to the 1:100 year ARI event will be conveyed through overland flow and road side swales to drainage detention basins within the site for storage and/or treatment prior to infiltration.

The proposed drainage strategy adopts a similar approach to the management of stormwater that is currently being used at the KSIA. The existing industries for example are primarily located on the main entrance road (Marriott Road) where road side swales are used to collect stormwater from the road reserves.

As the site is zoned Industrial, fertiliser use is expected to be minimal. Landscaped POS areas will incorporate native species that will not require irrigation once established. Native vegetation will also be used in stormwater detention/retention areas to aid infiltration, control erosion and provide a degree of water quality treatment.

7.1.1 Post-development Drainage Design

Design of the drainage system focuses on maintaining the pre-development hydrological regime at the site as closely as possible, while concentrating on the protection of groundwater and surface water resources.

In order to establish the current baseline hydrological conditions at the KSIA, RPS has developed an XPSWMM surface water model of the site to determine the surface water catchment boundaries, pre-development surface water flow rates and the required volumes of stormwater detention needed on site to maintain the pre-development conditions. Figure 13 provides an assessment of the pre-development drainage flow paths and catchment boundaries.

Lidar data was received for the KSIA area and was used to create a digital elevation model for the area, which magnified the surface relief and drainage features for the area.

The preliminary drainage and earthworks designs provided in Figures 14 to 16 and Appendix 8 will need to be further refined at the subdivision stage. Although preliminary, the drainage and earthwork concepts demonstrate that the KSIA is capable of managing stormwater in events up to the 1 in 100 year ARI, while incorporating suitable best management practices.

Note that the drainage basins located in Figure 14 are indicative only for this OWMS. All drainage basins will be located in designated drainage reserves, the location of which will be determined at lot scale WMP stage, with due consideration to environmental factors such as groundwater clearance and wetland impacts.

7.1.2 Minor Drainage System

Rainfall will be retained on site and infiltrated as close to source as possible using the following practices:

- All rainfall on the permeable surfaces, particularly uncleared land surrounding the lots will infiltrate as per existing conditions.
- The use of rainwater tanks to collect run-off from roof areas will be encouraged as a potential source of water, and as a means of reducing enhanced run-off from paved surfaces.

- Lots will infiltrate rainfall in events up to the 1:10 year ARI event through the use of vegetated swales/ detention areas

- Road drainage within the development will incorporate roadside conveyance swales and limited piped network designed to accommodate the 10-year event.

Roads throughout the KSIA will incorporate vegetated roadside swales where possible. The swales will typically be 0.6 m deep and 3.6 m wide at the surface. Road side swales along Kemerton Road (Catchments 2 to 5 shown on Figure 14) will require larger or deeper swales (RPS has modelled 9 m wide swales at the surface that are 0.6 m deep), however this will need further refinement once the actual lot sizes and locations are confirmed at the detailed WMP phase. Swales can be located on one or both sides of the road reserve; the location will be affected by the final placement of services and the railway corridor. Refer to Figure C below for a schematic diagram of a typical cross section of the possible road and roadside swale design at the KSIA.

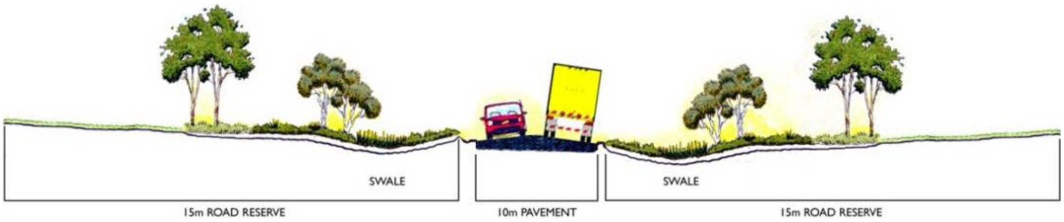


Figure C: Schematic Cross-section of Road and Swale Design at the KSIA

7.1.3 Major Drainage System

As water sensitive urban design approaches generally rely on infiltration, it is most effective for smaller, frequent storm events. Traditional methods including earth fill to create building pads and flood flow paths to convey larger floodwaters downstream are often required to augment water sensitive design practices when the rates of surface run-off significantly exceed the infiltration rate.

Due to the expansive area, the KSIA needs to be designed with a mix of water sensitive design and traditional design methods. Water sensitive design principles will be employed for the minor events while traditional design methods will need to be applied in areas where a shallow water table is present (eastern extent of the KSIA), notably using earth fill to construct pads for buildings, roads and car park or hard standing areas. Detailed drainage plans will be required to be developed for individual sites, consistent with the strategies outlined in this OWMS, with the details to be provided in future WMPs.

Various engineering reports have been prepared throughout the development and planning of the KSIA to provide drainage strategy recommendations; many however rely on the artificial lowering of groundwater below the AAMGL by using sub-soil drainage systems to minimise fill and incorporate traditional piped drainage systems, as they reflect the policy requirements prior to water sensitive urban design. RPS considers these approaches would no longer be acceptable to the DoW as the wetlands would be impacted and nutrient rich groundwater would be exported from the site and discharged to the Wellesley River. Setting of the CGL will be undertaken at WMP stage in accordance with DoW (2013a) *Water resource considerations when controlling groundwater levels in urban development*, with due consideration to: infrastructure protection; protection of Groundwater Dependent Ecosystems (levels and quality); and facilitating free drainage outflow from the site.

The refinement of the drainage strategy, incorporating current drainage best practice, is to maximise the infiltration within the development area of each lot. Broadly, this strategy relies on the use of undeveloped/uncleared areas on each lot for infiltration, along with the use of vegetated swales/ detention areas for run-off from “clean water” sources including roof areas and pedestrian paved areas surrounding the building pads, to avoid the need for substantial drainage control structures.

The strategy also relies on the use of designated drainage infiltration areas for storage and infiltration of the larger flood events. All drainage basins will be located in designated drainage reserves, the location of which will be determined at lot scale WMP stage, with due consideration to environmental factors such as groundwater clearance and wetland impacts. Drainage areas will be appropriately vegetated to improve water quality treatment and sediment stabilisation.

The refined drainage strategy and development plan involves filling the developed portions of Lots with earth fill (preferably sourced from on-site material) to provide sufficient clearance to groundwater from building foundations. Hence, groundwater levels under adjacent undeveloped portions of the blocks could be as high as the natural surface without compromising the developed (earth filled) areas.

With this arrangement, sub-soil drainage beneath the developed areas may not be required, and only the portion of each block that is developed may require earth fill, depending on the depth to the water table.

In areas with the groundwater near the surface, earth fill levels for the developed portions of each block would need to be a minimum of 1.5 m from the AAMGL to guard against the potential for groundwater contamination and flooding of developed areas. As mentioned, setting of the CGL will be undertaken at WMP stage in accordance with DoW (2013a) with due consideration to: infrastructure protection; protection of Groundwater Dependent Ecosystems (levels and quality); and facilitating free drainage outflow from the site

For larger storms (>10 year ARI), roads and hardstand areas will be designed to convey the major flood flows towards the road reserve where vegetated swales and overland flow will be used to convey flood flows to drainage basins located within individual sub-catchments, as shown on Figure 14.

Preliminary earthworks plans, completed by the project engineers, Wood and Grieve Engineering are provided in Figures 15 and 16 and indicate that areas of cut to fill have been investigated in order to provide a minimum clearance of 1.5 m to AAMGL over a majority of the site. The engineering plans will be further refined as subdivision commences and detailed design is completed.

In summary, the revised drainage strategy for major events, incorporating current best practice, involves the following:

- filling of land parcels within each lot to provide adequate building envelopes and a minimum clearance of 1.5 m to AAMGL (with reference to DoW 2013a)
- lots to infiltrate all events up to the 10 year ARI through the use of vegetated swales / detention areas for "clean" hard standing areas and infiltration in undeveloped portions of lots
- events greater than the 10 year ARI from the lots will be directed to the road reserve and road side swales (designed to have capacity for the 10 year ARI)
- roadside swales and overland flow through the road network will convey large flood flows to vegetated detention basins for storage and treatment prior to infiltration. Flow to Wellesley River shall be maintained at pre-development flow rates to ensure the hydrological regime and water quality is maintained at pre-development conditions.

7.1.3.1 Stormwater Storage Requirements

The stormwater modelling for the site has been completed by RPS using XPSWMM software. The stormwater treatment system shown in Figure 14 details the areas and volumes of stormwater detention for the 1, 10 and 100-year events to maintain pre-development conditions where possible.

The site has been divided into ten post development catchment areas. Stormwater storage areas have been sized to accommodate the 1:100 year ARI event within catchments 1 to 7. Catchments 8 to 10 are sized to cater for up to the 1:100 year ARI event with over flow to Wellesley River being restricted to the predevelopment 1:10 year ARI flow rates.

Appendix 8 contains a table summarising the stormwater requirements for each of the 10 sub-catchments.

The invert of all drainage structures will be designed to achieve a minimum clearance of 0.3 m to the MGL across the site to comply with DoW policy (DoW 2013a) and ensure that the drainage features will be free of standing water except for short periods of time after heavy rainfall.

The outline drainage design provided in Figure 14 is preliminary and is subject to variation following confirmation of the staged planning boundaries of the KSIA and lot boundaries and sizes. Detailed subdivision layouts will be confirmed at the WMP stage along with the detailed drainage and earthwork designs. Refer to Appendix 8 for further details on the stormwater storage requirements and further model assumptions and detail.

7.2 Water Quality Treatment

In addition to the above management measures, the following best management practices and treatment measures shall be put in place to retain the quality of stormwater. These measures shall be in accordance with the DoW Water Quality Protection Note 52 "Stormwater Management at Industrial Sites". Industrial sites require effective management of stormwater run-off from roofs, pavements, exterior materials storage and process areas to avoid flooding and contamination of sensitive water resources.

7.2.1 Structural Treatment Systems

7.2.1.1 Soil Amendment

Soils within the lots will be amended to minimise the risk of soil and groundwater contamination from the industrial land uses. As a minimum, the soils beneath vegetated swales or stormwater detention areas within lots will be amended to an underlying depth of 0.3 m; however, the landowners may decide to amend the entire building footprint beneath the hardstand area for ease of earthworks.

7.2.1.2 Drainage Areas

Drainage basins located in designated drainage areas will attenuate and infiltrate flood flows for major rainfall events. Vegetated conveyance swales will be used to convey stormwater through the site, in lieu of a piped drainage network wherever possible, which replicates the approach to managing stormwater for the developed industries existing at the site. Swales will incorporate rock pitching and erosion control measures, particularly along the central main road (Kemerton Road) which provides the main flood flow path through the KSIA. Vegetation will be included in all suitable stormwater structural controls for amenity, to minimise erosion, maintain soil infiltration, restrict water flows and remove particulate and soluble pollutants, particularly nitrogen. The plants species used in drainage areas will be appropriately selected with reference to "Vegetation guidelines for stormwater biofilters in the south-west of Western Australia" (Monash 2014) and include native species as much as possible.

7.2.1.3 Building Control Measures

The DER has responsibility under Part V of the *Environmental Protection Act 1986* (EP Act) for the licensing and registration of prescribed premises, the issuing of works approvals and administration of a range of regulations. The DER also monitors and audits compliance with works approvals, licence conditions and regulations and takes enforcement actions as appropriate.

Certain industrial premises with the potential to cause emissions and discharges to air, land or water are known as "prescribed premises" and trigger regulation under the EP Act. The EP Act requires a works approval to be obtained before constructing prescribed industrial premises and makes it an offence to cause an emission or discharge unless a licence or registration is held for the premises.

Heavy industry exceeding specified production rates, including for example the manufacturing or blending of chemicals, food processing, animal feed manufacturing, scrap metal recovery, liquid waste facility and bulk storage of chemicals, is subject to licensing. It requires a works approval and monitoring by the DER, which requires the site to follow strict land-use management practices, and an annual monitoring regime and reporting program.

Possible building control measures include:

- Each premises preparing relevant plans to manage spillages should they occur. The Plans would include keeping spill response equipment on site, training staff in the use of equipment and plan for notifying relevant emergency services and government agencies to seek external assistance if required.

- Keep rainfall from directly contacting working areas where stormwater is allowed to mix with process effluent and chemicals, by installing roofs, placing structures, or moving industrial operations indoors.

- Prevent stormwater, which flows across the industrial area, from contacting industrial areas, indoors or out, by using properly designed berms or grading and contained drains.

- Storage of chemicals and handling areas should be bunded to allow containment and recovery of spills.

- Paved areas exposed to rainfall where dust, litter or spilt substances accumulate should be regularly cleaned using methods that prevent drainage or leaching of fluid into the surrounding environment.

- Provide sufficient facilities for rubbish disposal. Discouraging waste dumping in drains through the use of signage and restricted access.

7.2.1.4 In-line Controls

- The use of gross pollutant (litter), oil and sand traps at drain/soakwell entry points.

- Storm drain inlets that drain the loading areas should be equipped with a shutoff valve to keep oil, grease or fuel out of the drain in the event of a spill so that they can be isolated in the event of large fluid spills, until the contaminant is removed.

- Sand or membrane filters appear to be particularly effective if used in combination with detention or retention ponds. These shall be required and shall operate by diverting the first flush of run-off (often carrying the most pollutants) to the filter and routing the remainder of the water to the pond.

- Oil/water separators shall be installed in the vehicle loading areas to remove oily constituents from fuel spills.

Appropriate building control measures will be assessed and stipulated by the DER, where required, for those industries those are required to be regulated by the DER.

7.2.2 Non-structural Treatment Systems

Non-structural controls can be used to provide additional stormwater quality management and can include establishing operation and maintenance activities and employee education. The site will use the following non-structural controls to improve stormwater quality and reduce contamination.

7.2.2.1 Employee Education

Successful storm water pollution and contamination control relies in large part on appropriate training and education of employees. Industry operators will be responsible for the training and education of employees, and the preparation of appropriate Operation and Management Plans specific to their sites and industries.

7.2.2.2 Nutrient Control and Landscaping

An Operation and Management Plan with handover procedures will also be developed to ensure ongoing compliance with landscaping specifications. It is expected that these measures will provide improvement of stormwater quality through ensuring:

- Appropriate native plant species are continually used.
- Basins and swales are maintained.
- Recommended fertiliser, pesticide and irrigation regimes are followed.

7.2.3 Contingency Measures

Each proposal for commercial and industrial development at the KSIA will be assessed independently by the Shire of Harvey, DPaW and DoW. The assessment will consider the individual site conditions such as the type of underlying soil, depth to the water table, proximity to rivers and wetlands and their significance and potential contamination of groundwater. The proponents will be required to implement appropriate pollution control and management measures suitable for the proposed industry.

In an event of a spill or incident leading to possible contamination of stormwater, contingency measures should be put in place. Possible contingency measures may include:

- Site operators and designated staff should be trained to supervise the response to spills.
- Equipment such as absorbent litter should be available to clean up minor chemical spills. Hose-down of floor residues into drains should be avoided.
- When chemicals have escaped into drains, water sampling should be arranged using the services of an analytical laboratory accredited by the National Association of Testing Authorities. Results should be compared against guideline criteria for local water values and necessary recovery and remedial action taken without delay.
- Reintroduce or increase the public awareness program.

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8.0 GROUNDWATER MANAGEMENT

Many of the proposed stormwater management measures will improve stormwater quality and subsequently groundwater quality through the following mechanisms. These have been detailed in Section 7.0 and are summarised below:

- Groundwater abstraction for industrial use not to exceed the DoW groundwater allocation available at the KSIA, to minimise disturbance to wetlands and existing users.
- Maintain groundwater levels and quality at pre-development levels by encouraging infiltration where possible and suitable through the site.
- Reducing water velocities by adopting water sensitive design measures to allow for infiltration at source of the common rainfall events and the use of vegetated roadside swales in lieu of a piped road drainage network. Roadside swales will incorporate rock pitching and structures (weirs) to reduce water velocities.
- Use of soil amendment, as previously discussed in Section 7.2.1.1, particularly in areas used for infiltration of minor events (e.g. swales) and possibly beneath development building pads to reduce the leaching of nutrient and contaminants through the soil profile and into the Superficial aquifer.

8.1 Groundwater Levels

Current DoW policy requires that drainage structures, where practical, do not intercept groundwater. This is intended to reduce the mobilisation of groundwater (and potential negative impacts to groundwater dependent ecosystems), ensure that drainage systems function properly, reduce maintenance requirements and reduce the disease vector risk from mosquitoes.

Water sensitive urban design concepts to be implemented on site, for example swale drains (to replace a piped road drainage network) and infiltration of stormwater in undeveloped (permeable) areas of each lot promotes the infiltration of rainfall and recharge of the Superficial aquifer at source.

A suitable clearance to finished floor levels from AAMGLs will be confirmed and detailed at the WMP stage. The geotechnical report recommended a clearance of 1.5 m to AAMGL to be achieved to finish lot levels. Refer to Figures 15 and 16 for further earthworks details.

As discussed in Section 3.2.2, any required groundwater controls (e.g. subsoil drains) would be undertaken in accordance with *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013a) and agreed between DoW and the proponent at subdivision stage, to ensure protection of groundwater dependent ecosystems.

Stormwater storage areas and swales will be designed with a minimum 0.3 m clearance from the base of the swale to MGL to ensure that water is infiltrated within the required 96 hours (WAPC 2008a), with due consideration of DoW (2013a).

8.2 Groundwater Quality

Groundwater quality will be maintained at predevelopment conditions and possibly improved through best management practices. In addition to the practices summarised in Section 7.0 and 8.0 above, additional industry specific BMPs that may be used across the site include:

- Industry operators within the site will be required to implement industrial BMPs for their industry with regard to protection of water resources. These may include oil and water separators or bunding of vehicle wash-down areas and limitations on the quantity and period of time that hazardous materials can be held on site.

- The use of vegetated swales and bunding where possible to divert and collect water in suitable uncontaminated areas of the lots for infiltration.

- The use of a clay layer or impermeable membrane under building envelopes or potentially contaminated process water streams to ensure no leaching of contaminants to groundwater.

- A post-development groundwater monitoring program within lots and reporting to the DoW to ensure compliance with prescribed licence conditions and environmental impact reporting.

9.0 WETLAND MANAGEMENT

The KSIA Structure Plan has been developed to ensure that a majority of the high value CCW and REWs are contained within the Industry Buffer and Regional Open Space.

Department of Parks and Wildlife (DPaW) and DoW have been consulted with respect to establishing appropriate wetland buffers at this stage of investigation. The primary outcomes of the consultation involved the completion of mapping that showed the depth to AAMGL at the wetland, with shallower depths generally considered to present a higher potential risk of impact. Figure 12 shows the depth to AAMGL and wetland mapping that was undertaken as part of the Wetland Risk Analysis (RPS 2016), which is provided in Appendix 5.

The wetland analysis provides general management strategies for the development and it is proposed that specific management strategies for individual wetlands are undertaken on a case by case basis with the individual lot proponent and regulator at subdivision stage, guided by the information provided in the Wetland Risk Analysis report (RPS 2016). Section 4.2 further discusses the wetland analysis including the recommendations for further detailed wetland assessment to be undertaken at the subdivision stage.

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10.0 POST-DEVELOPMENT MONITORING

10.1 Monitoring Program

The staged, long-term subdivision of the KSIA will occur over several decades and will require a targeted land use specific monitoring program. The program will need to be industry specific and will vary from an urban estate for example where a two or three year monitoring program would typically commence following practical completion of each stage of subdivision.

It is recognised that a post-development monitoring program is necessary at the KSIA due to the proposed land uses and proximity to water resources. However, the sampling parameters, frequency and duration of the post-development monitoring program will be influenced by the industries that locate to the KSIA, the area of subdivision and the proximity of the subdivision to water resources including wetlands, groundwater and the Wellesley River.

As discussed above in Section 7.2.1.3 Building Control Measures, heavy industry exceeding specified production rates will be subject to licensing by the DER, which requires the site to follow strict land use management practices, and an annual monitoring regime and reporting program.

As not all land uses will be subjected to licensing by the DER, a local post-development monitoring program will be completed which will detect the possible accumulative effect to groundwater and surface water resources due to the change in land use.

An overview of the possible monitoring is provided below, however this will need to be accurately confirmed in the future WMPs. In particular, any post-development monitoring programs required by the DoW will need to give consideration to avoiding duplication of DER monitoring requirements.

10.2 Groundwater

Post-development groundwater quality monitoring will occur on a quarterly basis over a period of three years following practical completion of each stage of subdivision. It is likely that the current bores will be destroyed or will degrade with time making them unsuitable for further monitoring. Where bores are destroyed or are no longer available for use, a new bore shall be installed in a location as close as possible to ensure consistency in the monitoring regime. The parameters that will be measured post-development need to be targeted towards the industries that locate to the KSIA, however are likely to include:

- on site – pH, Temperature, Salinity, Dissolved Oxygen, Electrical Conductivity, Redox

- Laboratory analysis – ASS Parameters, Total Nitrogen, Total Phosphorous, Ortho-Phosphorous, NOx-N, Ammonium.

Groundwater levels will be monitored monthly to track changes in water levels over the seasons. A comparison to pre-development conditions and weather patterns will be completed to determine if the development of the KSIA is having an effect on groundwater levels and quality.

Additional management plans to be completed prior to subdivision will confirm additional monitoring requirements.

10.3 Stormwater

Opportunistic surface water monitoring of the drainage areas will occur for water quality analysis once each year following the first winter flush and two months later, for a period of three years following practical completion of each stage of subdivision. The sampling locations will be confirmed in subsequent WMPs when drainage locations and any DER monitoring requirements are confirmed. Surface water quality will be measured for the same water quality parameters as the groundwater monitoring.

10.4 Performance Values

The post-development groundwater monitoring results will be compared to the baseline (pre-development) conditions with trigger values set as pre-development concentrations plus 20% for groundwater, and stormwater monitoring trigger values will be based on ANZECC water quality guidelines.

The final baseline and trigger values will be determined and reported on in future WMPs. If water quality parameters exceed trigger values on two consecutive sampling occasions, contingency measures shall be employed.

10.5 Contingency Plans

In an event where a post-development monitoring event exceeds performance values for two consecutive monitoring events, the Shire of Harvey (SoH) and DoW will be notified and an investigation will be undertaken to determine the cause of the exceedances, the impacts and the required contingency measures.

Possible contingency measures may include:

- identification of the pollution source
- removal of the pollution source, if possible
- review of individual groundwater pumping rates and volumes

- improved management of industrial products
- further soil amendment in infiltration areas
- increased planting of nutrient stripping vegetation in drainage areas
- reintroduce or increase the public awareness program.

10.6 Reporting

The post-development results of the monitoring program will be compared against the pre-development data and reported annually to the SoH and DoW and will be reviewed annually in conjunction with the SoH and DoW. The report will provide details of any variations the development has had on the hydrological conditions and propose necessary contingency plans where required.

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11.0 AREAS TO BE INVESTIGATED POST-OWMS

As per the water management framework developed for the KSIA and described in Section 1.2.3, the preparation of lot-scale WMPs will be required as a condition of subdivision approval and will include the following design measures in more detail:

- compliance with this OWMS criteria and objectives to the satisfaction of the SoH and DoW
- confirmation of alternate water supply options and provide details of water requirements of the subdivision and how this will be achieved (with reference to Guidelines for the approval of non-drinking water systems in Western Australia (DoW 2013b))
- confirm wastewater treatment and disposal details including the location and design of any ATU, or septic tank and leach drains required on site
- in-depth stormwater drainage design including final drainage basin and swale dimensions
- detailed information on structural and non-structural BMPs to be implemented within the subdivision
- final lot configuration and sizes including finished floor levels, minor and major drainage layouts and overland flow paths
- management of construction works, including details of licensing for dewatering or dust suppression, management of ASS and wetlands
- detailed monitoring program for groundwater and surface water monitoring including sampling locations
- confirming performance values and list of contingency measures
- finalised implementation plan including roles and responsibilities of all parties involved
- further details of any specific wetland or foreshore assessments and management plans as required to support subdivision.

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12.0 IMPLEMENTATION OF OWMS

The effectiveness of this OWMS will rely on the implementation of this document by both the Industry Operators and the future proponents undertaking the subdivision of the KSIA. The following operation and maintenance program detailed in Table 9 below is proposed.

Table 9: OWMS Roles and Responsibilities

Principles	Role	Responsibility	Time-scale
Water quality monitoring (separate to lot-specific monitoring as required by DER)	Groundwater monitoring	The proponents	Quarterly, until three years after practical completion of the development
	Surface water (stormwater basin) monitoring	The proponents	Annually during the first flush and two months later, until three years after practical completion of the development
Water quantity monitoring (separate to lot-specific monitoring as required by DER)	Groundwater level monitoring	The proponents	Monthly, until three years after practical completion of the development
Drainage Infrastructure	Maintenance of drainage infrastructure	The proponents	As required until three years after practical completion of the development. The extent of the maintenance commitment will be confirmed with the Shire of Harvey (SoH) at the WMP stage of the development.
Reporting	Report on monitoring results	The proponents	Annually, until three years after practical completion of the development
Public information	Community awareness and education	LandCorp	Upon settlement with lot purchasers

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13.0 REFERENCES

AGC Woodward-Clyde. 1994. *Review of the Environmental Hydrogeology of the Core and Service Industry Areas at Kemerton.*

Aquaterra. 2002. *Kemerton Water Study Phase 2*. Report Prepared for Kemerton Technical Working Group, comprising LandCorp, Department of Mineral and Petroleum Resources (MPR) and the Water and Rivers Commission, April 2002.

Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. 2000. *National Water Quality Management Strategy*, Australian and New Zealand Environment and Conservation Council, Canberra.

Bamford, M.J. and Bamford, A.R. 1999. *Kemerton Fauna Study and Review 1998.*

Bamford, M.J. and Davis R.A. 2003. *Kwinana – Bunbury Gas Pipeline Fauna Review.*

Bowman Bishaw Gorham. 1999. Kemerton Water Study Phase 1. Prepared for LandCorp, Department of Resources Development, Water and Rivers Commission, Water Corporation.

BSD. 1997. *Kemerton Expansion Study – Final Draft Report, Volumes 1 & 2*, prepared for Department of Resources Development, Land Corp, Western Australian Planning Commission and South West Development Corporation, BSD Consultants Pty. Ltd.

Cardno. 2010a. *Hydrological Monitoring at Kemerton Industrial Park*. Cardno, Perth.

Cardno. 2010b. *Kemerton Industrial Core Fauna Survey*, Cardno, Subiaco.

Cardno. 2010c. *Kemerton Industrial Core Flora and Vegetation Survey*, Cardno, Subiaco.

Coffey Environments. 2007. *Kemerton Industrial Park Environmental Overview for the KSIA Strategy Plan*. Coffey, Perth.

Douglas Partners. 2011. *Report on Preliminary Geotechnical Investigation, Kemerton Industrial Park,* For Landcorp. Douglas Partners, Perth

English, V and Blyth, J. 1997. *Identifying and Conserving Threatened Ecological Communities in the South West Botanical Province*. Project 702.

Department of Environment. 2004. DEC *Potentially Contaminating Activities, Industries and Landuses*

Department of Health. 2012. *Code of Practice for Onsite Sewage Management.* Consultation Draft- November 2012.

Department of Health. 2011. *Code of Practice for the Design, Manufacture, Installation of Aerobic Treatment Units.*

Department of Health. 2003. Country sewerage policy – draft for public comment.

Department of Health. 1996. Government sewerage policy – Perth metropolitan region.

Department of State Development et.al. 2009. *Kemerton Industrial Park Strategy Plan* Department of Water. 2010a. *Water Quality Protection Note 52: Stormwater Management at Industrial Sites.* Department of Water, Perth.

Department of Water. 2016. Water quality protection note no. 70. Wastewater treatment and disposal – domestic systems. March 2016 (interim update).

Department of Water. 2013a. *Water resource considerations when controlling groundwater levels in urban development.* Department of Water, Perth.

Department of Water. 2013b. Guideline for the approval of non-drinking water systems in Western Australia. Urban Developments. December 2013.

Department of Water. 2008a. *Interim: Developing a Local Water Management Strategy.* Department of Water, Perth.

Department of Water. 2007. *Kemerton Groundwater Subareas: Water Management Plan.* Department of Water, Perth.

Department of Water. 2005. *Local Area Management Plan for the Groundwater Resources of the Kemerton Subareas.* Department of Water, Perth.

Department of Water. 2004–2007. *Stormwater Management Manual for Western Australia*, Department of Water, Perth.

Economic Consulting Services. 2000. *Kemerton Industrial Estate Land Use Options.* Prepared for Land Corp.

Geological Survey of Western Australia. 1982. *Harvey – Lake Preston Urban Geology, Parts of 1:50,000 Sheets 2031 I and 2031 IV*, Geological Survey of Western Australia

Government of Western Australia. 2007. *State Water Plan*, Department of the Premier and Cabinet, Perth, Western Australia.

Government of Western Australia. 2006. *State Planning policy 2.9 Water Resources*, Western Australian Planning Commission, Perth, Western Australia.

Government of Western Australia. 1986. *Environmental Protection Act: Environmental Protection (Unauthorised Discharges) Regulations 2004*. Government of Western Australia, Perth.

Marsden Jacobs Associates. 2011. *Wellington Dam and Upper Collie Water Supply and Demand – Extracts Sections Relevant to Kemerton Industrial Park*. Marsden Jacobs Associates Pty Ltd, Perth.

MIC. 2010a. *Australind Environmental Report 2010.* Millennium Inorganic Chemicals Limited. Millennium Inorganic Chemicals.

MIC. 2010b. E*nvironmental Report 2010. Kemerton* TiO_2 *Processing Plant.* Millennium Inorganic Chemicals Limited. Millennium Inorganic Chemicals.

Monash University. 2014. Vegetation guidelines for stormwater biofilters in the south-west of Western Australia. Monash Water for Liveability Centre.

Muir Environmental. 1999. *Report of Biological Survey – Phase 1: Kemerton Industrial Estate*. Report prepared for LandCorp, Perth.

Parsons Brinkerhoff. 2011a. Kemerton Industrial Park - Ecological Management Plan. Parson Brinkerhoff

Parsons Brinkerhoff. 2011b. Kemerton Industrial Park - Wetland Management Plan. Parson Brinkerhoff

RPS. 2016. Wetland Risk Analysis. Kemerton Strategic Industrial Area. Report prepared for Landcorp.

TME, Coffey Enviroments, William James Landscape Architects. 2009. *Kemerton Industrial Park Strategy Plan*. TMW, Perth.

WAPC. 2008. *Better Urban Water Management.* Perth, Western Australia.

WAPC. 2003. *Planning Bulletin no. 64: Acid Sulfate Soils*, Department of Planning and Infrastructure, Perth.

WAPC. 2000. Industry 2030 Greater Bunbury Industrial Land and Port Access Planning.

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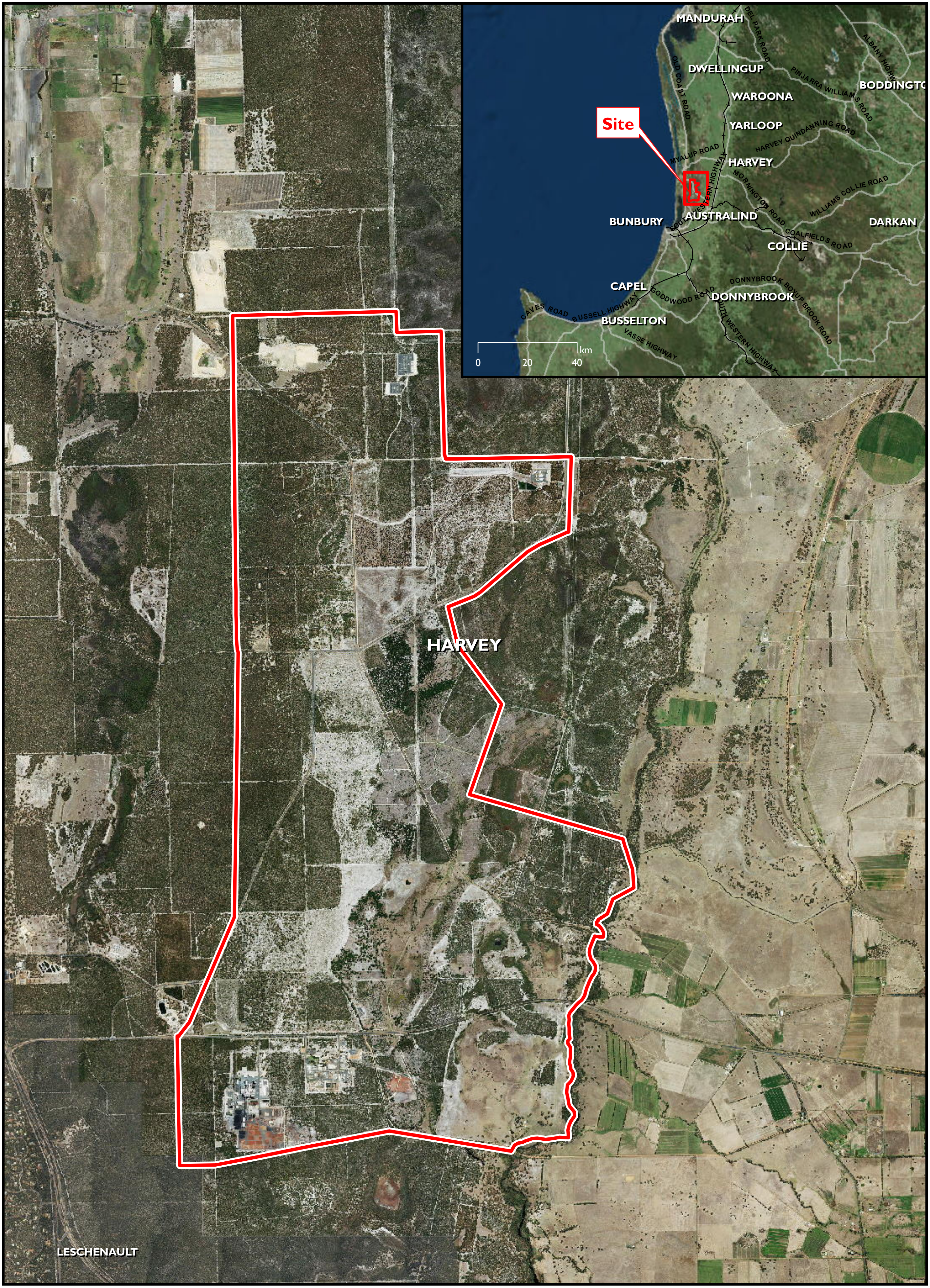
FIGURES



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RPS

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GDA 1994 MGA Zone 50

m
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Figure 1

Site Location

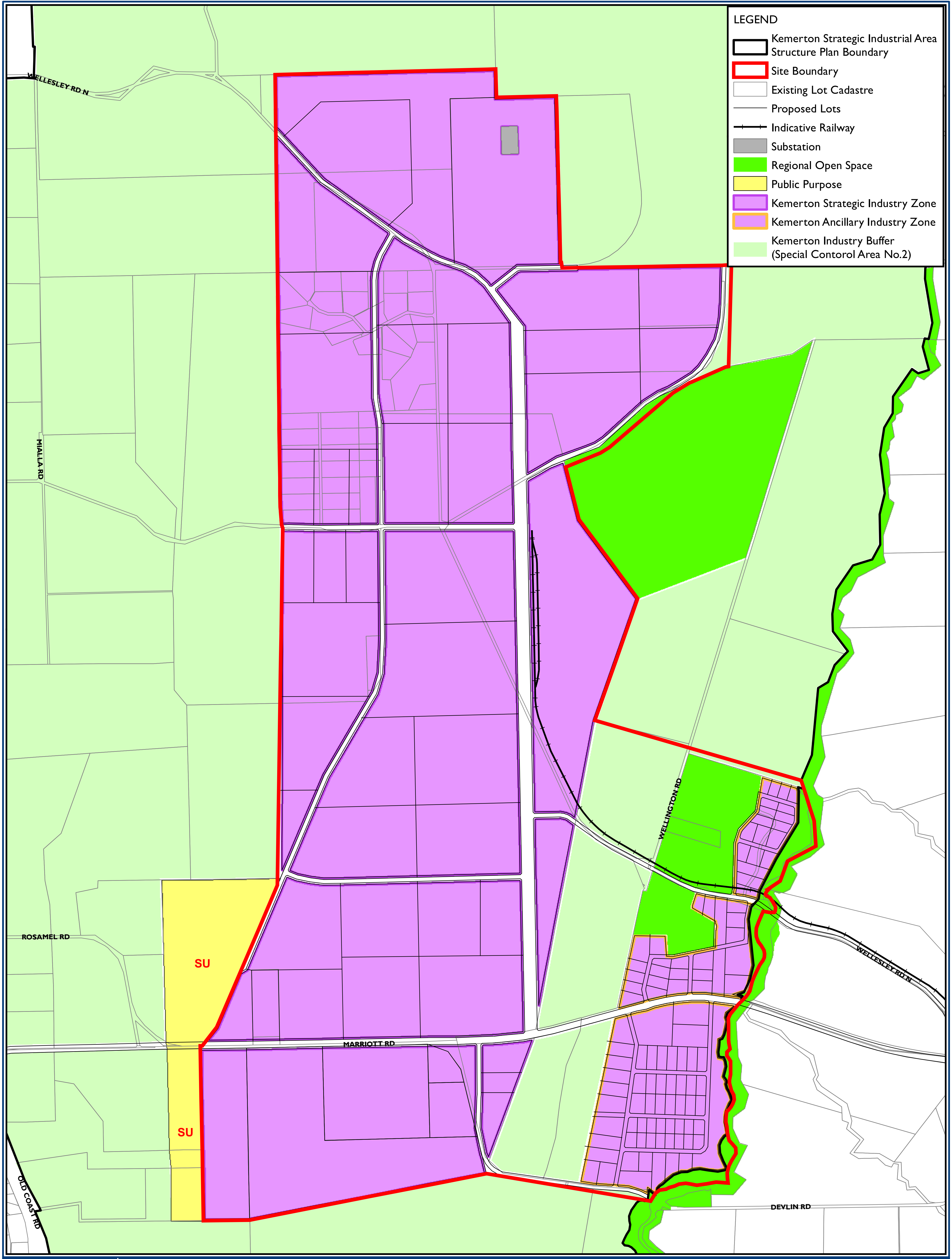

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Figure 2

Local Structure Plan

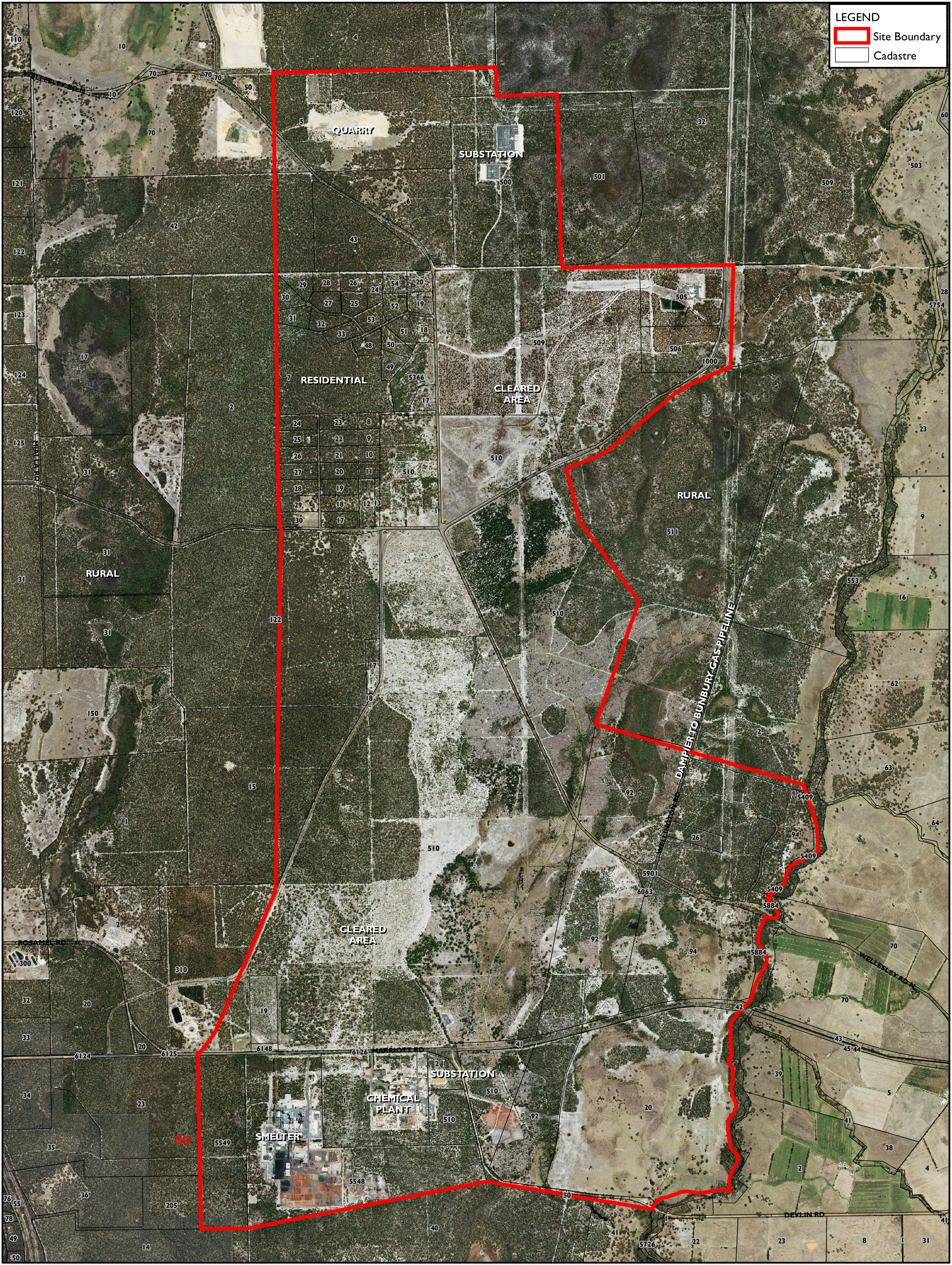

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Figure 3

Existing Land Uses

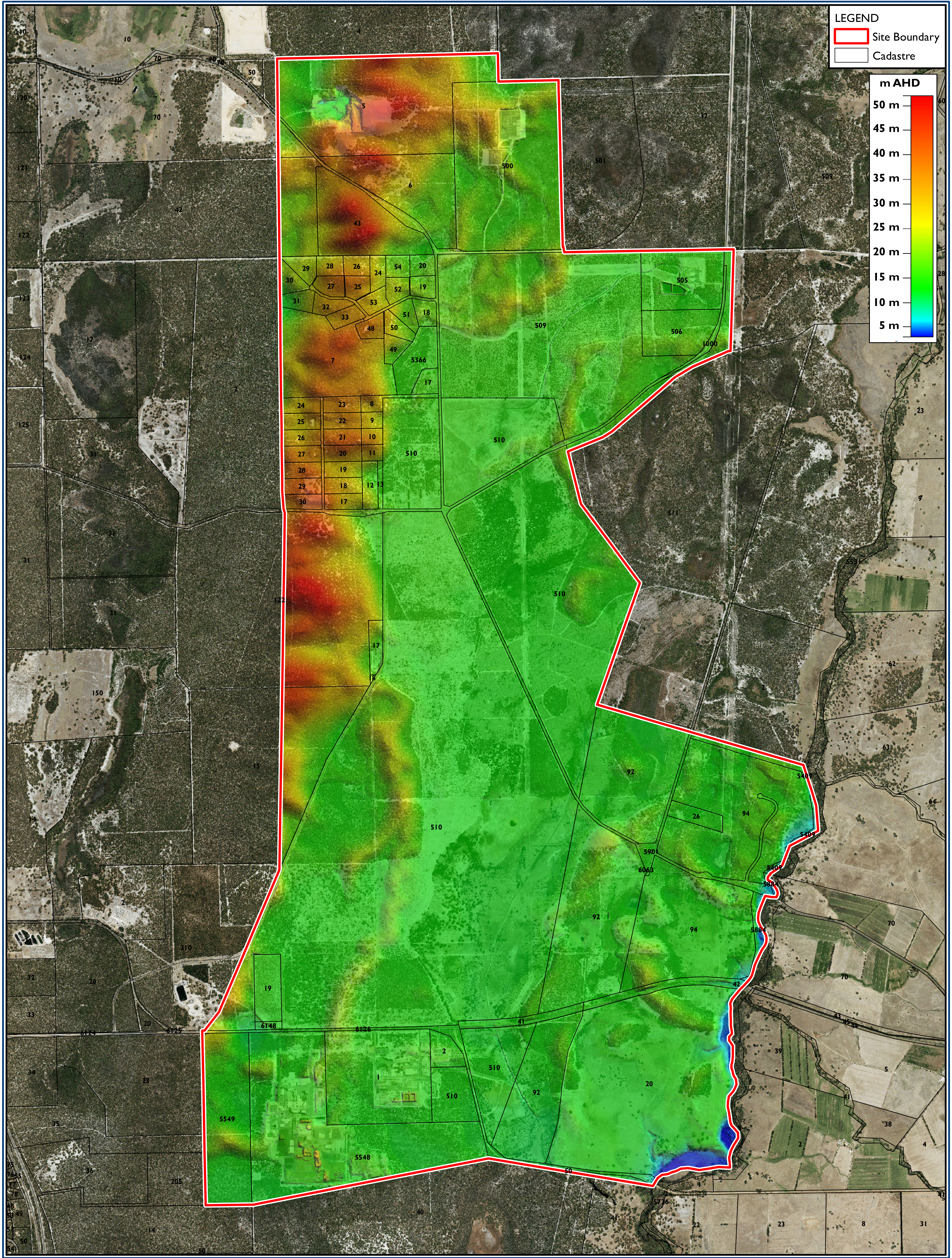

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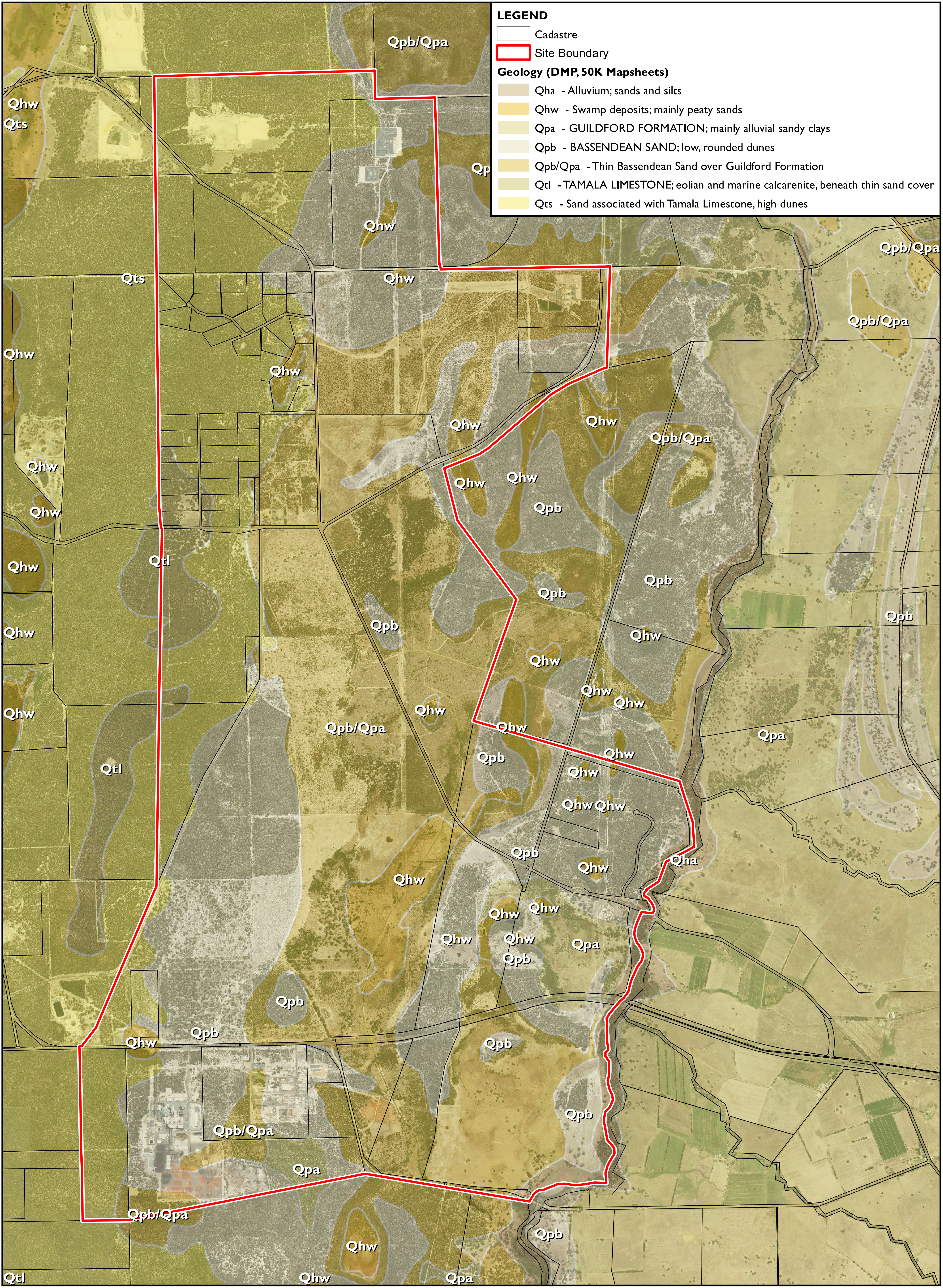
Figure 4

Topography



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GDA 1994 MGA Zone 50

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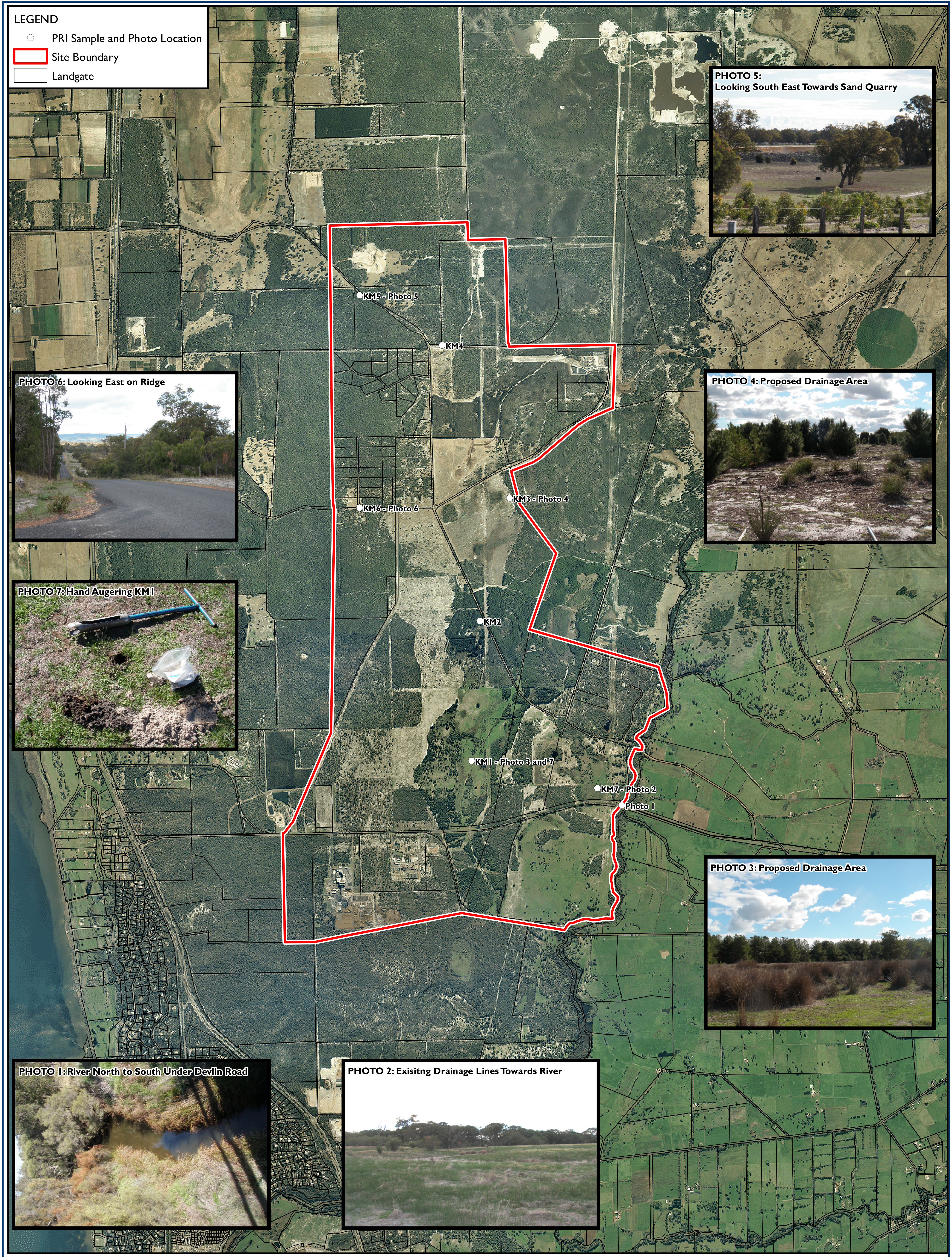
Figure 5

Soil Types



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GDA 1994 MGA Zone 50

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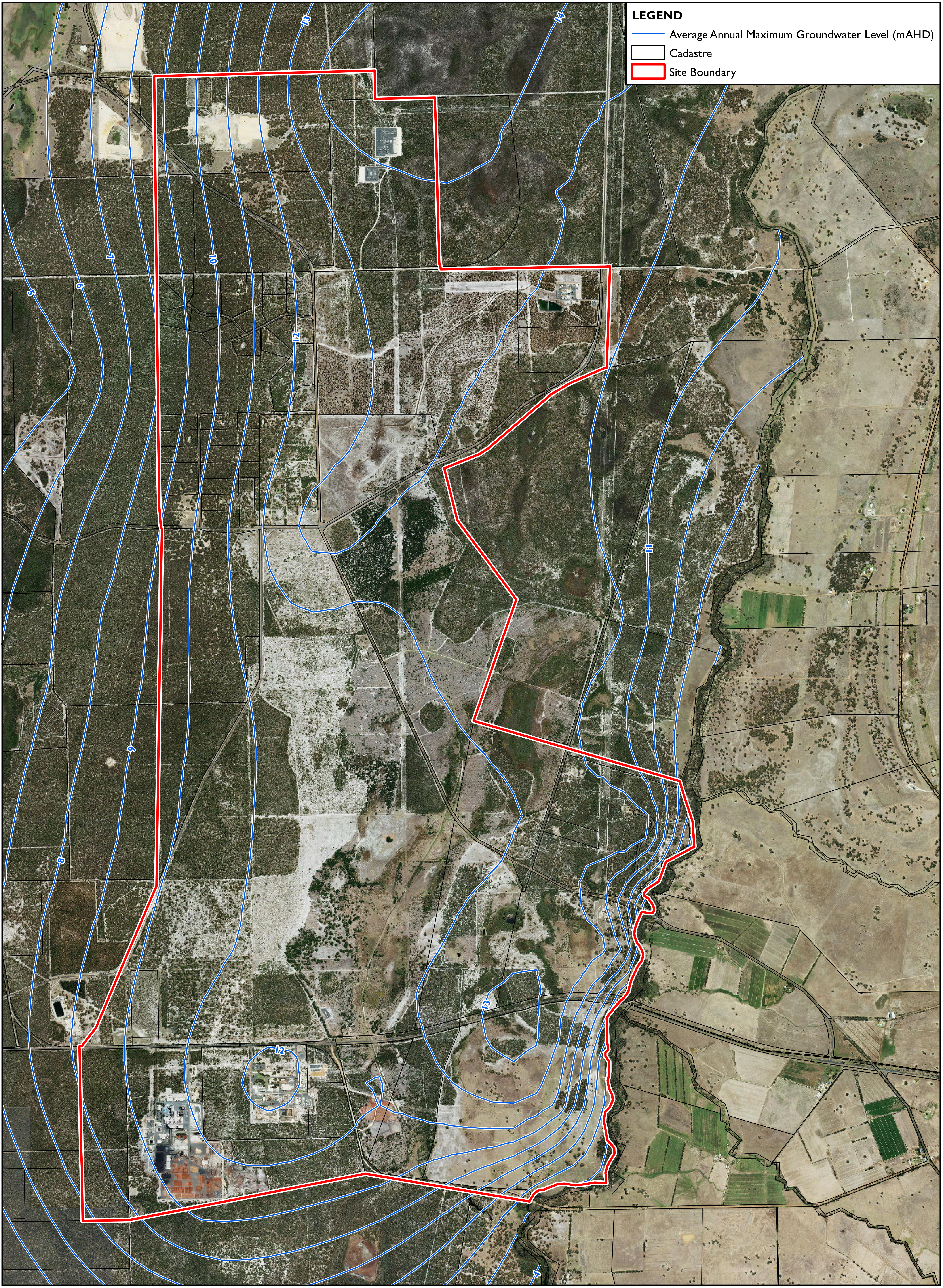
Figure 6

PRI Sample Locations



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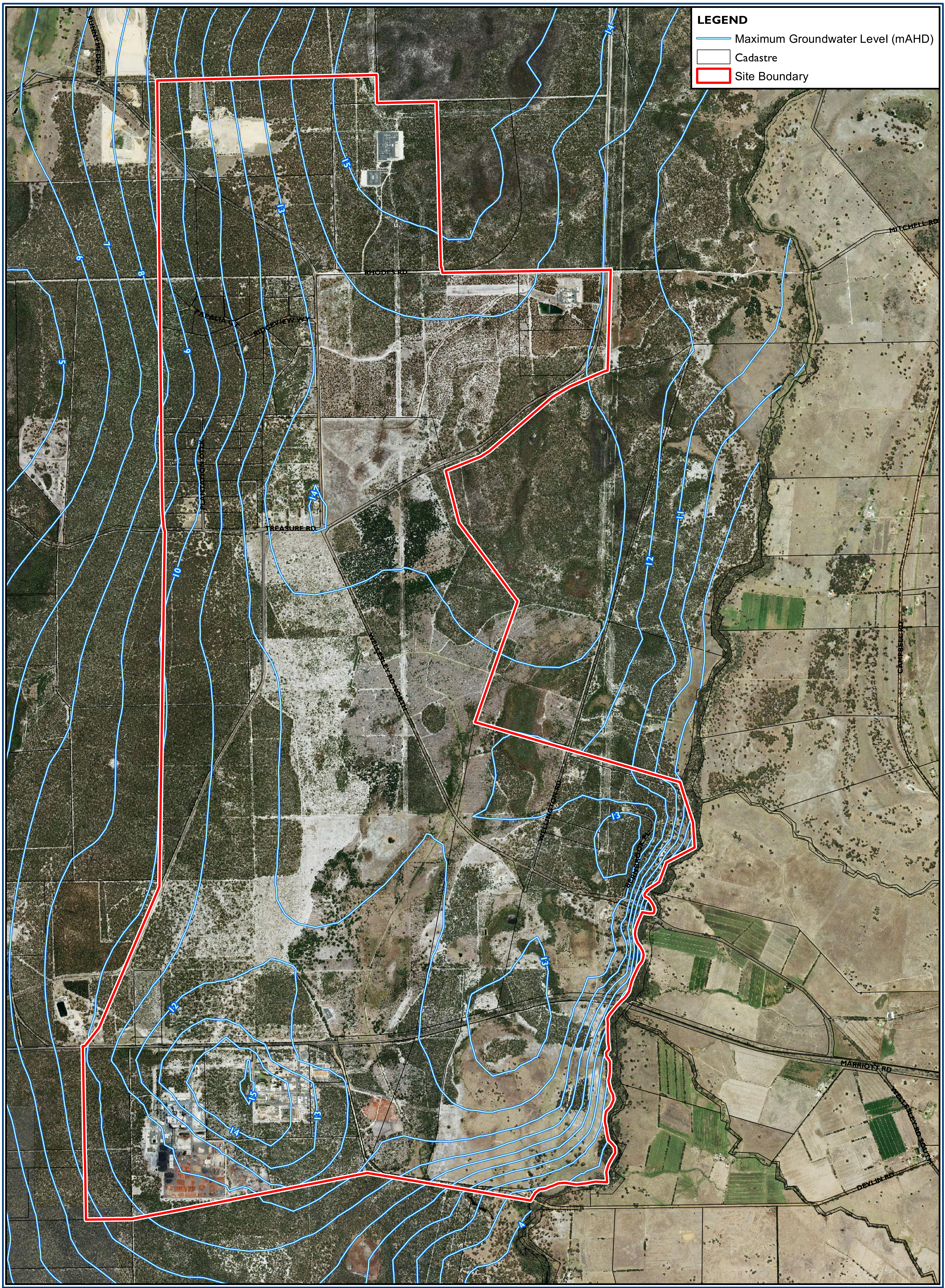
Source: Orthophoto - Landgate, Feb 2016

GDA 1994 MGA Zone 50

Figure 7

Average Annual Maximum Groundwater Level (AAMGL)



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GDA 1994 MGA Zone 50

0 0.125 0.25 0.5 0.75 1 km

Figure 8

Maximum Groundwater Level (MGL)

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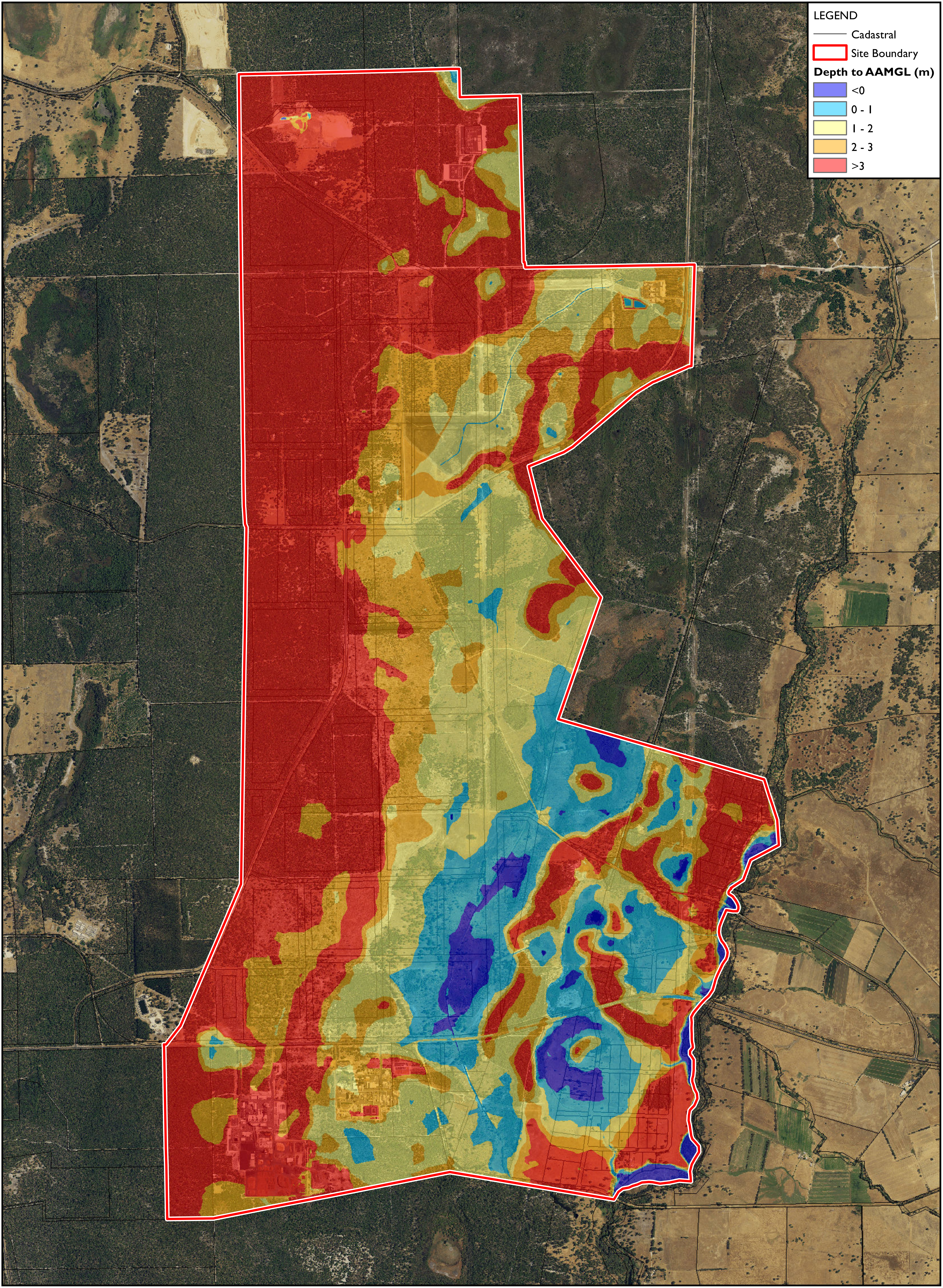

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Job Number: D1054201
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Scale: 1:25,000 @ A3
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Source: Orthophoto - Landgate, Feb 2015

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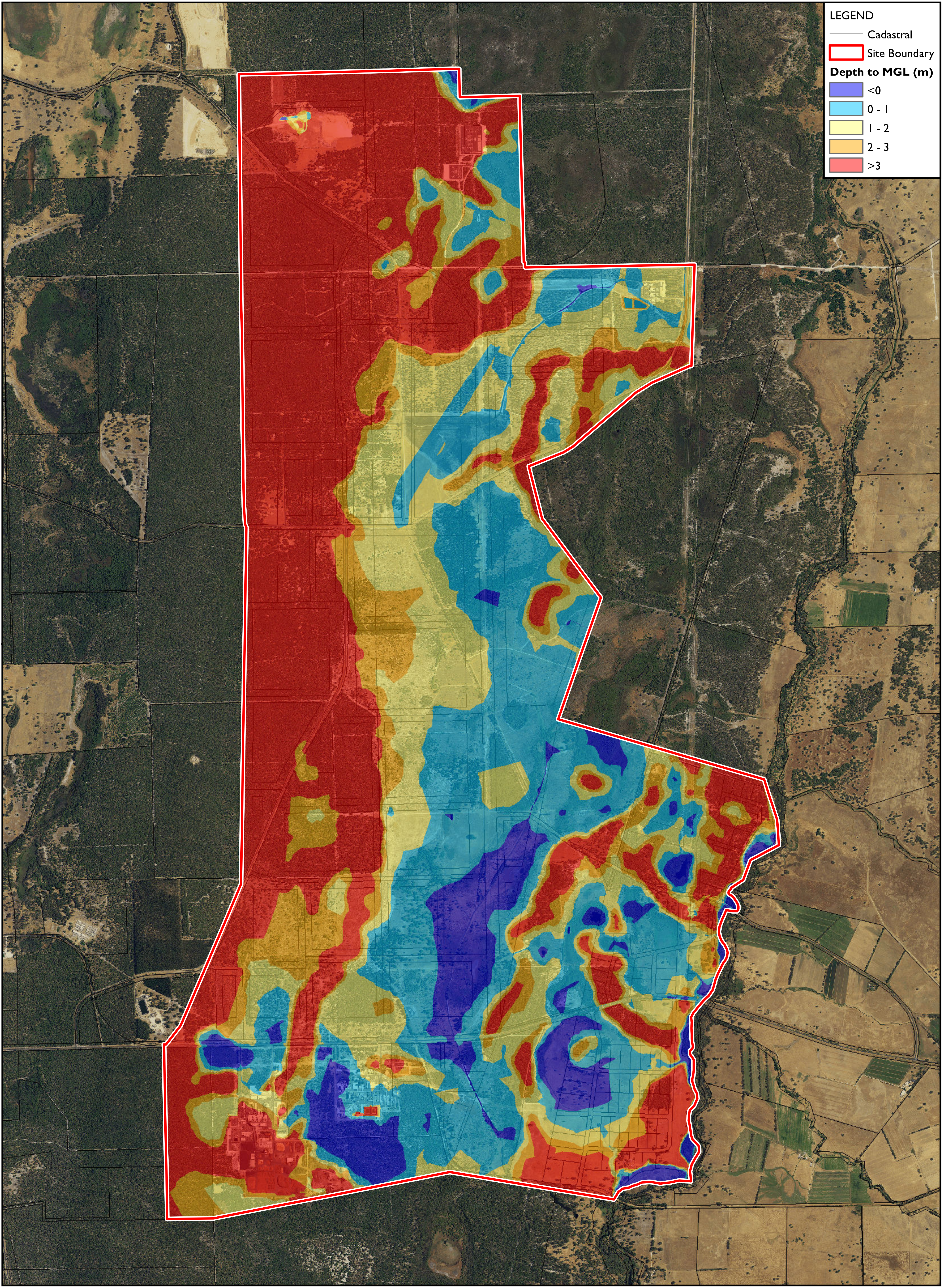
Figure 9

Pre-development Depth to AAMGL



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Created by: MA
Source: Orthophoto - Landgate, Feb 2015

Figure 10

Pre-development Depth to MGL

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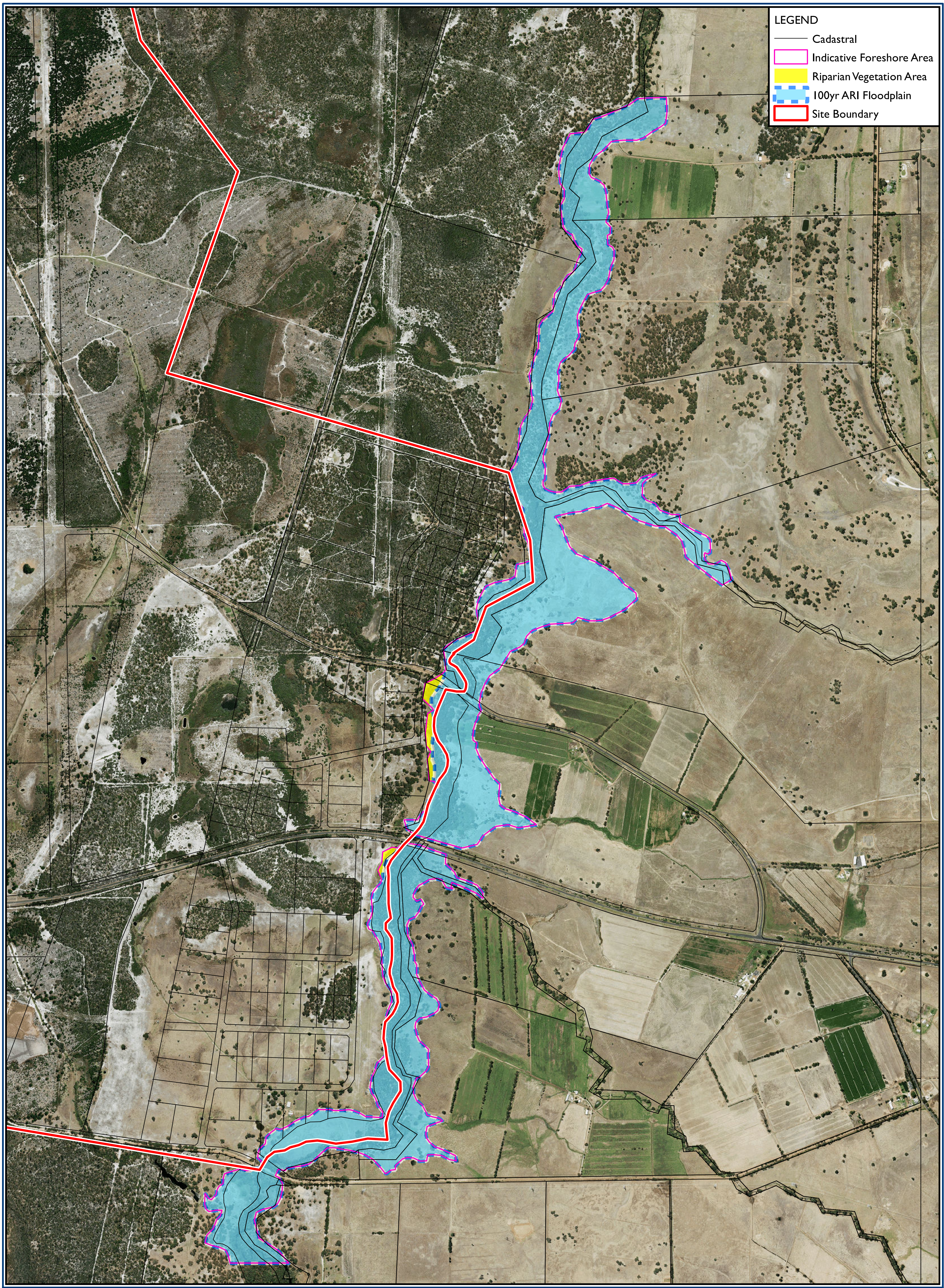

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GDA 1994 MGA Zone 50

0 0.15 0.3 0.6 km

Figure 11

Indicative Foreshore Area

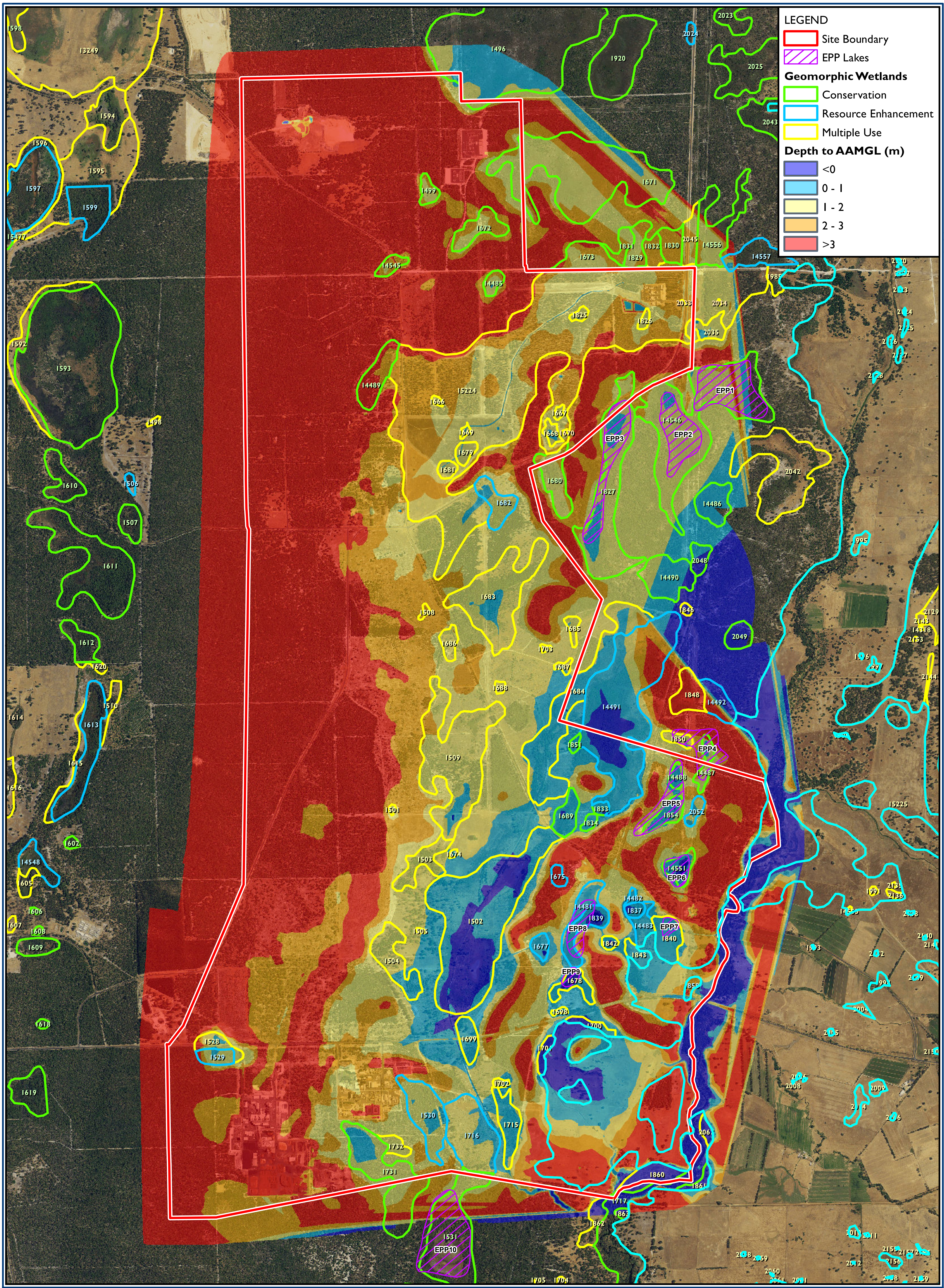

Figure 12

Pre-development depth to AAMGL and Wetland Mapping

RPS

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GDA 1994 MGA Zone 50

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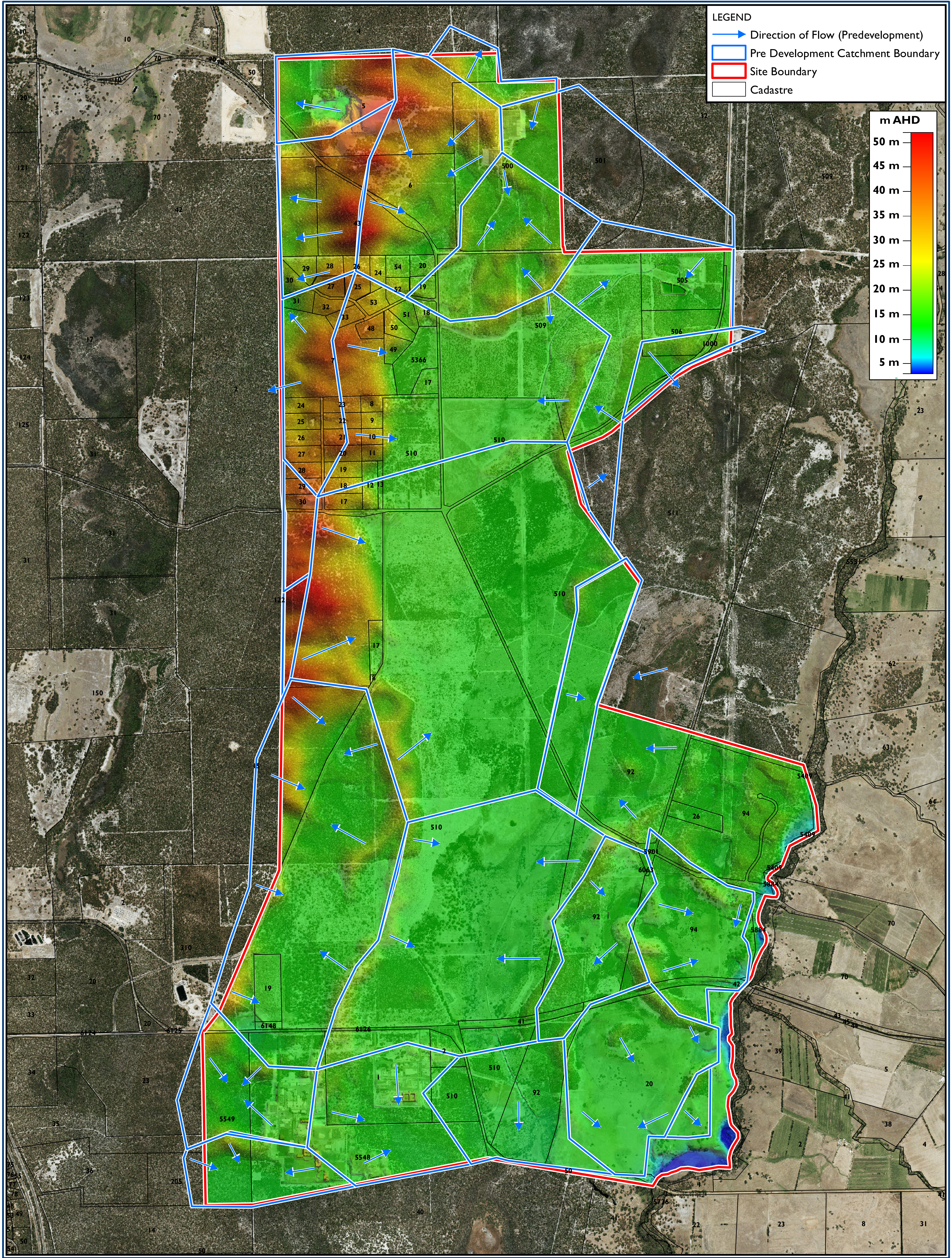

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Source: Orthophoto - Landgate, 2016 Cadastre - Landgate, 2011 LIDAR - DoW, 2011

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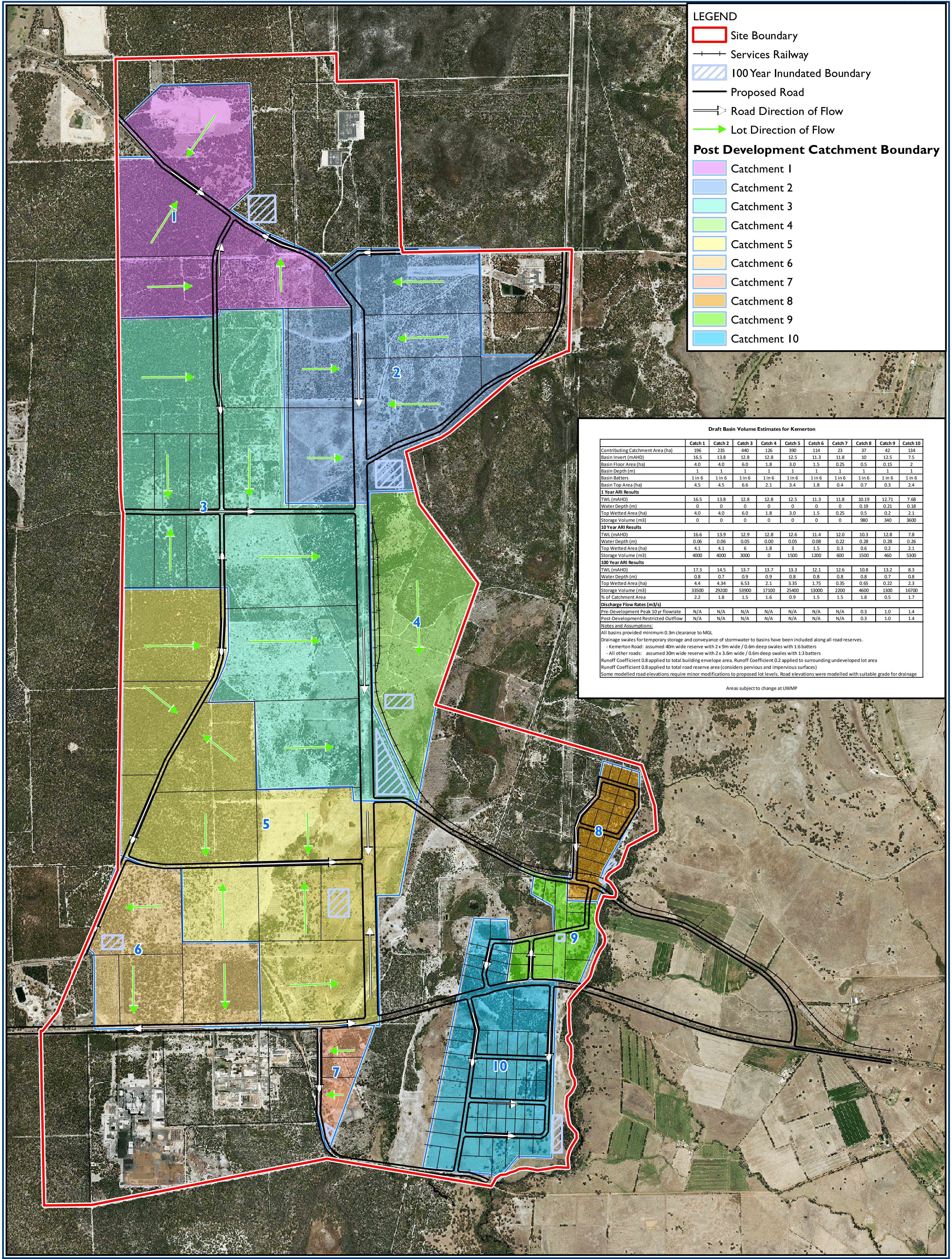
Figure 13

Pre Development Drainage Patterns



Draft Basin Volume Estimates for Kemerton

	Catch 1	Catch 2	Catch 3	Catch 4	Catch 5	Catch 6	Catch 7	Catch 8	Catch 9	Catch 10
Contributing Catchment Area (ha)	196	235	440	126	390	114	23	37	42	134
Basin Invert (mAHD)	16.5	13.8	12.8	12.8	12.5	11.3	11.8	10	12.5	7.5
Basin Floor Area (ha)	4.0	4.0	6.0	1.8	3.0	1.5	0.25	0.5	0.15	2
Basin Depth (m)	1	1	1	1	1	1	1	1	1	1
Basin Batters	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6
Basin Top Area (ha)	4.5	4.5	6.6	2.1	3.4	1.8	0.4	0.7	0.3	2.4
1 Year ARI Results										
TWL (mAHD)	16.5	13.8	12.8	12.8	12.5	11.3	11.8	10.19	12.71	7.68
Water Depth (m)	0	0	0	0	0	0	0	0.19	0.21	0.18
Top Wetted Area (ha)	4.0	4.0	6.0	1.8	3.0	1.5	0.25	0.5	0.2	2.1
Storage Volume (m3)	0	0	0	0	0	0	0	980	340	3600
10 Year ARI Results										
TWL (mAHD)	16.6	13.9	12.9	12.8	12.6	11.4	12.0	10.3	12.8	7.8
Water Depth (m)	0.06	0.06	0.05	0.00	0.05	0.08	0.22	0.28	0.28	0.26
Top Wetted Area (ha)	4.1	4.1	6	1.8	3	1.5	0.3	0.6	0.2	2.1
Storage Volume (m3)	4000	4000	3000	0	1500	1200	600	1500	460	5300
100 Year ARI Results										
TWL (mAHD)	17.3	14.5	13.7	13.7	13.3	12.1	12.6	10.8	13.2	8.3
Water Depth (m)	0.8	0.7	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.8
Top Wetted Area (ha)	4.4	4.34	6.53	2.1	3.35	1.75	0.35	0.65	0.22	2.3
Storage Volume (m3)	33500	29200	53900	17100	25400	13000	2200	4600	1300	16700
% of Catchment Area	2.2	1.8	1.5	1.6	0.9	1.5	1.5	1.8	0.5	1.7
Discharge Flow Rates (m3/s)										
Pre-Development Peak 10 yr flowrate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	1.4
Post-Development Restricted Outflow	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	1.4

Notes and Assumptions:

All basins provided minimum 0.3m clearance to MGL

Drainage swales for temporary storage and conveyance of stormwater to basins have been included along all road reserves.

- Kemerton Road: assumed 40m wide reserve with 2 x 9m wide / 0.6m deep swales with 1:6 batters
- All other roads: assumed 30m wide reserve with 2 x 3.6m wide / 0.6m deep swales with 1:3 batters

Runoff Coefficient 0.8 applied to total building envelope area. Runoff Coefficient 0.2 applied to surrounding undeveloped lot area

Runoff Coefficient 0.8 applied to total road reserve area (considers pervious and impervious surfaces)

Some modelled road elevations require minor modifications to proposed lot levels. Road elevations were modelled with suitable grade for drainage

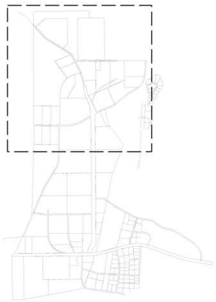
Areas subject to change at UWMP

RPS

Job Number: D1054201
Doc Number: 014
Date: 04.08.16
Scale: 1:25000 @ A3
Drafted by: MA
Source: Orthophoto - Landgate, 2016 Cadastre - Landgate, 2011

Figure 14

Post Development Drainage Concept



LOCALITY PLAN
SCALE 1:100,000

PLAN
SCALE 1:10,000 @ A1

NOTES

GENERAL

1. THE EXISTING CONTOUR INFORMATION HAS BEEN TAKEN FROM LIDAR INFORMATION SOURCED BY MCMULLEN NOLAN AND PARTNERS.
2. DESIGN AREAS MAY EXCLUDE SOME PARTS OF THE KEMERTON INDUSTRIAL PARK NOT SUBJECT TO THIS EXERCISE.

ASSUMPTIONS:

THE PRELIMINARY EARTHWORKS PLANNING HAS BEEN COMPLETED, BASED ON THE FOLLOWING ASSUMED PARAMETERS:

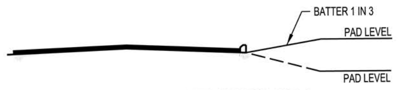
- BUILDING PAD AREAS HAVE BEEN BASED ON A FLAT LEVEL.
- MINIMUM DESIGN LEVELS IN BUILDING PAD AREAS HAVE BEEN TAKEN AS 1.5m ABOVE ANNUAL AVERAGE MAXIMUM GROUNDWATER LEVELS (AAMGL). SOME BUILDING AREAS ARE BASED ON ROAD LEVEL AND/OR TOPOGRAPHY RELATED INTERFACING REQUIREMENTS.
- MINIMUM LEVELS FOR ROADWORKS ABOVE AAMGL ARE AS 1.0m, WITH FLOOD ROUTING OF ROADS TO PROPOSED BASIN AREAS WHERE APPLICABLE.
- ROAD LEVELS TIE IN AT ESTATE BOUNDARIES FOR INTERFACING PURPOSES.
- NO ASSESSMENT OF ROADWORK LEVELS EXTERNAL TO THE CORE WAS UNDERTAKEN.
- MARRIOTT ROAD EXISTING ROAD LEVELS HAVE BEEN RETAINED FOR THE EXTENT OF THE DEVELOPMENT.
- NO CONSIDERATION WAS GIVEN TO RAILWAY LAYOUT OR DESIGN.
- NO ASSESSMENT OF RETAINING WALL REQUIREMENTS WAS UNDERTAKEN.
- NO CONSIDERATION WAS GIVEN TO THE EXISTING POWER POLE LEVELS IN KEMERTON ROAD (CENTRAL MAJOR ROAD RUNNING NORTH /SOUTH), AS RELATED TO FUTURE DESIGN LEVELS.
- NO ASSESSMENT OF POTENTIAL GEOTECHNICAL REMEDIATION WAS UNDERTAKEN AS A PART OF THE EXERCISE.
- GRAVITY DEPENDANT CIVIL INFRASTRUCTURE WAS NOT CONSIDERED AS A PART OF THIS EXERCISE. THIS WILL NEED TO BE INCORPORATED AT DETAILED DESIGN STAGE.

EXISTING EXTRACTION LICENCES:

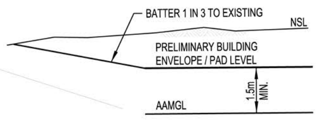
- EXISTING EXTRACTION LICENCES HAVE NOT BEEN INCLUDED AS A PART OF THE BASE INFORMATION. THIS WILL NEED TO BE INCORPORATED IN A MORE DETAILED EXERCISE.

LEGEND

17	DESIGN CONTOURS
10	EXISTING CONTOURS
15.80	PRELIMINARY BUILDING ENVELOPE / PAD LEVEL
10.0	AAMGL LEVELS (PROVIDED BY RPS)
	PROPOSED ROAD
	EXISTING ROAD
▨	FUTURE PROPOSED DRAINAGE
	BATTER LINE
▨	BUILDING ENVELOPES
▬ ▬ ▬	EARTHWORKS PLANNING BOUNDARY
26	EXISTING LOT NUMBERS
	NEW BUILDING ENVELOPS
	WETLAND BUFFER



TYPICAL BUILDING ENVELOPE LOT / PAD LEVEL DETAIL 1
SCALE: INDICATIVE



TYPICAL BUILDING ENVELOPE LOT / PAD LEVEL DETAIL 2
SCALE: INDICATIVE

NOTE:

BUILDING ENVELOPES, LOT LAYOUTS AND ROAD CONFIGURATIONS ARE INDICATIVE ONLY. EARTHWORKS PLANNING HAS BEEN UNDERTAKEN AS A DESKTOP CONCEPT BASIS ONLY AND IS SUBJECT TO DETAILED DESIGN AND FORMAL APPROVALS. ACTUAL DESIGN LEVELS MAY VARY CONSIDERABLY TO THOSE SHOWN.

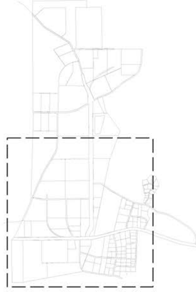
RPS

Job Number: D1054201
Doc Number: 015
Date: 04.08.16
Scale: @ A3
Drafted by: MR
Source: Wood & Greeve Engineers

0 250 500 750 1000 metres

Figure 15

Post Development Earthworks and AAMGLs (1)



LOCALITY PLAN
SCALE 1:100,000

PLAN
SCALE 1:10,000 @ A1

NOTES

GENERAL

1. THE EXISTING CONTOUR INFORMATION HAS BEEN TAKEN FROM LIDAR INFORMATION SOURCED BY MCMULLEN NOLAN AND PARTNERS.
2. DESIGN AREAS MAY EXCLUDE SOME PARTS OF THE KEMERTON INDUSTRIAL PARK NOT SUBJECT TO THIS EXERCISE.

ASSUMPTIONS:

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- ROAD LEVELS TIE IN AT ESTATE BOUNDARIES FOR INTERFACING PURPOSES.
- NO ASSESSMENT OF ROADWORK LEVELS EXTERNAL TO THE CORE WAS UNDERTAKEN.
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- NO ASSESSMENT OF POTENTIAL GEOTECHNICAL REMEDIATION WAS UNDERTAKEN AS A PART OF THE EXERCISE.
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EXISTING EXTRACTION LICENCES:

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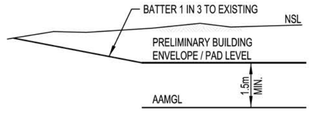
LEGEND

17	DESIGN CONTOURS
10	EXISTING CONTOURS
15.80	PRELIMINARY BUILDING ENVELOPE / PAD LEVEL
10.0	AAMGL LEVELS (PROVIDED BY RPS)
	PROPOSED ROAD
	EXISTING ROAD
▨	FUTURE PROPOSED DRAINAGE
	BATTER LINE
▨	BUILDING ENVELOPES
	EARTHWORKS PLANNING BOUNDARY
26	EXISTING LOT NUMBERS
	NEW BUILDING ENVELOPS

NOTE:

BUILDING ENVELOPES, LOT LAYOUTS AND ROAD CONFIGURATIONS ARE INDICATIVE ONLY. EARTHWORKS PLANNING HAS BEEN UNDERTAKEN AS A DESKTOP CONCEPT BASIS ONLY AND IS SUBJECT TO DETAILED DESIGN AND FORMAL APPROVALS. ACTUAL DESIGN LEVELS MAY VARY CONSIDERABLY TO THOSE SHOWN.

TYPICAL BUILDING ENVELOPE LOT / PAD LEVEL DETAIL 1
SCALE: INDICATIVE



TYPICAL BUILDING ENVELOPE LOT / PAD LEVEL DETAIL 2
SCALE: INDICATIVE

RPS

Job Number: D1054201
Doc Number: 016
Date: 04.08.16
Scale: @ A3
Drafted by: MR
Source: Wood & Greeve Engineers

Figure 16

Post Development Earthworks and AAMGLs (2)

APPENDIX 1

Kemerton Water Study – Phase 2

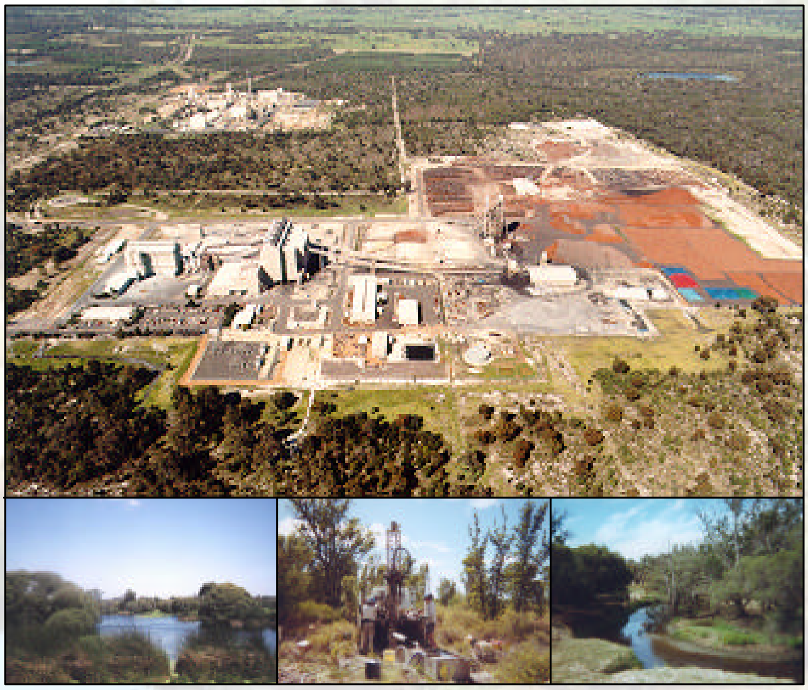
LANDCORP / MPR / WRC

KEMERTON WATER STUDY

PHASE 2

DATA VOLUME

APRIL 2002



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Document No. R002-c

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LANDCORP / MPR / WRC

KEMERTON WATER STUDY – PHASE 2

FINAL REPORT

APRIL 2002

Joe Ariyaratnam
Water Resources Engineer

Hugh Middlemis
Principal Water Resources Engineer

Project No. 211
Document No. R002-c

This report is made available on the basis that it will be kept strictly confidential by the recipient and not disclosed to any third party by that recipient without the prior written approval of LandCorp and Aquaterra. Any request for access to the contents of this report by a third party must be referred to LandCorp. LandCorp may give or refuse such approval with or without conditions in its absolute discretion.

Background and Objectives

Aquaterra were engaged by the Kemerton Technical Working Group, comprising LandCorp, Department of Mineral and Petroleum Resources (MPR) and the Water and Rivers Commission (WRC), to complete the second phase of water studies for the Kemerton Industrial Estate. The major objectives for the Phase 2 Study, may be grouped as follows:

- The acquisition of additional hydrogeological data and the assessment of these new data together with existing information to address a range of specific (water-related) environmental objectives;
- The development of a level of understanding of the interactions between the significant values of the surface water, groundwater and dependent ecological systems (this was largely achieved through the development and use of a multi-layered groundwater model); and
- The development of a refined Water Management Strategy that identifies inter-relationships between water and environmental values and issues, so that the development and operation of Kemerton is environmentally sustainable.

Water Management Strategy

The Water Management Strategy (presented in Section 10) is designed to be acceptable to authorities, with the water supply based on sustainable groundwater abstraction, and impacts that meet the established Ecological Water Requirements (EWR). The strategy conforms to the Environmental Water Provisions (EWP) Policy of the Water and Rivers Commission (WRC), as well as to the water sensitive drainage management policies of the WRC and local councils. The Strategy also conforms to environmental management policies of the Department of Environmental Protection (DEP), particularly regarding wetlands and vegetation.

The outcome of implementing the Water Management Strategy will be the achievement of sustainable and efficient water use, with minimal potential impacts from development and operation of the industrial Estate, whilst maintaining environmental values of significant wetlands, watercourses and vegetation. The Water Management Strategy is capable of practical implementation to maximise development potential of the Kemerton Industrial Estate.

The reader is directed to Section 10 for detail on the Water Management Strategy. The following sections provide a summary of the work that was undertaken and the key findings of the Kemerton Water Study Phase 2.

Monitoring and Assessment

Existing data related to climate, topography, drainage, hydrology, hydrogeology and groundwater allocations and usage was collated. The groundwater data was used to develop an average annual maximum groundwater level (AAMGL) surface for use in conceptual drainage design. Field work was also undertaken to construct new monitoring bores and obtain additional data on groundwater levels and water quality. There is now a comprehensive network of deep and shallow groundwater monitoring bores across the Kemerton area.

Existing environmental information related to wetlands, and wetland and dryland vegetation was also collated, and field work was undertaken to obtain new information. Wetland management categories were reviewed, and vegetation and floristic structures evaluated. This work was completed by ATA Environmental, who also assisted Aquaterra in addressing hydro-environmental relationships.

A register of existing contamination and remediation activities was compiled, along with a summary of existing industrial water management procedures, and existing and potential future wastewater availability. Current and future water demand estimates were compiled and used in the subsequent groundwater modelling tasks to assess abstraction sustainability.

Recommendations for monitoring and assessment programmes are presented in the Water Management Strategy (Section 10).

A separate Data Volume and CD presents all the existing and new information obtained during this Phase 2 Water Study. A summary of the information is presented in various sections in this Report Volume.

ASR Assessment

A desktop assessment of the suitability of aquifer storage and recovery (ASR) for the Estate was undertaken. Aquifer storage and recovery (ASR) involves directing available water to a suitable aquifer during periods of water excess (commonly winter), which is later recovered from the aquifer during periods of demand. At Kemerton, there are suitable storage aquifers, although groundwater levels are generally shallow and are in hydraulic continuity with wetland areas, which could be impacted (by injection or pumping) unless very careful management procedures are implemented. There are no identified sources of good quality water for ASR in the Kemerton area, with the local rivers being brackish to saline and the potential wastewater treatment plant providing brackish quality water. Despite limitations, these sources could be used in centralised ASR schemes involving deep aquifers (which also have brackish water quality), with potential annual volumes of around 1 to 4 GL, which can be compared to the high water demand case for the industrial Estate of 14 GL/annum. The potential for an ASR scheme was assessed through groundwater modelling, which showed that ASR does not significantly reduce drawdown impacts on wetlands or vegetation due to groundwater abstractions, although it does improve water use efficiency. A simpler, cheaper (and not centralised) ASR method involves infiltrating (at source) enhanced runoff from paved surfaces on the estate to provide relatively good quality recharge water, consistent with water sensitive design principles. This is recommended in the Water Management Strategy, and was also implemented in the groundwater model predictions.

Conceptual Drainage Design

Urban and industrial development typically increases the water input to the natural hydrological system, due to enhanced runoff from extensive paved surfaces and a reduction in interception and evapotranspiration losses due to less vegetation. Traditional drainage methods involve using earthfill to create building pads, and collecting and conveying runoff via roadways, pipes and channels to receiving water bodies (with associated nutrients). Water sensitive design principles are now being promoted, involving the infiltration of stormwater into the soil near its source using soakwells, shallow swale drains or sheet runoff into permeable areas such as lawns, garden beds, pervious pavements etc. This results in extra recharge to the aquifer, which is available for re-use in the development by subsequent groundwater pumping (this aspect was addressed in the groundwater modelling predictions). As water sensitive design generally relies on infiltration, it is most effective for smaller, more frequent storms. Traditional methods are often required to augment water sensitive design practices when the rates of surface runoff significantly exceed the infiltration rate (which commonly occurs in areas of high water table such as near wetlands).

The drainage strategy for the Kemerton Industrial Estate should consist of a combination of traditional design and water sensitive design, as detailed in the Water Management Strategy (Section 10). The key benefits of the proposed drainage management strategy include:

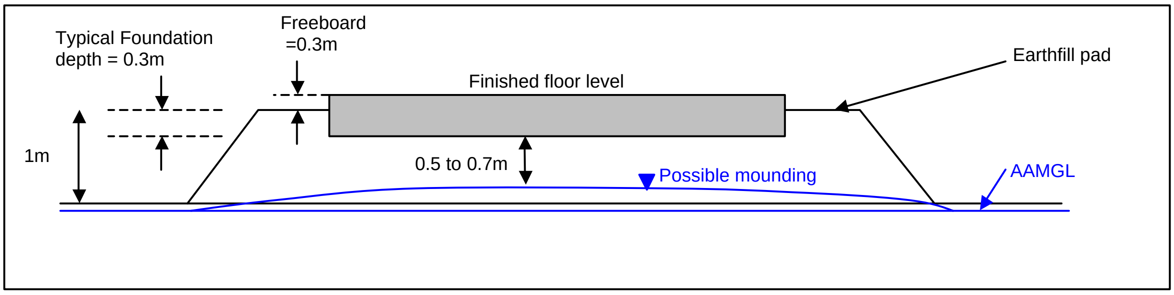
- Minimising the capital costs for development by avoiding the need for trunk drainage and extensive earthfill areas (which were shown to be not economic/feasible); and
- Maximising the infiltration of runoff to recharge the aquifer for later use through abstraction, which is consistent with water sensitive design principles.

Detailed drainage plans will be required to be developed for each site, consistent with the requirements outlined below, notably the depth to the average annual maximum groundwater level (AAMGL) as shown in the summary table below. Information regarding topographic elevations and AAMGL surface (in mAHD and depth below ground) is presented in the Water Management Strategy (Section 10). Note that the only wetlands that can be used for drainage purposes are those classified as Multiple Use (MU), which are typically located through the eastern part of the Estate. There are generally no constraints associated with the development of MU wetlands, provided that the hydrological functions (eg. seasonal inundation) and any remaining ecological functions are preserved or replicated.

Drainage Design Requirements

Drainage Design Requirement	**AAMGL Depth Below Existing Ground Level**			
	0m	0.5m	1.0m	>1.5m
Developed Areas of Blocks				
1. Minimum elevation above surrounding ground surface for earth fill pad	1 m	1 m	0.5 m	0.3 m
2. Floor level freeboard to 100 year ARI flood from local runoff	0.3 m	0.3 m	0.3 m	0.3 m
3. Floodways to convey greater than 10 year ARI flood	Yes	Yes	Yes	Yes
4. Surcharge of roads and hardstand areas for greater than 10 year ARI floods (ie. use these features to convey the major flood flows towards existing drains and natural overland flow paths)	Yes	Yes	Yes	Yes
5. Roof and pavement runoff to spoon drains or rock spalls which dissipate to the groundwater	Yes	Yes	Yes	Yes
6. Soakwells and shallow on site storage depressions	Yes	Yes	Yes	Yes
7. Ponding in lower infiltration capacity areas	Yes	Yes	Yes	Yes
8. Invert levels of drainage structures above AAMGL	Yes	Yes	Yes	Yes
9. Pollution control devices at source (eg. oil separators)	Yes	Yes	Yes	Yes
10. Rainwater tanks for water supply	Yes	Yes	Yes	Yes

Drainage Design Requirement	**AAMGL Depth Below Existing Ground Level**			
	0m	0.5m	1.0m	>1.5m
Undeveloped Areas of Blocks				
11. Shallow swale drains to convey ponded surface water to existing drains or Multiple Use wetlands (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
12. Shallow diversion swale drains around building pads (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
13. Low flow culverts under roads that intercept sheet flow runoff	Yes	Yes	No	No
14. Culverts under roads that intercept existing open drains	Yes	Yes	Yes	Yes



Groundwater Model

A multi-layered groundwater model has been established, with features to represent the superficial and confined aquifers in the Kemerton area, and detailed stream-aquifer interaction, drainage and evapotranspiration processes. The model has been accurately calibrated to monitoring data on rainfall, evaporation, groundwater level and licensed abstraction over a 11 year period (1990 - 2000). The model is capable of assessing:

- Sustainability of proposed abstractions within the Estate;
- Drawdown impacts on nearby users and specific locations near key wetlands and groundwater dependent vegetation;
- Impacts on river and drain flows, evapotranspiration and other components of the overall water balance;
- Potential for inflows from the sea (saltwater intrusion); and
- Different wellfield design scenarios to minimise offsite impacts and optimise production.

The calibrated groundwater model has been used to model a number of abstraction scenarios from various aquifer units represented in the model. To minimise drawdown impacts on wetlands and vegetation, and to minimise potential inflows from the coast, it was found that it was necessary to find a balance between:

- Limiting abstractions from the superficial formation (to minimise wetland and vegetation drawdown impacts and thereby meet EWR/EWP constraints); and,
- Not abstracting too much from the Leederville formation and Cattamarra Coal Measures (to reduce the potential risk of saline intrusion).

EWR/EWP Issues

The primary objective of the WRC's policy on Ecological Water Requirements (EWRs) and Environmental Water Provisions (EWPs) is to provide for the protection of water dependent ecosystems while allowing for the management of water resources for their sustainable use. The policy document provides the following definitions:

- **Ecological Water Requirements** (EWRs) *are "the water regimes needed to maintain ecological values of water dependent ecosystems at a low level of risk"*
- **Environmental Water Provisions** (EWPs) *are "the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts: they may meet in part or in full the EWRs".*

The hydrological, hydrogeological and environmental information collated for the Study was used to establish hydro-environmental relationships in terms of EWRs/EWPs, which were used in developing a groundwater model to assess the impacts of proposed groundwater pumping. Based on discussions with the WRC, the EWRs adopted are the critical groundwater drawdown tolerance limits for dryland as well as wetland ecosystems, based on the best published scientific information available (Froend & Zencich, 2001). The impact of proposed abstractions on the wetlands and vegetation was assessed to determine whether the Environmental Water Provisions (EWPs) are within the EWR criteria.

Ecological Water Requirement (EWR) Criteria
Critical Tolerance Levels of Groundwater Drawdown Impact for
Dryland and Wetland Vegetation

Category	Critical Levels of Drawdown
Category 1: 0 - 3m depth to groundwater	0.75 m
Category 2: 3 - 6m depth to groundwater	1.25 m
Category 3: 6 - 10m depth to groundwater	1.75 m
Annual Drawdown Criteria	0.25m

A range of Kemerton water demand predictions over 30 years were run through the groundwater model to assess the predicted drawdown impacts (the EWPs) in relation to the EWR criteria. This led to the development of strategies for sustainable groundwater abstractions to meet projected water demands for Kemerton, consistent with EWR/EWP policy.

Water Supply Development

The optimal prediction scenario for the Kemerton High Demand case (14 GL/yr, plus abstractions by existing industries) provides sustainable abstraction from a number of bores in the superficial formations, Leederville Formation and Cattamarra Coal Measures. A summary of the total abstraction and water quality for this scenario is given below. Note that this assessment has been based on an average water quality for each aquifer. Groundwater investigations completed as part of this study has shown that the salinity (as TDS) of the Leederville Formation and Cattamarra Coal Measures is as low as 400 mg/L and

950 mg/L respectively. The model predicted very little risk of saline intrusion for this case. All the EWR/EWP criteria were also met for this scenario.

Groundwater Supply – Optimal Prediction Scenario

Aquifer	No. of Bores	Total Abstraction	Average TDS
Superficial formations	6	1 GL/yr	750 mg/L
Leederville Formation	8	4 GL/yr	800 mg/L
Cattamarra Coal Measures	18	9 GL/yr	2,500 mg/L
Total	32	14 GL/yr	1,890 mg/L

Further modelling showed that greater abstractions were sustainable, with reduced impacts on wetlands and vegetation, but greater potential risk of saline intrusion. Abstraction at Very High to maximum Demand (18 to 23 GL/yr, plus existing abstractions) is sustainable by pumping only from the confined Leederville and Cattamarra Coal Measures aquifers. The average water quality for these two scenarios would be approximately 1,930 and 1,980 mg/L respectively.

A number of sensitivity simulations were also performed to assess the impact of climate variability and variation in aquifer parameters. The results were found to be insensitive to climate variability ('dry case' and 'wet case' scenarios), and somewhat sensitive to variations in the values of the horizontal and vertical hydraulic conductivity parameters. A higher vertical conductivity results in greater drawdown impacts in the superficial formation due to an increase in downward leakage, and reduced impact on the confined aquifers. A lower horizontal hydraulic conductivity results in an increase in drawdown within both the unconfined and confined units. However, the predicted long term drawdowns were still within the applied environmental constraints.

These results provide a sound argument to support an application for a groundwater abstraction licence for the Kemerton Industrial Estate of at least 14 GL/yr (in addition to existing abstractions), and suggest that a total of 18 to 23 GL/yr could be earmarked for the Estate for future use.

Alternative Water Supplies

Although this work has shown that local groundwater systems can supply Kemerton's water demands, access to additional water resources could also be met by alternative sources, notably the transfer of water from the Wellington Dam, and wastewater reuse. The Water Corporation has indicated that it has obtained all the necessary approvals to provide a water supply by pipeline from the Wellington Dam to Kemerton. However, it needs the commitment of a major industry with a significant water demand to justify the implementation of this option, which remains a viable alternative.

There is significant potential for wastewater treatment to reduce the basic water supply demand for Kemerton. There is an existing wastewater treatment plant at the Millennium Inorganic Chemicals (MIC) site, although the produced water is currently being discharged to the ocean (around 1 GL/yr of 30,000 mg/L TDS water). It is recommended that consideration be given to the further treatment of the existing wastewater volumes to a sufficient quality so that it could be reused by existing or future industries. There is construction work currently being undertaken to relocate the Australind and Eaton domestic wastewater treatment plants into Kemerton. This could provide an additional source of water (projected at 1.3 to 2.6 GL/yr from 2010 to 2040), which could be used to meet certain water requirements of industries, provided the water is of adequate quality.

Increased water usage as Kemerton is developed will also result in the generation of substantial wastewater volumes (4 to 15 GL/yr for the Low to High Demand cases). The Water Corporation is considering the potential introduction of an industrial wastewater treatment plant into the Estate (although little work has been done to date). Synergistic development of these wastewater treatment plants should be possible, to produce water with a range of quality that could be utilised by existing and/or future industries, thereby reducing the water supply demands.

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FIGURES

FIGURES (CONTINUED)

FIGURES (CONTINUED)

TABLES

TABLES (continued)

TABLES (continued)

APPENDICES

1.1 BACKGROUND

Aquaterra have been engaged by the Kemerton Technical Working Group, comprising LandCorp, Department of Mineral and Petroleum Resources (MPR) and the Water and Rivers Commission (WRC), to complete the second phase of water studies for the Kemerton Industrial Estate. More background information on previous work is provided in Section 2.

The Greater Bunbury area is strategically important to the South-West Region of Western Australia and the State as a whole. The area is expected to continue to experience strong economic and population growth, much of which is related to the export and downstream processing of the region's primary resources. Planning for industrial and employment growth in the area has led to a proposal for expansion of industrial areas in the Bunbury Region. The proposal, summarised in a Western Australian Planning Commission (WAPC) report entitled "Industry 2030, Greater Bunbury Industrial and Port Access Study Report", was released for public comment in May 1998. The draft report for public comment essentially summarised the following draft reports prepared by various consultants:

- Kemerton Expansion Study (BSD Consultants);
- Bunbury-Kemerton Transport Corridor Study (BSD Consultants);
- Preston Industrial Park Land Use and Port Access Study (Feilman Planning Consultants, 1997);
- Bunbury Port Access Road Concept Study (Halpern Glick Maunsell/ Main Roads).

A key component in the "Industry 2030" report was the expansion of the Kemerton Industrial Estate. The Estate is located approximately 17km north of Bunbury and encompasses some 5,429 ha (core 1151 ha, and buffer of 4278 ha). The Final Industry 2030 report released in April 2000 recommended the expansion of the core to 2106 ha and the buffer area (including inter industry buffer and support industry area) to 5437 ha. The State Government has approved the Kemerton expansion.

In response to the public and state government regulating agency submissions and findings of the "Industry 2030" final report, management of water issues were identified as being important issues to address, and further investigations were required to prepare a detailed water management strategy.

Two key research studies have been completed on flora and fauna in the Kemerton region and to increase the level of understanding of the surface water, groundwater and ecological relationships within the Kemerton area (Phase 1). The studies undertaken were:

- Report of Biological Survey - Phases 1 and 2: Kemerton Industrial Estate (Muir Environmental);
- Kemerton Water Study - Phase 1 (Bowman Bishaw Gorham and Rockwater Pty Ltd).

The Kemerton Water Study Phase 1 incorporated the findings of the biological survey report and specifically aimed to:

- Collate, review and summarise existing data relating to water resources, associated environmental issues (wetlands and the Wellesley River) and the proposed industrial area (water supply requirements, wastes, potential water contaminants, etc.);

- Determine what data are unavailable or incomplete but are required to complete later phases of the study; and to specify investigations to obtain the additional data;
- Assess potential impacts associated with planned developments; and
- Develop a draft preliminary water management strategy.

The Kemerton Water Study Phase 1 identified and prioritised the further study and investigation requirements necessary to develop a water management strategy, which is the focus of this report on the Kemerton Water Study Phase 2.

1.2 WATER STUDY OBJECTIVES

Key environmental issues regarding the Kemerton Industrial Estate have been identified by WRC and DEP (summarised in EPA Bulletin 902). The EPA's goal is to ensure that the integrity, functions and environmental values of regionally significant wetlands, watercourses and vegetation are maintained. The following specific issues are required to be addressed as part of the Phase 2 Water Study:

- Protecting regionally significant wetlands, water courses and vegetation;
- Maintaining a sustainable groundwater balance; and
- Protecting water quality in the Wellesley River and Leschenault Inlet.

A further issue relating to containing and isolating solid and liquid wastes from the hydrological systems was identified, but is not part of this Phase 2 Water Study scope.

The Study brief outlined the major objectives for the Phase 2 Study, which may be grouped as follows:

- Acquisition of additional hydrogeological data and the assessment of these new data together with existing information to address specific environmental objectives (specific additional data requirements are related to hydrology, hydrogeology, sustainable groundwater abstractions, wetlands, vegetation, drainage and industrial water management procedures);
- Development of a level of understanding of the interactions between the significant values of the surface water, groundwater and dependent ecological systems (this is largely achieved through the development and use of a multi-layered groundwater model); and
- Development of a refined Water Management Strategy that identifies inter-relationships between water and environmental values and issues, so that the development and operation of Kemerton is environmentally sustainable.

A key outcome of the Phase 2 Water Study is a Water Management Strategy for the Kemerton Industrial Estate that is capable of practical implementation to maximise development potential, and that addresses the above key environmental issues. The outcome of implementing the Water Management Strategy will be the achievement of sustainable and efficient water use, with minimal potential impacts from development and operation of the industrial Estate, whilst maintaining environmental values of significant wetlands, watercourses and vegetation. The water management strategy can form part of an Environmental Management System (EMS) to be implemented in the Estate.

For the Water Management Strategy to be acceptable to relevant authorities, it must be designed to achieve sustainable and efficient water use practices, and minimise environmental impacts. For example, the strategy needs to conform to the Environmental Water Provisions Policy of the Water and Rivers Commission (WRC) regarding Ecological Water Requirements (EWR's) and Environmental Water Provisions (EWP's), as well as to the drainage management policies of the WRC and local councils. The Strategy also needs to conform to environmental management policies of the Department of Environmental Protection (DEP), particularly regarding wetlands and vegetation.

Importantly, this report and the Water Management Strategy provides much of the technical information required by the WRC to set water allocations, consistent with their policies. This report can also serve as a bore completion report for the WRC, documenting the results of the drilling programme undertaken for this Study.

The Water Management Strategy also needs to be capable of practical implementation. This means that it must be suitable for providing management guidance for design, development, and management of land within the expanded core of the Estate. Proposed industrial Estate tenants should be able to use the Strategy in detailed engineering design for their specific site, consistent with overall water, drainage and environmental management of the Estate. Essentially, the Water Management Strategy provides a tool for structure planning, earthworks and drainage design.

1.3 SCOPE OF WORK

The brief presented a detailed scope of work in terms of issues that need to be addressed and general activities that need to be undertaken, listed under several major issues headings. Table 1.1 presents a summary of tasks listed under each of the individual issues/activities that were undertaken.

Table 1.1
Individual Scope Items and Study Tasks

SCOPE ITEM	TASKS
Existing Environment	Water management procedures Contamination/ remediation information Water demand estimates Wastewater availability
Surface Hydrology	Meteorological data Collate river flow and water quality data Topographic digital elevation model Conceptual drainage design
Hydrogeology	Existing groundwater production and monitoring bores Groundwater allocation Redevelopment and sampling of existing monitoring bores Construction of additional superficial monitoring bores Construction of additional confined aquifer monitoring bores Average annual maximum groundwater level Aquifer storage and recovery
Vegetation and Wetlands	Wetland management categories Wetland and Dryland vegetation and floristic structure Groundwater dependent ecosystems Hydro-environmental relationships Ecological Water Requirements (EWR), Environmental Water Provisions (EWP)

SCOPE ITEM	TASKS
Groundwater Modelling	Review of existing groundwater model Development of refined groundwater model Scenario modelling (water supply abstractions and impact prediction)
Water Management Strategy	Groundwater contamination and vulnerability assessment Wetland evaluations and management objectives Water quality objectives Ecological Water Requirements Environmental Water Provisions Water supply options Monitoring and assessment programme

1.4 REPORT STRUCTURE

The report is structured under the following main headings:

Executive Summary - overall summary of project findings, conclusions and recommendations.

1. *Introduction* - background to the project, and scope of work.
2. *Existing Environment Overview* - overview of the Kemerton Industrial Estate and previous work, together with a discussion of existing and proposed industries and land use.
3. *Water Management and Demand* - summary of existing industrial water management procedures, register of contamination and remediation activities and summary of water demand estimates and wastewater availability.
4. *Surface Hydrology* - overview of the surface hydrology, collation of existing hydrological data (rainfall, flow etc), and analysis of surface-groundwater interactions.
5. *Hydrogeology* - overview of the geology and hydrogeology for the area; collation of information on existing production bores, water allocations and groundwater monitoring networks; and results from the redevelopment and sampling of existing bores; the section also addresses the construction of additional superficial and confined aquifer monitoring bores, groundwater levels and water quality in each of the aquifers.
6. *Aquifer Storage and Recovery* - a desktop assessment of the suitability of aquifer storage and recovery for the Estate.
7. *Vegetation and Wetlands* - development of wetland management categories; discussion of wetland and dryland vegetation and floristic structure; groundwater dependent ecosystems; analysis of hydrological-environmental relationships; assessment of ecological water requirements; and outlining performance monitoring programmes.
8. *Drainage Management* - development of a topographic digital elevation model; development of the average annual maximum groundwater level (AAMGL) surface; conceptual drainage design and preparation of a drainage management strategy.
9. *Groundwater Modelling* - review of existing groundwater model; development of groundwater model with detailed surface-groundwater interaction features (including drainage aspects); model calibration and sensitivity analysis; prediction scenarios to assess abstraction options and impacts on groundwater dependent ecosystems; evaluation of environmental water provisions.

10. Water Management Strategy - development of an overall strategy addressing environmental and groundwater issues.

11 & 12. References - references used as part of the study in alphabetical and chronological order.

A separate data report volume has also been prepared.

2.1 KEMERTON INDUSTRIAL ESTATE OVERVIEW

The Kemerton Industrial Estate is located in the Shire of Harvey in the southwest region of Western Australia (Figure 2.1). It is located approximately 140km south of Perth and 17km northeast of Bunbury. The Australind townsite and Leschenault Estuary are located to the west of the Estate. The Binningup and Myalup townsites are located approximately 2km and 2.5km respectively to the west of the Estate. Figure 2.1 also shows the boundaries of the three groundwater management subareas that intersect in the Kemerton area.

Figure 2.2 shows the location of the industrial area together with the buffer and core industry boundaries. The buffer boundary is bounded to the east by the Wellesley River, to the west by the Old Coast Road, and the southern most tip is the confluence of these two boundaries. The northern boundary of the buffer is approximately 13km north of this southern confluence. These boundaries and the layout of the Estate are based on the final concept plan as discussed in the Industry 2030 document (WAPC, 2000). The original core boundary is zoned for heavy industrial development, and the first heavy industrial facilities were established in 1988/89. The expanded core boundary is not yet zoned for heavy industry.

A summary of land areas in the Estate from the expansion study is given in Table 2.1 (WAPC, 2000).

Table 2.1
Summary of Land Areas for Kemerton Industrial Estate

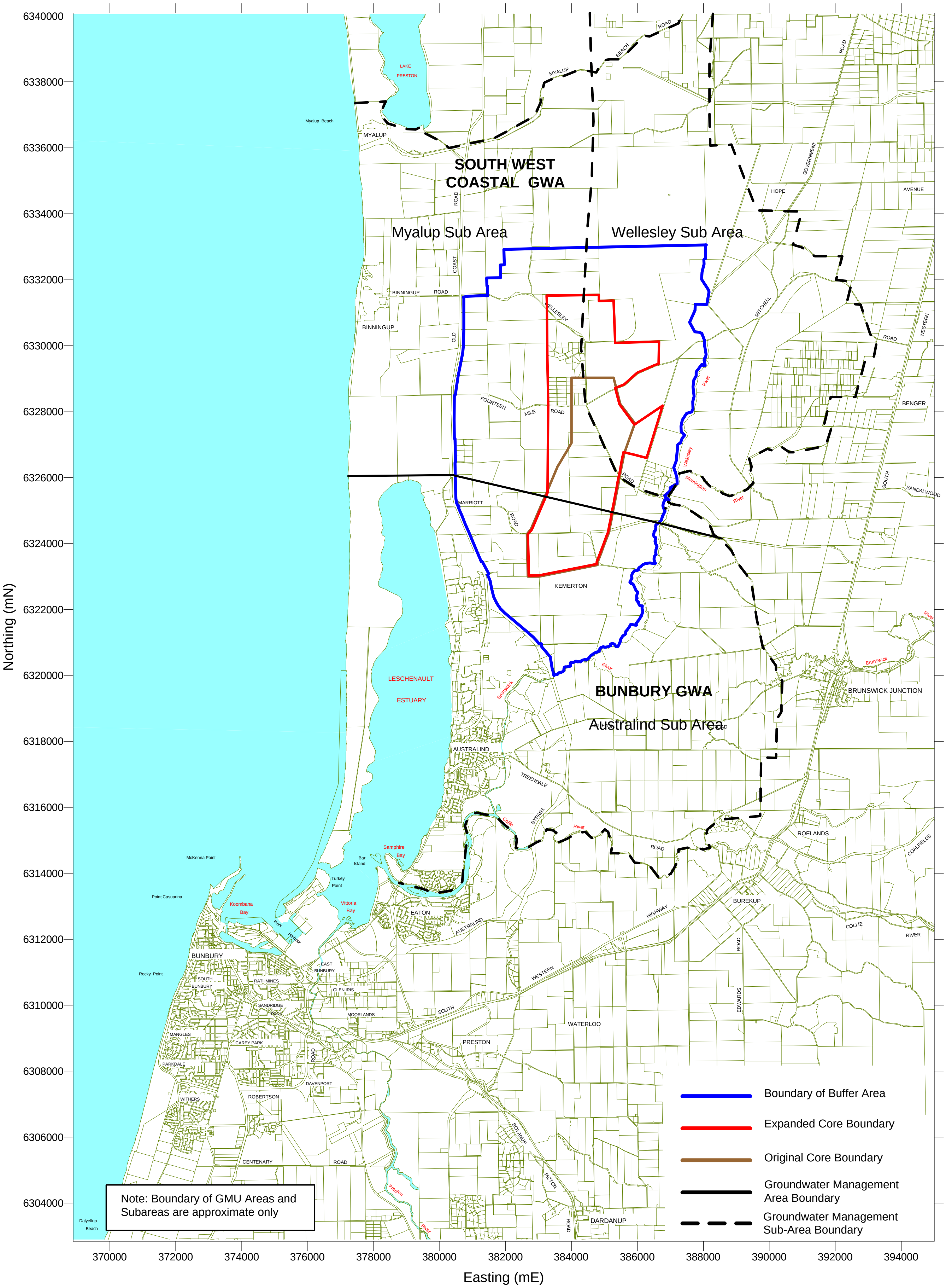
	Existing	Expansion	Total
Area of Industrial Estate (ha)	5429	2114	7543
Area of Industrial Core (ha)	1151	955	2106
Area of Industrial Buffer (ha)	4278	1812	5437 (1)

Note: (1) Total does not add because portion of existing (old) industrial buffer is now included in industrial core

2.2 PREVIOUS WORK

A number of previous studies have been undertaken to assess various issues relevant to the development of the Estate. A brief description of the more recent major studies undertaken is given below.

- Industry 2030, WAPC, 2000 - the report presents the State Government's adopted strategic planning framework for addressing the industrial land and port access needs of the greater Bunbury region over the next 30 years.
- Kemerton Phase 1 Water Study, BBG & Rockwater, 1999 - the first phase of the water study attempted to collate and review available water data and carried out a desktop assessment of the potential impacts of development (including water supply and drainage) on groundwater, wetlands, groundwater dependent vegetation and catchments of the Estate. The study also prepared a draft water management strategy and proposed management measures to mitigate adverse impacts to allow development to proceed.



Original plan prepared for Industry 2030 – Greater Bunbury Industrial Land and Port Access Planning

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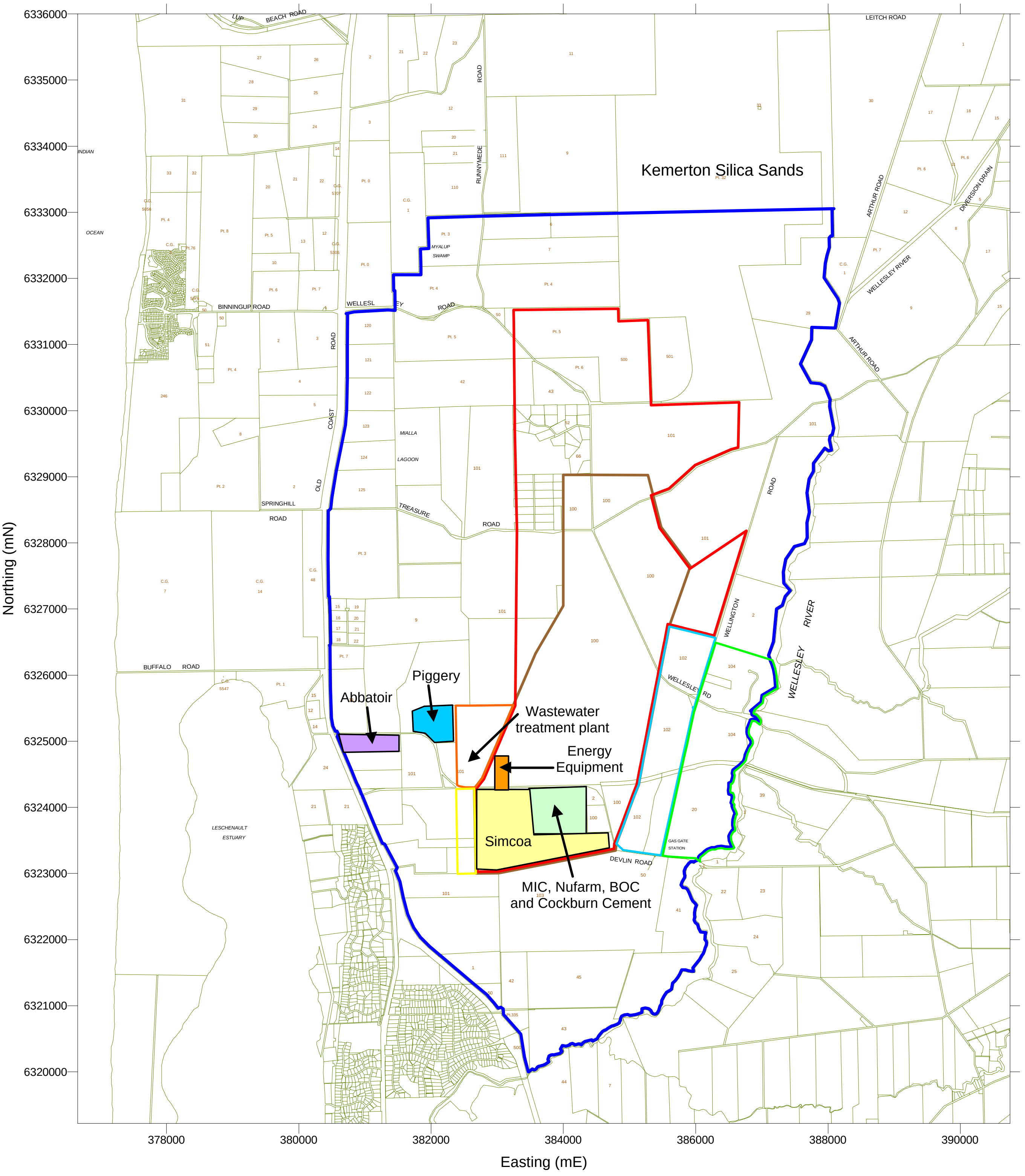
aquaterra

Regional Location Map
Figure 2.1



- Boundary of Buffer Area
- Expanded Core Boundary
- Original Core Boundary
- Boundary of Support Industry Area
- Boundary of Inter Industry Buffer Area
- Boundary of Public Utility
- Boundary of Investigation Area for Public Utility

Original plan prepared for Industry 2030 – Greater Bunbury Industrial Land and Port Access Planning

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Kemerton Industrial Estate
Figure 2.2

- Industrial Water Supply and Wastewater Management for the Kemerton Industrial Estate, Burns and Roe Worley, 1998 - the study carried out an assessment of the future water demand for Kemerton and an analysis of methods for wastewater disposal and related water and wastewater infrastructure. The sizing of a wastewater pipeline and the identification of a pipeline route were also completed, together with a strategy for developing a common user facility. Future recommendations for environmental and engineering studies were also made.
- Kemerton Expansion Study, BSD Consultants, 1997 - the objectives of the study were to identify opportunities and constraints for the expansion of the Estate, identify ways of planning within existing constraints, nominate an appropriate industrial core and buffer area and prepare a structure plan to ensure Kemerton remains a premier planned industrial Estate responsive to the needs of industry.
- Kemerton Industrial Park Water Supply Foundation Planning, Rust PPK, 1996 - the report presents a review of possible water sources, available water data, water supply requirements and the environmental approval process. The study was completed for the Office of Water Regulation to supply water to the Estate in a competitive and commercial fashion.
- Kemerton Industrial Park Future Water Supply Options (Preliminary Environmental Review), BHP Engineering, 1992 - the report was commissioned by the Water Authority, and assessed various water supply options for the Estate. Each option was evaluated on the basis of impact to wetlands, down river flow regimes, infrastructure relocation and social impacts.

2.3 EXISTING INDUSTRIES

All existing industries within the Estate are located off Marriott Road (Figure 2.2). The two main industries in the Estate are Millennium Inorganic Chemicals (MIC) and Simcoa Operations. There are also a number of ancillary industries (BOC Gases, Nufarm-Coogee and Cockburn Cement) that support the operations of MIC. A brief description of each is given below.

- Millennium Inorganic Chemicals Ltd (MIC) - operates a titanium dioxide plant and is the largest industry in terms of water requirements and wastewater discharge.
- Simcoa Operations Pty Ltd - operates the only fully integrated silicon metal production plant in the world. The industrial site consists of a sawmill, two charcoal retorts, two submerged arc electric furnaces, a filter house and product packaging and dispatch facilities. Raw materials used by the plant include low ash charcoal and quartzite.
- British Oxygen Corporation (BOC Gases) - operates an air separation plant. The plant was commissioned in November 1988 to supply MIC with their oxygen and nitrogen requirements. The plant processes air by removing dust, moisture and carbon dioxide, before cooling down the process and producing oxygen and nitrogen.
- Nufarm-Coogee Pty Ltd (Nufarm) - operates a chlor-alkali plant on a site immediately adjacent to the eastern boundary of MIC’s plant site. Some process chemicals used by MIC are sourced from Nufarm’s chlor-alkali plant.
- Cockburn Cement - operates a lime slaking plant, supplying slurry lime for MIC’s operations. The process involves hydration of the lime to a slurry, which is then pumped to the MIC site.

In addition to the above, Kemerton Silica Sands operates a sand mining operation just north of the Estate. The company mines silica sand, which is exported for glass making. The mining comprises a dredging operation from which sand is pumped to a processing plant, which extracts heavy minerals by an electromagnetic process.

2.4 LAND USE

Large portions of the core area have been cleared with grazing activity mainly in the eastern half of the industrial Estate. There are also large areas of dense and scattered remnant vegetation, mainly in the buffer, as well as a number of Environmental Protection Policy (EPP) Wetlands. The grazing, horticulture and dairy farming activities around the study area generally extend to the north, east and west, with a number of major market gardens west of the study area (BSD, 1997). An abattoir and piggery are situated on Lot 26 and Lot 2 Rosamel Road respectively (Figure 2.2).

The Kemerton Expansion Study (BSD, 1997) identified a range of appropriate land uses within the buffer area. The wetland chain west of the ridge and the vegetated areas surrounding it were nominated as a 'vegetated buffer' to prevent impacts on the visual amenity from Old Coast Road. The balance of the buffer area was considered to be suitable for a range of industries including the following:

- Rural pursuits
- Rural industry
- Forestry
- Silviculture
- Extractive industry
- Radio TV installation
- Viticulture, horticulture, market garden
- Public utility
- Piggery
- Stockholding and sale yards

In addition to the above, intensive agricultural farming and private stables were also identified as being potentially suitable. The suitability of both these industries is largely dependent on depth to groundwater and other environmental constraints.

The characteristics of the surface and groundwater systems are presented in Sections 4 and 5, after discussion of the existing water management issues.

3.1 WATER MANAGEMENT PROCEDURES

Existing major industries in the Kemerton Industrial Estate were requested to provide information on any on-site water management procedures in place. A summary of the responses received from each industry is presented below. The existing industries are mainly clustered in the southern part of the core area, except for Kemerton Silica Sands, a sand mining operation just north of the Estate.

3.1.1 Simcoa Operations Pty Ltd

Water supply for the Simcoa site is sourced from two production bores drawing water from the superficial and Yarragadee aquifers. The production bore in the Yarragadee serves as the primary bore, and the superficial bore is maintained as a standby or backup facility. There are also three pairs of monitoring bores around the site, which are monitored regularly for water level and quality. Records of abstraction from the production bores and monitoring of observation bores are included in an annual Wellfield and Aquifer Review submitted to the WRC. Simcoa are committed to managing its water resource in a responsible manner to prevent or minimise any significant environmental impact on existing water resources and the surrounding wetlands. Procedures are in place for the WRC to be notified if abstraction rates are likely to exceed the allocation limit, or if monitoring suggests a significant depletion in aquifer storage or degradation in groundwater quality. Available reports, and monitoring data collated for this Study indicate no evidence to date of these effects.

On site water management procedures are documented in a Wastewater Management Plan (Simcoa, 1991) and Environmental Monitoring and Management Plan (Simcoa, 1996). The site operates a water treatment plant for water pumped from the production bores. The treatment involves aeration (for iron removal) and sand filtration. The treated water is then pumped to a process water tank, which is used to meet potable and process water requirements. The process water is used in a closed circuit cooling system, which occasionally needs to be supplemented with water from the process water tank. Prior to potable use, the water from the process water tank is treated to meet potable water quality, and then pumped to a potable water tank. This treatment involves RO filtration, UV treatment and chlorination. Approximately a third of the water from the process water tank provides for potable requirements and the remainder is used in the process and for dust suppression. The site also has a fire water tank which is used solely for fire fighting purposes, and contains untreated water pumped from the production bores.

The main sources of wastewater are indirect sources such as stormwater runoff, water treatment plant effluents, laboratory wastes and the recycling of process water for dust suppression and irrigation. Wastewater is discharged via drainage channels or pumped to a polyethylene lined settling pond where, after solids have settled out, it is recycled for on site use for dust suppression and irrigation purposes. Laboratory liquid effluents are diluted prior to discharge into the settling pond. The settling pond is cleaned out on average every two years. Overflow from the settling pond is not controlled, and infiltrates into local parkland and bushland.

A second settling pond captures stormwater runoff from a large hard surfaced catchment area (~ 300,000m^2) which is used for storage and drying of timber. The hardstand area is bounded by a 10cm high kerb, which narrows to a channel conveying water towards the settling pond. The runoff material contains sawdust and blocks of wood, and frequently overflows into local bushland. Runoff from dust suppression is also directed into the settling pond. Stormwater runoff around the site is managed by a series of drains and open channels, which are lined with limestone rock. The settling pond is used to recover water and irrigate the parkland used by employees. Samples of wastewater from the settling pond are collected and analysed on a weekly basis.

A number of oil/water separation facilities are also in place around the workshop area. Discharge from the workshop washdown bays and refuelling bays is directed towards the oily water separators. The waste is then pumped out and held in tanks at an environmental station, and then disposed of to a landfill site. Wastewater and any overflow from the oily water separators is also pumped to the settling pond.

3.1.2 Kemerton Silica Sands

Water requirements for the Kemerton Silica Sands (KSS) sand mining operation, located just north of the Estate, are sourced from two production bores currently in use on the site, drawing water from the superficial aquifer. There also exists a network of 12 monitoring bores, which are monitored monthly for water level and quality and reported to the WRC and DEP.

The pumping and mining operations mainly result in a redistribution of water across the mine site, with some net loss occurring due to evaporation during the summer months. The process water supply is primarily made up of return water used in the process and supplemented by water from the production borefield. Groundwater from the production bores is also used to maintain water levels in the dredge pond and for the slurrying of fines to the slime pond. Excess water from the slime pond is returned via an open trench to the dredge pond. The water reclaimer from the stockpiles has recently been changed resulting in an improvement in the water capture and recycling from the mine process area.

Drains have also been placed around the mine site to recycle water from processing. Water from the production borefield is also the source for on site potable water requirements.

There are also a number of environmentally sensitive wetlands surrounding mining operations at KSS. These wetlands generally only contain water during the winter months. The water levels in the wetlands are also regularly monitored and reported to the DEP. A recent audit by the DEP has recommended that KSS, in consultation with the WRC, develop compliance or investigative criteria to define ‘unacceptable changes’ in wetland water levels. KSS plans to initiate consultation with the WRC to put such a program in place. Under environmental commitments to the DEP, KSS are required to monitor *‘water from the water management system delivered to wetlands where unacceptable changes resulting from project related groundwater abstraction occurs’*.

3.1.3 Millennium Inorganic Chemicals (MIC)

Water management procedures applicable to the site, located in the southern part of the Estate, are largely covered under the “MIC’s Environmental Management Systems” manual.

Process water requirements for the site are sourced from three production bores abstracting water from the Leederville aquifer and the Cattamarra Coal Measures aquifer. This water is treated prior to use in the process. There also exists a network of 17 monitoring bores around the site, which are regularly monitored for water level and water quality. These results, together with monthly production volumes are reported to the WRC in the form of an annual Aquifer Performance Review.

All wastewaters, excluding stormwater, are directed to the wastewater treatment plant. Process water pumped from the clarifier overflow tanks is tested for pH and turbidity prior to being directed to either the clean or dirty holding pond. The treated water is pumped approximately 11km through a pipeline and discharged to the ocean. The pipeline is fitted with flow differential instrumentation to detect a break in the line. The treatment plant currently discharges around 1 GL/yr to the ocean, with an effluent water quality of around 30,000 mg/L Total Dissolved Solids (TDS). Nutrient concentrations are generally around 0.35 mg/L for nitrate and 0.05 mg/L for phosphorous.

There are a number of sumps and drains placed across the site to manage on-site stormwater drainage. The level and quality of water in the sumps is sampled weekly. Tanks and dangerous goods are bunded to ensure any potential spills, overflows or leaks are contained within. A Standard Operating Procedure (SOP) also exists to manage washdowns on site.

3.1.4 Nufarm-Coogee Pty Ltd

Process and potable water requirements for Nufarm, located in the southern part of the Estate, are sourced from production bores owned and operated by MIC. The potable water for Nufarm is treated by MIC prior to delivery. All effluent produced from the process, and runoff from the salt slabs, is pumped to the wastewater treatment plant operated by MIC. Uncontaminated stormwater runoff from around the site is conveyed to a number of soak wells located around the site.

There is a network of monitoring bores around the site, which primarily serve to monitor salinity levels in the groundwater. The site operates two main recovery bores, both pumping continuously at an average total rate of 115 kL/d to recover contaminated saline water. The dewatered effluent is piped to MIC's wastewater treatment plant, and the treated effluent is discharged to the ocean. Groundwater recovery operations on site are administered by a groundwater well licence held with the WRC.

3.1.5 BOC Gases

As for Nufarm, process and potable water requirements for BOC Gases, located in the southern part of the Estate, is supplied by MIC. The water is treated on site for potable needs using side stream filters and water softeners through a cooling tower. The wastewater from the cooling tower is conveyed to a concrete lined pit, which is then pumped back to MIC to be treated in the wastewater treatment plant, and discharged to the ocean. Drains situated around the building manage local stormwater runoff.

3.1.6 Cockburn Cement

Water requirements for Cockburn Cement, located in the southern part of the Estate, are also supplied by MIC. As for Nufarm, the potable water is treated by MIC prior to delivery. All stormwater runoff and other discharges are conveyed to a sump, the contents of which are pumped back to MIC's wastewater treatment plant for treatment and discharge.

3.2 CONTAMINATION AND REMEDIATION REGISTER

Major industries in the Kemerton Industrial Estate were requested to provide information on any known contamination sources and/or issues on site. A summary of the responses received from each industry is presented below.

3.2.1 Simcoa Operations

Potential environmental impacts and contamination sources at the Simcoa site are documented in the site's Environmental Monitoring and Management Plan (Simcoa, 1996), Pollution Control Plan (Simcoa, 1988) and Wastewater Management Plan (Simcoa, 1991).

Discussion with environmental personnel on site has suggested that there have been a number of "reasonable sized" hydrocarbon leaks in past years. These incidents have been dealt with in accordance with DEP requirements and in conjunction with the DEP. There are two main hydrocarbon storage tanks on site, an underground diesel tank (20,000 L capacity) and a 3000 L capacity above ground tank, which is bunded to contain any spills and leaks. The most recent incident was in early 2000 when hydrocarbon discharge from the air separation plant leaked into the ground. The remediation program involved the recovery of approximately 20 tonnes of contaminated soil (~ 20m^2 area), which was disposed of at the regional refuse site. To prevent re-occurrence of the incident, the area was bunded and pipework installed to convey the discharge into a below ground storage tank. The underground tank captures the oily waste, and the waste product is pumped out and disposed of at the regional refuse site. The management of on-site contaminated soil is covered under a Soil Contamination Policy, which requires contaminated soil to be stored in designated containers on site, and then disposed of in an appropriate manner at the regional refuse site on Stanley Road.

There are three main water contamination sources on the site.

- Leaching of stockpiled timber and timber wastes and stormwater runoff from roads and the coarse woodchip stockpile - potential to leach organic compounds such as tannins from stockpiled waste timber, and infiltrate into the water table aquifer;
- Use of recycled wastewater for irrigation and dust suppression; and
- Pre-treatment plant back-flush residues - potential for compounds such as iron and manganese contained in the back flush reside to infiltrate into the underlying aquifer.

In managing the above risks, routine sampling is conducted of the settling pond and three sets of paired superficial aquifer groundwater monitoring bores. The shallow monitoring bore has a screened interval across the water table surface and the deeper bore is screened at the base of the superficial formation. These bores were initially used to determine baseline concentration levels, and have since been sampled frequently. To date, there has been no evidence of groundwater contamination as sampled from the three pairs of observation bores around the site. Analytical results from sampling of the settling pond has also indicated no adverse affects from leachate that may be contained within the site based wastewater stream.

Simcoa have documented procedures, which will be implemented in the event that monitoring indicates a significant deterioration in water quality. This procedure involves:

- Notification of the DEP and the WRC, and if applicable, consultation with statutory authorities and independent consultants;
- Identification of the source and the degree of impact;
- Taking all reasonable measures to isolate and remedy the source of impact;
- Reviewing and maintaining monitoring programs to determine the effects of the source; and
- Reporting back to relevant statutory authorities.

A number of dangerous goods and chemicals are also stored on site. These include LP gas, flammable liquids (diesel, petrol and solvents), water treatment chemicals and laboratory chemicals. The storage of these goods is covered under a licence held with the Department of Minerals and Energy (DME).

3.2.2 Kemerton Silica Sands

There are no known sources of contamination currently at KSS, and no known remediation activities. The benign nature of the process and the minerals concerned makes it highly unlikely for contamination on site to occur. Groundwater bores and nearby wetlands are frequently analysed for a range of heavy metals, water quality and nutrient parameters.

There are a number of Ministerial conditions and commitments under various environmental protection acts, which KSS are required to adhere to. The following commitments relate to contamination and remediation activities on site:

- Wetlands - requirement to protect EPP wetlands and lakes in the project area, and for monitoring of water levels and the condition of surrounding vegetation;
- Storage and release of environmentally hazardous chemicals including fuel, oil and other hydrocarbons: KSS are required to recover or remove and dispose of spills or leaks of chemicals from the contaminated material within 24hrs of becoming aware of the spill or leak; and
- All fuel transfer points are required to be graded and/or lined in order to be able contain and recover any spilled product.

3.2.3 Millennium Inorganic Chemicals (MIC)

There are no known sources of contamination on site. There has been some contamination with high salinity brine due to operations at the adjacent Nufarm site, which has affected the MIC site. As discussed above, recovery bores are in place on the MIC site to recover contaminated groundwater.

Actions to be taken in the event of any contamination are covered under the site’s Environmental Management System. These include:

- Site contamination audits to identify any contamination of a site and plan for remedial action so that the site will conform to any future use, and off-site impacts are reduced to acceptable levels.

- Contamination activities shall be identified by reviewing site history, industrial process, products and wastes, disposal practices, records for chemical or effluent spills and to identify potential contaminants.
- A sampling program shall be designed and implemented to assess concentrations and distribution of contaminants. Different chemical contaminants shall be assessed for potential effects on humans and the environment, and exposure pathways determined.
- Remediation programs may include the removal and disposal of contaminated soil to a secure area, in-situ treatment of soil, encapsulation of contaminated area, restricted access to areas, and the extraction and treatment of contaminated groundwater.

There are also strict monitoring requirements for waters discharged from the wastewater treatment plant and the receiving environment. Discharge water, the marine environment and groundwater bores are analysed for a range of biological, water quality and radiation parameters.

3.2.4 Nufarm-Coogee Pty Ltd

On-site contamination issues at Nufarm relate to salinity. In 1989/1990, salinity contamination occurred as a result of leakage from underground pipes. The development of the saline groundwater plume was characterised by high sodium chloride salts, and to a lesser extent, sulphate salts. The likely source of the plume was identified as the salt stockpile at the western part of the plant site, and to a lesser extent, the on site stormwater runoff and plant drainage system. Apparently, the drainage pipes were constructed from the wrong material and were constructed in such a way for any leaks to be virtually undetectable. To reduce the potential for ongoing contamination of the superficial aquifer, the base of the stockpile was resealed, the underground pipes were replaced with above ground drains and a program of groundwater recovery was initiated to target the saline plume. There have also been very minor leakages from joints in the salt slab.

Recovery pumps have been in place for a number of years, and regular reports are submitted to the Department of Environmental Protection regarding the performance of the recovery programme and groundwater salinities. Operational history of the recovery bores is summarised in Table 3.1 (over page).

Nufarm also conduct regular inspections and maintenance of areas that could be potential sources of ongoing and/or future saline water spills. Monitoring records indicate that groundwater recovery pumping is continuing to reduce the size of the saline plume.

3.2.5 BOC Gases

There are no known contamination incidents or remediation programs in place at BOC Gases. An annual HAZOP inspection is completed by an independent auditor to keep a record of chemicals that are stored on site.

3.2.6 Cockburn Cement

There are no known contamination incidents or remediation programs in place at Cockburn Cement. There is no on site fuel and chemical storage.

Table 3.1
Recovery Pumping for Remediation of Saline Plume at the Nufarm-Coogee Site

Date	Description
2000	Dewatering ceased from KM16 in June 2000. Bores KM8, KM10, KM11, KM12 continue as dewatering bores
1999	Dewatering continuing from bores KM8, KM10, KM11, KM12, NRB01 and NRB03.
1998	Recovery bore NRB02 is shut down. A new recovery bore NRB03 located just south of the Nufarm salt dissolvers constructed.
1996	Recovery continued from wells KM8, KM10, KM11, KM12, NRB01 and NRB02.
Nov 1995	Observation well KM12 converted to a low yielding recovery well.
1995	Wells KM10, KM11, NRB01, NRB02 and KM10 operated continuously as recovery wells.
1994	Wells KM10, KM11, KM16, NRB01 and NRB02 continued to operate as contaminant recovery wells.
1992-97	Pumping commenced from KM8 to recover poorer quality groundwater arising from a hydrochloric acid spill reported to have occurred in June 1992. Additional geophysical surveys undertaken on half yearly basis to monitor plume extent and possible migration.
Nov 1990	Nufarm commissioned a geophysical survey of the area down hydraulic gradient of their plant site to attempt to delineate the extent of the saline plume. Based on the survey results, a second recovery well NRB02 was constructed and commissioned Jan 1991.
Aug 1990	Nufarm commissioned the construction of a pilot recovery well NRB01. Abstractions of up to 100 kL/d are discharged to MIC's wastewater disposal system.
1989	KM8 was pumped intermittently to abstract poorer quality groundwater believed to have originated from drainage overflow.
1989-97	KM10, KM11 and KM16 pumped to recover highly saline groundwater, which originated from brine leachate (located west of the Nufarm plant site) prior to Sept 1989. The plume extends generally in a south westerly direction.

3.3 WATER DEMAND ESTIMATES

Initial water requirements for the Estate have been assessed in the Burns and Roe Worley study (1998). The study concluded that the annual water demand may increase from around 1 to 2 GL/yr currently to a high growth case of 14 GL/yr. The report suggested that the groundwater resources of the region are capable of supplying this volume, although a portion may need to be desalinated to produce high quality process water. The study reported that the least expensive method of meeting future water demand was through extraction from deeper aquifers, however the sustainable yield from these aquifers is yet to be established. Alternative water sources to supplement surface and underground sources were identified as discharge from the Collie Power Station and treated municipal effluent from the Water Corporation (there are now known to be other additional sources, as discussed later). The projected water demand estimates were based on a number of different growth scenarios as summarised in Table 3.2. Due to the requirement for high quality process water, an allowance has been made in each case for desalination to achieve the required quality.

Since the Burns and Roe Worley Study (1998), water demand estimates have been revised based on interest shown by a number of potential industries. The high demand scenario is likely to be between 14 and 18 GL/yr, with a maximum potential demand of 23 GL/yr (Table 3.2).

Table 3.2
Projected Water Demand

Scenario	Demand	Comments
Low Growth	7 GL/yr	Status quo with demand dictated by the expansion of MIC and Simcoa Operations. Included also is the possibility of titanium sponge production and few small unspecified industries.
Medium Growth	10 GL/yr	Volume required is higher to meet the demands of a synthetic rutile plant, wool processing, iron briquetting plant and a pulp mill.
High Growth	14 to 18 GL/yr	High growth scenario view considering the full development of Kemerton with a wide range of industries including an aluminium smelter, power station and other industries.
Maximum	23 GL/yr	High growth demand plus the introduction of a 'high water demand' industry

In addition to the above Low to High growth (but not Maximum) scenarios, Burns and Roe Worley (1998) also estimated the likely water demand and wastewater production for different types of industries. This information has been reproduced in Table 3.3, and the following categories denoting water volume have been used. Note that the following categories apply for individual industries shown in Table 3.3, and not for the overall water demand of the Estate.

- High - Greater than 1,000 ML/yr
- Medium - Less than 1,000 ML/yr and greater than 300 ML/yr
- Low - Less than 300 ML/yr and greater than 30 ML/yr
- Negligible - Less than 30 ML/yr

Table 3.3
Water Usage and Wastewater Production for Different Industries

	Project	Water Usage	Wastewater
Group 1	Alumina Smelter	Medium	Low
	Alumina Refinery	High	High
	Specialised Alumina Products	Low	Low
Group 2	Steel Mill	High	High
	Iron Briquetting	Low	Low
Group 3	Chlor Alkali, Soda Chemicals, Fertiliser / Superphosphate / Chemicals, Ammonium Nitrate Emulsion, Phosphoric Acid	Low	Low
	Sodium Cyanide, Nitric Acid	Medium	Low
	Ammonia, Sulphuric Acid	High	High
Group 4	Rare Earths, Gallium	High	High
	Tantalum, Lithium Metal / Chemicals	Low	Low
Group 5	Synthetic Rutile	Medium	Medium
	Heavy Mineral Sands Separation, Titanium Slag, Titanium Metal	Low	Low
	Titanium Dioxide (MICL expansion)	High	High
Group 6	Timber Mill, Timber Products / Fibreboard, Wool Processing, Agricultural Product Processing	Low	Low
	Pulp & Paper Mill	High	Low
Group 7	Activated Silicas, Fused Silica, Fumed Silica (Simcoa expansion), Silanes & Silicones, Silicon Carbide, High Purity Silica, Silica Sand	Low	Low
Group 8	Lime, Cement/Lime	Low	Low
Group 9	Air Separation	Low	Low

	Project	Water Usage	Wastewater
Group 10	Hydrogen Peroxide, Kaolin Plant, Oxalic Acid, Bentonite, Xanthates / Metham Sodium, Zeolites, Zirconium Chemicals, Zirconium Metal	Low	Low
Group 11	Coal Power Station	High	High
	Combined Cycle Gas Power Station	Med	Low

Note:
High - >1000 ML/yr; Medium - 300 to 1000 ML/yr; Low - 30 to 300 ML/yr; Negligible - <30 ML/yr.

With an increase in water demand, there is also going to be an increase in the amount of wastewater requiring disposal. The Burns and Roe Worley Study (1998) identified a number of possible methods of wastewater disposal from the Kemerton Industrial Estate. These options included evaporation, deep well injection, on-site treatment and re-use, sequential re-use and ocean outfall. The ocean outfall option was concluded to be the most viable means of disposal.

The same growth scenarios considered above for water demand were examined by Burns and Roe Worley (1998) to look at the volumes of wastewater which are likely to be generated. Table 3.4 summarises likely wastewater volumes under the low, medium and high growth scenarios.

Table 3.4
Projected Wastewater Production Under Different Scenarios

Scenario	Waste	Comments
Low Growth	4 GL/yr	Primarily consists of discharge from MIC (3GL/yr) with smaller contributions from other industries. Wastewater would have a TDS of ~25,000 mg/L and would be potentially scale forming.
Medium Growth	8 GL/yr	Addition of industries such as synthetic rutile production, pulp and paper mill and supporting industries. The TDS of wastewater is not likely to be as high as above due to the dilution effect of other industries.
High Growth	15 GL/yr	Long term high growth scenario view point and used to design the wastewater pipeline from Kemerton.

3.4 WASTEWATER AVAILABILITY

The Burns and Roe Worley Study (1998) identified the possible use of treated industrial wastewater as a supplement to meet water demands for the Kemerton Industrial Estate. The use of water from the Collie Power Station or the Water Corporation's municipal wastewater treatment plants were considered. In each case, the cost of treatment needed to be less than the cost of water supply from other sources, and nutrients in the treated wastewater could limit their potential use.

3.4.1 Domestic Wastewater Treatment Plant

For this Phase 2 Water Study, discussions were initiated with the Water Corporation with regard to likely volumes of treated wastewater that might be available for re-use from the proposed Water Corporation's Domestic Wastewater Treatment Plant. This proposed domestic treatment plant is designed to take the load of the existing Australind and Eaton treatment plants. When commissioned (late 2002), it is predicted to be treating between 1.5 and 1.7 ML/d.

The progressive design capacity for the treatment plant is as summarised below:

- Stage 1: 2010 - 3.6 ML/d (1.3 GL/yr)
- Stage 2: 2025 - 5.4 ML/d (2.0 GL/yr)
- Stage 3: 2040 - 7.2 ML/d (2.6 GL/yr)

At this stage, it is proposed to reuse the treated effluent for irrigation purposes. However, the preferred position of the Water Corporation is for effluent reuse within the Estate for industries, as well as irrigation within the buffer area. The Water Corporation is keen to initiate discussions with interested parties for potential use of the treated effluent (G. Golowyn, *pers.comm.*). It may also be possible for the influent to be treated to the level required by a potential customer (eg. microfiltration). Currently, it is proposed that the influent be treated for nitrogen and phosphorus to reduce total nitrogen to < 7.5 mg/L and total phosphorus to < 1 mg/L.

The Burns and Roe Worley Study (1998) also identified the potential availability of treated municipal wastewater from Bunbury over a longer time frame. The flow from Bunbury is about 7 ML/d, and provided the economics are attractive, a pipeline along the Old Coast Road could be constructed to service the Kemerton Industrial Estate.

3.4.2 Industrial Wastewater Treatment Plant

An industrial wastewater treatment plant is also proposed for the area. Discussions with the Water Corporation (G. Hughes, *pers.comm.*) indicated that no work has commenced on estimating preliminary design capacities with the exception of some environmental work in the area. Potentially, a large proportion of the wastewater generated by the industries may be available for re-use. No further details were available for documenting in this report.

3.4.3 MIC Wastewater Treatment Plant

The existing MIC wastewater treatment plant currently discharges around 1 GL/yr to the ocean, with an effluent water quality of around 30,000 mg/L Total Dissolved Solids (TDS). Nutrient concentrations are generally around 0.35 mg/L for nitrate and 0.05 mg/L for phosphorous. This treated water quality is not suitable for re-use by the existing industries, but it may be suitable for use by future industries, or for further treatment by any future wastewater treatment plants at Kemerton.

This Section of the report presents summaries of hydrological data collated as part of the scope of work for the Phase 2 Water Study. The data is presented in full in the separate Data Volume.

4.1 SURFACE HYDROLOGY OVERVIEW

The Estate generally has low topographic relief, apart from a ridge aligned in a north-south direction on the central-west side of the Estate. The major surface drainage feature around the Estate is the Wellesley River, which forms the eastern and south eastern boundaries of the industrial Estate.

In the Kemerton area, the Wellesley River continues in a south westerly direction from the Wellesley River Diversion Drain (Figure 2.2), which carries irrigation drainage flows from the South West Irrigation co-operative around Harvey (about 15 km north-east of Kemerton). Further to the south of the industrial Estate, the area is drained by the Collie and Brunswick Rivers. The other main drain in the area is the Mangosteen Drain, and there are numerous smaller drains, which have been constructed to lower the water table in local areas. Most of the runoff occurs during winter in response to rainfall, and the low flows in the rivers during the summer consist predominantly of groundwater discharging baseflow (Deeney, 1989), and irrigation drainage flows.

Due to the low topographic relief, parts of the Estate are seasonally inundated, especially on the east. A number of artificial drains have been constructed in the area to drain (multiple use) wetlands and cleared palusplain. These drains generally flow to the east and south, discharging into the Wellesley River.

The area has a number of permanent and seasonal wetlands in the eastern half and on the western boundary of the Estate (Myalup Swamp & Mialla Lagoon). The Benger Swamp is the largest wetland in the area and lies approximately 2 km west of the Wellesley River.

A number of the wetlands, which lie outside the core of the industrial area, are protected by the EPA’s Environmental Protection (Swan Coastal Plain Lakes) Policy (EPP). A number of lakes within the western chain of wetlands are subject to System 6 recommendations due to their high conservation value. This is discussed further in Section 7.

The Leschenault Estuary is the closest of a series of coastal lakes to the Estate. It receives virtually no runoff and is maintained by direct rainfall and groundwater inflow. Lake Preston, which lies more than 4 km in a north westerly direction from the northern end of the Estate is the largest of these coastal lakes.

Hydraulic connection between the wetlands and the local groundwater system is likely to be highly variable. Many of the wetlands in the area are directly connected to the water table aquifer, however some of these wetlands may be perched features above the regional water table due to the lower permeability in the wetland sediments.

Water quality in the wetlands will be dependent on hydraulic connection to groundwater and the concentration of salts through evapotranspiration processes.

The water table occurs very near to the surface all year round in the eastern part of the industrial Estate.

4.2 METEOROLOGICAL DATA

The industrial Estate experiences a Mediterranean type climate characterised by hot dry summers with high evaporation and cool wet winters during which much of the rainfall occurs. Although temperatures are high in summer, they are lower than inland areas due to local onshore breezes. The evaporation and rainfall control seasonal fluctuations in the water table aquifer.

4.2.1 Rainfall

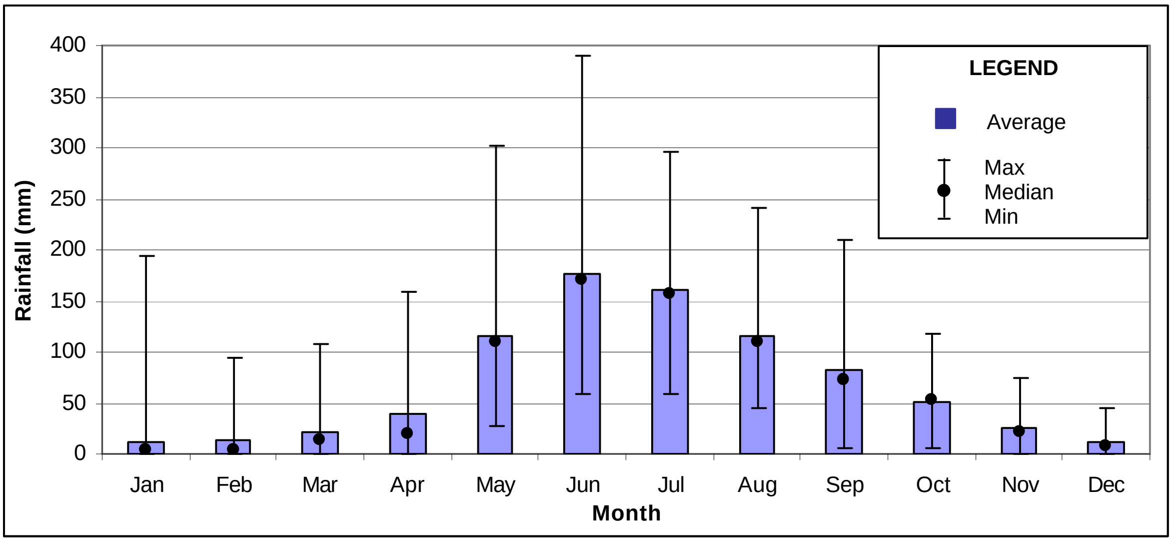
There a number of rainfall stations in the vicinity of the Kemerton Industrial Area. Details for each of the stations are presented in Table 4.1.

Table 4.1
Details of Rainfall Stations

Code	Context Name	Easting	Northing	River Basin Name	Start Date	End Date
009513	Brunswick Junction	392451	6319674	Collie River	01/01/09	-
009634	Australind (Parkfield)	379397	6326852	Collie River	01/01/13	-
009643	Australind (Rosamel)	380057	6325782	Collie River	01/01/19	01/01/63
009657	Burekup (Rosedale)	386185	6315598	Preston River	01/01/42	-
009687	Brunswick State Farm	388417	6314947	Collie River	01/01/15	01/01/19
009885	Bunbury	376026	6312948	Preston River	01/01/85	-
509243	Harvey Diversion Drain	382839	6336898	Harvey River	20/05/83	24/05/00

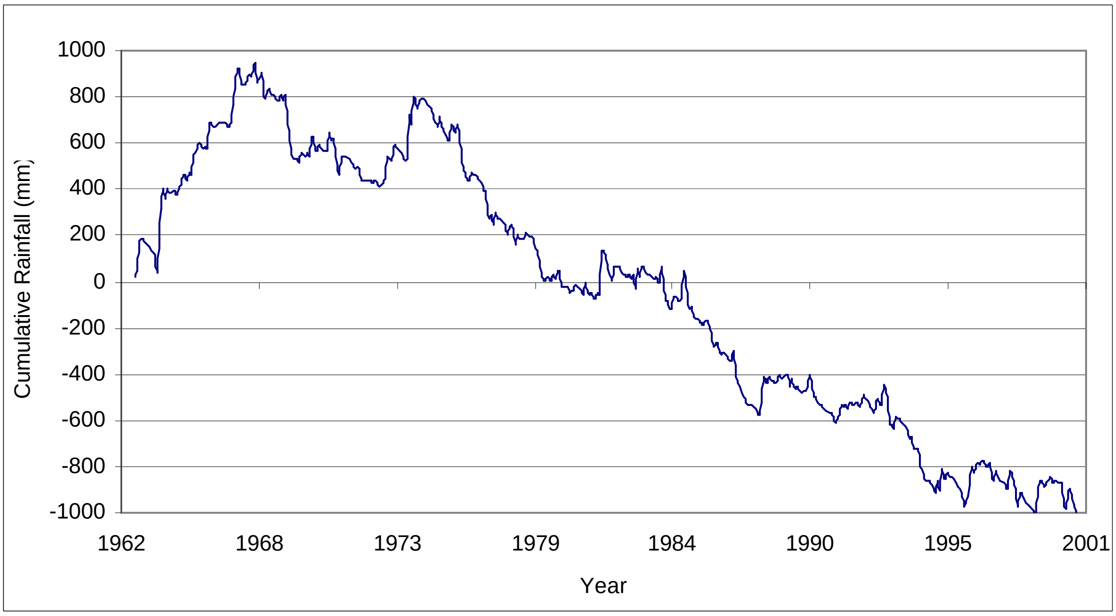
Data was obtained for the Harvey Diversion Drain and Australind (Parkfield) rainfall stations. Figure 4.1 shows average monthly rainfall for the Parkfield station. The average annual rainfall for the site is approximately 830mm, with almost 80% of the rainfall recorded between May and September. Historical rainfall data for the two stations and the location of all rainfall stations is presented in the Data Volume.

Figure 4.1
Average Monthly Rainfall - Parkfield Station



Rainfall for the area has generally been below average since the mid 1970s. Figure 4.2 shows a plot of residual annual rainfall for the Parkfield station. The residual rainfall curve is constructed based on the cumulative difference between the monthly rainfall and (long term) monthly averages. The curve is useful to put into context recent rainfall data against historic fluctuations. A rising slope indicates above average rainfall, a flat trend indicates an average rainfall period, and a falling slope indicates below average rainfall. It is apparent that rainfall figures over the last 25 years have been on the decrease and are generally below average. The annual rainfall average since 1975 has been approximately 765mm, which is significantly lower than the long term average of 830mm.

Figure 4.2
Residual Rainfall Curve - Parkfield Station



Note:
Residual rainfall curve has been constructed on data since 1963 as this was the longest continuous set of data available.

4.2.2 Evaporation

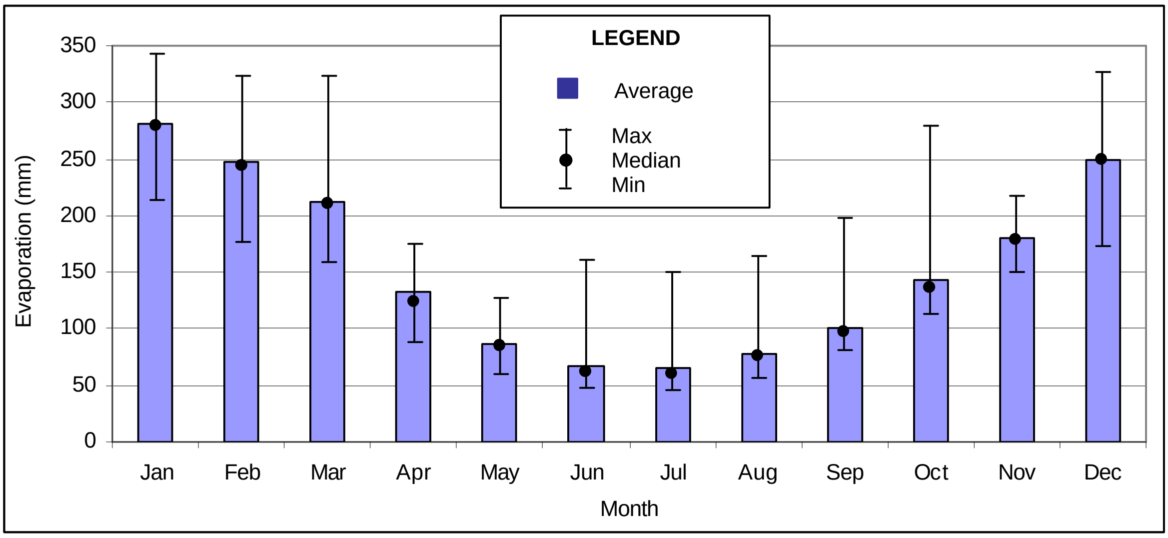
Evaporation data was obtained for the Wokalup and Roelands stations which are situated near the Estate. Details for each of the stations is given in Table 4.2.

Table 4.2
Evaporation Stations

Code	Context Name	Easting	Northing	Start Date	End Date
009642	Wokalup	395719	6333510	01/02/1968	-
009657	Roelands	386266	6315230	01/01/1983	-

Figure 4.3 shows average monthly evaporation for the Wokalup station, which is situated closest to the Estate. Average annual evaporation for the site is approximately 1840mm, which is about 1000mm greater than the average rainfall for the nearby Parkfield site. Most of the evaporation (almost 80%) occurs between the low rainfall months of October to April (compared to most rainfall, which falls during the remainder of the year between May and September). Note however that that Wokalup station is likely to experience a higher annual rainfall as it is located further inland towards the Darling Range.

Figure 4.3
Average Monthly Evaporation - Wokalup Station



4.3 RIVER FLOW AND WATER QUALITY DATA

4.3.1 River Flow

Flow data was extracted from the Water and Rivers Commission databases for the four stations (Table 4.3) located in the vicinity of the Kemerton Industrial Area. Figures in the Data Volume present the location of each of the WRC gauging stations.

Table 4.3
WRC Flow Gauging Stations

Code	Context Name	Name	Easting	Northing	River Basin Name
612032	Brunswick River	Cross Farm	382139	6319598	Collie River
612043	Collie River	Rose Road	388239	6314898	Collie River
613019	Harvey Diversion Drain	Myalup	382839	6336898	Harvey River
612039	Wellesley River	Juegenup	386039	6323198	Collie River

Plots and tables in the Data Volume summarise daily and monthly streamflow totals for each of the above stations. Monthly flow for the Wellesley River is presented in Figure 4.4 over the available period of record, and average daily flow is summarised in Table 4.4.

As expected, there is a high seasonal variation at each of the stations with the exception of the Harvey Diversion Drain. A large proportion of annual flow for each of the rivers occurs between the months of June and September. Average daily flows during the low flow (Oct - May) and high flow (Jun - Sep) periods over the interval of record available for each of the above stations is summarised in Table 4.4.

Figure 4.4
Monthly Streamflow - Wellesley River

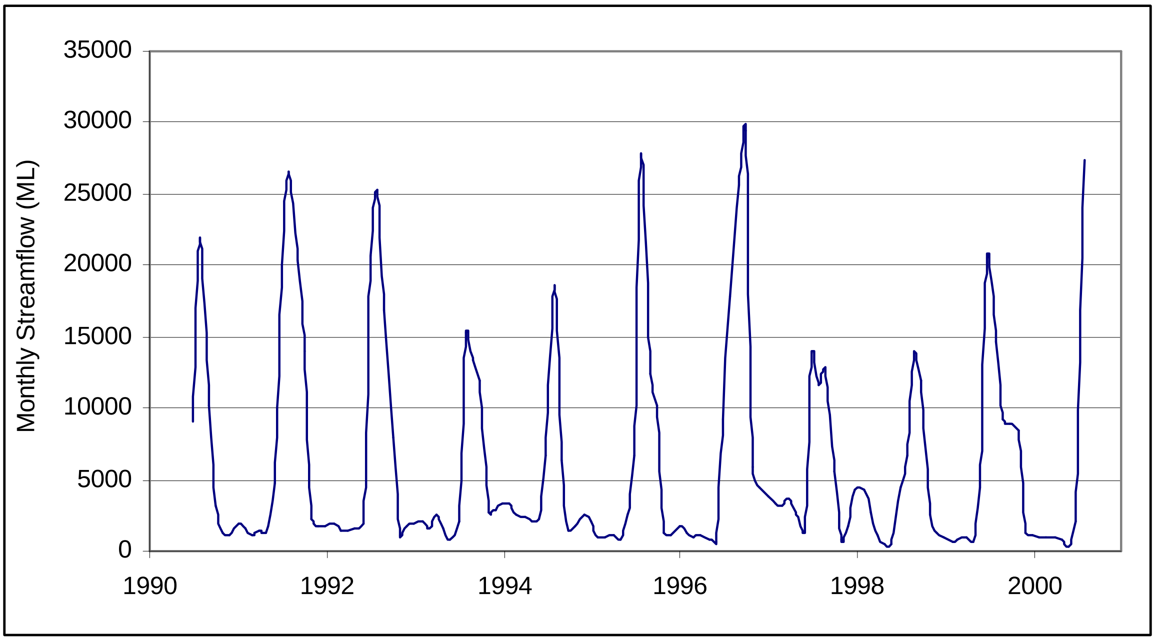


Table 4.4
Average Daily Flow for WRC Gauging Stations

Station	Period of Record	Average Daily Flow (kL/s)	
		Low Flow Period	High Flow Period
Brunswick River	Jun 90 - Jul 00	1.30	11.22
Collie River	May 96 - Aug 00	1.61	9.63
Harvey Diversion Drain	Jun 82 - Apr 00	0.12	0.12
Wellesley River	Jun 90 - Jul 00	0.74	5.17

Note:
High flow period - June to September; Low flow period - October to May

4.3.2 River Water Quality

River quality data was also extracted from Water and Rivers Commission databases for the above stations and two additional stations, details of which are presented below (Table 4.5). The extracted data is presented in the Data Volume.

Table 4.5
WRC River Water Quality Stations

Code	Context Name	Name	Easting	Northing	River Basin Name
612048	Bear Drain	-	391191	6335215	Collie River
612217	Flaherty Brook	Roelands	391129	6315285	Collie River

Note:
Stations presented in Table 4.3 also have records of water quality.

A summary of variations in selected water quality parameters over the period of record for each of the above stations is presented in Table 4.6.

Table 4.6
Summary of Water Quality Data from WRC Gauging Stations

	Brunswick River	Wellesley River	Collie River	Harvey Div Drain	Flaherty Brook	Bear Drain
Period of Record	6/90 - 8/95	6/90 - 1/96	5/96 - 3/97	6/82 - 8/98	6/66 - 12/71	5/66 - 12/71
Colour (Hu)	2.0 - 170	22 - 260	15 - 123	5.0 - 470	10	5.0 - 140
Conductivity (uS/cm)	180 - 2030	200 - 2000	620 - 2960	180 - 1580	-	-
Turbidity (ntu)	0.1 - 54	3.7 - 92	2.2 - 67	0.2 - 100	-	-
pH	6.2 - 8.1	6.3 - 8.9	6.7 - 8.2	5.8 - 9.8	7.0	6.4 - 6.9

A summary of the water quality for the rivers and drains around the Estate is discussed below (WRC, 2001), and summarised in Table 4.7.

Table 4.7
Classification of Nutrient Status (WRC, 2001)

Site	Total Nitrogen (mg/L)			Total Phosphorus (mg/L)		
	1995-97	1996-98	1997-99	1995-97	1996-98	1997-99
Wellesley River	Moderate	Moderate	Moderate	High	High	High
Brunswick Estuarine	High	High	High	High	High	High
Lower Brunswick	-	-	High	-	-	High
Collie Estuarine	Moderate	Moderate	Moderate	Moderate	Low	Low

Notes:
Estuarine TN Concentrations - "Low" - 0.3-0.6; "Moderate" - 0.6-0.9; "High" - 0.9-1.5 mg/L
Riverine TN Concentrations - "Low" - 0.75-1.1' "Moderate" - 1.1-1.7; "High" - 1.7-2.8 mg/L
Estuarine TP Concentrations - "Low" - 0.02-0.06; "Moderate" - 0.06-0.1; "High" - 0.1-0.14 mg/L
Riverine TP Concentrations - "Low" - 0.03-0.08; "Moderate" - 0.08-0.15; "High" - 0.15-0.4 mg/L

4.3.2.1 Wellesley River

Water quality in the Wellesley River is relatively poor with high concentrations of total phosphorus (TP) and moderate concentrations of total nitrogen (TN). Suspended solids in the river are also high (median concentration of 32 mg/L), and dissolved oxygen levels are currently acceptable. There are also very high amounts of organic carbon, which has the potential to place significant oxygen demand on receiving waters. The high nutrient content of the Wellesley River is largely due to the Wellesley catchment, which has an extensive irrigation and drainage network.

4.3.2.2 Brunswick River

The lower and estuarine reaches of the Brunswick River are closest to the Estate. Monitoring has indicated high concentrations of TN and TP in the lower and estuarine reaches of the Brunswick River. Moderate to high concentrations of dissolved organic carbon have also been found in these areas. Surface water salinity changes from fresh during winter to brackish during summer and autumn. Dissolved oxygen levels are acceptable in the upper profile of the river but is often much lower towards the bottom. There is also little tidal intrusion into the lower Brunswick River, resulting in limited stratification.

4.3.2.3 Collie River (Estuarine Reach)

Monitoring of the estuarine reach of the Collie River has indicated moderate concentrations of TN and low to moderate concentrations of TP. The average TP concentration has decreased from 0.13 to 0.07 since

1995. There is a strong seasonal salinity pattern with brackish conditions during winter in response to freshwater inputs, and more saline conditions during summer. Bottom waters also have a higher salinity due to the intrusion of tidal water. The surface waters are well oxygenated and dissolved oxygen concentrations are higher at the surface than at the bottom all year round.

4.3.3 Nutrient Management Options

Management options which have been proposed in WRC (2001) to combat nutrient enrichment, deoxygenation and sedimentation in the Wellesley River and the lower and estuarine reaches of the Collie and Brunswick Rivers are summarised in Table 4.8.

Table 4.8
Management Options for River Water Quality

Issue	Management Option
Nutrient Enrichment	• Improved fertiliser management and stock control to prevent animal wastes entering rivers • Vegetated buffer zones for rivers and fencing for stock and protection of riparian vegetation • Rural catchment filters and improved management of urban and rural drainage • Education about sources and control of nutrients • Sewerage infill programmes
Deoxygenation	• Stock control to prevent animal wastes directly entering rivers • Vegetated buffer zones to intercept runoff • Sewerage infill programmes • Removal of weeds and revegetation with native species
Sedimentation	• Revegetation of riparian areas and fencing for stock and protection of riparian vegetation • Stock control (watering points and alternative water supply) • Restoration and protection of degraded river banks and improved rural drainage design • Education on timing of earthworks for development, drainage and farm management

The Estate is located on the Swan Coastal Plain which is bounded to the east by the Darling Scarp and to the west by the coastline. The coastal plain is characterised by a broad alluvial plain, with lines of sand dunes and limestone near the coast (GSWA, 1982).

The geology and hydrogeology for the Kemerton area have been well documented in a number of published sources including Commander (1988 & 1989) and Deeney (1989a and 1989b) and has been mapped by the Geological Survey (GSWA, 1981 & 1982). A summary of this information is presented in the following sections.

5.1 GEOLOGY

The underlying geology at Kemerton consists of superficial sands, resting on the Leederville Formation, overlying the Yarragadee Formation or the Cattamarra Coal Measures. A brief description of each of the units is given below (after Commander (1989) and Deeney (1989)).

The Leederville Formation underlies the superficial sands across the entire Coastal Plain, whereas the Yarragadee Formation is only present in the southern part of the estate (and further south towards Bunbury), where it overlies the Cattamarra Coal Measures. In the northern parts of the Study area, the Cattamarra Coal Measures (CCM) directly underlie the Leederville Formation (unconformably). The Yarragadee Formation is regarded as being in hydraulic connection with the top of the Cattamarra Coal Measures in the Kemerton area (Commander, 1989). The key units in regard to potential water supplies are the superficial formation, the Leederville Formation and the Cattamarra Coal Measures.

The superficial formation (Quaternary) consists of sand, limestone, silt and clay units of the Guildford Formation, Bassendean Sand, Tamala Limestone and Safety Bay Sand. Peaty sand deposits can also occur, associated with swamps and wetlands. There is a noticeable variation in lithology both vertically and laterally, and the thickness ranges from about 20 m to 50 m. A brief description of each of these units is given in Table 5.1 after Deeney (1989) and Commander (1988).

Table 5.1
Units of the Superficial Formations

Unit	Description
Guildford Formation	Can be divided into a clay member to the east and a sand member in the west. The clay member consists of brown or grey clay and sandy clay. The sand member consists predominantly of grey, poorly sorted, fine to very coarse-grained quartz sand with minor beds of brown or grey clay. This unit has a maximum thickness of about 35m. The Guildford Formation outcrops east of the Kemerton area.
Bassendean Sand	Consists of white to pale grey (occasionally brown) moderately sorted, fine to medium grained quartz sand. It unconformably overlies the Guildford Formation, and may reach a maximum thickness of about 30m. The Bassendean Sand outcrops as low dunes in the eastern and central parts of the Kemerton area.
Tamala Limestone	Comprises limestone, calcarenite and sand, with minor clay. It occurs towards the west near the coastline and has a maximum thickness of about 90m.
Safety Bay Sand	Consists of calcareous sand and unconformably overlies the Tamala Limestone. It occurs as a narrow strip of mobile dunes along the coastline, with a maximum thickness of about 50m.

The Leederville Formation (Early Cretaceous) consists of quartz sandstone, siltstone and shale. The Leederville extends across most of the Coastal Plain, and is overlain by the superficial formations. Drilling along the Binningup bore line (Figure 5.7) found the formation to thin eastwards and the maximum thickness encountered was 170m. Commander (1989) divided the formation into an upper sandy section and a lower section which is predominantly shale.

The Yarragadee Formation (Late Jurassic) is predominantly sandstone and directly underlies the Leederville formation in the southern part of the Kemerton area.

The Cattamarra Coal Measures (Early-Middle Jurassic) consists of weakly cemented quartz sandstone and weakly consolidated siltstone and shale. The formation can be up to 2 km thick generally. It underlies the Yarragadee Formation until it pinches out south of Kemerton, and lies unconformably beneath the Leederville formation in the central to northern Kemerton area.

5.2 HYDROGEOLOGY

The hydrogeology of the major aquifer units for the Kemerton and surrounding area is summarised below after Commander (1988) and Deeney (1989), and a number of other unpublished sources.

5.2.1 Superficial formations

The superficial formation aquifer is an anisotropic unconfined aquifer with a saturated thickness of approximately 20 to 40m. It consists predominantly of clay and sand in the east and sand and limestone in the west. The transmissivity generally increases from east to west and ranges from 50 to 1150 m^2/d. Topography, drainage and surface geology influence the hydrogeological regime of the superficial formation, giving rise to the potential for groundwater mounding to occur in areas of high relief (AGC Woodward-Clyde, 1993). The Kemerton area lies within the Myalup groundwater flow system. A low mound (Mialla Mound), centred on and to the north of the Estate has formed in the water table and locally modifies groundwater flow directions.

The aquifer is recharged by rainfall but a large proportion of the infiltration is lost due to evapotranspiration processes from the wetlands and areas where the water table is at a shallow depth. Recharge rates have been estimated to be higher in the central part of the coastal plain than in the east or west because of low clay content, shallow water table and low topographic gradient. Estimates of groundwater recharge for the area range between 25% and 60% of annual rainfall. The predominance of downward head differences in nested monitoring bores indicates that regular recharge occurs throughout the area. Pumping in areas of shallow water table has been identified as a way of increasing the renewable groundwater resource, as it would induce greater recharge and substantially reduce local discharge losses by evapotranspiration. However, there could also be environmental impacts associated with implementation of this approach.

Groundwater flow is generally westwards from the Darling Scarp, and seasonal variations in the water table are in the order of 1 to 2m. Variations in water level can usually be correlated with variations in rainfall. The presence of wetlands, drains and lakes complicates the groundwater flow regime. The hydraulic gradient is relatively steeper to the west, towards the ocean, and is low in the central part of the coastal plain. Groundwater discharges locally to watercourses, swamps and wetlands (including Myalup Swamp), the Wellesley River, Leschenault Inlet, to the Leederville Formation and to the Indian Ocean across a saline interface. Inflow into the superficial formation also occurs from the Leederville Formation and from the Harvey River Diversion Drain. In the Kemerton area, Deeney (1989) estimated groundwater throughflow (Myalup flow system) to represent 7-17% of the potential rainfall recharge to the superficial aquifer.

Groundwater to the west of the Wellesley River is generally fresh to marginal (250 to 1,500 mg/L TDS) and to the east, it is generally brackish. In local discharge areas west of the Wellesley River, the salinity can be as high as 20,000 mg/L TDS. Fresh groundwater (< 500mg/L TDS) is generally more extensive at the water table than at the base of the aquifer. The groundwater salinity generally increases in the direction of groundwater flow but there are significant local variations due to variations in permeability, irrigation, evapotranspiration process and leakage from the Guildford clay. A saline interface is present along the western boundary of the aquifer at the coast.

5.2.2 Leederville Formation

The Leederville Formation is recharged mainly by downward leakage from the superficial formation. There is a vertical head difference of about 8 m between the Superficial and Leederville Formations in the southern part of the Estate. This indicates downwards leakage from the superficial aquifer into the Leederville Formation. Upwards leakage from the Yarragadee Formation to the Leederville may also occur in some areas (AGC Woodward-Clyde, 1993). The main recharge area around Kemerton for the Leederville aquifer is between the Wellesley River and Myalup Swamp, where there is a downward vertical gradient and the overlying superficial formation is predominantly sand.

Regional groundwater flow is westward, discharging offshore. Discharge is also likely to occur through upward leakage into the superficial formation between Myalup Swamp and the saline interface closer to the coast. Artesian flows may be encountered in the low lying area west of Myalup Swamp. The hydraulic gradient is low and seasonal variation in potentiometric head is of the order of 0.5 m. Exploratory drilling for industries within the Estate indicated an aquifer transmissivity of about 400 m^2/d.

Water is freshest (850 to 1,500 mg/L TDS) between the main recharge area and the saline interface near the coast. The remainder of the aquifer is brackish to saline (1,500 to 19,000 mg/L TDS). The saline interface is estimated to occur at around 45 m depth in the Leederville (below the base of superficial formation) at a distance of between 1 km and 2 km inland from the coast.

5.2.3 Yarragadee Formation

The Yarragadee Formation consists predominantly of sandstone and is only present in the southern part of the Estate. Head measurements along the Picton Line (south of the Estate) indicate that the Yarragadee Formation and the Cattamarra Coal Measures form a single flow system (Wharton, 1979). Recharge to the aquifer along the Picton Line occurs in the south or southeast (Wharton, 1979), and groundwater flows east to west, discharging out to sea.

The salinity of the formation (as intersected by the Picton Line bores) is between 300 and 8000 mg/L. Groundwater is freshest in the upper part of the flow system, and is brackish to saline in the lower part (Wharton, 1979). Brackish groundwater at shallow depths near the coast at Bunbury may be associated with a salt water interface which has moved inland as a result of pumping.

5.2.4 Cattamarra Coal Measures

The Cattamarra Coal Measures (CCM) (formerly known as Cockleshell Gully Formation) is a confined multilayered aquifer composed of siltstone and shale interbedded with sandstone. Based on groundwater salinity, the formation is divided into two parts separated by a shale layer - an upper sequence containing fresh groundwater and a lower sequence containing brackish groundwater (Rockwater, 1996). From monitoring bores on the Binningup Line, potentiometric heads in the CCM are higher than those in the Leederville Formation. This indicates that recharge by downward leakage probably does not occur around the Binningup Line, although it could occur further to the north. Recent test bore drilling has indicated that static water levels in the upper part of the CCM at Kemerton are about 6 to 7 m higher than in the lower part of the CCM. This indicates a potential restriction of groundwater flow between the lower and upper parts of the CCM (Rockwater, 1996). The natural seasonal variation in potentiometric head is of the order of 0.5 m, and artesian flows may be encountered in low lying areas near the coast. Exploratory drilling by Rockwater (1996) for industries within the Estate estimated an aquifer transmissivity of 400 to 1500 m^2/d.

The groundwater salinity ranges between 2,510 and 26,100 mg/L TDS. The active flow system in the west contains brackish groundwater (2,500 to 7,000 mg/L TDS) and the remainder of the aquifer is saline. The salinity levels are probably a reflection of the distance from recharge and the low permeability of the sediments. In the Kemerton area, the salinity in the Cattamarra Coal Measures is brackish (<3,000 mg/L).

5.3 EXISTING GROUNDWATER PRODUCTION BORES AND ALLOCATIONS

5.3.1 Production Bores

The major industries in the Estate abstract water for process and potable requirements from unconfined and confined aquifers. A brief summary of the production bores for each industry is outlined below:

- *Simcoa Operations Pty Ltd (Kemerton Silica Smelter)* - operate two production bores, PB1 and PB2. Bore PB2 extracts water from the Yarragadee Formation and is the primary source of water. Bore PB1 has been used intermittently as a back up and extracts water from the superficial formation. Problems have been encountered with treatment of groundwater extracted from the superficial formation due to high TDS, dissolved organics and hydrogen sulphide.
- *Millennium Inorganic Chemicals (MIC)* - operate three production bores, KW-1, KW-3 and KW-4. Bore KW-1 draws water from the Leederville formation and bores KW-3 and KW-4 from the Cattamarra Coal Measures.
- *Sons of Gwalia (Kemerton Silica Sands)* - operate two production bores, KW7 and KW14, both extracting water from the superficial formation.
- *Nufarm-Coogee* - No production bores. All water requirements for the site are provided by MIC.

Available details for each of the production bores are summarised in Table 5.2 (next page) from a number of sources.

The typical usage for each of the production bores is presented in Section 9.4.

5.3.2 Water Allocation

Details of currently active groundwater licences in the Kemerton Industrial Estate was obtained from the Water and Rivers Commission's Water Resource Licensing (WRL) database. The extracted data covers an area extending approximately 25 km north and 25 km east from the coordinate 370100 mE 6312800 mN. Complete licensing details are presented in the Data Volume. Table 5.3 (next page) summarises allocation data for each of the industries and collates all other allocations according to the groundwater area and aquifer unit.

Table 5.2
Details of Production Bores

Bore ID	Operator	Date Completed	Total Depth (m)	Slotted Interval (m)	Aquifer	Water Level (mbgl)[(1)]	Yield (kL/d) [(2)]
PB1	Simcoa Operations	May 1988	27.8	18.4 - 24.8	superficial	7.22	400
PB2	Simcoa Operations	Jun 1988	250.4	227.7 - 250.4	Yarragadee	12.70	1,000
KW-1	MIC	Jul 1987	153.7	121.6 - 153.7	Leederville	11.67	1,500
KW-3	MIC	Aug 198	177.3	165.0 - 177.3	CCM	9.79	1,500
KW-4	MIC	Nov 1987	239.0	209.0 - 239.0	CCM	10.76	2,700
KMB7	Kemerton Silica Sands	Apr 1995	28.5	16.5 - 28.5	superficial	2.55	800
KMB14	Kemerton Silica Sands	Dec 1995	28.6	16.6 - 28.6	superficial	-	-

Notes:
(1) Water level measured at time of bore construction (mbgl - metres below ground level).
(2) Yield refers to the recommended yield at time of construction
(3) CCM - Cattamarra Coal Measures

A summary of the allocation limit and current licensed allocations for each aquifer within each groundwater sub area (refer to Figures 2.1 and 5.1 for sub-area boundaries) was supplied by the WRC and is summarised in Table 5.4.

Table 5.4
Allocation Limit and Licensed Allocations (kL)

Groundwater Subarea	Aquifer	Allocation Limit	Current Allocation	% Allocated
Australind	superficial formation	900,000	716,400	80%
	Leederville Formation	4,000,000	4,252,500	106%
	Yarragadee Formation Sth	4,000,000	3,311,000	83%
	Cattamarra Coal Measures	1,000,000	545,000	55%
Wellesley	superficial formation	3,000,000	1,469,800	49%
	Leederville Formation	0	1,000	-
	Yarragadee Formation Sth	0	0	-
	Cattamarra Coal Measures	0	0	-
Myalup	superficial formation	11,900,000	4,819,550	41%
	Leederville Formation	500,000	432,000	86%
	Yarragadee Formation Sth	0	0	-
	Cattamarra Coal Measures	0	0	-

Note:
The current allocation and % allocated data is for the region of interest (area extending approximately 25 km north and 25 km east from the coordinate 370100 mE 6312800 mN).

Groundwater licensing policy for the Kemerton area is documented in the Bunbury Groundwater Area Management Plan (WAWA, 1994) and South West Coastal Groundwater Management Plan (WAWA, 1989). The Estate falls into both the Australind, Wellesley and Myalup sub areas (Figure 5.1). A summary of the groundwater licensing and allocation policy for the three areas is given in Table 5.5.

Table 5.3
Summary of Groundwater Allocation Details

Licence Number	GW Area Name	GW Name	Aquifer Name	Usage Category	Allocation Limit (kL)
Industries in the Kemerton Industrial Estate					
61061	Bunbury	Australind	Yarragadee South	Industrial	2,800,000
61062	Bunbury	Australind	Cattamarra CM	Industrial	545,000
61063	Bunbury	Australind	Leederville	Industrial	1,300,000
61185	Bunbury	Australind	Yarragadee South	Industrial	292,000
61186	Bunbury	Australind	Superficial	Industrial	73,000
60367	SW Coastal	Wellesley	Superficial	Industrial	1,000,000
100789[(1)]	Bunbury	Australind	Superficial	Dewatering	25,500
62016	Bunbury	Australind	Superficial	Abattoir	75,000
Other Large Allocations (>250,000 kL/yr)					
97731	Bunbury	Australind	Leederville	Water Supply	2,000,000
64746	SW Coastal	Myalup	Superficial	Domestic	1,600,000
99073	Bunbury	Eaton	Yarragadee	Water Supply	1,500,000
98419	SW Coastal	Myalup	Superficial	Vegetables	480,000
62577	SW Coastal	Myalup	Superficial	Vegetables	450,000
54249	SW Coastal	Wellesley	Superficial	Vegetables	420,000
102,029	SW Coastal	Myalup	Superficial	Vegetables	390,000
53615	SW Coastal	Myalup	Superficial	Domestic	300,000
100776	SW Coastal	Myalup	Superficial	Domestic	270,000
97161	Bunbury	Australind	Leederville	Golf	262,500
Other Allocations					
Various Licence Numbers	Bunbury	Australind	Superficial	Various Categories (eg. gardening, general purpose, industrial, commercial, water supply and public open space)	542,900
	Bunbury	Dardanup	Superficial		2,000
	Bunbury	East Bunbury	Superficial		18,000
	Bunbury	Eaton	Superficial		6,180
	SW Coastal	Coastal	Superficial		5,450
	SW Coastal	Island Point	Superficial		500
	SW Coastal	Lake Preston	Superficial		150,000
	SW Coastal	Myalup	superficial		1,329,550
	SW Coastal	Wellesley	superficial		49,800
	Bunbury	Australind	Leederville		145,000
	Bunbury	Dardanup	Leederville		3,000
	Bunbury	Eaton	Leederville		105,800
	Bunbury	East Bunbury	Leederville		43,500
	SW Coastal	Myalup	Leederville		432,000
	SW Coastal	Wellesley	Leederville		1,000
	Bunbury	Australind	Yarragadee		219,000
	Bunbury	East Bunbury	Yarragadee		10,000
	Bunbury	Eaton	Yarragadee		20,000
TOTAL LICENSED ALLOCATION					
					7,190,080 kL
					4,292,800 kL
					4,841,000 kL
					545,000 kL

Notes:
(1) Bore not currently in use by Nufarm-Coogee

Table 5.5
Groundwater Licensing Policy

Australind Sub Area	Myalup Sub Area	Wellesley Sub Area
• All abstraction >1500 kL/yr must be licensed • Special rural zones restricted to domestic supply of 1500 kL/yr, usually obtained from the superficial • No further private allocation from the Leederville, only small requests for public purposes • All abstraction in Yarragadee must be licensed • Applications >10,000 kL/yr in superficial formation should be considered on local availability, but set as "take what you can get" • Large requirements should be sourced from the Yarragadee and Cattamarra Coal Measures • Abstractions over 250,000 kL/yr require metering • Licensee to install one monitoring well if abstraction to exceed 500,000 kL/yr • All Leederville, Yarragadee and Cattamarra Coal Measures wells require sealing off from overlying formations to stop intermixing of varying quality groundwaters	• superficial aquifer – the available resource allocated so that local abstractions do not exceed 4000 kL/ha. Potential users on the west of Myalup Swamp should be warned of the higher salinity groundwater. Additional licences should be carefully considered regarding possible impacts to existing users. Large abstractions should be refused. SRZ lots should be allocated 1500 kL/lot/year. • Leederville Aquifer - As there is significant water available in the superficial and evidence exists that overdraw of the Leederville may be occurring, no new licences should be issued.	• superficial aquifer - east of the Wellesley River, any groundwater found should be available for abstraction. Potential users should be advised of the difficulty of obtaining supplies and the likelihood of high salinities. West of the river, allocation should be on a first come basis and large local draws should be avoided. Abstractions should not exceed 4000 kL/ha. SRZ Lots should be allocated 1500 kL/lot/year. Likely wetland impacts must be considered. • Leederville Aquifer - Groundwater licences should not be issued from this subarea as it is the recharge area for the Leederville Fm, an aquifer already under stress.

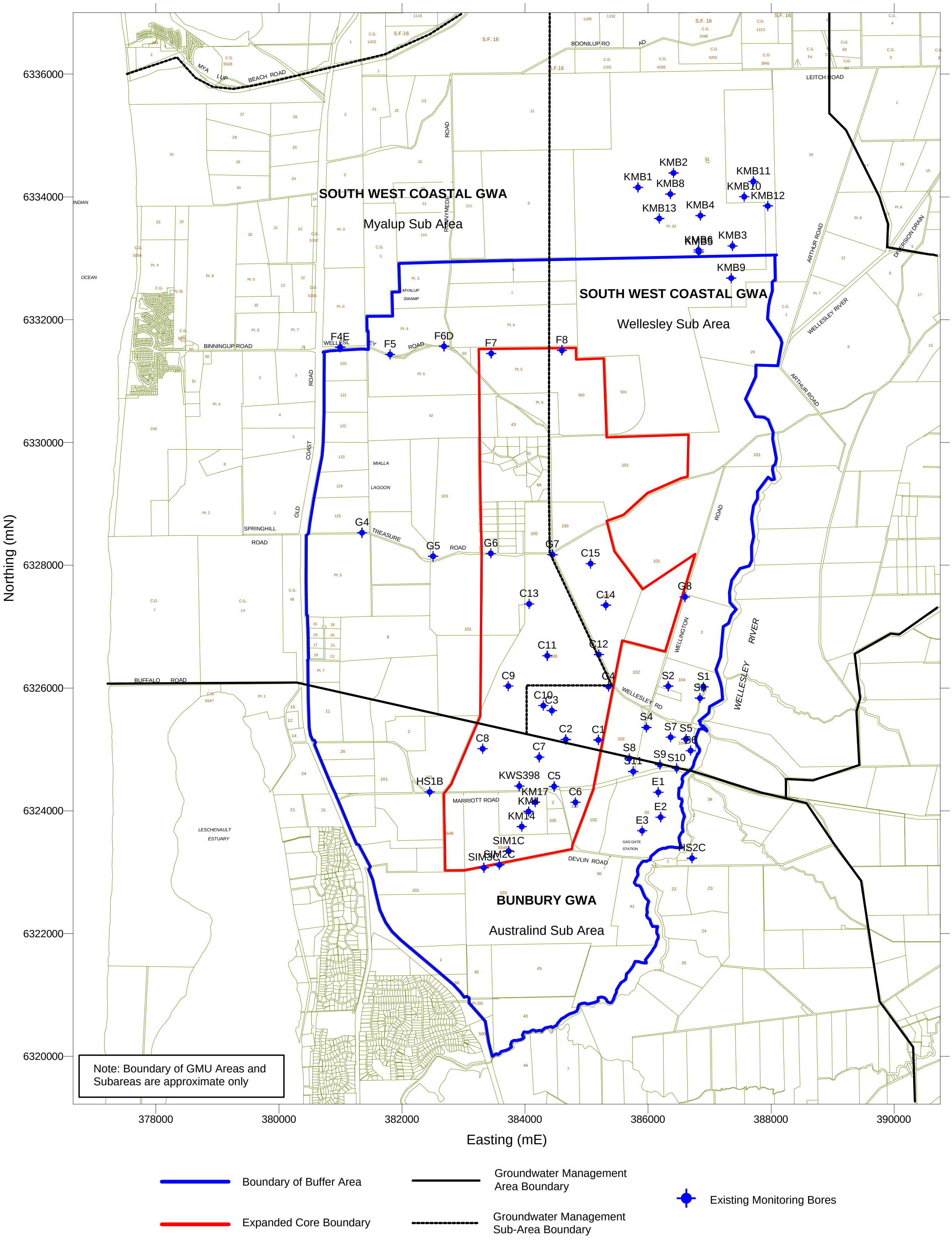
5.4 EXISTING GROUNDWATER MONITORING NETWORKS

There are a number of groundwater monitoring networks in the Kemerton Industrial Estate, with regular monitoring programmes. These include:

- WRC Network - number of bores which make up the southwest coastal, Harvey shallow and Kemerton monitoring networks. A number of these bores were monitored and sampled as part of this study;
- MIC - monitoring bores KM1 to KM17 and MB01 to MB03 (located across the plant site) with data regularly reported to the WRC. Bores KM4, 14 and 17 were monitored and sampled as part of this study;
- Simcoa Operations - monitoring bores Sim1 to Sim3 (shallow and deep monitoring bore at each location) with data regularly reported to the WRC. The shallow bores were sampled and monitored as part of this study; and
- Kemerton Silica Sands - monitoring bores KMB1 to KMB13 (situated across the plant site) with data regularly reported to the WRC. These bores were all sampled and monitored as part of this study.

A complete catalogue of available groundwater monitoring, location and water quality data is presented in the Data Volume. Figure 5.1 presents the location of these monitoring bores, and groundwater management sub-area boundaries.

Groundwater monitoring data for WRC monitoring bores was extracted from WRC's WIN database. This data included water quality data and location details for each of the bores. Data from the WRC, Simcoa and MIC monitoring networks were also used in the calculation of the average annual maximum groundwater level (Section 8.2).



Original plan prepared for Industry 2030 – Greater Bunbury Industrial Land and Port Access Planning

Existing Monitoring Bores
Figure 5.1

5.5 REDEVELOPMENT, SAMPLING AND ANALYSIS OF EXISTING SUPERFICIAL BORES

The Kemerton Water Study Phase 1 report (BBG-Rockwater, 1999), indicated the need to redevelop and sample existing monitoring bores in the area to resolve inconsistencies in the TDS/EC ratio from previously analysed samples. The results of the redevelopment and monitoring tasks are discussed below, after presentation of relevant background information.

5.5.1 Phase 1 Study Groundwater Monitoring Bore Network

Figure 5.1 presents the location of the 68 existing superficial monitoring bores identified in the Phase 1 study in the Kemerton area.

Ownership details for the bores may be summarised as:

- C, S and E series bores: constructed in 1994 for LandCorp as part of the Kemerton Industrial Estate baseline monitoring program, and are not currently monitored.
- F, G and HS series bores: part of the WRC South West Coastal and Harvey Shallow monitoring networks.
- KM series bores: owned and monitored by MIC.
- KMB series bores: owned and monitored by Kemerton Silica Sands (Sons of Gwalia).
- KWS3/98 bores: owned but not monitored by the Water Corporation.
- SIM series bores: owned and monitored by Simcoa.

5.5.2 Sampling and Analysis Plan

All existing monitoring bores, which could be located, were developed by airlifting using a trailer mounted air compressor. After redevelopment, the bores were allowed to recover and stabilise for at least one day prior to sampling.

The sampling plan adopted is consistent with best practice procedures, as outlined in AS/NZS 5667.11:1998 Water Quality - Sampling (Part 11: Guidance on sampling of groundwaters).

After re-development and recovery, the bores were purged by bailing sufficiently prior to sampling to ensure that the water sample was representative of the aquifer. While the bore was being purged, it was monitored for changes in temperature, electrical conductivity and pH. The sample was collected once there were no significant variations in these parameters.

The samples were stored in a sealed chilled esky and delivered to a NATA accredited laboratory (Australian Environmental Laboratories) with the appropriate chain of custody documentation.

All samples were analysed for the following water quality parameters:

- pH;
- Total dissolved solids (TDS) and electrical conductivity (EC); and
- Major cations (K^+, Na^+, Mg^{2+} Ca^{2+}, Fe^+) and anions (Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, NO_3^-).

Twelve selected monitoring bores were also analysed for nutrients. These bores were located immediately up-hydraulic-gradient of EPP wetlands, and also on ridgelines, with a view to identifying whether there are any substantial differences between nutrient concentrations in these two areas.

The analysis quantified concentrations of following nutrients:

- Nitrogen - total nitrogen, Kjeldahl nitrogen, nitrate, nitrite and ammonia; and
- Phosphorus - total phosphorus and ortho phosphorus.

5.5.3 Results of Field Investigation

The redevelopment and sampling of existing monitoring bores within the Estate was completed between the 22nd of January and 7th of February 2001. Table 5.6 summarises construction details and water chemistry details collected during the field investigation and from previous reports.

All bores were located, with the exception of bores F7 and F8 due to access restrictions. Coordinates for each of the monitoring bores were recorded using a GPS during the field investigation (to provide consistent coordinate data rather than a mix of GPS and surveyed information). Location and bore construction data for F7 and F8 were obtained from WRC records.

Available surveyed ground level information was obtained from reports for the majority of the existing monitoring bores. Ground levels for the remainder of the monitoring bores were obtained from the digital elevation model (DEM) constructed for the area. Construction details including the depth drilled and slotted interval were obtained from a range of sources including wellfield assessment reports, borehole logs, and other previous reports.

The remainder of the information was collected during the field investigation. The bore depth and water level was measured prior to sampling. The pH, electrical conductivity (EC) and temperature data presented in Table 5.6 is that recorded prior to sampling. Field pH measurements ranged between 3.6 and 7.6 (average of 5.7), suggesting weakly acidic waters. A large variation was seen in the electrical conductivity, with measurements ranging from as low as 100 µS/cm to greater than 20,000 µS/cm.

In the process of sampling monitoring bores, two wetlands were also sampled. Details of the sampling locations and field water chemistry records are presented in Table 5.7. A sample was collected from each wetland and analysed for water quality parameters and nutrients.

5.5.4 Water Quality Interpretation

The Phase 1 study raised the issue of an inconsistency in the TDS/EC ratio in the superficial monitoring bore samples. It was reported that the TDS/EC ratio ranged between 0.33 and 10.0, and, for 14 of the 24 sites, the ratio was greater than one. The TDS/EC ratio should typically be between 0.55 and 0.76 (Hounslow, 1995). These erroneous TDS/EC ratios were from water quality data collected at the time of installation of the baseline monitoring bores for LandCorp (Woodward-Clyde, 1994). This suggests that a number of the wells may not have been developed well enough after initial construction.

From the recent sampling programme (Jan-Feb 2001), the ratio between the total dissolved solids (TDS) and electrical conductivity (EC) ranged between 0.61 and 0.67, which is within the typical range expected. This suggests that redevelopment of the monitoring bores has corrected the large variation in the TDS/EC ratios reported in the Phase 1 study. Previous studies (Woodward-Clyde, 1994) reported concentrations of iron as high as 1,000 mg/L. This was again thought to be a result of poor well development techniques.

The maximum concentration of iron recorded from the recent sampling program was 95 mg/L.

Table 5.6
Bore Construction and Field Data Water Chemistry Details - Existing Monitoring Bores

Bore ID	Easting (mE)	Northing (mN)	Ground RL (m)	Date Drilled	Drilled Depth (m)	Tagged Bore Depth (mbgl)	Slotted Interval (m)	Water Level (mbgl)	Sampling Date	pH	EC (uS/cm)	Temp (deg C)	Observation
C10	384298	6325712	14.42	Apr-1994	5.51	5.60	3.51 - 5.51	3.05	31/01/2001	5.39	105	24	Clear light brown
C11	384362	6326525	13.97	Apr-1994	5.69	5.65	3.69 - 5.69	2.63	12/02/2001	4.11	135	19	Clear light orange/brown
C12	385199	6326545	13.25	Apr-1994	6.18	6.00	4.18 - 6.18	2.10	12/02/2001	5.03	265	19	Clear light brown
C13	384067	6327369	15.40	Apr-1994	5.78	5.51	3.78 - 5.78	4.01	12/02/2001	5.08	180	20	Clear light green
C14	385314	6327349	13.47	Apr-1994	5.63	5.50	3.63 - 5.63	2.05	31/01/2001	5.1	310	21	Clear dark brown
C15	385065	6328026	14.28	Apr-1994	4.57	4.85	2.57 - 4.57	2.25	31/01/2001	4.85	365	22	Clear light brown
C1-D	385193	6325153	12.73	Apr-1994	15.13	13.75	13.13 - 15.13	2.10	12/02/2001	5.39	555	19	Brown milky
C1-I	385195	6325152	12.73	Apr-1994	5.82	5.75	3.82 - 5.82	2.10	12/02/2001	5.36	270	19	Clear light yellow
C1-S	385194	6325153	12.73	Apr-1994	2.75	1.65	0.75 - 2.75	*Dry*					
C2-D	384666	6325163	12.06	Apr-1994	12.04	14.90	10.04 - 12.04	1.33	12/02/2001	5.95	1075	19	Light brown very milky
C2-I	384666	6325163	12.06	Apr-1994	4.06	2.70	2.06 - 4.06	1.17	12/02/2001	5.53	265	18	Brown milky
C2-S	384663	6325161	12.06	Apr-1994	2.05	1.90	0.05 - 2.05	1.18	12/02/2001	4.86	140	21	Clear light orange/brown
C3-D	384436	6325632	12.78	Apr-1994	14.82	15.05	12.82 - 14.82	1.45	31/01/2001	5.36	115	22	Light brown milky
C3-I	384435	6325631	12.78	Apr-1994	5.58	5.60	3.58 - 5.58	1.50	31/01/2001	5.33	165	22	Clear light orange/brown
C3-S	384435	6325631	12.78	Apr-1994	1.69	1.65	0.19 - 1.69	1.30	31/01/2001	5.41	150	25	Clear dark brown
C4-I	385355	6326021	12.36	Apr-1994	5.69	5.70	3.69 - 5.69	1.30	31/01/2001	5.06	655	20	Clear light brown
C4-S	385357	6326022	12.36	Apr-1994	2.28	2.55	0.28 - 2.28	1.40	31/01/2001	5.04	720	20	Light brown slightly milky
C5-I	384472	6324396	12.00	Apr-1994	5.71	5.80	3.71 - 5.71	1.45	31/01/2001	5.16	595	21	Light brown milky
C5-S	384472	6324396	12.00	Apr-1994	2.31	2.30	0.31 - 2.31	1.40	31/01/2001	5.93	345	22	Light brown milky
C6	384819	6324138	12.11	Apr-1994	5.15	5.75	3.15 - 5.15	1.90	12/02/2001	6.54	665	19	Light brown slightly milky
C7	384231	6324873	12.87	Apr-1994	5.84	5.80	3.84 - 5.84	1.75	31/01/2001	5.37	120	23	Clear light brown
C8	383311	6325010	13.26	Apr-1994	5.59	5.65	3.59 - 5.59	3.35	12/02/2001	5.31	165	20	Clear light green
C9	383728	6326031	13.12	Apr-1994	5.06	4.17	3.06 - 5.06	2.77	12/02/2001	4.84	380	18	Clear light orange/brown
E1	386166	6324301	13.29	Apr-1994	6.00	6.15	4.00 - 6.00	1.20	07/02/2001	7.18	320	21	Light brown milky
E2	386204	6323895	13.54	Apr-1994	5.93	5.95	3.93 - 5.93	1.55	07/02/2001	4.45	985	20	Orange brown slightly milky
E3	385904	6323674	12.43	Apr-1994	5.55	5.60	3.55 - 5.55	1.75	07/02/2001	5.27	2750	19	Light brown milky
F4	380946	6331546	11.35	Feb-1979	31.00	7.10	5.5 - 30.5	*Dry*					
F4E	380997	6331550	11.35	Feb-1979	-	28.52	-	7.66	07/02/2001	7.18	1980	18	Clear light brown
F5	381807	6331433	6.59	Feb-1979	20.00	20.25	0.0 - 20.0	2.87	01/02/2001	6.88	720	21	Light brown milky
F6	382751	6331574	15.14	Jan-1979	31.20	7.05	6.2 - 31.2	*Dry*					
F6D	382684	6331566	15.14	Jan-1979	-	17.75	-	7.86	06/02/2001	7.3	980	19	Clear light brown slightly milky
F7	383450	6331450	14.12 (5)	Oct-1979	33.00	-	0.0 - 33.0	*Bores not measured or sampled as no access*					
F8	384600	6331500	18.63 (5)	Jan-1979	26.50	-	1.0 - 26.5						
G4	381351	6328529	12.29	Nov-1978	30.00	28.90	17.0 - 29.0	8.83	07/02/2001	7.56	1765	19	Clear light green slightly milky
G5	382506	6328145	7.74	Nov-1978	38.00	34.50	7.0 - 35.0	2.08	01/02/2001	6.55	590	22	Light green slightly milky
G6	383444	6328192	38.50	Nov-1978	50.00	47.40	10.5 - 50.0	26.72	07/02/2001	7.59	435	22	Light brown milky
G7	384445	6328172	14.64 (5)	Jan-1979	33.00	31.10	2.0 - 32.0	1.96	01/02/2001	5.18	160	21	Clear light brown
G8	386598	6327483	13.36 (5)	Jan-1979	6.00	-	1.0 - 6.0	*Borehole destoryed, no sample taken*					
HS1B	382451	6324307	35.72	-	54.00	32.30	26.0 - 32.0	26.85	01/02/2001	7.02	485	22	Clear light brown slightly milky
HS2C	386713	6323227	7.49	-	6.00	6.15	2.0 - 6.0	3.90	01/02/2001	7.02	5210	19	Clear light brown slightly milky

Bore ID	Easting (mE)	Northing (mN)	Ground RL (m)	Date Drilled	Drilled Depth (m)	Tagged Bore Depth (mbgl)	Slotted Interval (m)	Water Level (mbgl)	Sampling Date	pH	EC (uS/cm)	Temp (deg C)	Observation
KM14	383946	6323742	14.82	Jul-1989	22.60	22.10	16.6 - 22.6	-0.50	*No field measurements taken as sampled by Millenium Chemicals*				
KM17	384164	6324139	15.00	Jul-1989	25.70	25.20	20.7 - 25.7	-0.50					
KM4	384058	6323987	14.89	Nov-1988	10.60	10.10	2.0 - 10.5	-0.50					
KMB1	385836	6334154	17.60	Jan-1993	24.00	23.10	11.4 - 23.4	2.55	06/02/2001	4.96	605	18	Clear light green/brown
KMB10	387562	6334003	15.28	-	-	19.65	-	1.55	06/02/2001	5.18	195	19	Clear orange brown
KMB11	387712	6334251	16.16	-	-	14.35	-	2.30	06/02/2001	4.73	98	20	Dark yellow brown slightly milky
KMB12	387946	6333852	13.83	-	-	20.05	-	0.73	06/02/2001	7.48	775	18	Clear yellow brown
KMB13	386182	6333647	16.06	Aug-2000	26.60	24.90	14.6 - 26.6	-0.60	*Borehole blocked, no sample taken*				
KMB2	386414	6334390	16.81	Jan-1993	23.80	22.90	11.0 - 23.0	2.00	06/02/2001	5.59	330	19	Clear orange brown
KMB3	387372	6333201	14.71	Jan-1993	24.00	22.15	11.4 - 23.4	1.20	06/02/2001	5.86	609	19	Clear brown
KMB4	386851	6333695	16.03	Jan-1993	23.00	22.75	11.0 - 23.0	1.40	06/02/2001	7.44	1245	19	Clear light green
KMB5	386825	6333102	16.33	Jan-1993	22.00	21.90	10.16 - 22.16	2.05	06/02/2001	6.17	1300	18	Clear brown
KMB6	386819	6333134	15.60	Apr-1995	19.00	19.00	0.0 - 19.5	1.75	06/02/2001	3.64	590	20	Clear dark brown
KMB8	386362	6334046	15.67	-	-	20.08	-	1.75	06/02/2001	6.02	855	18	Clear brown slightly milky
KMB9	387352	6332677	14.46	-	-	19.95	-	1.65	06/02/2001	5.07	315	20	Clear yellow brown
KWS3/98	383907	6324402	13.20	1998	23.00	24.40	17.0 - 23.0	4.08	07/02/2001	5.47	740	18	Light brown milky
S1	386902	6326017	14.15	Apr-1994	6.14	5.95	4.14 - 6.14	2.70	31/01/2001	5.09	350	22	Light brown milky
S10	386465	6324692	13.55	Apr-1994	5.46	6.00	3.46 - 5.46	2.35	31/01/2001	4.53	1100	21	Light brown milky
S11	385759	6324640	14.15	Apr-1994	6.37	5.70	4.37 - 6.37	1.25	31/01/2001	6.03	1260	22	Very dark brown slightly milky
S2	386328	6326029	13.18	Apr-1994	5.53	5.85	3.53 - 5.53	2.47	12/02/2001	4.91	985	20	Clear light yellow brown
S3	386843	6325834	17.04	Apr-1994	5.29	4.00	3.29 - 5.29	*Dry*					
S4	385973	6325357	14.11	Apr-1994	5.97	8.60	3.97 - 5.97	1.95	31/01/2001	5.6	460	22	Dark brown milky
S5	386617	6325168	13.42	Apr-1994	5.87	5.80	3.87 - 5.87	1.90	31/01/2001	5.55	175	22	Clear light brown slightly milky
S6	386692	6324980	13.70	Apr-1994	5.00	5.85	3.00 - 5.00	2.50	31/01/2001	5.76	175	23	Light brown slightly milky
S7	386367	6325198	12.47	Apr-1994	6.07	6.05	4.07 - 6.07	0.95	31/01/2001	6.93	>20,000	23	Dark brown slightly milky
S8-S	385695	6324855	13.19	Apr-1994	2.10	2.35	0.10 - 2.10	0.65	31/01/2001	5.05	450	22	Clear dark brown
S9-S	386192	6324750	13.92	Apr-1994	2.00	1.90	1.50 - 2.00	1.00	31/01/2001	5.92	245	26	Clear dark brown slightly milky
SIM1C	383735	6323343	13.74	-	8.20	8.20	5.20 - 8.20	3.00	31/01/2001	5.48	180	22	Clear very light green
SIM2C	383583	6323118	13.53	-	8.60	8.60	5.30 - 8.60	3.30	31/01/2001	5.12	155	20	Clear very light brown
SIM3C	383330	6323072	12.53	-	6.20	6.20	3.20 - 6.20	2.90	31/01/2001	5.41	305	19	Clear very light green

Notes:

1. All information was obtained during the site work unless otherwise specified
2. All coordinates were obtained using a GPS (WGS 84 datum) during the site work, with the exception of bores F7 and F8 which were obtained from WRC records
3. Water chemistry and water level measurements made during time of sampling
4. Bore construction details and reduced ground levels obtained from previous reports
5. Ground level obtained from digital elevation model

Table 5.7
Wetland Sampling Locations and Field Water Chemistry

ID	Easting	Northing	Description of Location	pH	EC (uS/cm)	Temp (degC)	Comment
WET1	387768	6334253	Near bore KMB11	5.74	5430	25	Algae, unhealthy vegetation
WET2	386591	6325555	Off Wellesley Rd near bore S2	7.85	8970	30	Healthy vegetation

F:\jobs\211\A2\[Site Data.xls]Construction Details

Table 5.8 also shows that around 30 of the 68 samples have a large cation/anion (im)balance. Typically, if all the major cations and anions are accounted for, the cation/anion balance varies between -5.0% and +5.0%. Previous studies (Woodward-Clyde, 1996a) also indicated a cation/anion balance outside the ±5% range.

The presence of a large cation/anion (im)balance suggests that there are ions present in major amounts other than the typical major cations and anions which were analysed for. The samples (from the recent programme) with a large cation/anion balance also had a very strong colour, suggesting the presence of organic matter (S. Edmett, *pers.comm.*). The presence of organic compounds such as acetate ions in appreciable quantities could result in a large error in the cation/anion balance. The presence of organic compounds had been reported by previous studies (Woodward-Clyde, 1994), which found low level concentrations of hydrocarbons (TPH) in the groundwater. It was explained that anaerobic bacteria, which would be expected to occur in the unsaturated zone of the study area, and plants (eg. conifers) are natural sources of hydrocarbons. This study also documented the presence of tannins in all groundwater samples analysed.

The large cation/anion imbalance in bores sampled recently is especially marked for bores S4, S5, S8S, S11 and C14. All these bores are located around the proposed inter-industry buffer area (Figure 5.1). These bores lie in areas where natural conditions could result in higher organic concentrations. Discussions with staff at AEL indicated that other organic cations and anions, such as acetate, which may be contributing to the imbalance, cannot be analysed for, but that dissolved organic carbon concentrations can be evaluated. Therefore, by analysing bores for dissolved organic carbon that exhibit a range in cation/anion balance, it will be possible to establish whether organic compounds are responsible for the imbalance. It is recommended that these bores (S4, S5, S8S, S11 and C14), together with others with a good cation/anion balance (eg. bores C3-S and C4-I) should be sampled again and analysed for dissolved organic carbon. An outcome from this limited investigation would be recommendations for future sampling programmes.

A summary of the water quality parameters is presented in Table 5.9. The observed range in pH measured across all bores suggests the presence of weakly acidic to neutral waters. The large range in salinities and major ion components is largely due to the effects of the groundwater flow system varying from recharge to discharge zones across the area. Where salinity and ion levels are high, one would expect to find groundwater discharge zones. These are typically low lying areas where evapotranspiration processes result in the concentration of salts in the shallow groundwater. Areas with low salinity and ion levels would typically be recharge zones, which result in the flushing and dilution of salts in the shallow groundwater.

Table 5.8
Laboratory Analysis of Existing Bores - Water Quality Parameters

Bore ID	Water Quality Parameters				Major Cations					Major Anions					Balance (%)
	pH	EC (uS/cm)	TDS (mg/L)	TDS/EC Ratio	Fe (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	
C1-D	5.6	200	130	0.65	2.40	24	15.0	4.8	7.6	30	<1	15	30	2.1	13.41
C1-I	6.4	200	130	0.65	0.35	25	13.0	2.8	4.0	25	<1	25	15	0.8	13.48
C2-D	6.6	1000	640	0.64	6.20	200	8.2	9.1	24.0	230	<1	120	<10	2.7	14.32
C2-I	5.5	170	110	0.65	14.00	21	8.4	1.4	2.6	20	<1	20	15	0.2	7.81
C2-S	5.6	130	85	0.65	0.45	15	1.4	6.8	3.5	20	<1	15	<10	0.2	23.60
C3-D	5.2	110	70	0.64	1.70	16	3.4	1.4	2.7	25	<1	15	<10	<0.2	6.12
C3-I	5.4	160	100	0.63	1.90	20	5.2	1.2	2.6	35	<1	10	10	<0.2	-3.13
C3-S	5.4	140	90	0.64	1.10	12	2.6	4.4	4.0	25	<1	10	15	0.2	-2.04
C4-I	4.9	610	390	0.64	1.50	93	3.9	3.4	10.0	160	<1	5	25	<0.2	0.21
C4-S	4.8	680	440	0.65	2.20	98	4.6	3.1	11.0	180	<1	<5	20	<0.2	-0.49
C5-I	4.5	560	360	0.64	2.10	61	9.0	1.4	19.0	150	<1	<5	15	<0.2	-0.29
C5-S	6	290	190	0.66	0.45	38	9.5	5.6	3.6	55	<1	20	20	1.7	3.10
C6	6.8	620	400	0.65	5.00	130	3.2	2.6	6.8	100	<1	130	<10	1.1	12.78
C7	5.6	120	80	0.67	0.90	13	4.8	1.2	2.2	25	<1	10	<10	<0.2	3.34
C8	5.6	160	100	0.63	0.30	19	2.8	1.9	4.3	20	<1	10	<10	<0.2	29.82
C9	4.7	320	210	0.66	1.70	53	2.8	1.1	3.2	70	<1	<5	<10	0.2	15.35
C10	5.3	110	70	0.64	0.90	9.1	5.1	1.5	3.4	20	<1	5	25	<0.2	-13.95
C11	4.4	120	80	0.67	0.40	15	0.9	2.8	2.8	25	<1	<5	<10	0.3	19.11
C12	5.3	200	130	0.65	1.80	21	1.8	8.2	5.6	50	<1	10	<10	0.5	7.24
C13	5.2	180	120	0.67	0.30	22	3.0	1.2	4.6	35	<1	5	<10	0.4	15.56
C14	4.9	260	170	0.65	2.10	38	5.6	4.3	12.0	40	<1	10	45	<0.2	46.29
C15	5	310	200	0.65	1.60	33	9.6	3.0	8.4	85	<1	5	<10	<0.2	0.85
E1	4.6	260	170	0.65	4.00	36	3.9	4.5	10.0	75	<1	<5	15	1.9	4.92
E2	4.3	910	580	0.64	95.00	190	0.6	2.1	25.0	60	<1	<5	50	1.2	58.27
E3	5.4	2500	1600	0.64	0.35	550	<0.5	3.0	35.0	790	<1	10	130	0.9	3.42
F4	7.6	1900	1200	0.63	0.60	350	7.0	85.0	23.0	380	<1	450	60	4	5.20
F5	7.4	610	390	0.64	0.40	54	3.3	67.0	11.0	90	<1	160	75	1.3	-0.46
F6	7.2	900	580	0.64	0.55	88	3.7	100.0	11.0	140	<1	340	<10	2	1.36
G4	7.8	1800	1200	0.67	0.40	220	5.9	160.0	30.0	380	<1	380	70	1.8	4.51
G5	6.9	550	350	0.64	0.45	60	2.6	42.0	8.7	90	<1	130	55	0.2	-2.91
G6	6.9	390	250	0.64	0.55	54	2.9	24.0	8.0	88	<1	80	15	1.2	1.83
G7	5.6	160	100	0.63	0.45	16	3.6	6.8	3.3	30	<1	20	15	0.2	-3.14
HS1B	7.3	450	290	0.64	<0.05	23	2.3	52.0	7.4	50	<1	140	15	18	-0.52
HS2C	7.5	4600	2900	0.63	<0.05	590	8.6	260.0	84.0	1300	<1	300	100	<0.2	2.35
KM4	5.5	690	460	0.67	1.10	500	3.2	22.0	14.0	1000	<10	50	1.3	0.07	-
KM14	5.7	410	300	0.73	3.40	83	3.1	2.1	5.8	130	<10	30	<1	0.02	-
KM17	5.6	340	300	0.88	4.90	73	2.3	1.2	3.8	100	<10	20	4.6	<0.01	-
KMB 1	5	530	340	0.64	0.60	71	3.6	4.3	23.0	100	<1	5	95	1	3.84
KMB 2	5.8	260	170	0.65	0.90	51	1.8	4.4	3.0	68	<1	40	<10	0.8	2.71
KMB 3	6.5	550	350	0.64	0.25	94	2.8	13.0	9.0	140	<1	60	<10	0.5	5.81
KMB 4	7.9	1200	770	0.64	0.20	120	4.3	140.0	16.0	210	<1	330	<10	2.3	9.05

Bore ID	Water Quality Parameters				Major Cations					Major Anions					Balance (%)
	pH	EC (uS/cm)	TDS (mg/L)	TDS/EC Ratio	Fe (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	
KMB 5	6.7	1300	830	0.64	0.20	220	4.0	39.0	20.0	360	<1	120	<10	0.7	4.45
KMB 6	3.9	500	320	0.64	0.65	71	1.7	4.0	14.0	34	<1	<5	10	1	58.23
KMB 8	6.3	790	510	0.65	1.30	120	4.0	21.0	16.0	140	<1	70	15	2.1	17.09
KMB 9	5.2	250	160	0.64	0.35	41	1.4	3.0	5.0	71	<1	15	<10	0.5	2.67
KMB 10	5.2	180	120	0.67	0.45	35	0.8	1.2	1.7	30	<1	10	<10	0.6	26.17
KMB11	4.6	95	60	0.63	0.55	13	0.9	1.4	2.2	24	<1	<5	10	0.8	-3.38
KMB 12	7.5	700	450	0.64	0.15	65	2.9	78.0	9.6	80	<1	280	<10	1.5	4.94
KWS3/98	5.6	680	440	0.65	1.40	140	4.7	4.8	11.0	210	<1	25	20	1.6	4.10
S1	4.2	290	190	0.66	1.50	36	2.5	2.8	6.3	80	<1	<5	20	0.3	-7.85
S2	5.1	930	600	0.65	5.50	140	4.8	5.4	17.0	230	<1	10	20	0.3	5.40
S4	5.4	390	250	0.64	22.00	74	3.1	3.2	7.3	30	<1	30	35	<0.2	53.77
S5	5.3	180	120	0.67	0.85	31	2.8	1.5	4.3	45	<1	10	15	<0.2	59.04
S6	5.8	170	110	0.65	2.90	26	1.3	3.8	4.9	35	<1	15	15	0.3	6.25
S7	7.3	33000	20000	0.61	3.30	5500	39.0	180.0	970.0	10000	<1	890	520	0.3	3.38
S8-S	4.6	320	210	0.66	5.00	57	4.8	3.8	7.0	65	<1	<5	10	0.2	88.19
S9-S	5.6	160	100	0.63	7.50	16	5.0	2.6	6.0	25	<1	20	15	4.7	0.92
S10	4.9	1100	700	0.64	0.15	200	<0.5	0.8	6.6	230	<1	<5	140	<0.2	-0.64
S11	6.1	1200	770	0.64	11.00	250	3.4	6.4	26.0	210	<1	140	90	0.2	52.58
Sim 1S	5.3	190	120	0.63	0.65	20	4.0	1.8	4.4	40	<1	5	15	<0.2	-3.34
Sim 2S	5.6	150	100	0.67	0.15	16	3.5	2.3	3.8	20	<1	10	25	<0.2	-1.44
Sim 3S	5.7	250	160	0.64	0.20	40	3.0	1.6	4.0	50	<1	30	20	<0.2	-2.04
WET 1	6.1	4600	2900	0.63	2.60	940	25.0	23.0	84.0	1300	<1	60	35	<0.2	12.74
WET 2	7.6	8800	5500	0.63	1.10	1800	83.0	70.0	150.0	2500	<1	450	15	1.2	10.33

Table 5.10
Laboratory Analysis of Existing Bores - Nutrients (mg/L)

Bore ID	Total Nitrogen	Kjeldahl Nitrogen	Nitrate-Nitrogen	Nitrite-Nitrogen	Ammoniacal Nitrogen	Total Phosphorus	Ortho Phosphorus
C3-S	4.5	4.4	0.041	0.02	2.90	0.32	0.2
F5	1.8	1.5	0.26	0.027	0.26	0.87	0.008
G5	0.55	0.5	0.039	0.009	0.16	0.06	0.004
G7	2.1	2	0.038	0.018	0.73	0.03	0.003
HS1B	4.9	0.96	4	0.021	0.11	0.15	<0.003
HS2C	0.77	0.73	0.01	0.028	0.21	0.09	<0.003
KM4	1.1	1	0.087	<0.005	0.72	0.01	<0.003
KMB11	1.3	1.1	0.15	0.021	0.17	0.06	<0.003
S1	0.85	0.78	0.064	0.006	0.13	0.04	0.004
S7	9.2	9.1	0.076	0.054	1.7	0.07	0.005
S8-S	3	2.9	0.038	0.049	0.61	0.4	0.35
Sim 2S	0.2	0.19	0.005	0.006	0.037	0.01	0.003
WET 1	9.9	9.7	0.03	0.13	0.34	0.18	0.03
WET 2	5.1	4.7	0.28	0.071	0.013	0.16	0.021

Table 5.9
Summary of Water Quality Analysis

	Parameter	Range
	pH	3.9 - 7.9
	Electrical Conductivity (µS/cm)	95 - 33,000
	TDS (mg/L)	60 - 20,000
Cations	Iron (mg/L)	<0.05 - 95
	Sodium (mg/L)	9.1 - 5,500
	Potassium (mg/L)	<0.5 - 83
	Calcium (mg/L)	0.8 - 260
	Magnesium (mg/L)	1.7 - 970
Anions	Chloride (mg/L)	20 - 10,000
	Carbonate (mg/L)	<1
	Bicarbonate (mg/L)	<5 - 890
	Sulphate (mg/L)	<10 - 520
	Nitrate (mg/L)	<0.2 - 18

Figure 5.2 shows the results from the recent sampling program plotted on an expanded Durov diagram. Interpretations from water chemistry diagrams such as the expanded Durov can only be made for waters with a correct cation/anion balance. Therefore only samples with a cation-anion balance within the ±5% range have been plotted. The diagram indicates that the majority of the waters are of sodium chloride type (end point waters). A number of the samples also indicate the dominant presence of other ions such as calcium and sulphate. Figure 5.2 also shows historical water quality from WRC monitoring bores in the area. These bores also exhibit similar patterns to the recently analysed samples.

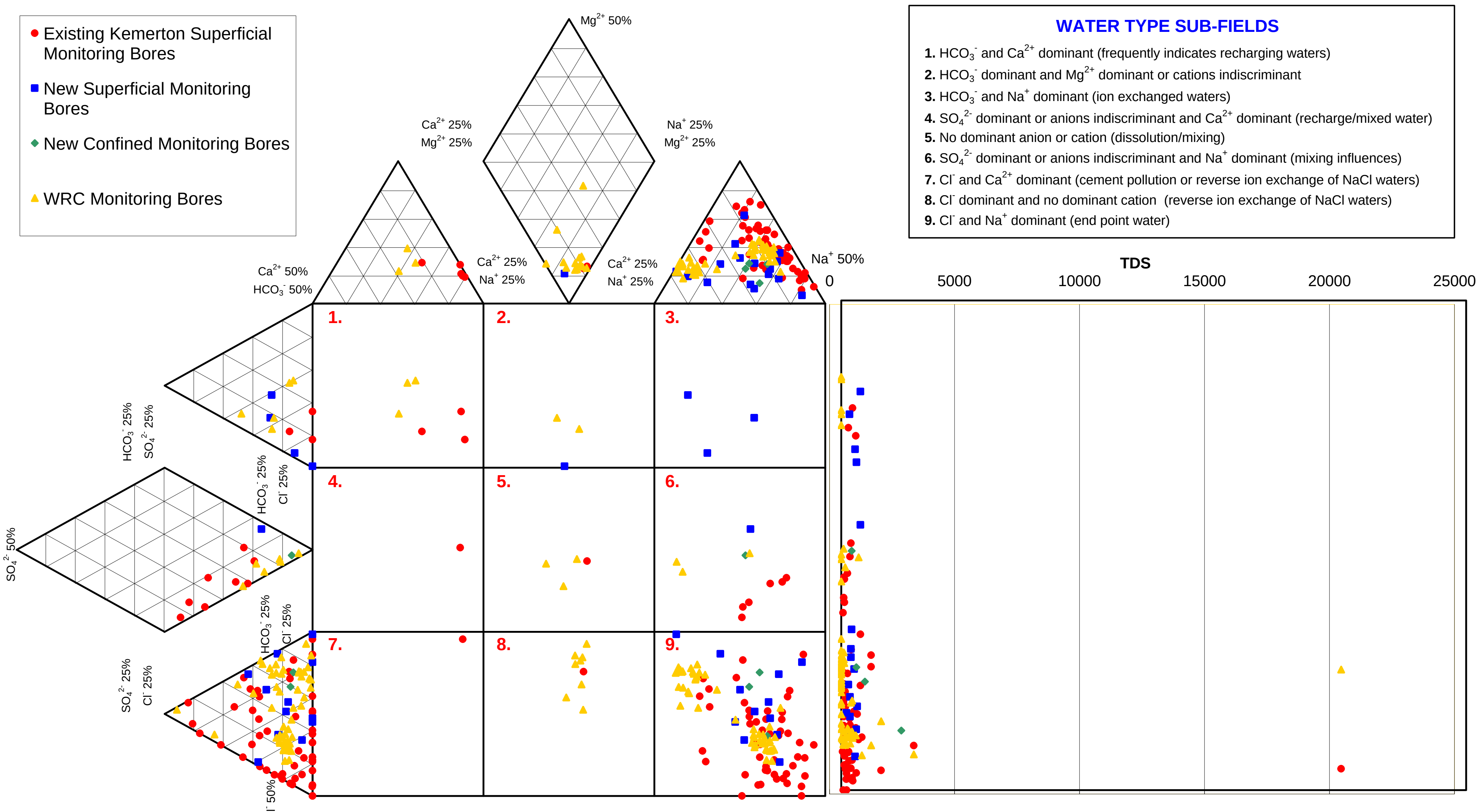
5.5.5 Nutrient Analysis

Selected bores were also analysed for total and fractional components of nitrogen and phosphorus. Table 5.10 presents the results of analysis for nutrients from selected bores and wetland sampling locations. Concentrations of total nitrogen ranged between 0.2 and 9.9 mg/L, and total phosphorus ranged between 0.0 and 0.9 mg/L. The ANZECC guidelines (2000) indicate that the desirable concentration of nitrogen and phosphorus in irrigation water is 5 mg/L and 0.05 mg/L respectively. An acceptable nitrogen concentration of 15 mg/L (short term use - 20yrs) is also specified. For aquatic ecosystems (lakes and rivers), the guideline concentrations for total nitrogen and phosphorus range between 0.4 to 1.6 mg/L and 0.035 to 0.05 mg/L respectively.

The desirable nitrogen concentration was exceeded in the two wetlands sampled (9.9 and 5.1 mg/L), and in bore S7 (9.2 mg/L), which also recorded the highest concentration of total dissolved salts. The acceptable concentration for nitrogen was not exceeded in any of the bores or wetlands sampled.

The desirable concentration of phosphorus was exceeded in all but four of the bores which were sampled, with a maximum concentration of 0.87 mg/L in bore F5. However, the ANZECC guidelines (2000) also indicate that total phosphorus concentrations can vary from more than 1 mg/L to less than 10 in polluted rivers, and total nitrogen can vary from 0.1 mg/L to greater than 10 mg/L in polluted rivers.

The seemingly high concentration of nutrients in some of the groundwater bores and wetlands is likely to be a direct result of infiltration from runoff from cleared farmland in the area. The issue of nutrient management is addressed as part of the water management strategy.



WATER TYPE SUB-FIELDS

1. HCO_3^- and Ca^{2+} dominant (frequently indicates recharging waters)
2. HCO_3^- dominant and Mg^{2+} dominant or cations indiscriminant
3. HCO_3^- and Na^+ dominant (ion exchanged waters)
4. SO_4^{2-} dominant or anions indiscriminant and Ca^{2+} dominant (recharge/mixed water)
5. No dominant anion or cation (dissolution/mixing)
6. SO_4^{2-} dominant or anions indiscriminant and Na^+ dominant (mixing influences)
7. Cl^- and Ca^{2+} dominant (cement pollution or reverse ion exchange of NaCl waters)
8. Cl^- dominant and no dominant cation (reverse ion exchange of NaCl waters)
9. Cl^- and Na^+ dominant (end point water)

aquaterra

Expanded Durov Diagram

Figure 5.2

Date: 01/05/2002

F:\jobs\211\X2\Report Figures\Word Figures\[Figure 5.2.xls]EXPANDED DUROV (1)

Project: Kemerton Water Study
Project No: 211

Description: Water Quality
Client: Landcorp

HydroCHEM 2.0

5.6 NEW SUPERFICIAL MONITORING BORES

5.6.1 New Superficial Bore Site Selection

The Phase 1 study identified the need for additional monitoring bores in the northern extension of the core and service areas, particularly in the wetland areas, although no specific locations or numbers of bores were proposed.

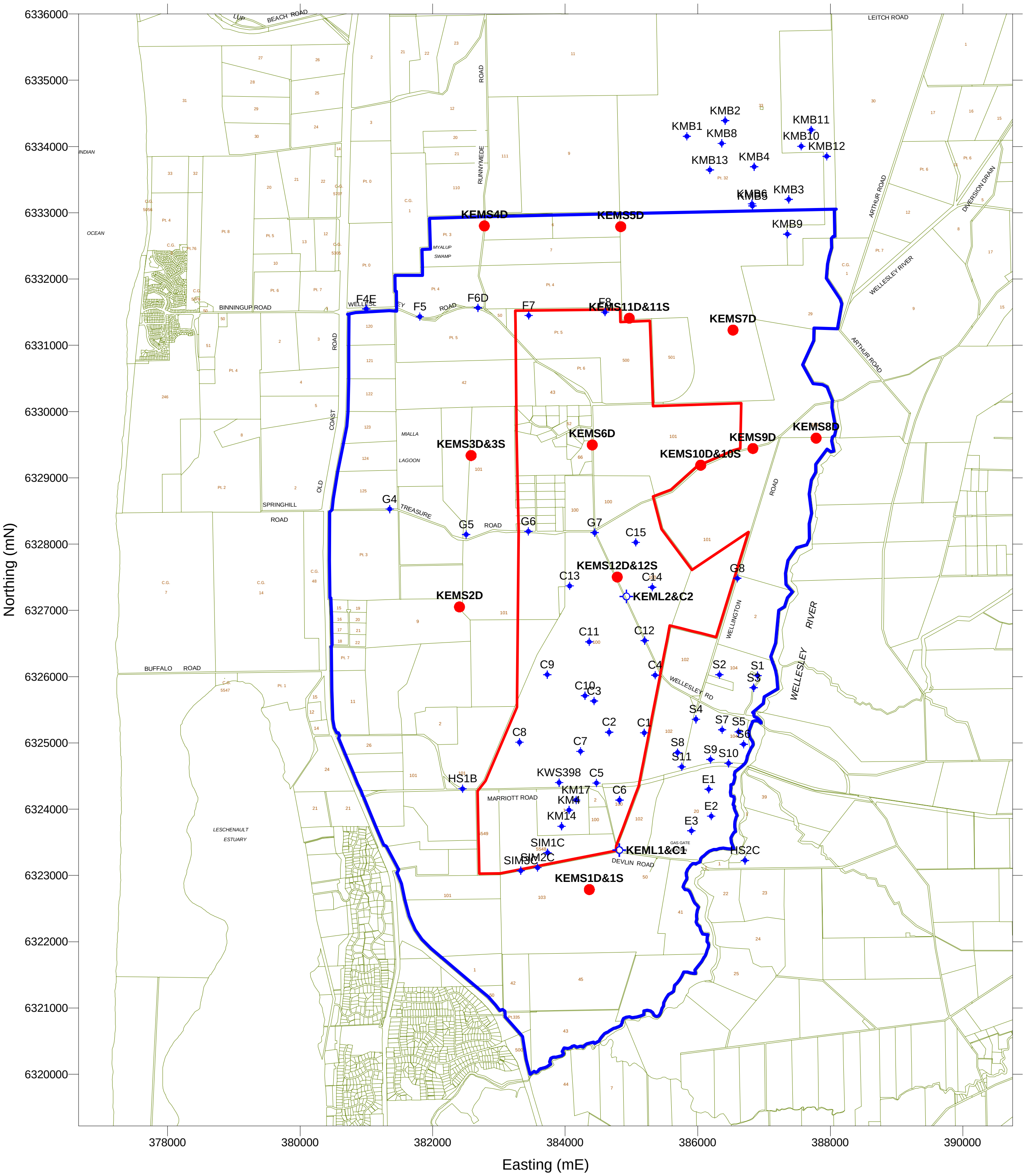
During this Phase 2 Study, an additional 17 monitoring bores were installed at 12 sites to complement the existing shallow groundwater monitoring network within the core and buffer areas. All sites had a piezometer constructed to a depth of approximately 20 m. Five of the twelve sites also had a shallow second piezometer constructed to a depth of approximately 5 m. Generally, the sites with a single piezometer were constructed in areas away from wetlands, to provide broad monitoring of the water table. Sites with a shallow and deep monitoring bore in the superficial aquifer were constructed in/adjacent to wetland areas where there is expected to be some variation in vertical heads. This variation could be due to upwards fluxes due to evaporation, or converging/diverging flow towards or away from water table lakes (and other water bodies), or due to perched water tables and water bodies.

The existing network of monitoring bores in the superficial aquifer is indicated in Figure 5.1. This figure was used as the basis for identifying, discussing and agreeing with WRC staff, locations for additional monitoring bores, based on the following criteria:

- Superficial bores to be located generally in the northern part of the expansion area, but including some bores on the eastern side in the vicinity of wetlands, where the existing network is sparse;
- Bores to be sited along existing tracks/fencelines for easy access, and in environmentally sensitive areas identified in the Phase 1 report (eg. areas of groundwater-dependent vegetation, and in areas where water-related constraints have been identified);
- Bores to be sited up-hydraulic-gradient of wetlands, and with discrete screened intervals at the base of the superficial formation and at the water table to quantify vertical hydraulic gradients and assess water quality differences;
- When siting near wetlands, the priority sites are those where there are existing gaps in the network near EPP and Conservation wetlands; and
- Confined aquifer monitor bores to be sited within about 2 km north and south of the centre of abstraction from the confined aquifers (at the MIC and Simcoa sites), and sited near existing or proposed additional superficial monitoring bores (near wetlands) to allow assessment of vertical hydraulic gradients and water quality differences.

The proposed location of additional superficial and confined aquifer monitoring bores was discussed and agreed with the government agency partners, notably the WRC. The location of the additional monitoring bores is indicated on Figure 5.3.

Kemerton Water Study (Phase 2)



Boundary of Buffer Area

Expanded Core Boundary

Existing Monitoring Bores

● New Superficial Aquifer Monitoring Bores (D-Deep; S-Shallow)

New Confined Aquifer Monitoring Bores (C-Cattamarra; L-Leederville)

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New Monitoring Bores
Figure 5.3

The bore naming protocol was discussed and agreed with the WRC, and may be summarised as follows:

Table 5.11
Bore Naming Protocol

Character string	Protocol	Description
First three digits	KEM	To signify the general Kemerton area
Fourth digit	S or L or C	To signify the aquifer that the bore is completed in:- **s**uperficial aquifer or **L**eederville aquifer or **C**attamarra Coal Measures aquifer
Fifth (and Sixth) digit	Numeral	To indicate the bore site number (sometimes needs two digits)
Additional digit	S or D	To indicate a **S**hallow or **D**eep screened horizon.

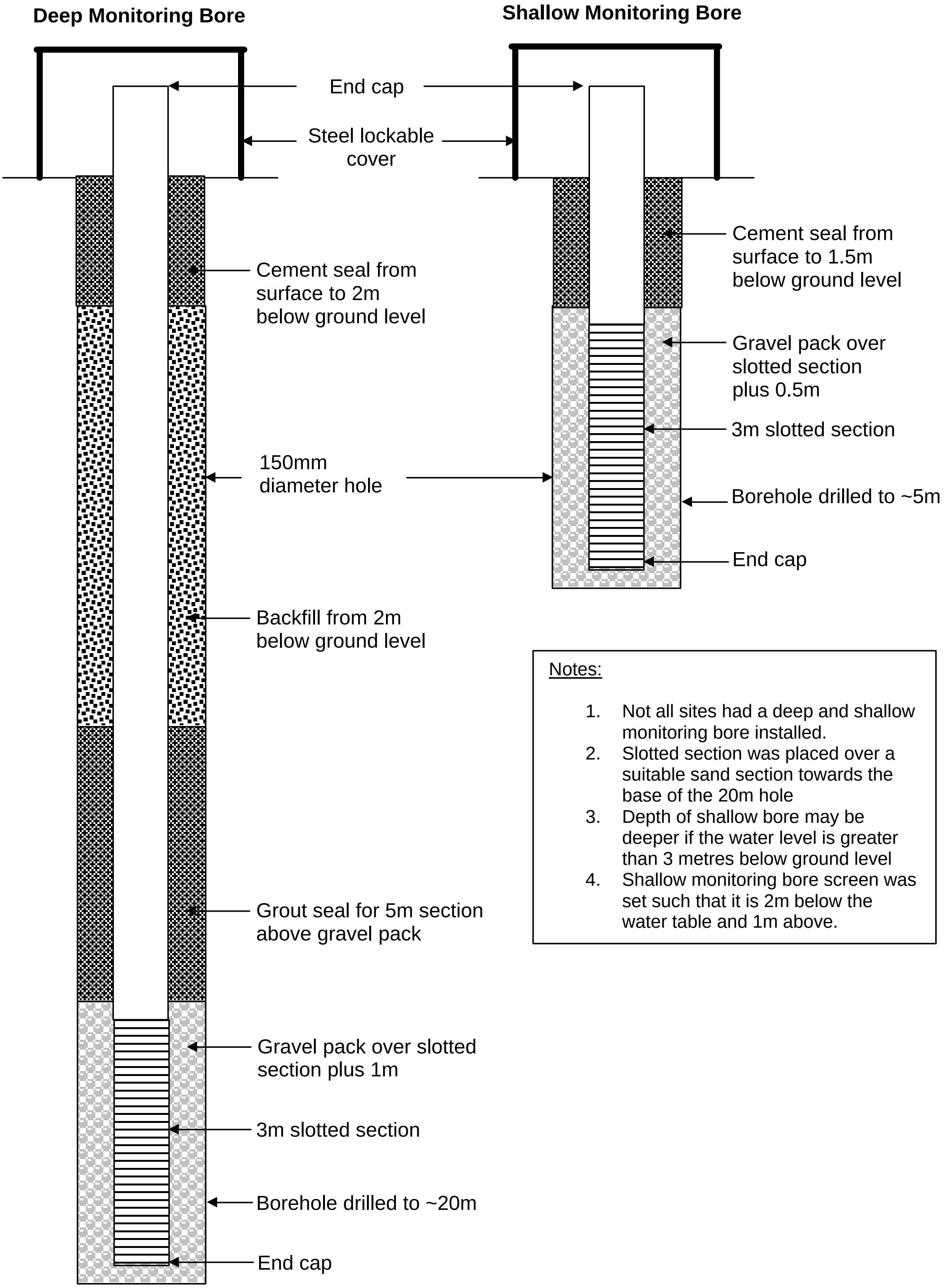
The bore design, which was also agreed with the Water and Rivers Commission, is indicated in Figure 5.4 for the shallow and deep superficial monitoring bores. The monitoring bores were installed using the mud-rotary drilling technique with environmental degradable drilling muds. Each piezometer was installed in a separate drill-hole, gravel packed and sealed with a bentonite cap placed above the monitoring interval. The deep piezometer was typically screened with a 3m slotted section towards the base of the hole over a suitable sand section. The shallow piezometer was screened with a 3 m slotted section at the base of the 5 m hole. If the water table was greater than 3m below ground level, the hole was drilled deeper and the screen set such that it was 2 m below the water table and 1 m above. The piezometers were then developed by airlifting to remove drill cuttings and drilling fluids in the borehole to allow flow from the contributing aquifer into the borehole.

5.6.2 Geology and Superficial Bore Construction

The typical shallow superficial geology encountered during drilling is summarised below:

- Grey to brown, fine to medium grained poorly sorted quartz sand, generally with organic material in the upper horizons (typically 0 - 1.5m).
- Band of dark brown fine to medium grained sand (coffee rock), of varying thickness (typically 1 -6m thick and at times was encountered over discrete intervals). On average, the coffee rock band would contain well indurated chips and was generally weakly to moderately cemented. Nodules of the indurated chips was also detected at times in other sand horizons further down the hole.
- Tamala Limestone was encountered only at one site (bore KEMS3D) at a depth of 14.5m. The limestone was pale grey, calcareous, well cemented with lenses of medium grained sand in a carbonate cement.
- The remainder of the hole to a depth of 20m was typically grey/brown fine to medium grained sand becoming more coarse grained and rounded with depth. Discrete horizons of silty/clayey sand was typically encountered over the whole horizon.
- Bores drilled further to the east close to the Wellesley River typically had more clayey sand in the upper horizons. Shell fragments and marine sediments (gastropods, bivalves etc) were also detected in these bores towards the base of the hole.

Table 5.12 presents construction and location details for the additional superficial monitoring bores constructed for the Phase 2 study. Field water chemistry measurements and airlift yields during bore development are presented in Table 5.13. Appendix A contains geological logs for each of the monitoring bores.



Notes:

1. Not all sites had a deep and shallow monitoring bore installed.
2. Slotted section was placed over a suitable sand section towards the base of the 20m hole
3. Depth of shallow bore may be deeper if the water level is greater than 3 metres below ground level
4. Shallow monitoring bore screen was set such that it is 2m below the water table and 1m above.

Schematic Design for Superficial Monitoring Bores
Figure 5.4

Table 5.12
New Superficial Monitoring Bore Construction Details

Bore ID	Easting	Northing	Ground RL (mAHD)	Date Drilled	Drilled Depth (m)	Bore Stick Up (m)	Screened Interval (mbgl)
KEMS1D	384363.6	6322787.2	12.16	20/03/01	20	0.60	17 - 20
KEMS1S	384362.8	6322786.8	12.16	20/03/01	6	0.63	3 - 6
KEMS2D	382405.0	6327052.0	11.86	21/03/01	20	0.63	17 - 20
KEMS3D	382580.0	6329337.0	8.22	22/03/01	15.5	0.52	11 - 14
KEMS3S	382580.0	6329338.0	8.22	22/03/01	6.5	0.50	2.5 - 5.5
KEMS4D	382780.0	6332801.0	12.44	23/03/01	20	0.55	15 - 18
KEMS5D	384838.0	6332790.0	16.07	24/03/01	20	0.49	17 - 20
KEMS6D	384408.0	6329496.0	15.16	23/03/01	20	0.52	17 - 20
KEMS7D	386532.0	6331229.0	16.28	29/03/01	20	0.55	17 - 20
KEMS8D	387786.0	6329599.0	11.36	27/03/01	20	0.56	17 - 20
KEMS9D	386832.0	6329443.0	14.45	27/03/01	20	0.50	17 - 20
KEMS10D	386044.7	6329190.3	14.19	28/03/01	20	0.65	17 - 20
KEMS10S	386044.5	6329190.9	14.19	28/03/01	5.5	0.65	2.5 - 5.5
KEMS11D	384967.1	6331408.4	14.86	29/03/01	20	0.57	17 - 20
KEMS11S	384966.5	6331409.0	14.86	30/03/01	5	0.50	2 - 5
KEMS12D	384785.4	6327502.7	13.96	24/03/01	20	0.53	17 - 20
KEMS12S	384785.3	6327503.1	13.96	26/03/01	5	0.51	2 - 5

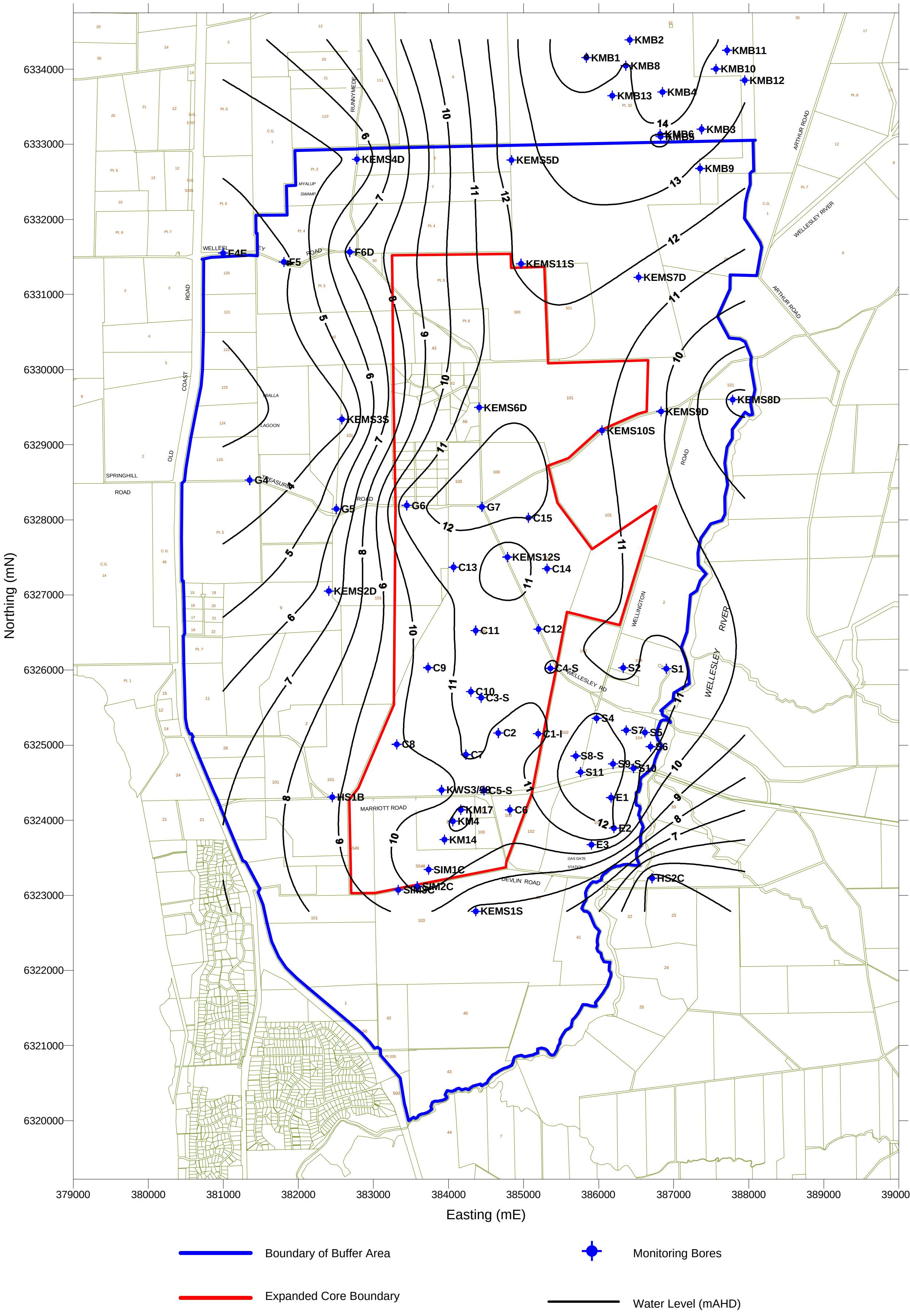
5.6.3 Superficial Aquifer Water Levels

Figure 5.5 presents a contour plot of superficial aquifer water levels constructed from monitoring of existing monitoring bores in January/February 2001, and water levels of additional monitoring bores collected in April 2001. The groundwater mound trending north south is clearly evident under the central and eastern parts of the Estate. East of the ridge, groundwater is less than 5 mbgl (metres below ground level) over most of the area, with large areas less than 2 mbgl, associated with the wetlands in this area (this is shown more clearly later, in Figure 8.3).

The installation of multilevel piezometers at five sites allows an assessment to be made of vertical groundwater gradients within the superficial formation. The difference in head between shallow and deep bores in the superficial formation, together with the likely reason why is given in Table 5.14. Data collected for existing bores with multilevel piezometers is also presented.

The presence of downward gradients in bores KEMS1 and KEMS10 suggests that it is a recharge zone, but it may also be due to the presence of semi-confining layers. Water level data from bores C3, C4 and C5 suggests the presence of a groundwater discharge zone with upward groundwater gradients. This is consistent with these bores being located in a very flat and low part of the catchment with summer groundwater levels less than 2mgbl.

However, groundwater salinity data (Section 5.4.3) shows that this area is underlain by some of the lowest salinity water, suggesting a recharge zone. This would tend to indicate a dynamic flow system, with recharge and discharge occurring at different times through the year.



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Water Levels (mAHD) Summer 2001
Figure 5.5

Table 5.13
New Superficial Monitoring Bore Water Level and Chemistry Details

Bore ID	Water Level (mbgl)	Airlift Rate (L/min)	PH	EC (mS/cm)	Description of Water Sample
KEMS1D	5.20	20	5.7	635	Grey brown translucent
KEMS1S	4.45	90	5.4	925	Light brown transparent
KEMS2D	5.53	60	6.6	610	Clear
KEMS3D	4.72	40	7.4	960	Clear
KEMS3S	4.72	1	7.4	1260	Light grey translucent
KEMS4D	7.37	10	6.9	585	Clear
KEMS5D	3.56	120	6.0	395	Grey transparent
KEMS6D	3.53	90	6.2	650	Light brown translucent
KEMS7D	4.50	60	6.6	500	Light brown translucent
KEMS8D	3.59	90	7.0	1050	Clear
KEMS9D	4.28	60	6.2	695	Light brown translucent
KEMS10D	3.32	120	6.7	680	Clear
KEMS10S	3.11	3	6.8	905	Light brown translucent
KEMS11D	2.63	60	5.9	1020	Brown transparent
KEMS11S	2.67	12	6.5	1105	Light brown transparent
KEMS12D	3.74	25	7.2	745	Light brown grey translucent
KEMS12S	3.77	1	7.1	1205	Light grey translucent

Notes:
Water level and chemistry measurements taken on 10/4/01

Table 5.14
Vertical Groundwater Gradients in Superficial Bores

Bore	Head Difference (m)	Explanation
Phase 2 Monitoring Bores		
KEMS1	0.75	Silty sand layer between 11 and 15.5m with large amounts of silty clay in some areas and layers of well cemented coffee rock
KEMS3	0.00	No difference in head
KEMS10	0.21	Presence of silty clay horizons between 9 and 17mbgl.
KEMS11	-0.04	Within Measurement error
KEMS12	-0.03	Within Measurement error
Existing Monitoring Bores		
C1	0.00	No difference in head
C2	0.16	Anomaly?
C3	-0.20	Groundwater discharge zone
C4	-0.20	Groundwater discharge zone
C5	-0.15	Groundwater discharge zone

Notes:
Head difference = shallow groundwater head - deep groundwater head

5.6.4 Superficial Aquifer Water Quality

The piezometers were developed and purged using a trailer mounted air compressor unit, allowed to recover and then sampled with a bailer. The samples were analysed for pH, electrical conductivity, total dissolved solids and major cations and anions. Detailed results of the sampling are presented in Table 5.15.

Table 5.15
Water Quality - New Superficial Monitoring Bores

Bore	pH	EC	TDS	Fe	Na	K	Ca	Mg	Cl	CO_3	HCO_3	SO_4	NO_3
KEMS1S	4.8	880	560	2.2	130	5.2	6.6	16	210	<1	5	65	0.7
KEMS1D	5.7	560	360	8.7	86	12	11	25	170	<1	55	10	5
KEMS2D	6.5	540	350	0.35	92	4.1	12	6.5	120	<1	75	20	0.9
KEMS3S	7.5	1200	770	<0.05	210	5.9	46	10	150	<1	350	100	0.5
KEMS3D	7.4	880	560	0.1	120	3.8	53	7.7	130	<1	270	25	0.4
KEMS4D	7.1	520	330	<0.05	90	3.4	19	3.3	50	<1	180	35	3.3
KEMS5D	7	320	210	0.25	48	3.3	5.6	4.1	75	<1	40	<10	0.5
KEMS6D	6.5	550	350	0.1	66	4.5	15	12	140	<1	70	<10	0.8
KEMS7D	6.6	440	290	0.25	57	3.5	13	7.4	85	<1	60	30	0.9
KEMS8D	7	960	610	<0.05	92	4.1	87	12	160	<1	280	<10	0.4
KEMS9D	6.4	610	390	2.5	79	3.9	27	9.5	95	<1	120	30	0.7
KEMS10S	6.8	820	520	2.3	150	6.2	15	8.6	150	<1	130	85	2.2
KEMS10D	7.1	610	390	0.3	680	3.7	35	11	110	<1	130	<10	0.7
KEMS11S	7.2	1000	640	0.55	160	8.3	27	17	230	<1	120	40	0.7
KEMS11D	5.9	930	600	0.95	160	3	12	16	240	<1	70	50	0.8
KEMS12S	7.2	1200	770	0.1	160	7.2	92	15	90	<1	480	80	2
KEMS12D	7.3	650	420	0.1	73	4	49	8.8	120	<1	200	<10	0.6

Notes:
All units in mg/L with the exception of electric conductivity which has been specified in μS/cm.

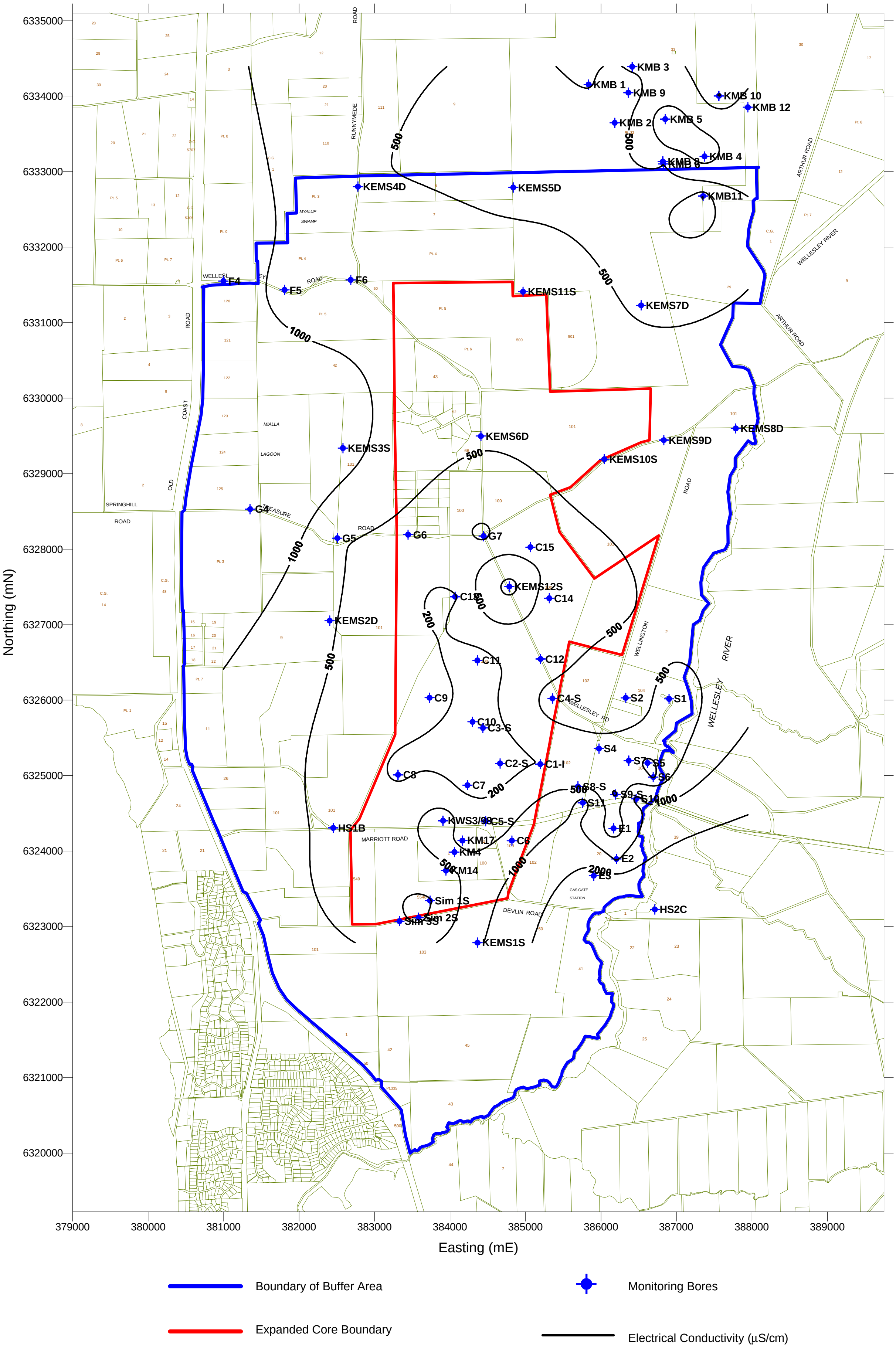
A summary of the results, with a comparison to the analysis of the existing monitoring bores is given in Table 5.16 below.

The results of sampling for the new monitoring bores are consistent with that from existing monitoring bores. The TDS/EC ratio for the new bores was also within the expected range, with an average ratio of 0.64. Figure 5.6 presents a contour map of electrical conductivity for the superficial formation using measurements from existing monitoring bores and the newly constructed monitoring bores. In the central part of the industrial area, salinity is less than 200 μS/cm (~130 mg/L TDS) which increases to over 1000 μS/cm (~650 mg/L TDS) to the east and west. This is consistent with the existence of a slight groundwater mound in the central to eastern parts of the Estate (Figure 5.5), with flow away from the mound to the east and west.

The construction of multilevel piezometers at five sites allows an assessment to be made of vertical changes in water quality in the superficial formation. The salinity of the shallow superficial bore was consistently greater than that of the deep superficial bore. For the five sites with multi level piezometers, the average salinity of the shallow system was 1000μS/cm and for the deep system, 720μS/cm. The higher salinity for the shallow bores is likely to be a result from evaporation processes concentrating salts in the upper horizons of the aquifer.

The results of sampling of the new bores are also displayed on the expanded Durov diagram discussed earlier (Figure 5.2). The plotting position of the new bores is consistent with that for the existing bores suggesting that the water is of sodium chloride type (end point waters).

Kemerton Water Study (Phase 2)



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Electrical Conductivity (mS/cm) Summer 2001

Figure 5.6

Table 5.16
Summary of Water Quality for New and Existing Superficial Monitoring Bores

Parameter	Existing Bores	New Bores
pH	3.9 - 7.9	4.8 - 7.5
Electrical Conductivity (µS/cm)	95 - 33,000	320 - 1200
TDS (mg/L)	60 - 20,000	210 - 770
Iron (mg/L)	<0.05 – 95	0.1 - 8.7
Sodium (mg/L)	9.1 - 5,500	48 - 680
Potassium (mg/L)	<0.5 – 83	3 - 12
Calcium (mg/L)	0.8 – 260	5.6 - 92
Magnesium (mg/L)	1.7 – 970	3.3 - 25
Chloride (mg/L)	20 - 10,000	50 - 240
Carbonate (mg/L)	<1	<1
Bicarbonate (mg/L)	<5 – 890	5 - 480
Sulphate (mg/L)	<10 – 520	<10 - 100
Nitrate (mg/L)	<0.2 – 18	0.4 - 5

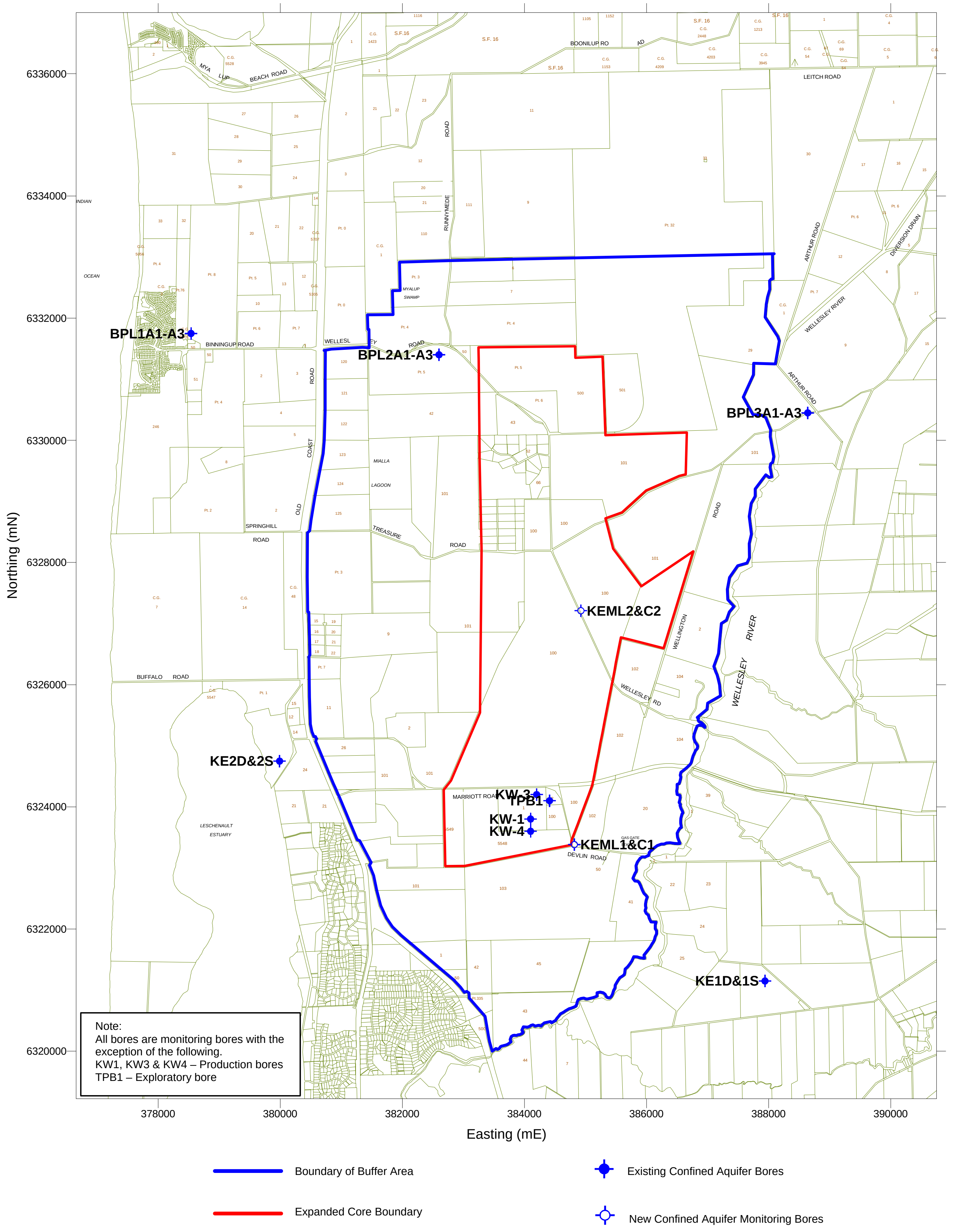
5.7 CONFINED AQUIFER HYDROGEOLOGY

5.7.1 Previous Exploration and Monitoring Programmes

There are three deep bore drilling investigations that have been completed in the vicinity of the Kemerton Industrial Area. These are:

- Binningup Borehole Line (Deeney, 1989) - six bores drilled at four sites (BPL1 to BPL4) on an east-west line across the coastal plain at Binningup, 20km north of Bunbury.
- Exploratory Drilling in the Kemerton Area (Commander, 1989) - four exploratory bores at two sites (KE1 and KE2).
- Kemerton Private (MIC) - water supply bores installed in the Cattamarra Coal Measures (KW-3 and KW-4) and Leederville Formations (KW-1). An additional exploratory bores (TPB1) was also drilled and screened across the Cattamarra Coal Measures.

A summary of the boreholes drilled as part of the above investigations is provided in Table 5.17. The location of each of the confined aquifer bores is given in Figure 5.7.



Note:
All bores are monitoring bores with the exception of the following.
KW1, KW3 & KW4 – Production bores
TPB1 – Exploratory bore

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Confined Aquifer Monitoring Bores
Figure 5.7

Table 5.17
Details of Existing Confined Aquifer Bores

Bore ID	Aquifer$^{(1)}$	Date Drilled	Easting	Northing	Top of Casing RL (mAHD)	Total Depth (m)	Screened Interval (m)	Water Level (mAHD)	Salinity (mg/L TDS)
Binningup Borehole Line									
BPL1A1	Lee	20/8/84	378539	6331748	2.95	806.5	102 - 108	2.5	890
BPL1A2	CCM	20/8/84	378539	6331748	3.39	806.5	341 - 347	3.9	2510
BPL1A3	CCM	20/8/84	378539	6331748	Abandoned	806.5	627 - 633	-	2230
BPL2A1	Lee	6/3/84	382600	6331400	16.09	600	65 - 71	3.5	850
BPL2A2	CCM	6/3/84	382600	6331400	16.15	600	268 - 274	3.8	4690
BPL2A3	CCM	6/3/84	382600	6331400	Abandoned	600	584 - 590	-	22000$^{(3)}$
BPL3A1	Lee	25/6/84	388639	6330448	13.53	800.5	114 - 120	7.8	6510
BPL3A2	CCM	25/6/84	388639	6330448	13.56	800.5	267 - 276	10.8	2500$^{(4)}$
BPL3A3	CCM	25/6/84	388639	6330448	Abandoned	800.5	-	-	-
BPL4A1	Lee	22/5/84	393139	6330348	16.03	802.6	72 - 76	9.1	8500$^{(3)}$
BPL4A2	CCM	22/5/84	393139	6330348	16.07	802.6	255 - 260	0.1$^{(2)}$	26100
BPL4A3	CCM	22/5/84	393139	6330348	Abandoned	802.6	560 - 566	-	26000$^{(3)}$
Exploratory Drilling in Kemerton (Kemerton Monitoring Network)									
KE1D	CCM	14/6/89	387939	6321148	17.45	474	321 - 327	3.09	2210
KE1S	Lee	23/6/89	387939	6321148	17.60	88.0	75 - 81	6.63	410
KE2D	CCM	7/7/89	379989	6324748	2.92	501	244 - 250	1.93	1040
KE2S	Lee	11/7/89	379989	6324748	2.75	127	121 - 127	1.74	780
Kemerton Private									
KW-1	Lee	28/7/87	384100	6323800	-	165	122 - 132 144 - 154	2.8	690
KW-3	CCM	31/8/87	384200	6324200	-	194	165 - 177	9.79$^{(5)}$	360
KW-4	CCM	13/11/87	384100	6323600	-	254	209 - 239	3.8	690
TPB1	CCM	05/9/96	384410	6324100	-	357.6	311 - 357	16.66$^{(5)}$	1300
PB2	Yarrag	24/6/88	-	-	-	250.4	228 - 250	12.7$^{(5)}$	-

Notes:
(1) Lee - Leederville Formation; CCM - Cattamarra Coal Measures
(2) Not representative of potentiometric head in the aquifer
(3) Insufficient supply to fully develop interval by airlift
(4) Salinity estimated from long-normal resistivity
(5) Water level given as metres below ground level (mbgl), not mAHD

A number of the above bores have been utilised as observation bores, and water level and quality data has been collected by the Water and Rivers Commission. Figures 5.8 and 5.9 present hydrographs for bores in the Leederville and Cattamarra Coal Measures Formations. Potentiometric head in the Cattamarra Coal Measures is generally higher than in the Leederville Formation (by approximately 1m on average). However, at locations further away from the coast (eg. at BPL4 and KE1), the potentiometric head in the Leederville Formation is on average approximately 5m higher than in the Cattamarra Coal Measures.

With the exception of one or two erroneous measurements, water levels in the Leederville Formation have remained fairly steady over the period of monitoring. Bore KE1S showed a large increase in water level in1993/94 and has since remained steady. The reason for the apparent change is not known. Water level fluctuations in the order of 0.5m can be seen in the Leederville Formation.

Figure 5.8
Groundwater Monitoring Hydrograph (Leederville Formation)

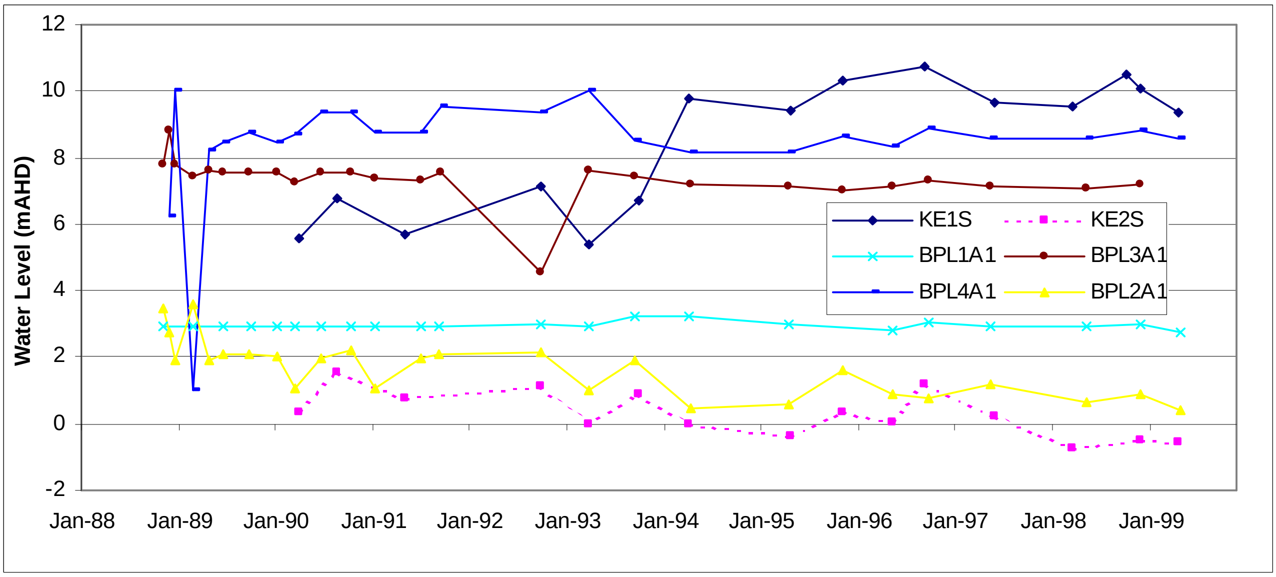
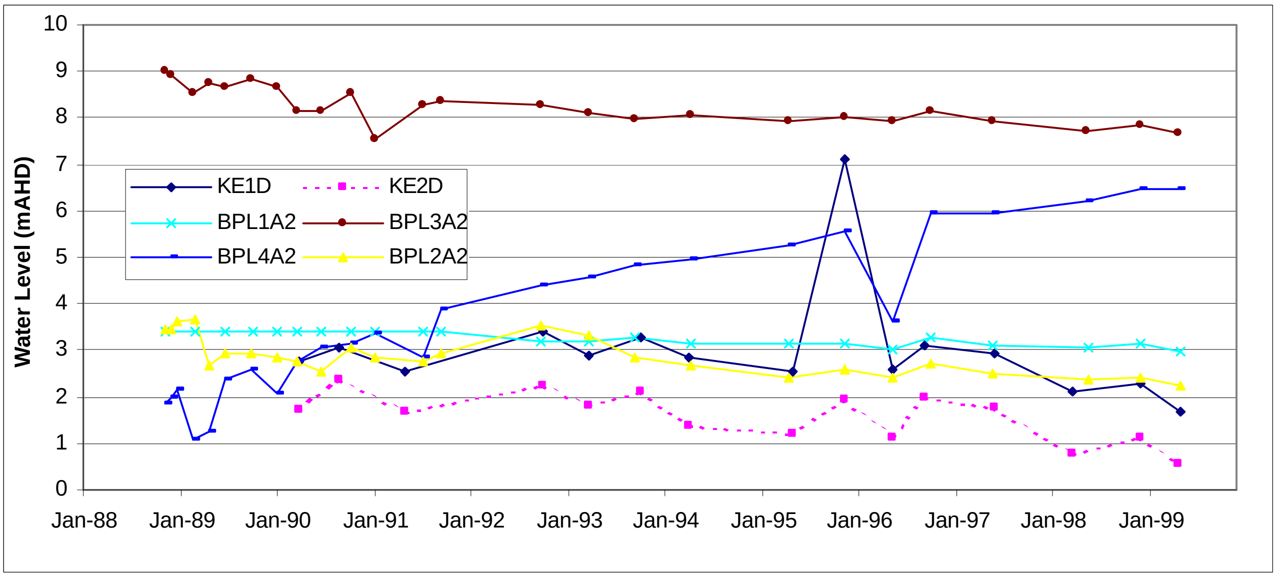


Figure 5.9
Groundwater Monitoring Hydrograph (Cattamarra Coal Measures)



Water levels in the Cattamarra Coal Measures have largely been steady over the monitoring period. The large increase in water level in bore KE1D by more than 4m in late 1995 appears to be an erroneous measurement. Bore BPL4A2 indicates a significant increasing trend over the monitoring period. However, construction records for the bore have indicated that the measured head is not representative of the potentiometric head in the aquifer (Deeney, 1989). It is likely that an adequate seal has not been established between the Cattamarra Coal Measures and the Leederville Formation, and heads are equilibrating to that in the Leederville Formation. As part of the field investigation, the confined bores were monitored for water level, the results of which are presented in Table 5.18.

Table 5.18
Water Levels for Confined Aquifer Monitoring Bores - March 2001

Bore ID	Ground Level RL (mAHD)	Water Level (mbgl)	Water Level RL (mAHD)
BPL1A1	2.75	1.50	1.25
BPL1A2	3.19	Flowing (Artesian)	> 3.19
BPL2A1	15.15	15.0	0.15
BPL2A2	15.21	12.9	2.30
BPL3A1	12.48	4.7	7.80
BPL4A2	14.90	8.0	6.90
KE1D	17.20	15.6	1.60
KE1S	17.33	3.9	13.40
KE2D	2.46	1.7	0.75
KE2S	2.34	3.3	-0.95

Note: mbgl denotes metres below ground level

5.7.2 Impacts of Existing Abstraction

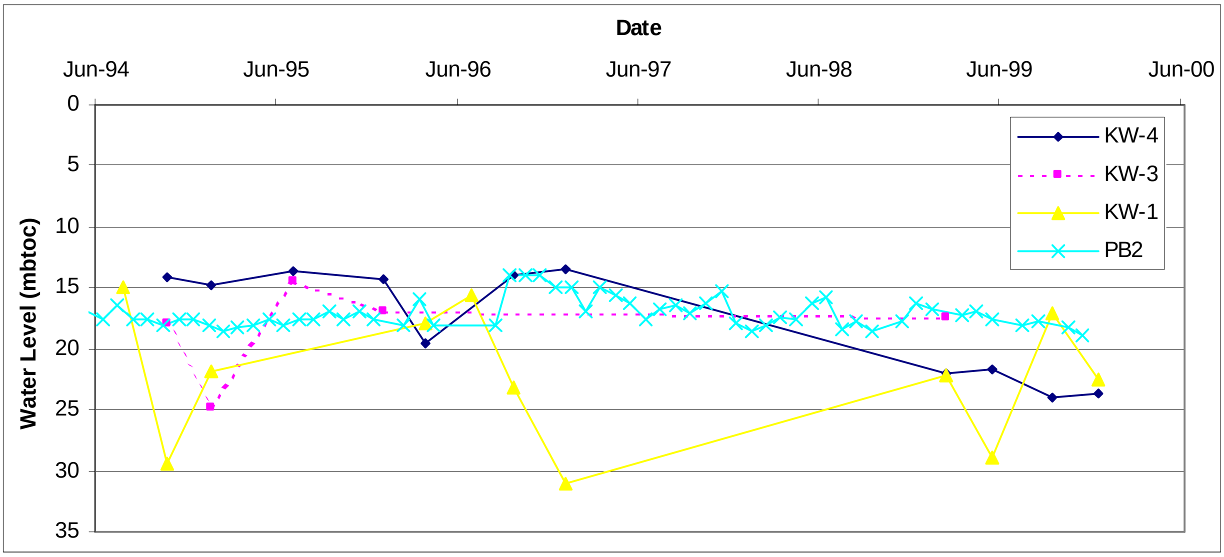
As summarised previously, MIC currently abstract from the Cattamarra Coal Measures by means of two production bores, KW-3 and KW-4, and from the Leederville Formation through KW-1. Simcoa abstract from the Yarragadee Formation from bore PB2. Historical monitoring and abstraction records from these bores were reviewed to assess impacts of groundwater abstraction to date on the respective aquifers. Figure 5.10 presents historical water level monitoring records for the three bores. It must be noted that the water level is that in the pumping bore and not the level in a nearby monitoring bore.

Water level in the pumping bore KW-1 (Leederville Formation) has varied between 15 and 30 mbgl over the period of monitoring. Bores KW-3 and KW-4 in the Cattamarra Coal Measures have varied between 15 and 25 mbgl, with bore KW-4 indicating a slightly decreasing trend in water level, due to abstraction in excess of their licence during 1998 and 1999. Fluctuations in water levels at other bores are most likely due to changes in pumping rates in the bores. The licensed allocation for MIC was exceeded in 1998 and 1999, and is likely to be reason for the slightly decreasing trend in water level. Water level in the pumping bore PB2 (Yarragadee Formation) has varied between 14 and 19 mbgl and has remained fairly steady over the period of monitoring. This data suggests that the groundwater pumping from the confined aquifers in the Kemerton area since 1994 has been sustainable.

Both MIC and Simcoa have installed monitoring bores in the superficial formation in the vicinity of the pumping bores to monitor any drawdown impacts due to abstraction. This data was reviewed to assess the impact of abstraction from the confined aquifers on water levels in the superficial formation. The hydrographs of the monitoring bores did not reveal any decreasing trends in water level indicating that the abstractions from the confined aquifers have had little impact on water levels in the superficial formation.

This abstraction and monitoring data was used in calibration of the groundwater model (see later).

Figure 5.10
Historical Groundwater Monitoring for KW-1, KW-3 and KW-4 (MIC) and PB2 (Simcoa)



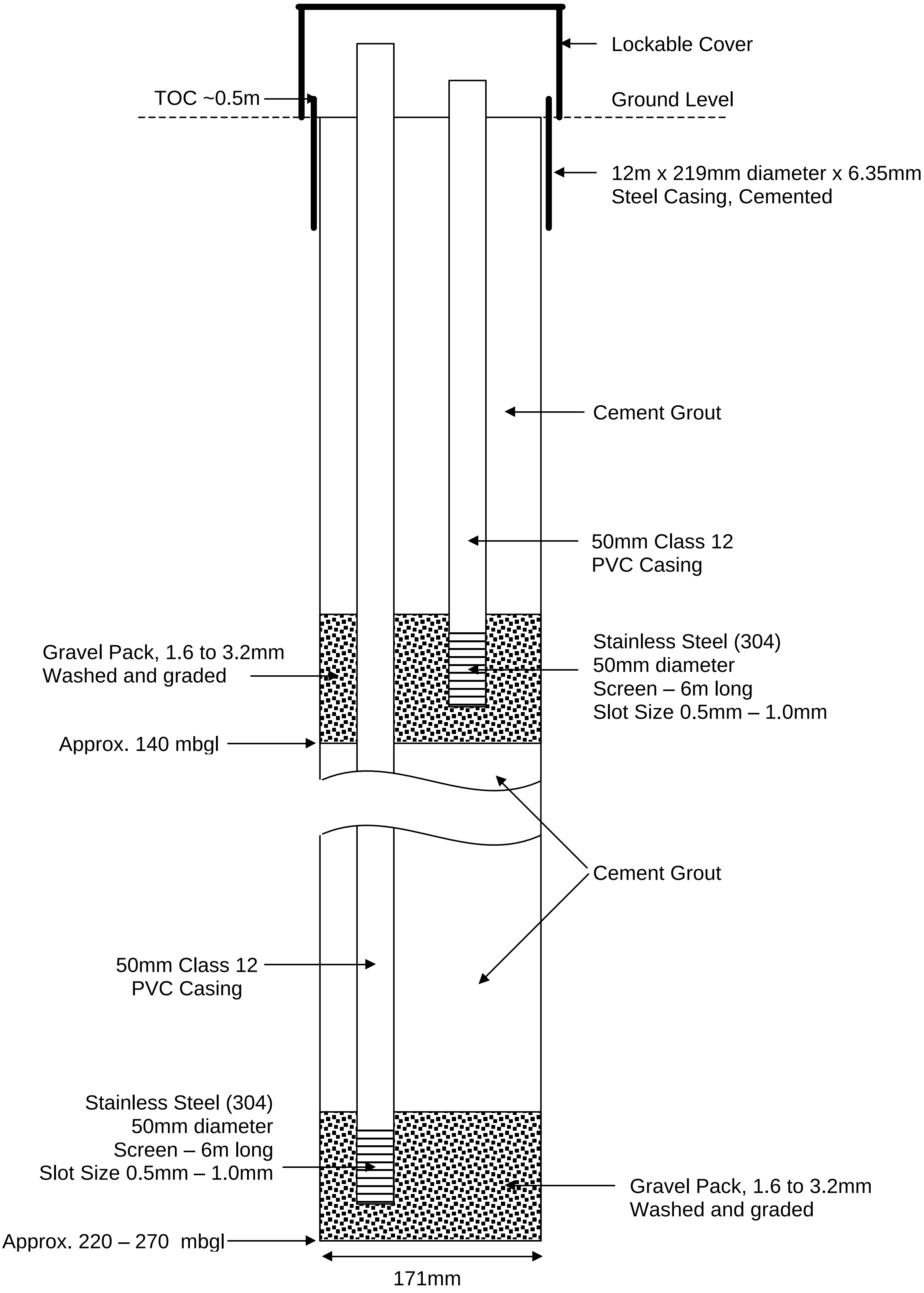
5.8 NEW CONFINED AQUIFER MONITORING BORES

5.8.1 New Confined Aquifer Monitoring Bore Site Selection

The Kemerton Phase 1 study report (BBG-Rockwater, 1999) identified the need for additional monitoring of the Leederville Formation and the Cattamarra Coal Measures to provide for more complete monitoring of water levels across the study area, and specifically to assess the impacts of production pumping in the existing Kemerton industrial complex.

The deep monitoring bore locations were chosen after discussions with the Water and Rivers Commission and LandCorp. Two sites were selected and paired piezometers were constructed at each site with monitoring intervals located within the Leederville Formation and the Cattamarra Coal Measures (Figure 5.7).

The construction detail for the paired monitoring bores is shown in Figure 5.11. The boreholes were drilled by Bunbury Drilling Company using mud-rotary drilling techniques. The upper hole diameter was drilled at 250mm to facilitate surface casing, while the remainder of the hole was drilled at a diameter of 170mm. The deep and shallow piezometers (placed within the same hole) were constructed using 50mm ND PVC class 12 blank casing with 6m stainless steel screens. The annulus surrounding the screens were gravel packed and a cement grout seal was placed between the two monitoring intervals to provide a discrete monitoring interval. After construction, the piezometers were airlifted to remove drilling fluids and fines, and to develop a hydraulic connection with the aquifer. Table 5.19 summarises the location and construction details for each monitoring bore. Construction and lithological logs are presented in Appendix B.



Schematic Design for Confined Aquifer Monitoring Bores
Figure 5.11

Table 5.19
New Confined Aquifer Monitoring Bore Details

Bore ID	Easting	Northing	Collar RL (mAHD)	Screened Interval (mbgl)	Static Water Level mAHD (10/5/01)	Water Quality TDS (mg/L)
KEML1	384817	6323382	12.269	115 - 121	-0.02	420
KEMC1				190 - 196	0.58	950
KEML2	384923	6327210	14.751	60 - 66	5.64	600
KEMC2				216 - 222	1.73	2400

Notes:
mAHD - metres above height datum, and mbgl - metres below ground level
KEML1 and KEML2 - Leederville Formation; KEMC1 and KEMC2 - Cattamarra Coal Measures

5.8.2 Deep Bore Geophysical Logging

Down-hole geophysical logging (natural gamma, resistivity and self-potential) was performed at both sites to confirm formation identification and to provide information for setting the screened interval. The results of the geophysical logging are presented in Appendix C. The geophysical logging did not include the superficial formation.

The geophysical gamma results show that the Leederville Formation generally comprises intervals of relatively low gamma readings (sands) with common intervals of high gamma readings (shales and silts). The underlying Cattamarra Coal Measures comprise relatively thick intervals of low gamma readings (thick sands) with thin intervals of high gamma readings (thin shales and silt horizons). The sand intervals within the Leederville Formation possess a higher gamma reading than the equivalent sands within the Cattamarra Coal Measures.

5.8.3 New Deep Bore Lithology and Water Levels

The lithological and bore completion logs for the two sites are presented in Appendix B.

The Leederville Formation at the bore sites generally consists of 2 to 10m thick beds of medium to coarse grained quartz sand with common feldspar. These sands are interbedded with 1 to 4m thick carbonaceous shales and silts, and at one site (KEM2) thicken markedly towards the base of the section. The Cattamarra Coal Measures (formerly known as Cockleshell Gully Formation) at the bore sites comprise generally of medium to coarse quartz sands with common garnet and cherty grains. The sequence also has uncommon thin horizons of grey shale that are generally 1 to 2 m thick.

The water levels for these bores (Table 5.19) are between -0.02 to 5.7m AHD. The levels indicate an upward potential head from the Cattamarra Coal Measures to the Leederville Aquifer of 0.6m at site KEM1 and a downward potential head of 3.8m at site KEM2. This is consistent with monitoring records from existing confined aquifer monitoring bores which have recorded downward and upward potential heads for both confined aquifers in different areas. The aquifer yields were recorded as 0.4 to 0.5 L/s during airlift development from both the Leederville Aquifer and the Cattamarra Coal Measures at both sites (Bunbury Drilling records).

5.8.4 New Deep Bore Water Quality

The monitoring bores were sampled using a Wattera pumping unit. The samples were collected in prepared plastic containers after three bore volumes of groundwater had been removed. The analysis included electrical conductivity, total dissolved solids and major cations and anions, and was performed by Australian Analytical Laboratories. The laboratory analysis results are presented in Table 5.20 below.

Table 5.20
Water Quality - New Confined Aquifer Monitoring Bores

Parameter	KEML1 (Leederville)	KEMC1 (CCM)	KEML2 (Leederville)	KEMC2 (CCM)
Total Dissolved Solids	420	950	600	2400
Iron, Fe	0.35	0.60	< 0.05	0.05
Sodium, Na	87	210	160	660
Potassium, K	12	14	7.8	30
Calcium, Ca	20	41	29	78
Magnesium, Mg	8.6	23	8.0	65
Chloride, Cl	100	310	200	1100
Carbonate, CO3	< 1	< 1	< 1	< 1
Bicarbonate, HCO3	160	250	200	320
Sulphate, SO4	20	50	30	210
Nitrate, NO3	27	0.8	0.3	< 0.2

Notes:
All units in mg/L with the exception of electric conductivity which has been specified in µS/cm.

Water quality analysis from the new confined aquifer monitoring bores indicate a groundwater salinity of 420 to 600mg/L TDS for the Leederville Formation and 950 to 2400 mg/L TDS for the Cattamarra Coal Measures. Previous confined aquifer drilling records indicate a groundwater salinity of 400 to 8,500 mg/L for the Leederville Formation and 350 to 26,000 mg/L for the Cattamarra Coal Measures.

5.8.5 Palynology Analysis

Palynology analysis was performed on shale samples collected from the drill cuttings at both sites, KEM1 and KEM2. The palynology analysis was performed by John Backhouse (UWA) to determine the stratigraphic relationships and the age of the formation that underlies the Leederville Formation. A copy of the report is included in Appendix D.

The age analysis indicates that the strata underlying the Leederville Formation is of early Jurassic age and chronologically correlated to the Cattamarra Coal Measures (formerly known as the Cockleshell Gully Formation).

6.1 CONCEPT

Artificial recharge is defined as a resource management process by which excess water and treated wastewater is directed into the ground to replenish an aquifer, either by spreading on the surface, by injection wells, or by altering conditions to increase natural infiltration. In recent years there has been an increasing acceptance that artificial recharge has the potential to provide effective and environmentally superior water and environmental management solutions to the alternatives of the long term depletion of groundwater resources (groundwater mining) and the development of surface water reservoirs.

Aquifer storage and recovery (ASR) is a specific type of artificial recharge by which water is recharged to a suitable aquifer during periods of water excess and is later recovered from the aquifer during periods of demand via the same bore.

There are both advantages and disadvantages in the use of ASR to meet water demands for the Estate. A summary is presented in Table 6.1, after Gerges (1999).

Table 6.1
Advantages and Disadvantages of Aquifer Storage and Recovery

Advantages	Disadvantages
Unconfined Aquifer • The unsaturated zone can be used for filtration and purification of injected water. • Injected water will form a lens which will float on top of the saline groundwater;	• Upconing may be a problem in highly saline aquifers; • Lens may move down the regional hydraulic gradient and slowly disperse; • Possibility of rising water tables affecting foundations • A sacrificial lens may need to be injected to allow for mixing and act as a buffer.
Confined Aquifer • Injected water will form a bubble displacing the native groundwater; • Bubble is pressurised in all directions and will not move appreciably between periods of injection and extraction; • Allows maximum recovery with sustained low salinity • Recovery from dual purpose injection/ production well; • Pressure generated from bubble will be transmitted over a large area.	• Expensive drilling operations; • High injection head at well requires infrastructure and energy if pumps involved.

6.2 GUIDELINES AND POLICIES FOR ASR

The WRC and DEP have statutory responsibility for the protection of water resources in Western Australia. The operation of an ASR scheme is likely to be subject to the following pieces of legislation (after Scatena & Williamson, 1999).

There exist also a number of non-statutory guidelines administered under the National Water Quality Management Strategy (NWQMS) for water quality protection and ecologically sustainable development. These guidelines have been jointly developed by ANZECC, ARMCANZ and NHMRC. The WRC has also produced a draft policy (WRC, 1996) which is designed to set the framework for protection of terrestrial water resources from pollution in Western Australia. Artificial recharge guidelines identifying potential problems for groundwater quality protection have been produced by Dillon and Pavelic (1996).

Table 6.2
Legislation Governing ASR

Legislation	Intent
Country Areas Water Supply Act 1947	Protection of public drinking water sources
Metropolitan Water Authority Act 1982	Protection of public drinking water sources
Metropolitan Water Supply, Sewerage and Drainage Act 1909	Protection of public drinking water sources
Rights in Water and Irrigation Act 1914	Administered by the WRC and it allocates rights to use, flow and control groundwater
Waterways Conservation Act 1976	Pollution prevention of WA's waterways
Environmental Protection Act 1986	Administered by the DEP and ensures control of water pollution
Swan Coastal Plain Lakes Environmental Protection Policy 1992	Administered by the DEP and WRC and prohibits impacts on certain wetlands identified for the policy
Health Act 1911	Administered by the Health Department of Western Australia and regulates waste disposal so it does not impact on human health resulting from groundwater contamination.

A protocol has been developed for the establishment of artificial recharge projects in Western Australia. A works approval and licences for infrastructure construction and subsequent discharge will need to be issued by the DEP. This licence will have a minimum requirement for the specification of recharge water quality criteria plus monitoring and reporting conditions. The recovery will need to be licensed with the WRC to allow abstraction from aquifers in proclaimed groundwater areas. Any proposed project will also require approval from the relevant local authority.

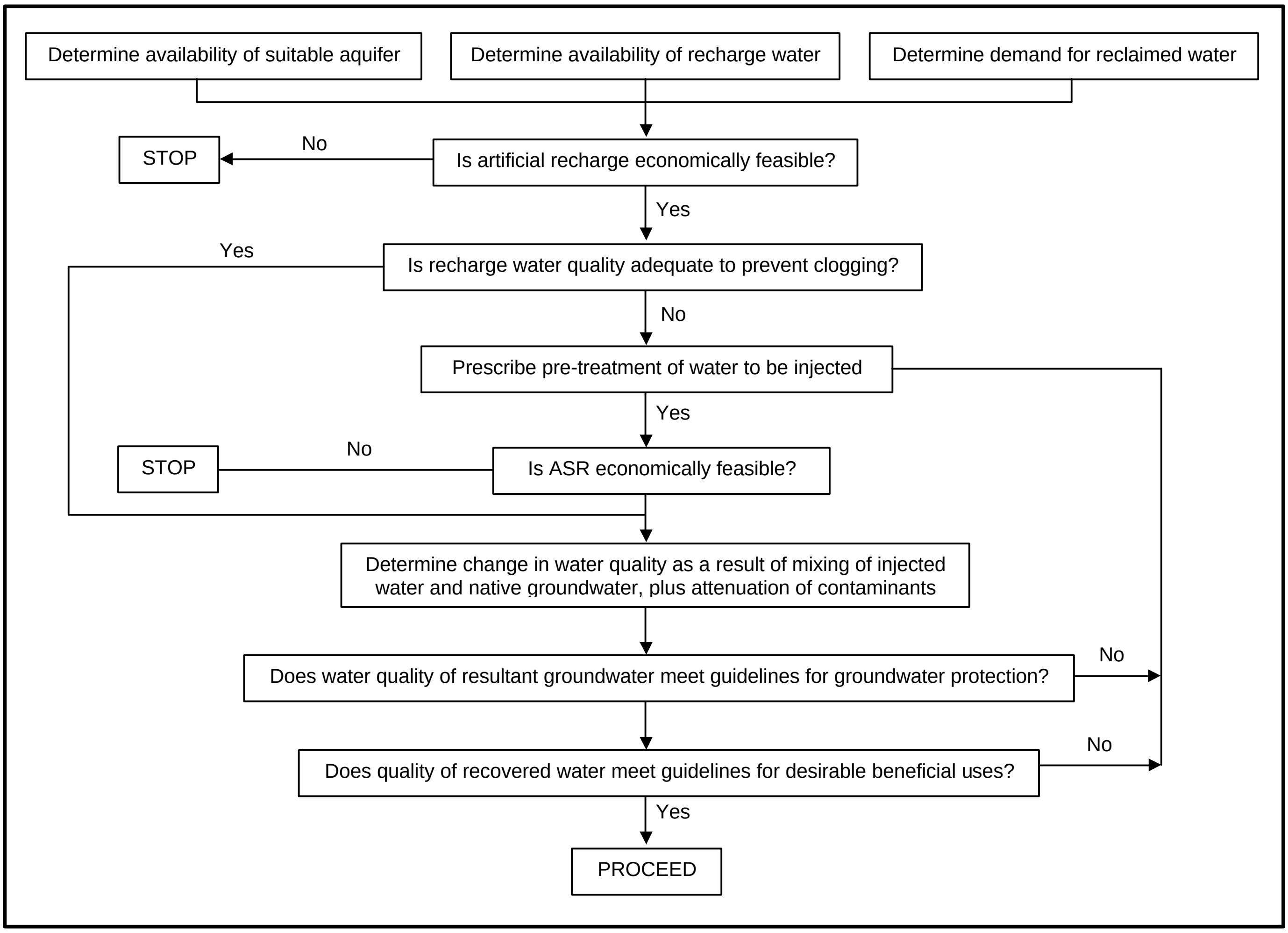
The viability of an ASR scheme largely depends on guidelines for groundwater protection. Guidelines for groundwater protection in Australia have been established as a National Water Quality Management Strategy (NWQMS, 1995a). The goal of groundwater protection is to ensure that groundwater resources can support their identified environmental values in an economically, socially and environmentally sustainable manner (Dillon, 1999). Figure 6.1 (after Dillon, 1999) presents a flow diagram summarising the procedures to be followed in determining the viability of an ASR scheme.

6.3 EXPERIENCE OF ARTIFICIAL RECHARGE IN WESTERN AUSTRALIA

Artificial recharge is used extensively in arid and temperate climates throughout the world, notably in the United States, Europe, the Middle East and Australia. There are many case histories and technical evaluations reported in the literature (e.g. Pyne 1994).

Western Australia has several operational artificial recharge schemes. For example, an artificial recharge scheme was developed by BHP Iron Ore in the early 1980's at Newman to augment the water resources of the mine and town borefields located in Ethel Gorge. This scheme relied on the infiltration of creek flood flows, controlled by Opthalmia Dam and recharged through a series of infiltration basins downstream.

Figure 6.1
Viability of an ASR Scheme



Other mining operations are using aquifer injection techniques to dispose of excess water; conceptually this is the same as the artificial recharge component of ASR. In the Pilbara, Hamersley Iron plan to use the Marra Mamba and Wittenoom formations to dispose of excess dewatering product at Nimmuldi. The Water Corporation are currently considering and/or developing schemes at Albany, Wicherina, Leonora and Jandakot in Perth (Martin et al, 2000).

Scatena and Williamson (1999) have recently undertaken a pre-feasibility study on the potential for artificial recharge in the Perth region. A summary of 13 prospective artificial recharge schemes appears in Table 6.3.

The common aims of the schemes are to manage the aquifer by maximising groundwater availability and controlling environmental impacts of existing abstractions such as declining groundwater levels and saline intrusion. Several of the proposed schemes have wastewater as the proposed source of recharge water whilst others are considering the use of stormwater or drainage water. Both surface infiltration and ASR schemes are under consideration. The superficial formation, Leederville Formation and Cattamarra Coal Measures are all under consideration as potential storage aquifers.

Table 6.3
Summary of Descriptions of Prospective Artificial Recharge Schemes in W.A.

Scheme	Description
Sewer Mining	Injection/infiltration of locally treated wastewater from conveyance mains to replenish groundwater abstracted locally for parkland watering.
Kwinana	Infiltration of treated effluent from the Woodman Point and Kwinana Wastewater Treatment Plants.
Lake Coogee	The injection of treated wastewater from the Woodman point wastewater treatment plant. Used to assist in the management of increased salinities due to over abstraction.
North Jandakot	Injection/infiltration of drainage water into the Bassendean Sand member of the superficial aquifer to compensate for increased abstraction using stringent water level and environmental criteria as controlling factors.
Cottesloe/Mosman Park/ Applecross	Injection of treated wastewater to prevent saline intrusion. May involve ASR.
Induced recharge (1) - Gwelup	Surface infiltration of surplus storm water. Excessive abstraction provides the hydraulic head difference to facilitate enhanced recharge rates.
Rockingham	Injection of wastewater or drainage water to prevent saline intrusion and opportunistic use for irrigation purposes. Managed abstraction from the Rockingham sand aquifer could be used to increase recharge from the superficial aquifer.
Perth South (1)- Jandabup	Injection of storm water to the Jandabup unit of the Leederville aquifer in the Jandakot area. The potentiometric surface is declining due to abstraction exceeding current rates of recharge.
Induced Recharge (2)	Surface infiltration of surplus/available drainage water via induced recharge in response to excessive abstraction.
Iron amelioration	Where dissolved iron concentrations are high in the superficial and Leederville aquifers; injection of oxygenated storm water will cause in situ iron precipitation, which may reduce the iron content of the recovered water. However, this may clog the aquifer.
Perth South (2) - Injection of treated wastewater	Injection of treated wastewater from the Woodman Point Treatment plant in the Yarragadee aquifer along the coastal strip. Groundwater supply in the area is limited and in high demand.
Perth South (3) - Darling Scarp	Injection to the Cattamarra Coal Measures in the lower southeastern fringe of the Darling scarp. May also recharge the Yarragadee aquifer.
Bold Park	Injection of potable waters to deep hot aquifers in the Yarragadee.

Note:
Revised from Scatena and Williamson (1999)

6.4 KEY ISSUES FOR AQUIFER STORAGE AND RECOVERY

A list of the main potential factors that may affect the feasibility of an ASR project together with the relevance to the Kemerton site appears below (Table 6.4).

Additional factors may affect the on-going operation of an artificial recharge scheme and result in the need for pre-treatment of the water and on-going maintenance of the injection wells, including:

- Suspended sediment in the injection water can cause clogging of the injection well and aquifer. This can result in the need for pre-treatment and frequent maintenance of the injection wells or seepage basins. Clogging is considered to be one of the major constraints of an ASR scheme, and may also be caused by chemical clogging by precipitation, biological clogging, gas binding and dispersion of clay minerals.
- The recovery efficiency of an ASR scheme needs to be high enough to make it economically viable. The recovery efficiency is defined as the proportion of recovered water fit for its intended use as a fraction of the injected water.

- Aeration of the water during the injection process can result in entrained air in the formation, reducing injection rates.
- Aquifer instabilities may arise from geochemical reactions resulting in the dissolution of aquifer material or precipitation of minerals near the injection well. Injection pressures need to be limited to that which will not damage the confining layers.
- Microbiological growth may inhibit the formation permeability, reducing injection rates. Such growth may be stimulated by many factors including oxygenation, sunlight and bio-chemical reactions.
- Temperature differences between the injection water and the formation water could inhibit and/or enhance injection rates.
- The injection well design should maximise the permeability of the well/receiving formation interface and minimise on-going maintenance requirements.

Table 6.4
Potential Factors Affecting ASR Feasibility at Kemerton

Issue	Relevance to Kemerton Industrial Estate
The availability of permeable geological units at an appropriate depth to accept artificial recharge.	In the case of Kemerton, the potential targets are the superficial formation, the Leederville Formation and the Cattamarra Coal Measures.
The ability of potential aquifers to accept additional recharge largely governed by the difference in pressure between the receiving formation and the pressure developed by the injection system.	At Kemerton the proximity of the water table to ground level presents a water management issue (ie.: difficulty of generating pressure difference). Groundwater storage needs to be developed and utilised without adversely affecting groundwater dependent wetlands (ie. water level constraints would apply).
Assessment of the compatibility of the quality of the injected water and the receiving formation water.	The available monitoring data suggests that the Wellesley River is brackish to saline in the Kemerton area and would probably not be suitable. Treated wastewater could be used as a low quality water recharge source.
The presence of other groundwater users that may be affected by the ASR scheme.	An ASR scheme at Kemerton would need to be managed at a catchment level with competing water users signed up and committed to the overall water management plan.
The anticipated flow-path and travel time of the injected water.	This would need to be evaluated by groundwater modelling possibly leading to a pilot development scheme. Potential issues are the loss of water to wetland areas, the contamination of potable water with lower quality injected wastewater and the mixing of fresh injected water with saline groundwater.
The regulatory and political environment associated with the approval process.	The Water and Rivers Commission as environmental regulators are promoting the appropriate use of ASR and would be consulted at each stage of the development of an Artificial Recharge scheme.

6.5 MONITORING REQUIREMENTS

Groundwater monitoring is necessary to ensure that groundwater quality is protected and that it is not impeding other abstraction sources and groundwater users in the area. It is also essential that the recovered groundwater is monitored to ensure that it is fit for its intended use.

The effect needed for groundwater monitoring will largely be dependent on potential risks of contamination associated with the scheme. The range of water quality parameters which need to be monitored for include salinity, turbidity, temperature, pH and dissolved oxygen (Dillon et al., 1999). However, this range will be dependent on site specific conditions and other contaminants associated with the recharge water which pose a risk to groundwater quality will also be included. Other parameters which will need to be monitored include pressure and flow. Other factors such as the frequency of sampling and the need for continuous monitoring devices will also need to be determined.

6.6 TECHNICAL ASSESSMENT OF ARTIFICIAL RECHARGE POTENTIAL AT KEMERTON

Water demands for the Kemerton Industrial Estate are difficult to project due to uncertainties in the nature of the industries which are likely to be established. The Burns and Roe Worley Study (1998) identified that the annual water demand may increase from the current 1 GL/yr to as high as 14 GL/yr for a high growth scenario. The medium growth scenario (10 GL/yr) equates to an average daily demand of 27 ML. Three potential sources of nominally suitable recharge water have been identified.

6.6.1 Wellesley River ASR Source

The Wellesley River has an annual average monthly flow of 6000ML, which equates to approximately 200ML/d, based on flow data collected between June 1990 and July 2000. Flow is highly seasonal, largely taking place in the winter months between June and September, when flows average about 450ML/d. A ten per cent capture of these flows would make available 45ML/d over a four-month period (or around 4GL total volume). However the Wellesley River is brackish to saline and is highly variable on a seasonal basis. On average, electrical conductivity values of 700 µS/cm during high flow periods (June to September) and 1400 µS/cm during low flow periods (October to May) have been recorded in the Wellesley River at the Juegenup monitoring station located towards the southern extent of the Kemerton development. Table 6.5 summarises observed groundwater quality in the area.

Table 6.5
Typical Groundwater Quality

Aquifer	Water Quality
superficial	Between 100 and 30,000 µS/cm but typically less than 1000 µS/cm from the recent sampling of the shallow monitoring bores
Leederville	Between 160 and 1400 µS/cm from Binningup Line bores and exploratory drilling in the Kemerton Area
Cattamarra Coal Measures	Between 400 and 4000 µS/cm from Binningup Line bores and exploratory drilling in the Kemerton Area

Note:
Measurements for Leederville and Cattamarra Coal Measures from time of drilling (1984- 89)

6.6.2 Mornington River ASR Source

No flow or quality data is available for the Mornington River. However the shallow gradient and close proximity to the Juegenup gauging station suggests that the water is of a similar quality to the Wellesley River.

6.6.3 Treated Wastewater ASR Source

Two wastewater treatment plants, one for industrial purposes and one for domestic purposes, are planned at Kemerton. The design capacity of the domestic treatment plant when commissioned is likely to increase from 1.5 ML/d to 3.6ML/d by 2010. The design capacity of the proposed industrial treatment plant will largely be dependent on the nature of the industries which are established and whether their discharge water is treatable. The artificial recharge of such water can be appropriate for lower quality purposes such as irrigation, industrial cooling and certain types of process water. As described in Table 6.3, several schemes are being considered that use storm, drain or wastewater as the source of recharge water, for example the Water Corporation scheme at Kwinana. The quality of the drainage water, and in particular the nutrient load, is an issue that would need to be addressed. The pre-treatment of the water is a major consideration for both effective recharge and the resultant quality of the stored water. Nutrient stripping in certain of the wetland areas that surround Kemerton could be incorporated into a pre-treatment process.

6.6.4 Stormwater ASR Source

There is also the potential to use urban runoff as recharge water for an ASR scheme. The expansion of the industrial core is going to result in a greater amount of urban drainage being generated. Best practice management procedures for drainage will ensure the urban water is of a quality suitable to be used as recharge water. There is also the potential to harvest excess runoff from nearby rural catchments which have been progressively cleared and developed for agriculture. If this approach is adopted, planning of the ASR scheme will need to be incorporated into the overall catchment management plan to ensure water quality objectives are met through best management practices. Other issues such as environmental flow requirements and flood risk management will also need to be considered.

6.7 ARTIFICIAL RECHARGE HYDROGEOLOGY AT KEMERTON

From Scatena and Williamson (1999) the geological units of the coastal plain (in the Perth region) are highly suited to artificial recharge due to the superficial eolian, alluvial and fluvial sediments and limestone formations overlying Phaenerozoic sedimentary sequences of sandstone, siltstone and shale……The most important aquifers occur in the superficial formations and the underlying Leederville and Yarragadee Formations.

Kemerton is situated on the coastal plain near to the confluence of the Wellesley and Mornington Rivers. The land slopes gently from east to west at a shallow gradient broken by localised dunes and a major coastal dune system, which reaches heights of around 35mAHD. The underlying geology at Kemerton consists of superficial sands resting on the Leederville Formation overlying the combined Yarragadee Formation and Cattamarra Coal Measures. The Yarragadee Formation is only present in the Bunbury area to the south, but it is probably in hydraulic connection with the top of the Cattamarra Coal Measures in the Kemerton area (Commander, 1989). The three units are in hydraulic continuity with each other, (ie. the leakage between the units varies according to the vertical permeability), although the Leederville and Cattamarra Coal Measures have lower bulk vertical permeabilities due to their layered nature (ie. the leakage between the units varies according to the vertical permeability).

The groundwater table in the superficial aquifer is mainly shallow and large areas of wetlands and groundwater dependant vegetation have developed as a result of the shallow water table in many areas. The groundwater potentiometric levels within deeper confined Leederville Formation and Cattamarra Coal Measures are also shallow.

From an environmental viewpoint, the shallow groundwater table means that groundwater abstraction has the potential to impact upon surface wetland features that are supported by groundwater. Artificial recharge has the potential to control these impacts by the prevention of long term declines in groundwater levels.

From an ASR standpoint, the shallow groundwater table results in a lack of natural storage in the unsaturated zone (above the water table) and an inability to develop adequate gravity-driven groundwater heads in recharge wells. Groundwater storage and an injection head would need to be developed by the reduction of groundwater levels through abstraction.

Further investigation would be required to develop methods to manage the potential conflicts between environmental and water resource issues. The following measures are worthy of further investigation:

- Careful selection of recharge/abstraction sites in areas of deeper groundwater;
- Exploitation of the confined Leederville and Cattamarra Coal Measures Formations in areas where the superficial aquifer is more hydraulically isolated from the wetlands by lower bulk vertical permeabilities; and
- An appropriate balance and timing of the recharge/abstraction cycle.

6.7.1 Superficial Formation ASR Potential

The superficial formation consists primarily of Pleistocene Tamala Limestone and Bassendean Sands.

Bassendean Sands

The sands consist of well-sorted, rounded quartz grains. The water table at Kemerton is close to the surface in many areas resulting in numerous surface water and wetland features (e.g. Myalup swamp and Mialla Lagoon). The aquifer has a 20 to 30m saturated thickness with large volumes of groundwater in storage. Salinity is low, generally less than 500mg/L due to direct rainfall recharge through the sandy surface soils. The shallow water table limits the potential for ASR in the Bassendean Sands.

Tamala Limestone & Associated Dune Sands

Groundwater from the Tamala Limestone discharges along the shores of Lake Preston and the Leschenault Inlet, and the swamps/wetlands in between. The aquifer contains a 20 to 30m thickness of generally fresh water (less than 1000mg/L), except west of the large coastal swamps, where salinity exceeds 2000mg/L due to a concentration of salt by evaporation. The water table is also very shallow near swamp and wetland areas, and there is limited potential for ASR in these areas.

The depth to water table exceeds 10m in the coastal dune system formed of sands associated with the Tamala Limestone. Permeability values range between 1 and 30m/d. Based on a 20m saturated aquifer thickness, this gives indicative aquifer transmissivity values of between 20 and 600m^2/d. The high transmissivity, aquifer thickness and relatively deep water table provides some potential for ASR in the higher dune areas.

6.7.2 Leederville Aquifer ASR Potential

The Leederville aquifer is a confined multi-layer groundwater flow system consisting of a maximum of 200m of interbedded sandstones, siltstones and shales. Average hydraulic conductivity reported for the Leederville Formation to the south of the Swan River in Perth (Davidson, 1995) is 0.5m/d suggesting a transmissivity value of about 100m^2/d for the Kemerton area. There is leakage from the overlying superficial aquifer.

The range in depth to water in the Leederville Formation around the Estate is summarised in Table 6.6.

Table 6.6
Range in Depth to Water - Leederville Formation

Bore	Depth to Water (m)	Distance Inland (km)	Period of Monitoring
BPL1A1	Artesian - 0.2	1.2	Nov 88 - May 99
KE2S	1.6 - 3.5	2.7	Apr 90 - May 99
BPL2A1	12.5 - 15.7	5.3	Nov 88 - May 99
KE1S	6.8 - 12.2	10.6	Apr 90 - May 99
BPL3A1	4.7 - 9.0	11.3	Nov 88 - May 99
BPL4A1	6.0 - 15.0	15.8	Nov 88 - May 99

Monitoring records from existing observation bores indicate an available potentiometric head of up to 15m in the Leederville Formation. The potentiometric head is very close to the surface in bores closer to the coast.

There is also likely to be a higher available potentiometric head along the topographic ridge which is located near bore BPL2A1. The elevation of the ground surface along the ridge is up to 40m greater than it is at bore BPL2A1, giving rise to a significant potentiometric head suitable for ASR.

Dissolved iron concentrations can be elevated within the Leederville aquifer, probably resulting from pyrite in the interbedded shale beds within the aquifer. The introduction of oxygenated recharge waters may lead to the precipitation of iron and the clogging of the recharge well and/or aquifer. Detailed hydrochemical evaluation would be required before committing to a Leederville ASR option.

6.7.3 Cattamarra Coal Measures Aquifer ASR Potential

The Cattamarra Coal Measures (previously referred to as the Cockleshell Gully member of the Cockleshell Gully Formation) consist of up to 1500m of interbedded marine fluvial sandstones and siltstones with minor coal seems. The aquifer is confined and contains large supplies of groundwater with salinity in excess of 2000mg/L.

The range in depth to water in the Cattamarra Coal Measures around the Estate is summarised in Table 6.7.

Table 6.7
Range in Depth to Water - Cattamarra Coal Measures

Bore	Depth to Water (m)	Distance Inland (km)	Period of Monitoring
BPL1A2	Artesian - 0.4	1.2	Nov 88 - May 99
KE2D	0.7 - 2.3	2.7	Apr 90 - May 99
BPL2A2	12.5 - 13.9	5.3	Nov 88 - May 99
KE1D	10.3 - 15.8	10.6	Apr 90 - May 99
BPL3A2	4.6 - 6.0	11.3	Nov 88 - May 99
BPL4A2	10.1 - 15.0	15.8	Nov 88 - May 99

The potentiometric head in the Cattamarra Coal Measures is typically around 1m higher than it is in the Leederville Formation. As with the Leederville Formation, the piezometric head in bores close to the coast is almost at the ground surface, and at times experience artesian flows. A transmissivity value of 400m^2/d and a storativity value of 0.0028 have been derived from a pumping test in the area (Rockwater, 1996). As discussed earlier for the Leederville Formation, there is the potential for higher potentiometric heads along the topographic ridge which is located approximately 6.5km inland (east of bore BPL2A2).

As for the Leederville Formation, the confined nature of the Cattamarra Coal Measures is likely to lead to a reduced chemical environment, and the introduction of oxygenated recharge waters may lead to the precipitation of iron and the clogging of the recharge well and/or aquifer. Detailed hydrochemical evaluation would be required before committing to an ASR option for the Cattamarra Coal Measures.

6.8 MANAGED ARTIFICIAL RECHARGE RATES

Logan's approximation to the steady state flow to a well equation can be adapted to give a tentative estimate of ASR recharge rates by assuming a representative depth to water table (available 'draw-up') and transmissivity of the aquifer. Experience elsewhere suggests that the actual long-term recharge achieved is about one third of the theoretical maximum and is shown by Logan's approximation:

$$T = \frac{1.2Q}{s}$$

Where T = transmissivity (m^2/d)
Q = injection rate (kL/d)
s = 'draw up' (m)

Potential recharge rates for a single bore in each of the three main aquifers are summarised in Table 6.8 below. The projected recharge rates are based on confined aquifer water levels of 30mbgl and unconfined levels of 15mbgl and suggest that acceptable recharge rates could be obtained.

Table 6.8
Managed Artificial Recharge Rate Predictions

Aquifer	Assumed Depth to Water Table (m)	Assumed Transmissivity (m^2/d)	Theoretical Recharge Rate (kL/d)	Projected Long Term Recharge Rate (kL/d)
superficial formation	15	100	1,250	420
Leederville Formation	30	100	2,500	1,000
Cattamarra Coal Measures	30	400	10,000	3,330

Theoretical calculations of the potential recharge into the superficial formation, Leederville Fm and Cattamarra Coal Measures suggests that annual input into boreholes spaced 2km apart could be in excess of 50 GL/yr. This theoretical calculation assumes that sufficient available storage volume exists in a dewatered aquifer system. In reality, the volume of recharge that could take place annually depends on available storage and available water resources.

6.9 CONCLUSIONS AND RECOMMENDATIONS OF ASR

Managed artificial recharge, either via infiltration or by injection is being considered at several locations in Western Australia as a means of maximising aquifer yields and/or managing the environmental impacts of groundwater abstraction. An ASR scheme can produce significant benefits for water resource development and management.

Two wastewater treatment plants planned for Kemerton represent possible sources of recharge water to the aquifer providing that there is a demand for relatively low quality, non potable water. Natural pre-treatment of recharge water could take place through Multiple Use category wetlands.

The Wellesley and Mornington Rivers are further possible sources of recharge water. In the Kemerton area, river water quality is good enough during winter to be suitable for injection into confined aquifers around Kemerton. The volumes potentially available are not substantial, however, and there would be impacts on ecological communities downstream of any river abstraction point. These issues need further detailed consideration before the rivers could be regarded as a realistic potential source of recharge water.

Enhanced runoff from the impermeable surfaces of the industrial estate would provide some of the most suitable ASR sources, and direct infiltration of this water is consistent with water sensitive design principles. Best management practices must be implemented to manage water quality, and potential impacts on wetlands.

The superficial formation, Leederville Formation and Cattamarra Coal Measures all represent potential storage aquifers, although the generally shallow depth to groundwater in each means that the groundwater storage potential may need to be further developed by abstraction. However, water levels in the superficial deposits are in hydraulic continuity with wetland areas which could be impacted by a reduction in groundwater levels (or an increase if excessive volumes are recharged). Artificial recharge could potentially be used to reduce such impacts by: the location of recharge/abstraction sites in areas of deeper groundwater (ie. away from wetlands); the exploitation of the confined Leederville and Cattamarra Coal Measures Formations where the effects on the superficial aquifer may be buffered from the wetlands by lower bulk vertical permeabilities; and an appropriate balance and timing of the recharge/abstraction cycle.

There are no identified sources of good quality water for ASR in the Kemerton area. The local rivers are brackish to saline and the wastewater treatment plant would also provide brackish quality water. Enhanced runoff from clearing and paved surfaces on the estate would provide relatively good quality water, which could be easily infiltrated in many areas at source, consistent with water sensitive design principles. Despite limitations, any or all of these sources could be used in artificial recharge schemes, with potential annual volumes of around 1 to 4 GL. This volume can be compared to the high water demand case for the industrial Estate of 14 GL/annum. The effect of this potential for an ASR scheme will be assessed through groundwater modelling (Section 8).

7.1 EXISTING ENVIRONMENT

7.1.1 Vegetation

The vegetation of the Kemerton Industrial Estate has been described previously by Muir (1999), who based his vegetation mapping of the Estate on aerial photograph mosaics, with associated ground truthing, and on previous work undertaken by Mattiske (1993), Semeniuk (1987) and Hill *et al* (1996). The Kemerton Industrial Estate is associated with four vegetation complexes (Heddle *et al.,* 1980). The vegetation community distribution is shown in Figure 7.1.

The western fringe of the Estate is associated with the Yoongarillup Vegetation Complex, which is dominated by Tuart (*Eucalyptus gomphocephala*) Tall Woodland to Open Forest with areas of Peppermint (*Agonis flexuosa*). This complex is the only example of extensive Tuart woodland within the Darling System. Most of the Tuart belt fringing the western side of the study area has been cleared for agricultural purposes and/or has been heavily grazed. The majority of the wetlands from the study area occur on the western side of the Park and are predominantly Swamp Paperbark (*Melaleuca rhaphiophylla*) and/or Moonah (*Melaleuca preissiana*) fringed wetland, often with sedgelands of *Baumea articulata* or *Juncus pallidus*.

The central or ridge portion of the Estate, which is immediately to the west of the Estate core area, is dominated by the Karrakatta Complex - Central and South, with Karrakatta yellow phase sands with Tuart, over Peppermint, Bull Banksia (*Banksia grandis*), Jarrah (*Eucalyptus marginata*) and Marri (*Corymbia calophylla*), with Tuart completely replaced by Jarrah on the deeper sands and Marri becoming more frequent on the localised moister areas.

The third and most prominent complex associated with the Estate is the Bassendean Complex - Central and South, which extends from the central ridge east towards the Wellesley River. The complex includes Jarrah/Banksia dominated woodland, with *Melaleuca preissiana/M. rhaphiophylla Eucalyptus rudis* fringing damplands and moister area and substantial areas of species rich damplands including *Pericalymma ellipticum/Kunzea ericifolia/Hypocalymma angustifolium/Astartea fascicularis* overlying the eastern fringe of the Park.

Small areas of the Vasse Vegetation Complex occur in the northwestern portion of the Estate, with wetlands dominated by a mixture of closed scrub of *Melaleuca* spp., occasionally with a fringing woodland of Flooded Gum (*Eucalyptus rudis*) and *Melaleuca* spp.

7.1.2 Wetlands

Several permanent, seasonal and ephemeral wetlands occur within the Kemerton Industrial Estate, predominantly over the western and eastern margins (Figure 7.2). Some of these are gazetted Environmental Protection (Swan Coastal Plain Lakes) Policy (EPP) (1992) wetlands and are protected from activities including draining, filling, mining, polluting or alteration to the hydrological function of the wetland. The majority of the wetlands are either groundwater fed basins (sumplands and damplands) or part of the seasonally waterlogged palusplain (damplands).

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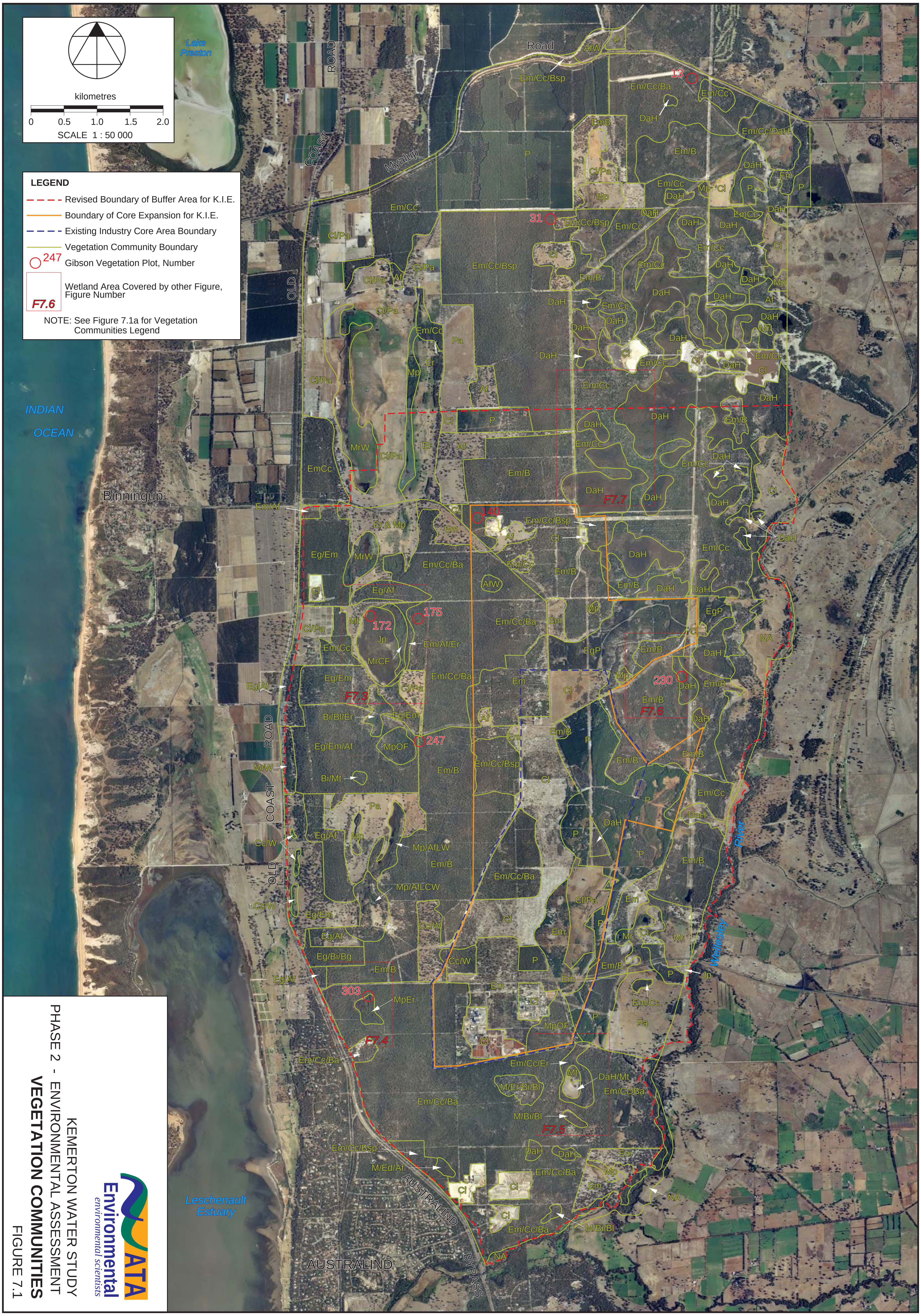

LEGEND

- - - Revised Boundary of Buffer Area for K.I.E.

— Boundary of Core Expansion for K.I.E.

- - - Existing Industry Core Area Boundary

— Vegetation Community Boundary

○ 247 Gibson Vegetation Plot, Number

F7.6 Wetland Area Covered by other Figure, Figure Number

NOTE: See Figure 7.1a for Vegetation Communities Legend

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PHASE 2 - ENVIRONMENTAL ASSESSMENT
VEGETATION COMMUNITIES
FIGURE 7.1

See Figure 7.1 for Vegetation Communities Map

Af - Scattered or Parkland Cleared *Agonis flexuosa*
AfW - *Agonis flexuosa* dominated Woodland
Bi/Bl/Er - *Banksia ilicifolia/Banksia littoralis//Eucalyptus rudis* Open Woodland
Bi/Bl- *Banksia ilicifolia/Banksia littoralis* dominated Woodland
Bl/Mt - *Banksia littoralis/Melaleuca teretifolia* Shrubland
CcOW - *Corymbia calophylla* Open Woodland
CcW - *Corymbia calophylla* Woodland
DaH - Species rich Dampland Heath
DaH/Mt - Species rich Dampland Heath with *Melaleuca teretifolia* Low Open Shrubland
EgP - *Eucalyptus globulus* Plantation
Eg/Bi/Bg - *Eucalyptus gomphocephala/Banksia ilicifolia/Banksia grandis* Woodland
Eg/Em - *Eucalyptus gomphocephala/ Eucalyptus marginata* Open Forest
Eg/Em/Af - *Eucalyptus gomphocephala/Eucalyptus marginata* dominated Woodland over scattered *Agonis flexuosa*
Eg/Af - *Eucalyptus gomphocephala* Tall Open Woodland with scattered *Agonis flexuosa*
Er - Scattered or Parkland Cleared *Eucalyptus rudis* trees
Em - Scattered Trees or Parkland Cleared *Eucalyptus marginata*
Em/Af - *Eucalyptus marginata/Agonis flexuosa* Woodland
Em/Af/Er - *Eucalyptus marginata/Agonis flexuosa/Eucalyptus rudis* Woodland
Em/B - *Eucalyptus marginata/Banksia attenuata/Banksia grandis* Woodland
Em/Cc/Ba - *Eucalyptus marginata/Corymbia calophylla/Banksia attenuata* Woodland
Em/Cc/Bsp.- *Eucalyptus marginata/Corymbia calophylla* /Mixed Banksia species Woodland
Em/Cc/daH - Scattered *Eucalyptus marginata/Corymbia calophylla* with species rich dampland Heath
Em/Cc/Er - *Eucalyptus marginata/Corymbia calophylla/Eucalyptus rudis* Tall Woodland
Em/Cc - *Eucalyptus marginata/Corymbia calophylla* Woodland
Jp - *Juncus pallidus* dominated Sedgeland
M/Bi/Bl- *Melaleuca* sp*./Banksia ilicifolia/Banksia littoralis* Low Woodland
M/Ed/Af - *Melaleuca* sp*/Eucalyptus decipiens/Agonis flexuosa* Closed Woodland
Mp - Scattered or Parkland Cleared *Melaleuca preissiana* trees
Mp/Er - *Melaleuca preissiana/Eucalyptus rudis* Closed Woodland
MpOF - *Melaleuca preissiana* Open Forest
Mp/AfLCW - *Melaleuca preissiana/Agonis flexuosa* Low Closed Woodland
Mp/AfLW - *Melaleuca preissiana/Agonis flexuosa* Low Woodland
Mr - Scattered or Parkland Cleared *Melaleuca rhaphiophylla* trees
MrCF - *Melaleuca rhaphiophylla* Closed Forest
MrW- *Melaleuca rhaphiophylla* Woodland or Fringing Woodland
Mt - *Melaleuca teretifolia* Closed Shrubland

Cl - Cleared
Pa - Pasture
Cl/Pa - Cleared/Pasture
NA - Not Assessed
P - *Pinus radiata* Plantation

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VEGETATION COMMUNITIES LEGEND

FIGURE 7.1a

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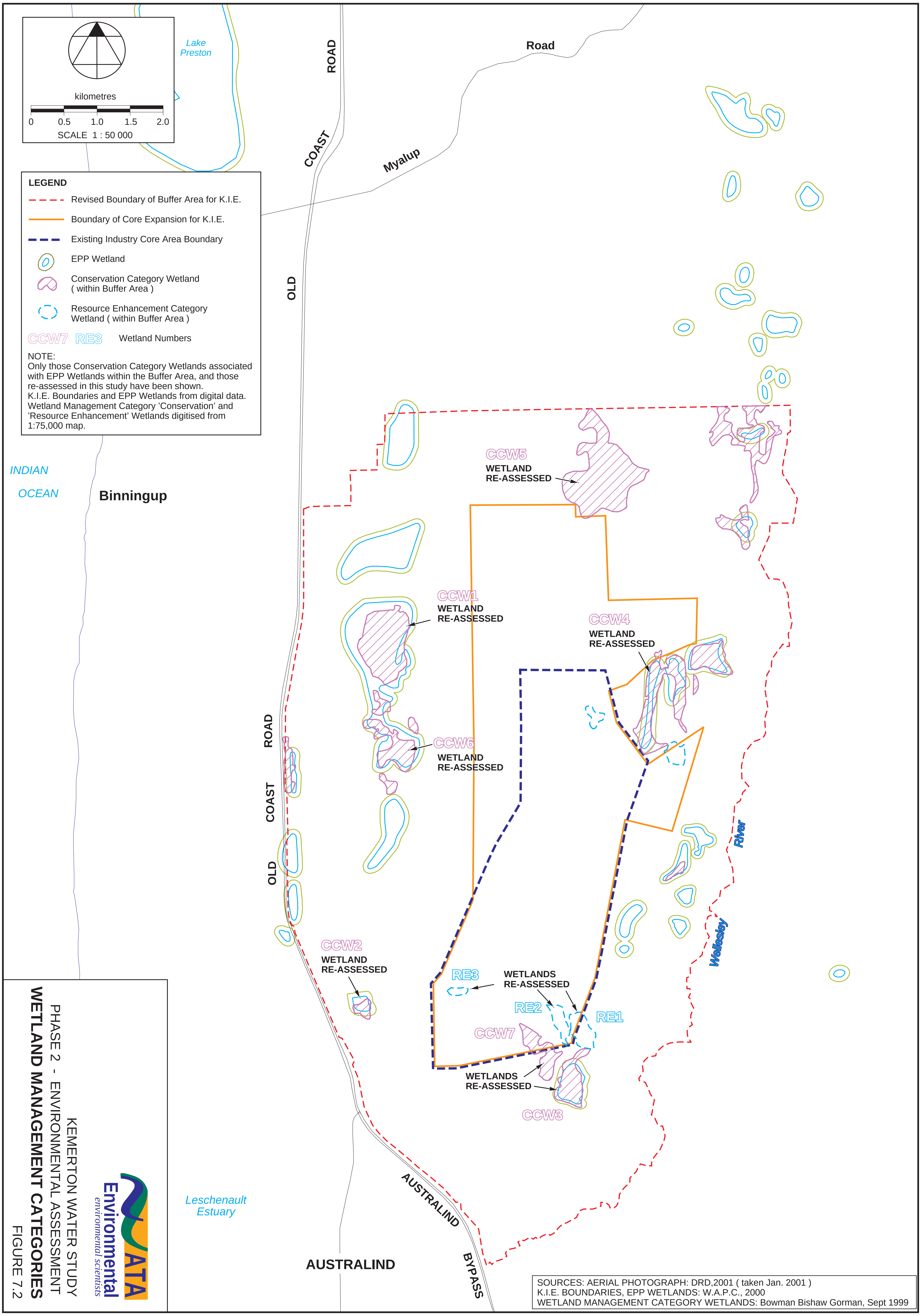

NOTE:
Only those Conservation Category Wetlands associated with EPP Wetlands within the Buffer Area, and those re-assessed in this study have been shown.
K.I.E. Boundaries and EPP Wetlands from digital data.
Wetland Management Category 'Conservation' and 'Resource Enhancement' Wetlands digitised from 1:75,000 map.

SOURCES: AERIAL PHOTOGRAPH: DRD,2001 (taken Jan. 2001)
K.I.E. BOUNDARIES, EPP WETLANDS: W.A.P.C., 2000
WETLAND MANAGEMENT CATEGORY WETLANDS: Bowman Bishaw Gorman, Sept 1999

KEMERTON WATER STUDY
PHASE 2 - ENVIRONMENTAL ASSESSMENT
WETLAND MANAGEMENT CATEGORIES
FIGURE 7.2

BSD Consultants mapped 17 EPP wetlands within the Kemerton Industrial Estate, most of which lie on the western side of the Estate (Figure 7.2). No EPP wetlands occur within the Core Area (BSD, 1997).

In addition to the EPP wetlands, the Water and Rivers Commission (WRC) has previously identified and assigned provisional management categories to each of the wetlands within the Kemerton Industrial Estate. These management categories include Conservation Category (CC), Resource Enhancement (RE) and Multiple Use (MU) wetland classifications.

Several Conservation Category and Resource Enhancement wetlands occur on the site, with the majority of the Conservation Category wetlands situated on the Gwalia Consolidated Ltd (Kemerton Silica Sands) lease in the northeast portion of the Estate, beyond the boundary of the Expanded Core Area (ECA). The Kemerton suite of wetlands is regarded by WRC (A. Hill, *pers.comm.*) as one of the largest remaining aggregations of relatively undisturbed wetlands within an uncleared block within the largely cleared Swan Coastal Plain. The Conservation and Resource Enhancement Management Category Wetlands within the Estate need to be protected from any disturbance and surrounded by an appropriate buffer zone. There are no constraints associated with the development of Multiple Use category wetlands.

Groundwater abstraction by industries operating within Estate have the potential to cause drawdowns in the superficial groundwater aquifer, which could impact on the wetlands. Although the wetlands are groundwater-dependent ecosystems, they are also supported by surface runoff and direct rainfall. The presence of Conservation and Resource Enhancement category wetlands is a potential constraint to development of the Estate, and abstractions will need to be managed to avoid impacting on CC and RE category wetlands. As this is likely to constrain the location of abstraction bores as well as the amount of groundwater abstracted within the Estate it is important that the wetland management categories are verified.

Seven Conservation Category and three Resource Enhancement category wetlands within the Estate were revisited and re-assessed using the questionnaire from the EPA Bulletin 686 as part of this study, and where necessary reclassified and boundaries redrawn.

7.2 ECOLOGICAL AND CONSERVATION VALUES OF VEGETATION AND WETLANDS

Ecological values have traditionally been attributed to large-scale species assemblages with an assumption that particular relationships and ecological processes are interconnected. In relation to EWRs, ecological values are defined as:

"*the natural processes occurring within water dependant ecosystems and the biodiversity of these systems*" (ARMCANZ, 1996).

In order to determine the EWR of a particular ecosystem, the ecological values of the ecosystem need to be identified. For ecosystems that are relatively undisturbed, these values are easily identified, whereas for ecosystems that have already undergone disturbance as a result of changes in land use, the values are not so easily identified.

The conservation values of the Estate were estimated during the Phase 1 Biological Assessment (Muir, 1999). Areas of inherent conservation value included those areas with high species richness and intact, unlogged forest woodland. Other areas included wetlands, particularly EPP wetlands and perched wetland sites containing Declared Rare or Priority Flora. Other areas of regional ecological significance include two floristic community types - Southern *Eucalyptus gomphocephala, Agonis flexuosa* woodland (Type 25) and *Banksia ilicifolia* woodland (Type 22). These communities are typically not well represented within National Parks or Conservation Reserves and are therefore regarded as conservation significant.

No Threatened Ecological Communities (TECs) are known from the Estate (English and Blyth, 1997).

Wetlands with the highest ecological values are those which collectively support a diverse wetland flora and are classified as Conservation Category wetlands. Within the Estate this includes several wetlands assessed as part of this study, the most important of which is Mialla Lagoon (CCW1, Figures 7.1 and 7.2), which had the highest score of wetlands re-assessed using the 686 Bulletin questionnaire. EPP wetlands were identified on the basis of their hydrological status and size in December 1991, and are not categorised as such on the basis of their ecological values.

7.3 WETLANDS MANAGEMENT CATEGORY REASSESSMENT

7.3.1 Reassessment Methodology

Wetlands with an existing Conservation Category were selected for re-assessment and revisited between the 28th and 30th March, 2001 and between the 1st and 3rd October, 2001. Several Resource Enhancement Category wetlands within the Expanded Core Area were also re-assessed during the latter visit (Table 7.1). Time, inaccessibility and budgetary constraints made the task of re-assessing all Conservation Category Wetlands within the Estate unfeasible, so wetlands were selected on the basis of their particular hydrological regime (i.e. dampland, sumpland, floodplain), wetland definition and the type of vegetation in each wetland.

The wetlands were re-assessed in the field using the EPA Bulletin 686 questionnaire (Parts IIA and IIB) as outlined in Appendix E2.

7.3.2 Wetland Management Category Reassessment

A total of 10 wetlands were re-assessed (7 Conservation and 3 Resource Enhancement Category wetlands). Only Conservation Category wetlands were initially re-assessed, however, the Technical Working Group requested that Resource Enhancement Wetlands within the Expanded Core Area also be re-assessed. Appendix E2 provides the re-assessment data sheets of all 10 wetlands. Of those re-assessed, only two (one Conservation and one Resource Enhancement category) were considered for re-classification.

The Conservation Category wetland, which is situated just outside the Expanded Core Area, within Gwalia Consolidated Ltd lease off Treasure Rd, was also a gazetted EPP wetland, and, on advice from the WRC, could not be considered for re-classification (M.Patt, pers. comm.). This decision has been accepted in this case even though the criteria for listing EPP or CC wetlands are quite different, and the wetland is nominally suitable for re-classification from Conservation to Resource Enhancement Category.

The wetland off Devlin Rd that was previously classified as a Resource Enhancement wetland was found to possess none of the natural attributes associated with an RE category wetland, as its native vegetation has been replaced with a Pine (*Pinus radiata*) plantation. Subsequently, the wetland has been downgraded to a Multiple Use Category wetland.

A package of information supporting the recommended re-classification will be forwarded to the Water and Rivers Commission for verification and approval.

Table 7.1
Wetlands Re-assessment

Wetland Name	Preliminary Management Category	Recommended Management Category
CCW1 (41S - Mialla Lagoon)	Conservation	Conservation
CCW2 (EPP Wetland/Sumpland (35S) off Marriot Rd)	Conservation	Conservation
CCW3 (EPP/clay sumpland (29S), zoniform type, off Devlin Road)	Conservation	Conservation
CCW4 (EPP/Sumpland (61S) off Treasure Rd, north of intersection with Wellington Rd)	Conservation	Resource enhancement (1)
CCW5 (Dampland (58D), off Boonilup Rd)	Conservation	Conservation
CCW6 (Sumpland (45S) South of CCW1)	Conservation	Conservation
CCW7 (Dampland (10D) off Devlin Rd)	Conservation	Conservation
REW1 (Sumpland (29D) off Devlin Rd	Resource enhancement	Multiple use
REW2 (Dampland (13D) west , off Devlin Rd)	Resource enhancement	Resource enhancement
REW3 (Dampland (49D) off Marriot Rd)	Resource enhancement	Resource enhancement

Note:
(1) Re-assessment scored this wetland as a Resource Enhancement wetland, but recommended downgrade rejected by WRC on basis of EPP Wetland status

7.4 WETLAND VEGETATION AND FLORISTIC STRUCTURE

7.4.1 Transect Methodology

In conjunction with the wetland re-assessments undertaken between the 28th and 30th of March, the vegetation structure in and around each of the Conservation Category wetlands was surveyed and mapped using transect sampling. Transects were located from the centre of the wetland to the outer edge of the fringing vegetation. The length of each transect was dependent on the number of vegetation types present and transition of vegetation types. All plant species occurring along each transect were recorded, however, due to the timing of the survey, many ephemeral species were unable to be identified. Wherever there was a transition between vegetation types along the transect, the location of the transition point was recorded using a Global Positioning System (GPS). These data were used to assist in the development of hydro-environmental relationships for use in the EWR/EWP process.

Many of the wetlands on the western side of the Estate have substantial areas of native vegetation remaining. Within some of these wetlands, the vegetation was too dense to undertake transect assessment from the centre of wetland outward. In these instances aerial photography generally indicated that the vegetation was fairly homogeneous. The wetlands on the western side of the Estate tended to be dominated by Swamp Paperbark over sedgelands of *Juncus pallidus* often with scattered Flooded Gum around the perimeter.

7.4.2 Wetland Vegetation Transects

Figure 7.2 indicates the location of each of the wetlands in the context of the Estate. The vegetation associations of the seven re-assessed Conservation Category Wetlands is described below and the vegetation of five of the wetlands is mapped in Figures 7.1 and 7.3 to 7.7. Due to the larger scale, the wetland vegetation mapped is at a much finer detail in Figures 7.3 to 7.7 than that mapped in Figure 7.1.

The results of the vegetation transect mapping are used later to help determine Ecological Water Requirements (EWRs) and propose Environmental Water Provisions (EWPs).

CCW1 (Mialla Lagoon) Transect

The eastern side of the wetland is surrounded by a *Eucalyptus marginata/Agonis flexuosa* Tall Woodland that gradually grades into a *Eucalyptus rudis* Closed Woodland (to 10m) with heavily grazed understorey (Figure 7.3). Further into the wetland this vegetation changes into *M. rhaphiophylla/E. rudis* Closed Woodland and then to a *M. rhaphiophylla* Low Closed Forest over a *Baumea articulata* Sedgeland (Plate 2 - Appendix E1) comprising the main wetland area. The central and western portion of the wetland is dominated by *Juncus pallidus/Baumea articulata* Sedgeland (Plate 1 - Appendix E1) with occasional *Typha orientalis*. The western portion of the wetland has previously been cleared, and the margins have become invaded by colonising species such as *Acacia saligna* and *Melaleuca teretifolia.* The wetland was dry at the time of the survey and in good to excellent condition with some evidence that the water level within the lagoon is high during the winter months. The vegetation was too dense to undertake transect assessment from the centre of the wetland outward, however aerial photography indicated that the central wetland vegetation is relatively homogeneous and is most likely vegetated with *Baumea articulata* Sedgeland throughout. There is a notable paucity of understorey species within the *M. rhaphiophylla* Low Closed Forest over a *Baumea articulata* Sedgeland association and a thick layer of leaf litter.

Other species (native and non-native) recorded along the transect line and from the various vegetation associations from the wetland (which included surrounding Jarrah/Flooded Gum woodland) included *Acacia saligna, Lepidosperma gladiatum, Juncus pallidus, Villarsia albiflora, Cassytha racemosa, Eucalyptus marginata, Corymbia calophylla, Hibbertia racemosa, Hardenbergia comptoniana, Conostephium pendulum, Juncus pallidus, Sonchus hydrophilus, Acacia saligna, Xanthorrhoea preissii* and *Briza maxima.*

CCW2 (EPP Wetland/Sumpland off Marriot Rd) Transect

The wetland consists of four principal vegetation associations (Figure 7.4):

- *Baumea articulata* Sedgeland - This association covers the wetland “basin” and is virtually uniformly comprised of *Baumea articulata* (Plate 3 - Appendix E1).
- *Acacia saligna* Tall Shrubland - This association (to 4m in height) occurs between the eastern margin of the *Baumea articulata* Sedgeland and the *Melaleuca preissiana* Closed Forest association.

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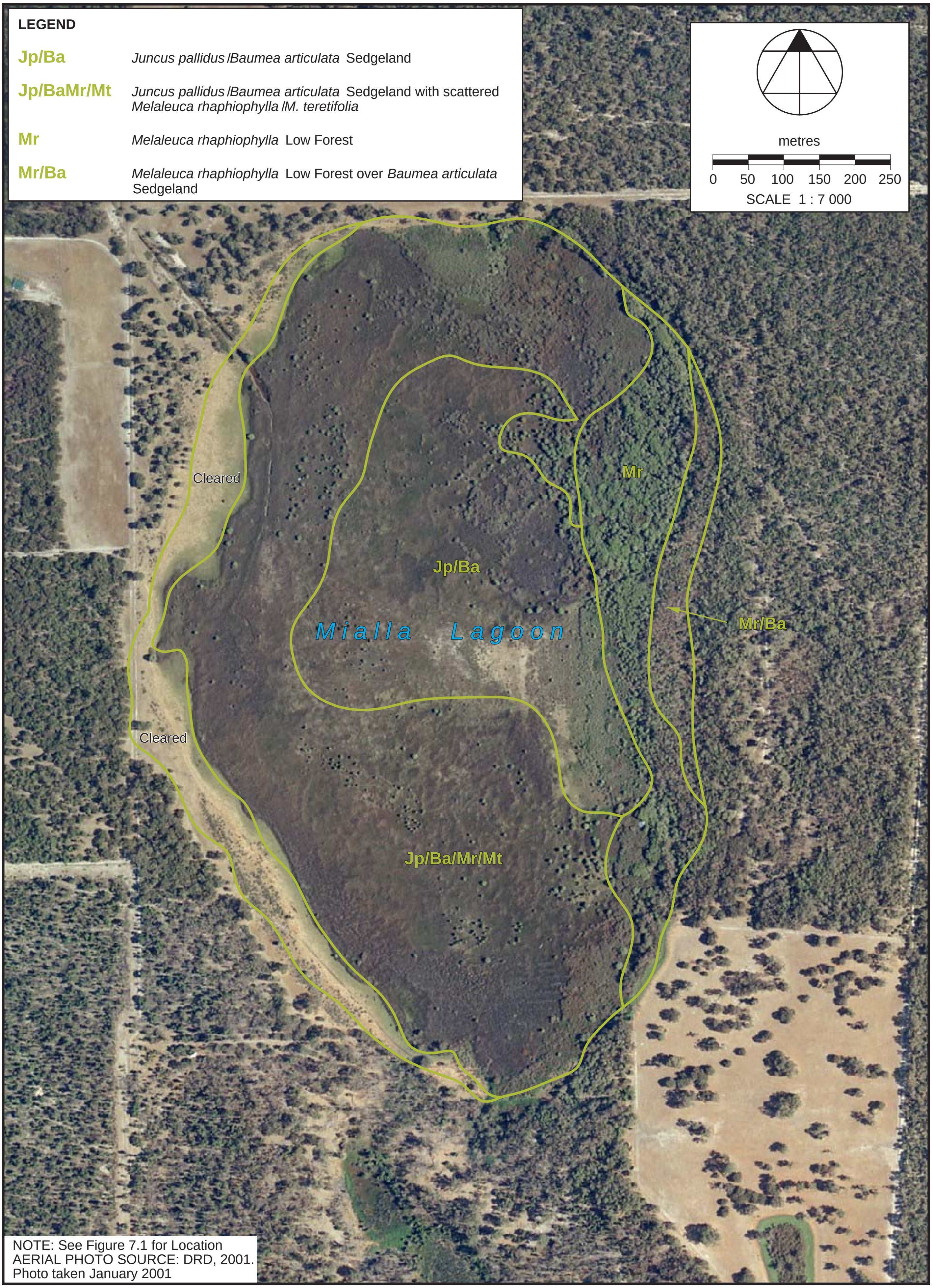

NOTE: See Figure 7.1 for Location
AERIAL PHOTO SOURCE: DRD, 2001.
Photo taken January 2001

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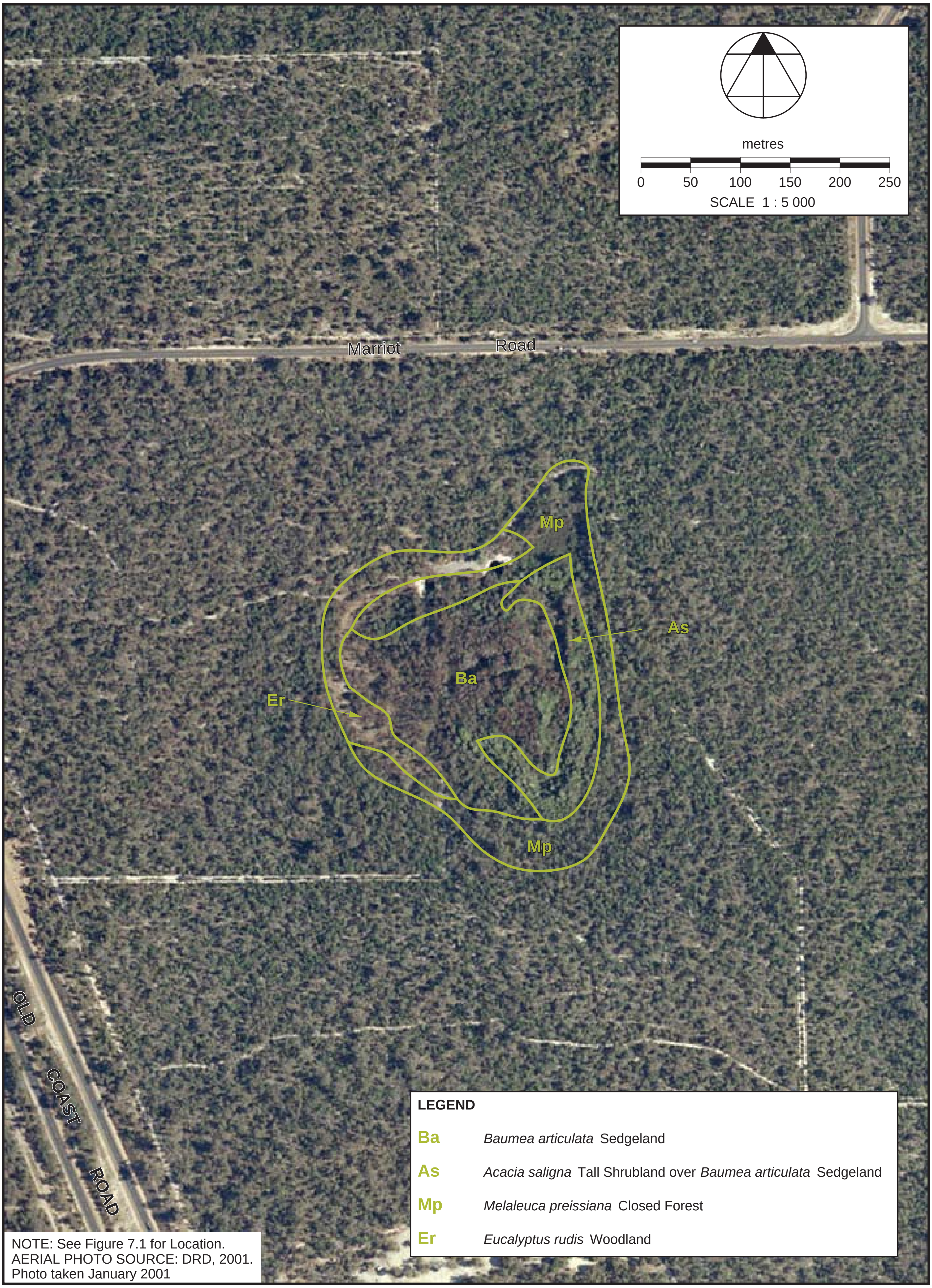
CCW1 - VEGETATION ASSOCIATIONS

FIGURE 7.3



LEGEND

Ba	*Baumea articulata* Sedgeland
As	*Acacia saligna* Tall Shrubland over *Baumea articulata* Sedgeland
Mp	*Melaleuca preissiana* Closed Forest
Er	*Eucalyptus rudis* Woodland

NOTE: See Figure 7.1 for Location.
AERIAL PHOTO SOURCE: DRD, 2001.
Photo taken January 2001

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CCW2 - VEGETATION ASSOCIATIONS

FIGURE 7.4

- *Melaleuca preissiana* Closed Forest - This association, to 10 m in height, and up to 30 m in width, is the largest in area associated with the wetland. As a result of the dense layer of leaf litter deposited on the ground, few understorey species occur. These were limited to *Baumea articulata* and the invasive Blackberry (*Rubus* sp.). Scattered Peppermint *Agonis flexuosa* and Flooded Gum (*Eucalyptus rudis*) occur beyond what appears to be the seasonally inundated zone of the *Baumea articulata* Sedgeland.
- *Eucalyptus rudis* Woodland - This association, to 15m in height, is prominent along the slightly elevated southern portion of the wetland. Few understorey species occur within this vegetation type.

Species (native and non-native) recorded from along the surveyed transect line and within the wetland vegetation associations include *Melaleuca preissiana, Eucalyptus rudis, Agonis flexuosa, Acacia saligna, Baumea articulata, Rubus sp., Banksia littoralis*, *Lepidosperma squamatum, Hibbertia racemosa, Spyridium globulosum* and *Melaleuca teretifolia.*

CCW3 (Clay sumpland, zoniform type, off Devlin Road) Transect

The interior of this wetland is largely devoid of native vegetation, having been cleared and extensively grazed by stock. Scattered *M. rhaphiophylla/Melaleuca teretifolia* shrubs to 2 metres are the only native components (Figure 7.5). The cleared bare area in the centre of the wetland is often inundated during the winter months (Muir, 1999). The inner western and eastern margins of the core portion of the wetland are fringed by a *Juncus pallidus* dominated Sedgeland to 15m wide which is bounded by a 30m wide zone of scattered *Melaleuca preissiana* trees (Plate 4 - Appendix E1), covered in *Cassytha racemosa*, to 3 m in height. This association merges into a *Melaleuca teretifolia* Low Closed Shrubland up to 20m wide. The southern and eastern extremes of the wetland are encompassed by Flooded Gum woodland to 25 m in height.

Prominent species (native and non-native) recorded from along the surveyed transect lines included *Melaleuca rhaphiophylla***,** *M. preissiana, Melaleuca teretifolia, Juncus pallidus, Astartea fascicularis, Eucalyptus rudis, Cassytha racemosa, Rumex crispus, Sonchus oleraceus* and *Cynodon dactylon.*

CCW4 (EPP/Dampland off Treasure Rd, north of intersection with Wellington Rd) Transect

The vegetation of this wetland was very similar to several other adjacent Conservation Category/EPP wetlands. CCW4 has a narrow outer fringe principally comprised of scattered *Melaleuca preissiana* (to 3m), with an inner, species rich dampland Closed Heath dominated by *Astartea fascicularis* to 50m in diameter (Plate 5 - Appendix E1) (Figure 7.6). Species associated within this association include*Oxylobium lineare* and *Hypocalymma angustifolium.*

Melaleuca incana ssp. *incana* /*M. lateritia* Closed Heath association surrounds an “island” comprised of a homogenous *Melaleuca rhaphiophylla* Low Woodland. Surrounding the wetland on the slightly more elevated sandy soil is Jarrah/Marri dominated Woodland.

Species (native and non-native) recorded from along the surveyed transect line and from within the wetlands vegetation associations include *Melaleuca rhaphiophylla, Melaleuca lateritia, Melaleuca incana* ssp. *incana, Oxylobium lineare, Astartea fascicularis, Hypocalymma angustifolium, Acacia pulchella* and *Xanthorrhoea preissii*.

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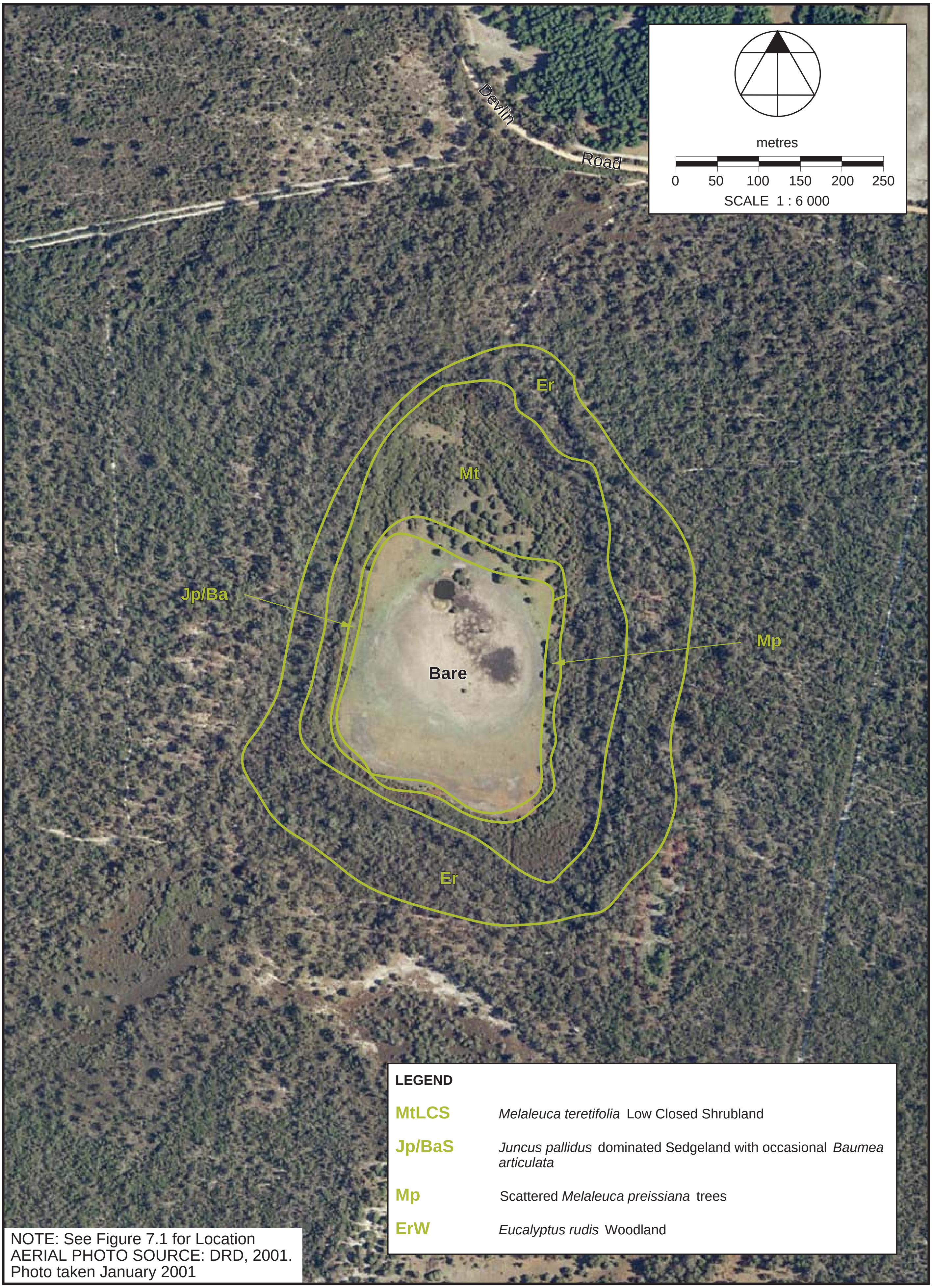

LEGEND

MtLCS	*Melaleuca teretifolia* Low Closed Shrubland
Jp/BaS	*Juncus pallidus* dominated Sedgeland with occasional *Baumea articulata*
Mp	Scattered *Melaleuca preissiana* trees
ErW	*Eucalyptus rudis* Woodland

NOTE: See Figure 7.1 for Location
AERIAL PHOTO SOURCE: DRD, 2001.
Photo taken January 2001

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CCW3 - VEGETATION ASSOCIATIONS

FIGURE 7.5

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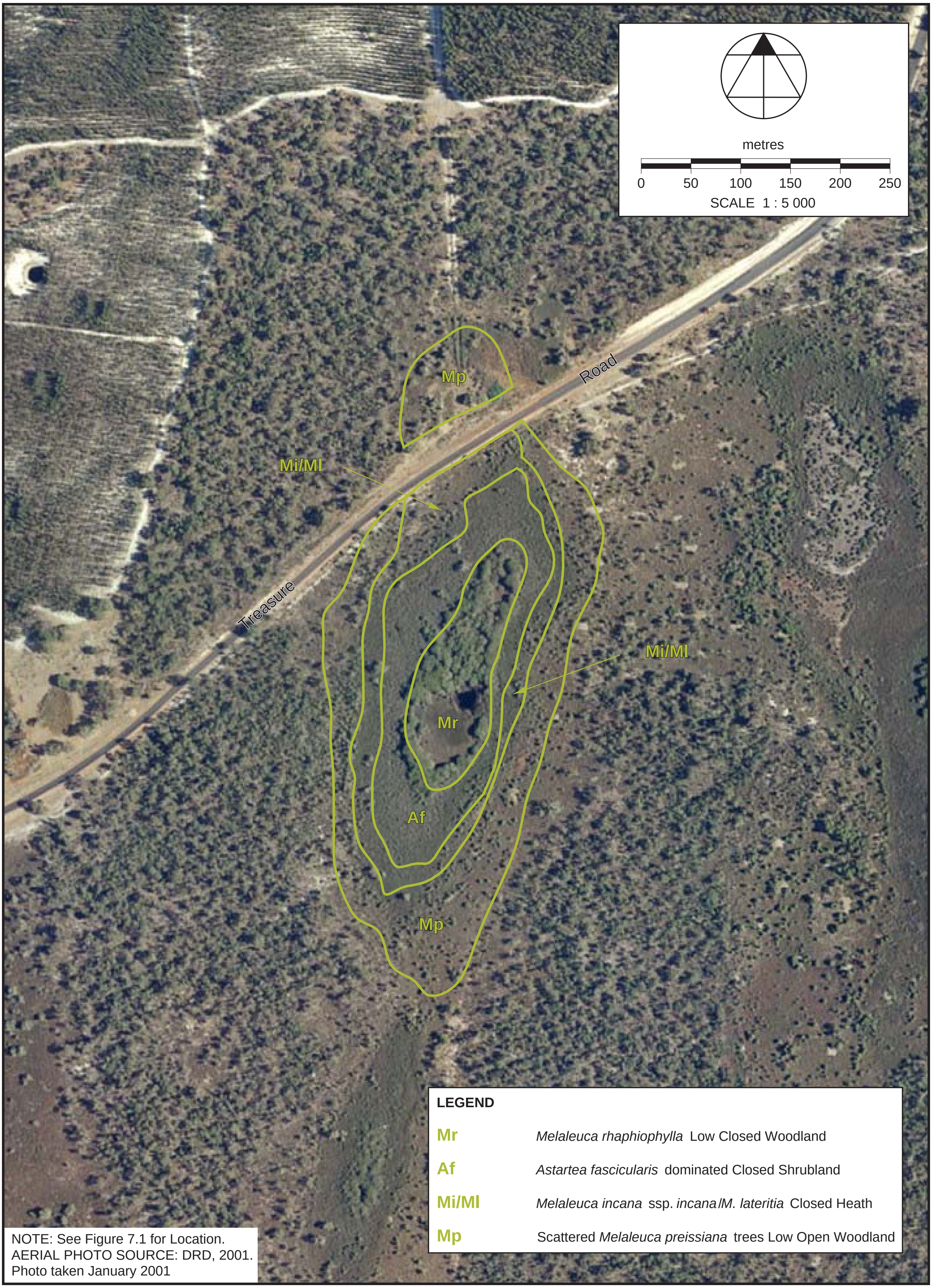

LEGEND

Mr	*Melaleuca rhaphiophylla* Low Closed Woodland
Af	*Astartea fascicularis* dominated Closed Shrubland
Mi/Ml	*Melaleuca incana* ssp. *incana*/*M. lateritia* Closed Heath
Mp	Scattered *Melaleuca preissiana* trees Low Open Woodland

NOTE: See Figure 7.1 for Location.
AERIAL PHOTO SOURCE: DRD, 2001.
Photo taken January 2001

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KEMERTON WATER STUDY, PHASE 2 - ENVIRONMENTAL ASSESSMENT

CCW4 - VEGETATION ASSOCIATIONS

FIGURE 7.6

CCW5 (EPP Dampland, off Boonilup Rd) Transect

This wetland is a winter-wet dampland basin with a diverse understorey dominated by *Pericalymma ellipticum/Hypocalymma angustifolium* Low Closed Heath (Plate 6 - Appendix E1) similar in structure to CCW4, with scattered *Melaleuca preissiana* (to 3m) and fringed by Holly-leaved Banksia *Banksia ilicifolia* Tall Open Shrubland. An “island” of scattered *Melaleuca rhaphiophylla* trees occurs in the middle of the assessed portion of the wetland. There was evidence of dieback on upland Jarrah (*E. marginata*) / Holly-leaved Banksia (*Banksia ilicifolia)* woodland that fringes the wetland (Figure 7.7).

Species (native and non-native) recorded the surveyed transect line and from within the wetlands vegetation associations include *Melaleuca preissiana, Pericalymma ellipticum, Hypocalymma angustifolium, Banksia ilicifolia, Eucalyptus marginata, Melaleuca incana* ssp. *incana, Pimelea rosea, Oxylobium lineare* and *Adenanthos obovatus.*

CCW6 (off Treasure Road, south of Mialla Lagoon) Transect

This wetland is dominated by a *Melaleuca preissiana* Closed Forest (to 10m) (Plate 7 - Appendix E1) lying marginally to the west of the ridge that run through the centre of the Estate. The vegetation is in good to very good condition and was wet under foot at the time of the survey with likely surface water during winter. No vegetation map was prepared for this wetland.

CCW7 (off Devlin Road on MIC) Transect

This wetland is vegetated with a mixed low open to closed thicket of Melaleuca, Kunzea and Astartea species with scattered *Melaleuca preissiana* trees fringing the perimeter of the wetland. The vegetation showed few signs of disturbance and was in a good to very good condition. Given that the wetland is classified as a dampland there is unlikely to be any surface water during winter. No vegetation map was prepared for this wetland.

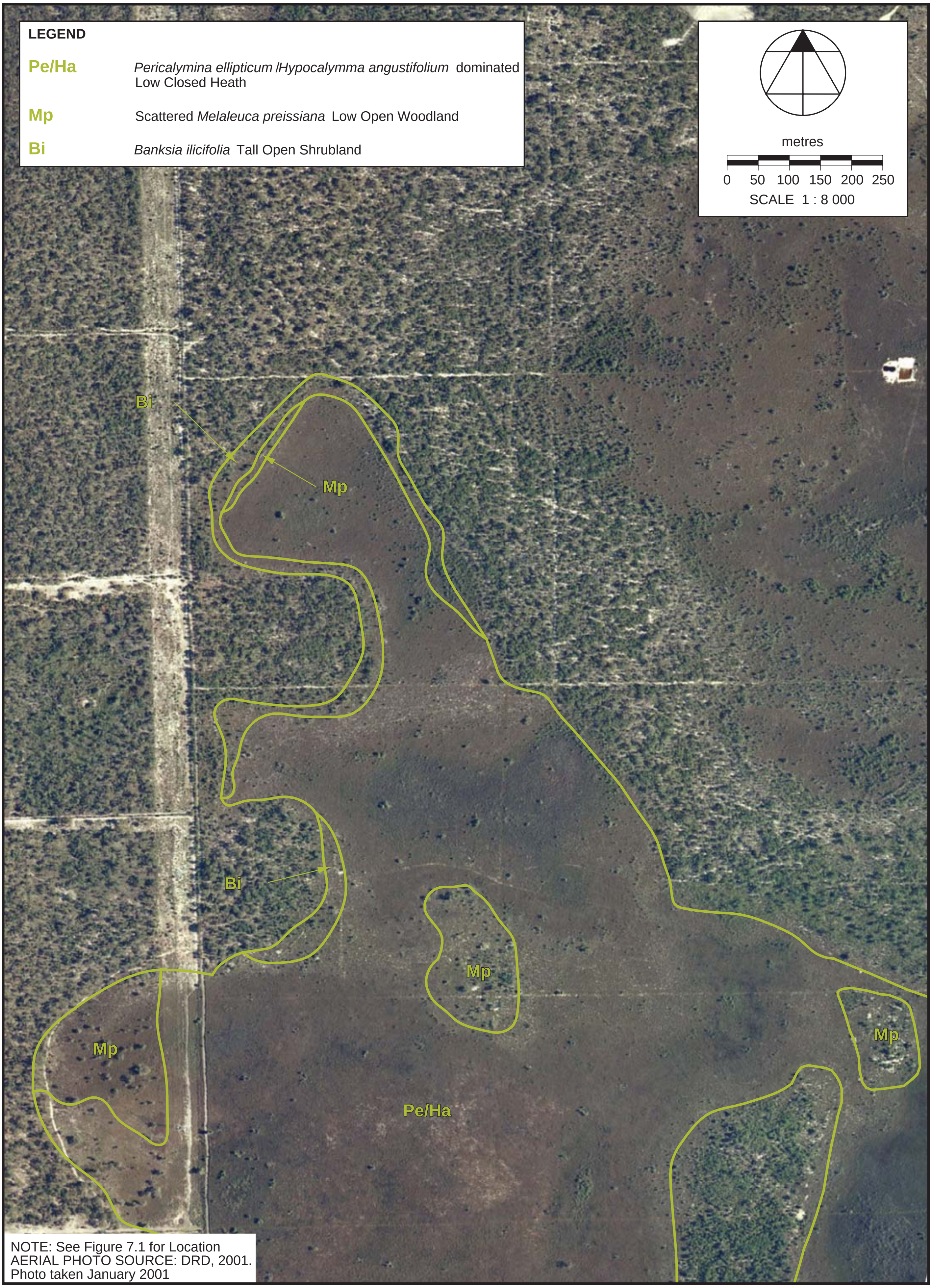
7.5 DRYLAND VEGETATION AND FLORISTIC STRUCTURE

7.5.1 Dryland Vegetation Communities

In order to determine the interim Environmental Water Requirements (EWRs) and subsequent Environmental Water Provisions (EWPs) for upland vegetation, it was necessary to refine the vegetation mapping undertaken by Muir (1999) during Phase 1 of the study. Whereas Muir (1999) mapped the Estate area according to broad vegetation communities, the mapping needed to be refined to a level where a clear determination of the groundwater dependant vegetation within 6m of the watertable could be made (refer to Section 7.4 for more detail on hydro-environmental relationships). The methodology involved a combination of interpretation of recent aerial photography and on-site ground truthing in conjunction with analysis of the original mapping and data by Muir (1999).

The refined vegetation map for the Estate, including dryland associations, is shown in Figure 7.1.

A total of 34 native vegetation communities were mapped from the Estate (Figure 7.1). The majority of these communities included Jarrah as a prominent overstorey component. The ridge that runs through the majority of the central portion of the Estate is dominated by a Jarrah dominated woodland, with *Banksia attenuata* the most common mid-stratum species. Marri and Peppermint are also abundant in several areas.



NOTE: See Figure 7.1 for Location
AERIAL PHOTO SOURCE: DRD, 2001.
Photo taken January 2001

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CCW5 - VEGETATION ASSOCIATIONS

FIGURE 7.7

The western fringe, which is covered by vegetation that is more open in structure, is dominated by a belt of vegetation that includes Tuart and Peppermint. The northeastern corner is dominated by dampland heath which is not dominated by any one species in particular but has several species evenly distributed.

Pine (*Pinus radiata*) and Tasmanian Blue Gum (*Eucalyptus globulus*) plantations are prominent through the eastern portion of the area. The vegetation types mapped by Muir (1999) in some areas along the eastern-most fringe of the site could not be verified due to inaccessibility.

7.5.2 Dryland Vegetation Monitoring Plots

A floristic assessment of eight 10m x 10m plots previously set up by Muir (1999) was undertaken to facilitate a comparison of the study area with areas elsewhere on the Swan Coastal Plain for which Gibson *et al.,* (1994) had data available. These monitoring plots are to be used as long-term vegetation monitoring plots. Five of the Gibson Plots were established within woodland habitats and three within wetland areas. Time constraints did not allow for any additional plots to be installed during this study. The survey was undertaken between the 1st and 3rd October, 2001, a time that was considered suitable for the identification of most species including ephemeral species. All flora species recorded (native and non-native) from the eight monitoring plots are shown in Appendix E3, while the location of each of the plots is indicated in Figure 7.1.

7.5.3 Dryland Vegetation Burnt Area

Prior to the previous flora and vegetation assessment of the Estate (Muir, 1999), a fire burnt out a significant portion of the Jarrah/Marri/mixed Banksia woodland north of Marriot Rd. This area was assessed during spring 2001 to confirm vegetation associations present and to determine whether Declared Rare or Priority Flora previously recorded from the Estate, occurred in this area. The assessment confirmed the vegetation as *Eucalyptus marginata/Banksia attenuata/Banksia grandis* woodland. No Declared Rare or Priority listed flora known from the Estate were recorded from the site.

7.6 HYDROLOGICAL-VEGETATION RELATIONSHIPS

7.6.1 Groundwater Dependent Ecosystems (GDEs)

Groundwater Dependant Ecosystems (GDEs) are ecosystems which have their species composition and their natural ecological processes determined by groundwater (Hatton and Evans, 1998). Ecosystems that occur where the depth to the groundwater is less than 6m are generally the most susceptible to any decline in the level of the groundwater table (such as in period of drought) as they have adapted to having shallow groundwater in the vicinity of their root system. The East Gnangara Water Stress Study (WAWA, 1992) suggested that dryland areas with a depth to groundwater of less than 6m were most affected by drawdown.

Groundwater dependant ecosystems within the Estate were mapped during Phase 1 of the Kemerton Water Study. However, the map showed only native vegetation within 5m of the groundwater table, rather than 6m that has been adopted for this study. Figure 7.8 presents the map of vegetation types, overlaid with areas within 6m of the average annual **minimum** groundwater level (refer to Section 8). The average annual minimum groundwater level was selected on the basis that this reflects the lowest level that would

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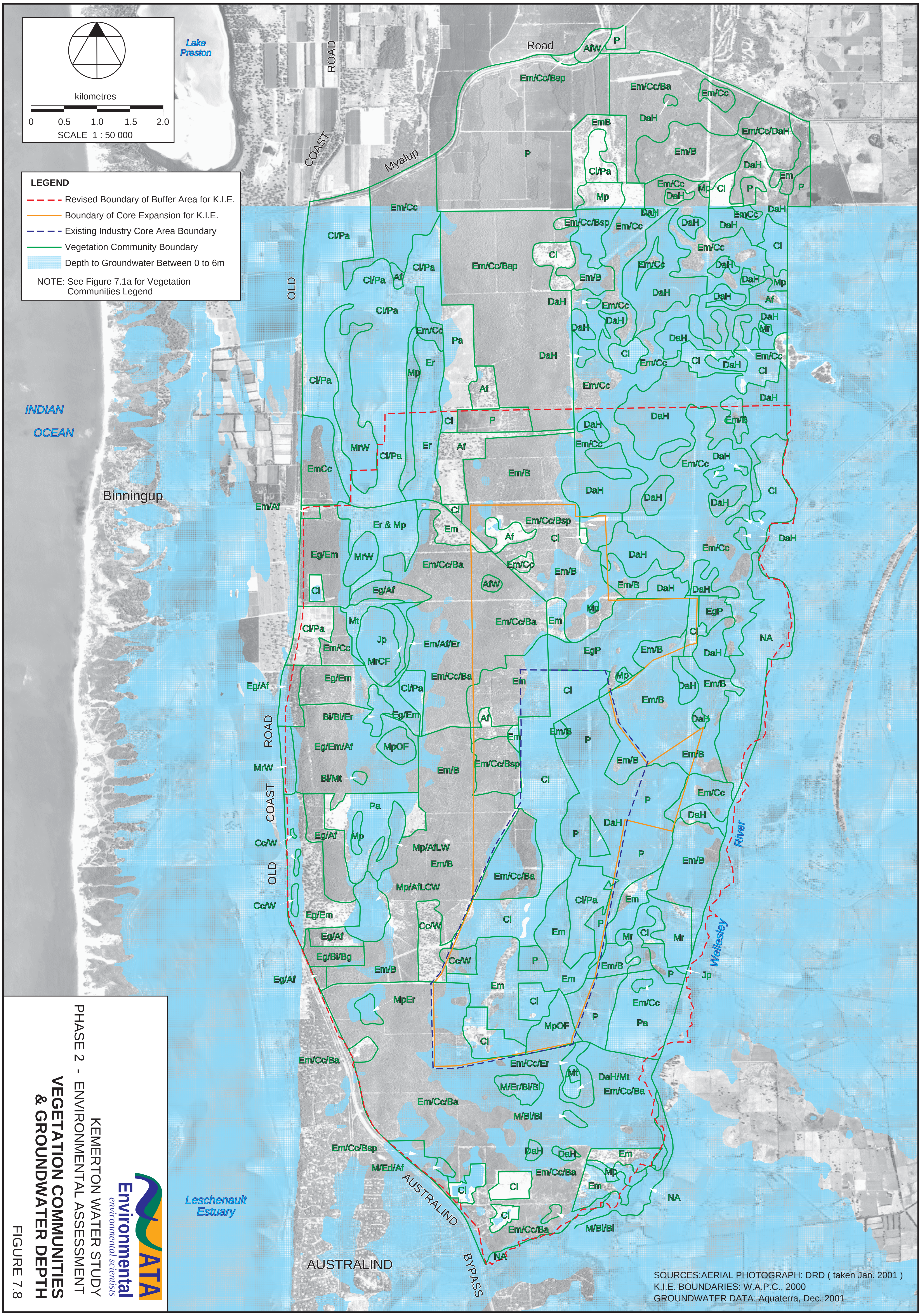

SOURCES: AERIAL PHOTOGRAPH: DRD (taken Jan. 2001)
K.I.E. BOUNDARIES: W.A.P.C., 2000
GROUNDWATER DATA: Aquaterra, Dec. 2001

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FIGURE 7.8

be expected to occur in most years (ie. the vegetation would presumably be adapted to this water table configuration).

Banksia ilicifolia is a species that is prominent within the Jarrah/Marri/Banksia woodland that is widespread throughout the Estate. *Banksia ilicifolia* is a phreatophytic plant species (ie accesses water from groundwater table) that is poorly adapted to a sudden or rapid decline in the water table (Groom *et al.,* 2000a). It is a species that is restricted in its distribution by the depth to groundwater (in the range 2m to 10m) (S. Nicoski and R. Froend, ECU, unpub. data). A reduction in the vigour and structure of *B. ilicifolia* is considered to be a significant indicator of both long and short term reduction of groundwater levels on shallow aquifers on the Swan Coastal Plain.

Shallow-rooted plant species generally do not have access to a groundwater resource that is greater than 1m in depth (Dodd *et. al.,* 1984) and as a consequence are less likely to die as a direct response to significant groundwater drawdown, although excessive drawdown may exacerbate the impact (Groom *et. al.,* 2000). Only a decrease in the level of the superficial aquifer will have an impact on groundwater dependant vegetation. Drawdown in deeper aquifers have been shown to have a minimal impact on the shallow superficial aquifer and consequently will have no impact on vegetation.

7.6.2 Ecological Water Requirements

Ecological Water Requirements (EWRs) are the specific water regimes that are required to maintain particular ecosystem components or ecological systems which are considered to be valuable or beneficial (WRC, 1997; 2000). The principle aim of calculating EWRs is to determine the water levels necessary to avoid the death of native vegetation. In the case of the Kemerton Industrial Estate, the ecosystems that are considered valuable are water-dependant ecosystems, in particular groundwater-dependent ecosystems, and also wetland systems.

EWRs have been determined using the best scientific data available and are the principle factors in determining the water allocation regimes or Environmental Water Provisions (EWPs) for a particular development. The best scientific information available comprises the vegetation and wetland mapping described in this Section of the report, and the groundwater modelling predictions described in later Sections, as well as previously published research, notably relating to the Gnangara Mound on the Swan Coastal Plain, and recent research by Edith Cowan University.

Dryland EWRs

The currently adopted criteria for dryland EWRs is based on recently published research by Froend and Zencich (2001), which supercedes research published 9 years ago relating to the Gnangara Mound (Gnangara Mound Vegetation Stress Study - WAWA, 1992). The Gnangara study investigated the causes of stress and deaths in vegetation on the Gnangara Mound during 1991. The study found that although groundwater abstraction was not the primary reason for vegetation stress and death, there was evidence that it exacerbated the problem during periods of low rainfall and high temperatures. Based on the findings from this study, the critical groundwater drawdown tolerance limits for phreatophytic ecosystems, including *Banksia ilicifolia,* were determined (Table 7.2).

Table 7.2
Critical Tolerance Levels of Groundwater Drawdown Impact of Dryland and Wetland Vegetation
(Froend *et al*., 1993)

Drawdown Impact	Critical Levels of Drawdown
Long Term	1.5m
Medium term	0.6m
Short term	0.4m
Annual	0.1m

The most recent research, however, is significantly different to the above. Three categories of water depth have been defined and a maximum tolerable drawdown allocated to each category (Table 7.3). In addition to this, the maximum allowable annual drawdown is 0.25m, which gives mature phreatophytic plants at least one growth season over which their roots can respond before losing contact with the groundwater level (Froend & Zencich, 2001). It has been noted by Froend and Zencich (2001) that this rate is less than the natural seasonal drawdown, but it has been considered necessary to allow gradual initiation of the root elongation response. This research has been used as the basis for establishing the hydrological-vegetation relationships for the Kemerton Water Study. The levels indicated in Table 7.3 have been applied in determining Ecological Water Requirements (EWRs) of dryland as well as wetland ecosystems within the Estate. Note that the criteria for setting EWRs is mainly based on research for Banksia species, for example *Banksia Ilicifolia*. There is however other species present in the study area (eg jarrah and tuart) which are likely to have alternative water requirements. There is however, no information available on critical drawdown limits for these species.

Table 7.3
Critical Tolerance Levels of Groundwater Drawdown - Dryland and Wetland Vegetation
(Froend & Zencich, 2001)

Depth to Groundwater	Maximum Amount of Drawdown
Category 1: 0 - 3m depth	0.75m
Category 1: 3 - 6m depth	1.25m
Category 1: 6 - 10m depth	1.75m

Wetland EWRs

EWRs for wetland ecosystems, particularly fringing wetland vegetation, are based on the principle that the extent and nature of wetland vegetation has a significant impact on other components of the wetland ecosystem and is essential in determining whether a wetland is ecologically “healthy”. By identifying the EWRs of the major components of the wetland ecosystem, other components should be protected as a result of their interdependent character (WAWA, 1992). For example, vegetation distribution affects the availability of feeding habitats for wading bird species and larval cycles of aquatic invertebrates.

The identification of water regimes to manage fringing vegetation has been the basis of setting the EWRs as outlined below:

- Published research suggests that trees such as Swamp Paperbark (*Melaleuca rhaphiophylla*) are tolerant of a drawdown of the groundwater table of up to 0.1m annually to a maximum of 1.5m (Froend *et. al.,* 1993) - this is consistent with the criteria presented in Table 7.2 above.
- Moonah (*Melaleuca preissiana*) is a plant species that is tolerant of extremes in water regimes (from seasonal flooding to deep groundwater levels) and any response to altered water regimes is only likely to occur over a period of decades (Froend *et. al.,* 1993).
- *Baumea articulata* is generally found where the water regime is between 1m below ground and 1m above ground level. Research on *B. articulata* Sedgelands on the Gnangara Mound has shown an average water regime for the species to range from 0.2m above surface to 0.6m below ground level at the end of the summer months (WAMA, 1992).
- The species-rich winter-wet depressions that cover much of the northeastern corner of the Estate, are dominated by shallow rooted species including *Pericalymma ellipticum, Astartea fascicularis* and *Hypocalymma angustifolium.* These species are not dependant on the groundwater for their water requirements, relying instead on soil moisture reserves and are unlikely to die in direct response to a groundwater drawdown event (Groom *et al.*, 2000b).

In summary, the EWRs for wetlands are basically the same as those for dryland systems in terms of drawdown (Table 7.3), although some wetlands also depend on seasonal inundation, which would involve contributions from surface runoff.

This information on Ecological Water Requirements (EWRs) is discussed further in Section 10, along with details regarding proposed Environmental Water Provisions (EWPs). These EWRs were also used as constraints in the groundwater modelling predictions to optimise groundwater abstractions (Section 9).

8.1 TOPOGRAPHIC DIGITAL ELEVATION MODEL (DEM)

Digital topographic data for the Estate was supplied by Kevron Geomatic Services from a previous project completed for the Department of Resources Development. The digital elevation model (DEM) was constructed using an aerial GPS and verified by ground truthing (10 data points). The data was supplied on a 25 x 25m grid and had an accuracy of ±1m. The ASCII data was gridded on a 25m spacing using Surfer to produce an elevation model for the area. A ‘nearest neighbour’ technique was employed to grid the data as the accuracy of the source data was of the same magnitude as the gridding interval. Figure 8.1 presents the digital elevation model for the Kemerton area, and Figure 8.2 presents a contour plan of the topographic surface.

These figures clearly show the surface relief and drainage features for the area. The topographic ridge tending north-south on the western side of the industrial Estate is the only pronounced feature of high elevation. The area to the east of the ridge (the estate area) is relatively flat with a number of topographic depressions.

8.2 AVERAGE ANNUAL MAXIMUM GROUNDWATER LEVEL (AAMGL)

The average annual maximum groundwater level (AAMGL) was calculated using monitoring data collected from bores owned by LandCorp, WRC, MIC, Simcoa and Kemerton Silica Sands. The methodology involved filtering through monitoring records to establish a set of monitoring bores which had a monitoring period of at least two years, and had at least one record during the winter period. The annual maximum groundwater level was extracted and then averaged over the period of monitoring record to obtain the AAMGL. Many of the bores within the core of the industrial area owned by LandCorp only had a monitoring period of two years. The AAMGL plot is therefore not based on a set of bores monitored continuously over a defined, long term period, nor do the bores cover a very wide area. In developing the AAMGL, a total of 71 bores was used over a 15km by 20km area.

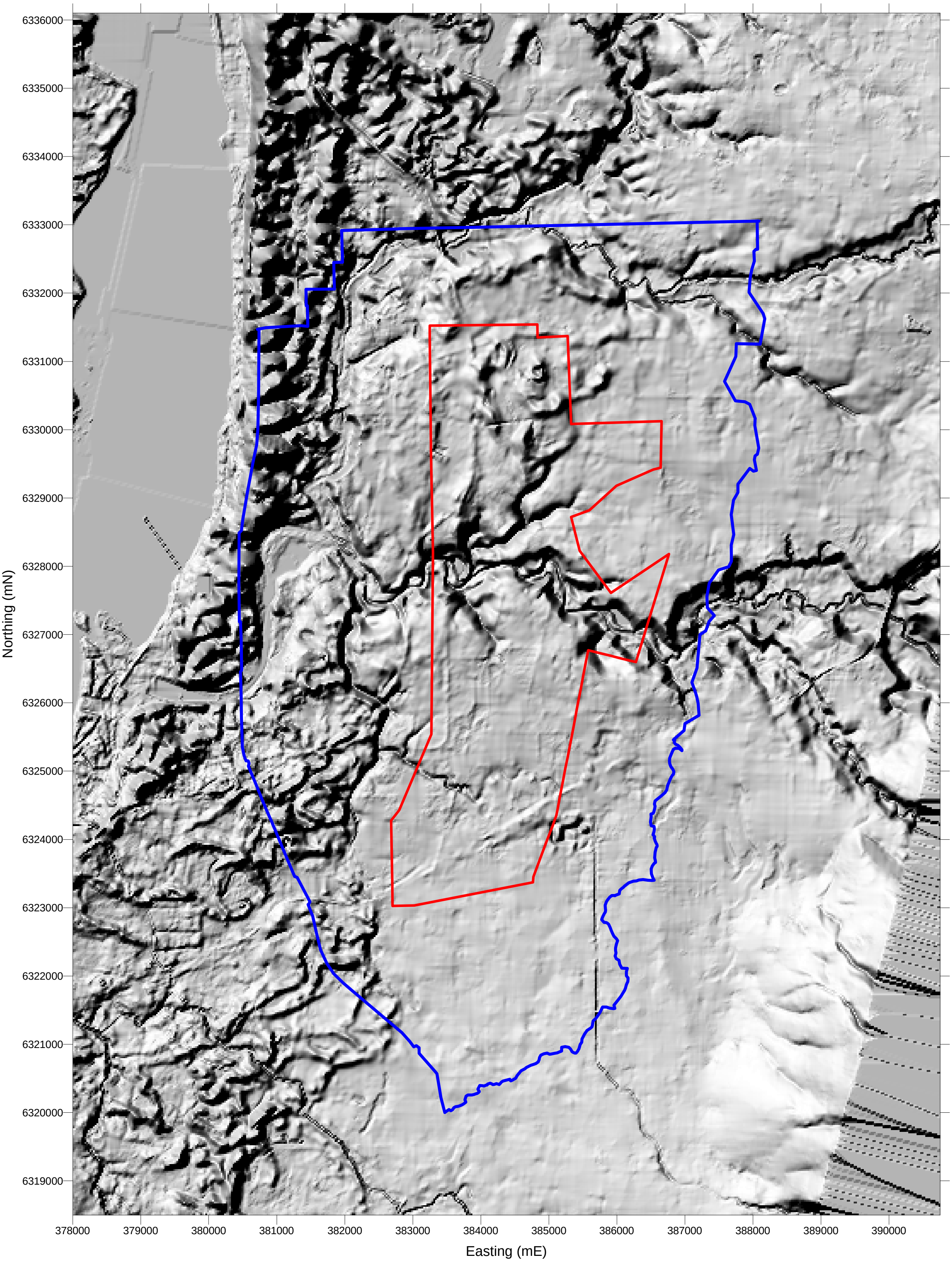
Figure 8.3 presents a contour map of the AAMGL (mAHD), with the bores which were used to generate the surface indicated on the map. The AAMGL surface and a digital terrain model for the area (see above) were used to view the AAMGL in terms of depth below ground level (Figure 8.3). As can be seen, the AAMGL for a large proportion of the eastern side of the Estate is within 2m of the ground surface.

The groundwater monitoring data was also used to generate an average annual **minimum** groundwater level (AAmGL) in the same way that the AAMGL was generated. The same set of bores described above were used to produce this surface. Figure 8.4 presents a plot of the AAmGL.

8.3 STORMWATER DRAINAGE SYSTEM PRINCIPLES

Each proposal for stormwater drainage for commercial and industrial sites is assessed independently by the Shire of Harvey and Water and Rivers Commission (WRC). The assessment considers the individual site conditions such as the type of underlying soil, depth to the water table, proximity to rivers and wetlands and their significance, contamination of the groundwater, etc.

Kemerton Water Study (Phase 2)



🟦	Boundary of Buffer Area
🟥	Expanded Core Boundary

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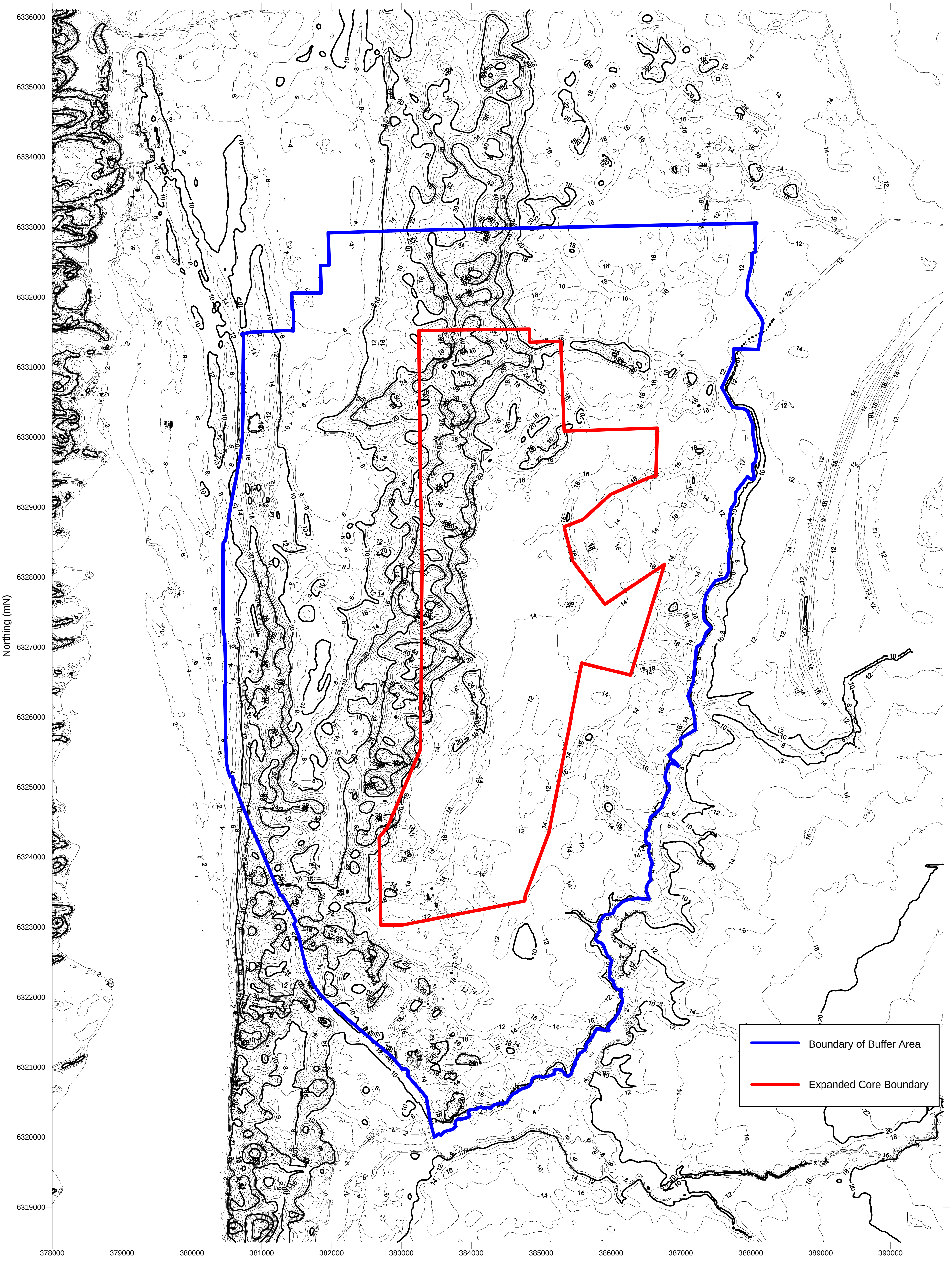
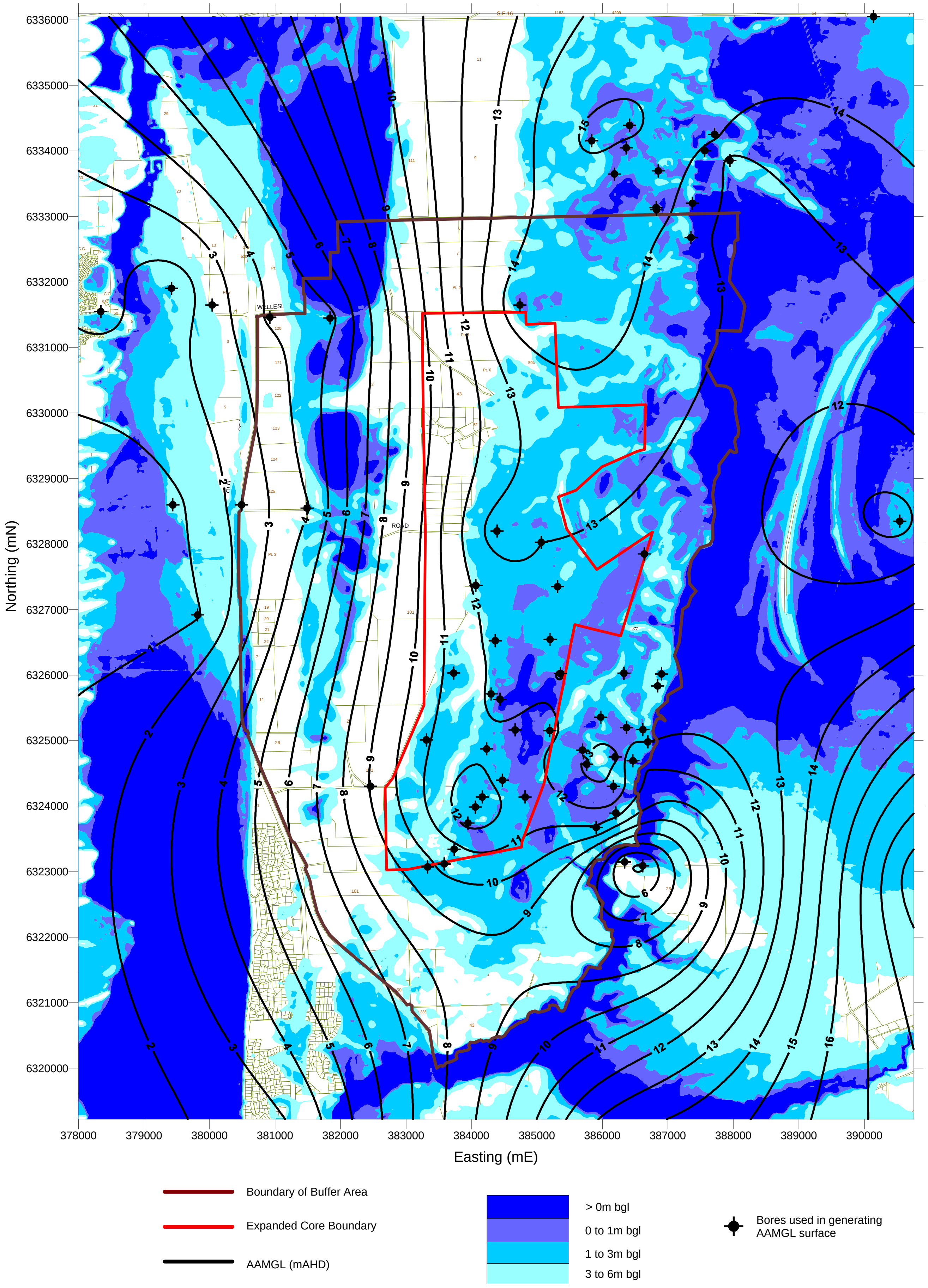
Digital Elevation Model
Figure 8.1



Digital Topographic Map
Figure 8.2

Kemerton Water Study (Phase 2)



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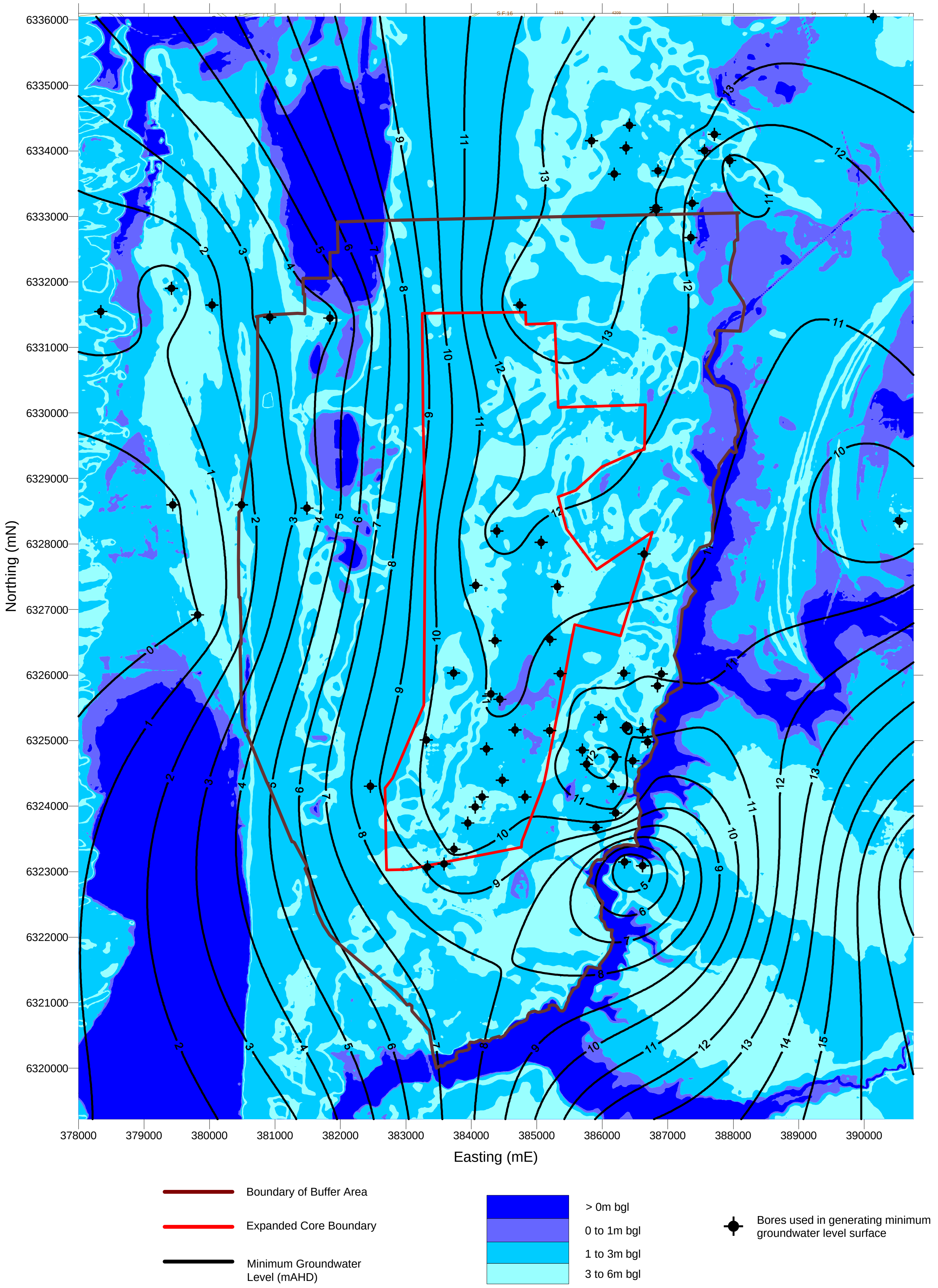
Average Annual Maximum Groundwater Level (AAMGL)
Figure 8.3



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Average Annual Minimum Groundwater Level
Figure 8.4

Traditionally, a council's general drainage criteria to be fulfilled for all commercial/industrial sites is as follows:

- Drainage network to contain the 10 year Average Recurrence Interval (ARI) event;
- Flood path to convey the 100 year ARI flood; and
- All drainage in landlocked (internally-draining) areas to be designed to satisfy the 100 year ARI event.

Current WRC policy also requires that any drainage structures be designed with invert levels above the AAMGL. This is intended to ensure that no groundwater below the AAMGL is exported from the site by pipes or constructed open drains or swales. It ensures that groundwater contributions to wetlands are maintained at existing levels and groundwater discharge is not above current amounts, so as to minimise the export of nutrients.

Urban and industrial development typically increases the water input to the natural hydrological system, due to enhanced runoff from extensive paved surfaces and a reduction in interception and evapotranspiration losses due to less vegetation. Traditional "hard engineering" type drainage systems use pipes and kerbed roads to discharge stormwater into downstream drainage basins. Kerbed roads are commonly used to form open channels to convey large flood events. The use of existing natural drainage paths is also encouraged rather than using engineered drainage structures.

With the relatively recent advent of the concept of water sensitive design, these "hard engineering" measures have been replaced with "soft engineering" systems, which are more consistent with sustainable development principles. Water sensitive design promotes the infiltration of stormwater into the soil near its source using soakwells, shallow swale drains or sheet runoff into permeable areas such as lawns, garden beds, pervious pavements etc. This potential extra recharge to the aquifer is available for re-use in the development by subsequent groundwater pumping (this aspect is addressed in the groundwater modelling predictions). Rainwater tanks collecting runoff from roof areas should also be encouraged as a potential source of water, and a means of reducing enhanced runoff from paved surfaces.

As water sensitive design generally relies on infiltration, it is most effective for smaller, more frequent storms. Traditional methods, such as using earthfill to create building pads and floodways to convey larger floodwaters downstream, are often required to augment water sensitive design practices when the rates of surface runoff significantly exceed the infiltration rate. This is commonly required in areas of high water table (eg. near wetland areas).

The Kemerton Industrial Development should be designed with a mix of water sensitive design and traditional design methods. Water sensitive design principles can be employed for the smaller, more frequent flood events. Traditional design methods may need to be applied in areas of shallow water table, notably using earthfill to construct pads for buildings, roads and car park or hardstand areas. Detailed drainage plans will be required to be developed for each site, consistent with the strategy outlined in this section, and with the details provided in Sections 8.5 to 8.7 (summarised in Table 8.1).

8.4 REFINEMENT OF DRAINAGE STRATEGY

8.4.1 Previous Drainage Strategies

A planning report for the expansion of the Kemerton Industrial Estate was undertaken by BSD (1997). The drainage strategy recommendations described in that report outline a more traditional drainage network system, with a main open drainage channel located in the central service corridor of the estate, collecting smaller feeder drains and subsoil drains from the individual blocks, prior to discharging into Wellesley River. However, this strategy reflects policy prior to the implementation of water sensitive design policies, with the main open drain and subsoil drains intended to lower the groundwater to minimise the amounts of earthfill required. Currently, this would not be acceptable to the Department of Environment, Water and Catchment Protection (DEWCP - previously WRC and DEP), as the groundwater and wetland levels would be impacted and nutrient laden groundwater would be exported from the site and discharged to Wellesley River and Leschenault Inlet. The inlet is already marginally eutrophic (nutrient enriched) as a result of excessive phosphorus loadings from its catchment.

The revised water management strategy for the Kemerton Industrial Estate undertaken by BBG-Rockwater (1999) recommended more appropriate drainage management principles for the Estate, including a minimum vertical groundwater clearance to buildings of 2 m across the estate. It was suggested that this could be achieved by subsoil drainage or earthfill. Areas where the water table was within 2 m of the ground surface were identified, and a subsoil drainage network was proposed, due to the expense of earthfill. The potential was identified for subsoil drains to impact on water table elevations near wetlands, along with the potential for increased export to the Wellesley River and Leschenault Inlet of nutrients held in the groundwater and soil profile. The BBG report identified that, based on experience in the Peel-Harvey Catchment, the WRC had adopted a general policy of requiring subsoil drains to be at or above the AAMGL, with earthfill to provide additional clearance above this level if required.

The BBG report also recommended that 80% of all stormwater, and the runoff from a 10 year, 72 hour storm, be retained on site for at least three days. Also, it was recommended that the drainage design should maximise on site retention and infiltration of stormwater and subsoil drainage water in drainage control structures. These structures should be designed to remove phosphorus and other contaminants from the water before it is discharged off site. The BBG report also identified stormwater as a useful supplementary source of water supply either directly via aquifer storage or indirectly by recharge to the wetlands to balance abstraction from borefields. This is consistent with the refined strategy proposed below.

More traditional drainage management approaches were considered prior to developing the refined strategy described below. For example, preliminary designs were developed for a network of sub-soil drains and trunk drainage pipelines, consistent with the conceptual designs outlined in the BBG (1999) and BSD (1997) reports. The aim was to scope a system to convey surface runoff volumes, and groundwater flows due to water table levels in excess of the AAMGL, away from the high water table areas in the east of the Estate and towards the Wellesley River. However, the AAMGL constraint on drain inverts, coupled with the low-lying topography and low dunes occurring between the Estate and the River, resulted in infeasible designs for the trunk drains.

Apart from the application of large areas of earthfill, the only option to the trunk drainage system is the infiltration of excess flows to groundwater where possible, and the direction of excess flows in high water table areas towards Multiple Use wetlands. The use of these wetlands as drainage basins is consistent with their Multiple Use management category, provided that the hydrological functions (eg. seasonal inundation) and any remaining ecological functions are preserved or replicated.

The refined drainage scheme strategy presented below minimises the capital costs for development (by avoiding the need for trunk drainage and extensive earthfill areas), and maximises the recharge to the aquifer and wetlands, which is consistent with water sensitive design principles. This is in contrast to traditional drainage systems where pipes and open channels convey the stormwater runoff directly to receiving water bodies. Solely traditional drainage systems have high relative capital costs, and result in the export of surface stormwater runoff and groundwater discharge (with associated nutrients) from the site to adjacent watercourses with minimal recharge back into the aquifer.

8.4.2 Refined Drainage Strategy

The refinement to this strategy now proposed for the Kemerton Estate is to maximise infiltration within the developed area of each block (ie. the area developed for buildings, car parks, etc), consistent with water sensitive design principles. Broadly, this strategy involves the use of undeveloped/uncleared areas on each block and throughout the Estate as natural retention basins for larger flows (that cannot be infiltrated within the developed areas), to avoid the need for substantial drainage control structures.

The strategy also involves the use of Multiple Use category wetlands as drainage basins for larger flood events. It should be noted that these “wetlands” are actually sumplands (ie. seasonally inundated with runoff and groundwater inflows). They typically occur on the eastern part of the Estate, and their use as drainage basins is consistent with their Multiple Use management category, provided that the hydrological functions (eg. seasonal inundation) and any remaining ecological functions are preserved or replicated.

The refined strategy involves retaining as much remnant vegetation as possible on each site, and the revegetation of existing cleared portions of each block that are not required for development. Whereas the developed portions of some blocks will require earthfill to provide sufficient clearance between the water table and foundations, groundwater levels under adjacent undeveloped portions of the blocks could be as high as the natural surface without compromising the developed (earthfilled) area.

This strategy allows for the undeveloped portion of each block to act as a natural drainage feature for the developed areas. As water tables approach the natural surface in the undeveloped area, higher rates of evaporation occur, and existing natural drainage features can convey excess water away from the site. With this arrangement, subsoil drainage beneath the developed areas would not be required, and only the portion of each block that is developed may require earthfill, depending on the depth to the water table.

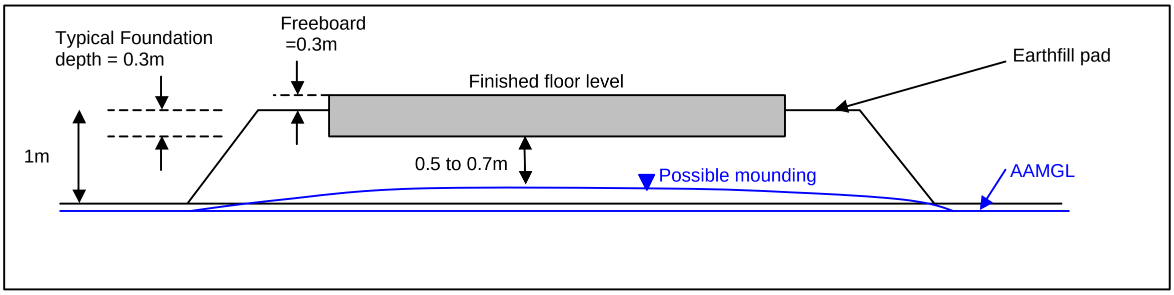
In areas with the groundwater near the surface, earthfill levels for the developed portions of each block would need to be a maximum of 1 m above the surrounding undeveloped areas. Less depth of fill would be required for areas with deeper water tables. Details on these design principles are given below.

8.5 DRAINAGE STRATEGY FOR DEVELOPED AREAS

Developed areas are defined as those areas of each block (or across the Estate generally) that are developed for roads, buildings, car parks, hardstand areas etc (ie. those areas with hard paved surfaces that generate more runoff than natural surfaces). Traditional drainage design methods are required to drain flows from large storms when the rates of surface runoff significantly exceed the infiltration capacity of the soil. Traditional design would include using earthfill to elevate the buildings, roads etc above flood waters and the water table, and using floodways to convey major flood flows away from these developed areas. Water sensitive design generally relies on infiltration at source, and is most effective for smaller, more frequent storms, and/or where the maximum water table elevation is well below ground level. The developed areas of the blocks should therefore use water sensitive design where possible, with traditional design where necessary.

8.5.1 Earthfill Requirements

Conservatively assuming a maximum groundwater mounding under buildings and roads of 0.2 m, and pavement foundation depths of 0.3 m, a maximum earthfill pad height of 1m would give a freeboard of 0.5 m between the groundwater and the pavement foundations, as shown in the sketch below. As there would be little to no infiltration under buildings or roads, the groundwater mounding would be minimal, and clearances of up to 0.7m could be obtained, which should be sufficient for most industries.



As the depth to Average Annual Maximum Groundwater Level (AAMGL) varies throughout the site (Figure 8.3), locations where the groundwater is close to the surface require more depth of earthfill than locations with greater depths to groundwater. For example, for areas with an AAMGL at the natural surface, a minimum depth of earthfill of 1 m over the developed part of the site would be required.

For areas where the groundwater is further from the surface, less depth of earthfill will be required. Some industries will require greater separation distances between foundations and the water table, which will require greater depths of earthfill, or relocation to more appropriate sites.

Typically, the WRC require that floor levels must be a minimum of 0.5 m above the 100 year ARI flood level, but preferably 1 m in industrial areas to guard against the potential for contamination. However, this requirement would apply to the flood level in Wellesley River and not the flood level due to the local runoff from the site itself. Although there is no flood mapping available for the Wellesley River, the natural surface levels within the Estate are well above the Wellesley River flood levels (Figure 8.2), so the WRC criterion is easily satisfied by natural relief.

By comparison, councils require that floor levels be 0.3 m above the 100 year ARI flood level due to local runoff. Hence, the Council criterion will govern floor levels, which should be set with a 0.3 m freeboard above the earthfill level.

Preferably, landlocked (internally draining) areas within Estate blocks should not be developed. However, if a landlocked area must be developed, additional earthfill would be required to ensure floor levels are not inundated by local runoff, to reduce the potential for subsequent contamination of the groundwater due to infiltration. All drainage in landlocked areas should be designed to accommodate the 100 year ARI flood from local runoff.

Other traditional design methods include using floodways to protect buildings from flooding during major events. In the developed areas of each block, floodways should be designed to convey flows from larger than the 10 year ARI storm. Floodways will typically be formed from roadways, car parks, and/or hardstand areas, and must be designed with an outlet to either the undeveloped part of the block for retention/infiltration, or to existing drainage systems.

8.5.2 Water Sensitive Design

Water sensitive design principles generally rely on infiltration of stormwater at its source, which is most effective for the smaller, more frequent, storms.

The drainage function for the developed areas of each block (buildings and paved areas) will vary according to the magnitude (and frequency) of the storm event. The site stormwater drainage network should have sufficient capacity for the more frequent flooding events, up to the 2 year ARI storm. Some minor ponding (storage) is acceptable in the lower areas if the surface runoff exceeds the infiltration rate. These areas should be self-draining so that ponding over an extended period of time does not occur.

In areas with high infiltration rates (sandy areas with the groundwater level well below the surface, say >2 m), on site storage of stormwater such as in soakwells and shallow depressions should be used. This provides the opportunity for infiltration of runoff all year, by directing stormwater runoff into the ground for subsequent re-use as a water supply through groundwater abstractions, and/or to buffer the drawdown impacts of groundwater abstraction.

In areas with low infiltration rates (clayey areas or areas with the groundwater near the surface, say <2 m), on site storage of stormwater should be utilised where possible, supplemented by overflow and conveyance systems for larger flood events. For example, during summer when groundwater levels are lower, there will be an opportunity for some on site infiltration. However, infiltration will be limited during (winter) periods of the year when groundwater levels are high, and stormwater runoff may need to be conveyed away from the developed part of the site during these periods, as described below.

For larger storms such as the 10 year ARI event, roads and hardstand areas should be designed to convey the major flood flows towards existing drains and natural overland flow paths (this is sometimes termed “surcharging”). These features also have a function as temporary water storages (ie. in the area between kerbs or within the banks of the drain), which provides a mitigating effect in terms of flood volumes. Surcharging of roads and hardstand areas in rarer events such as the 10 year ARI storm is acceptable. However, the functionality of the area would be affected by surcharging during the more frequent events (such as the 2 year ARI storm), and this would not be acceptable.

In areas that are contaminated, or contain potential contaminant sources, pollution control devices such as oil separators and other Best Management Practices should be implemented at the source of the pollutant. Best Management Practices are described in the WRC publication “A Manual for Managing Urban Stormwater Quality in Western Australia”. Other guidelines for developed areas are contained in the WRC Water Quality Protection Note “Industrial Sites Near Sensitive Water Resources”.

8.6 DRAINAGE STRATEGY FOR UNDEVELOPED AREAS

The undeveloped areas of blocks (areas with no buildings or paving) should generally remain in their natural state, retaining as much remnant vegetation as possible on each site. Revegetation of existing cleared portions of each block that are not required for development should be encouraged, to reduce the potential for nutrient export.

Where possible (eg. in high infiltration areas), storm runoff from developed areas should be directed to infiltrate and recharge the water table for subsequent contribution to water supply abstractions, and infiltration ponds or soakwells should be sited in undeveloped areas. However, in low infiltration areas, storm runoff or overflows from soakwells are likely to pond. To alleviate this ponding in the undeveloped areas of the block, shallow swale drains should be constructed, with inverts above AAMGL. These shallow drains should traverse the block to convey excess water away from the developed parts of the block and towards existing Multiple Use wetlands, existing drains or creeks. The potential for soil erosion in the swale drains should be reduced by constructing them on minimal grades (typically a maximum of 1%) and applying rock protection to susceptible areas such as entry points from developed areas.

Where roads intercept open drains or surface runoff flow paths, culverts should be installed to convey the flows under the road and prevent a “damming” effect. If surface flows or existing open drains are intercepted by developed areas, they should be diverted using shallow swale drains and reconnected to the existing drain downstream. Rock spalls should be used to protect the developed site from potential erosion.

This drainage infrastructure would only be required in low infiltration areas, as any surface runoff in high infiltration areas (eg. with deeper water tables) would quickly infiltrate.

8.7 RECOMMENDED DRAINAGE MANAGEMENT STRATEGY

The drainage strategy for the Kemerton Industrial Estate should consist of a combination of traditional design and water sensitive design, as detailed in the Water Management Strategy (Section 10). The drainage design requirements are affected by the depth to average annual maximum groundwater level (AAMGL) as shown in the summary table below. Note that the only wetlands that can be used for drainage purposes are those classified as Multiple Use, which are typically located through the eastern part of the Estate. There are generally no constraints associated with the development of MU wetlands, provided that the hydrological functions (eg. seasonal inundation) and any remaining ecological functions are preserved or replicated.

Table 8.1
Drainage Design Requirements

Drainage Design Requirement	**AAMGL Depth Below Existing Ground Level**			
	0m	0.5m	1.0m	>1.5m
Developed Areas of Blocks				
1. Minimum elevation above surrounding ground surface for earthfill pads	1 m	1 m	0.5 m	0.3 m
2. Floor level freeboard to 100 year ARI flood from local runoff	0.3 m	0.3 m	0.3 m	0.3 m
3. Floodways to convey greater than 10 year ARI flood	Yes	Yes	Yes	Yes
4. Surcharge of roads and hardstand areas for greater than 10 year ARI floods (ie. use these features to convey the major flood flows towards existing drains and natural overland flow paths)	Yes	Yes	Yes	Yes
5. Roof and pavement runoff to spoon drains or rock spalls which dissipate to the groundwater	Yes	Yes	Yes	Yes
6. Soakwells and shallow on site storage depressions	Yes	Yes	Yes	Yes
7. Ponding in lower infiltration capacity areas	Yes	Yes	Yes	Yes
8. Invert levels of drainage structures above AAMGL	Yes	Yes	Yes	Yes
9. Pollution control devices at source (eg. oil separators)	Yes	Yes	Yes	Yes
10. Rainwater tanks for water supply	Yes	Yes	Yes	Yes
Undeveloped Areas of Blocks				
11. Shallow swale drains to convey ponded surface water to existing drains or Multiple Use wetlands (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
12. Shallow diversion swale drains around building pads (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
13. Low flow culverts under roads that intercept sheet flow runoff	Yes	Yes	No	No
14. Culverts under roads that intercept existing open drains	Yes	Yes	Yes	Yes

9.1 MODELLING OBJECTIVES AND MODEL COMPLEXITY

The overall objective of the Kemerton Water Study Phase 2 is to develop a water management strategy capable of practical implementation to maximise the development potential for the Kemerton Industrial Estate. The aims of the water management strategy are to plan for sustainable and efficient water use, and to minimise potential impacts from development and operation of the Estate, whilst maintaining environmental values of significant wetlands, watercourses and vegetation.

In groundwater modelling terms, these objectives require the development of a model that incorporates the essential features of the hydrogeological system, and that can be used to predict the impacts of the development on those features. The essential features include:

- The superficial aquifer and underlying confined aquifers and groundwater flow systems; and
- Interaction processes between aquifers, rivers, wetlands, drains, and groundwater-dependent vegetation.

This requires the development of a complex, multi-layered numerical model to a regional scale, but with adequate resolution to accurately represent the surface-groundwater interaction processes. To predict the impacts of development, the model needs to be well-calibrated (“history-matched”) to monitoring data covering a range of climatic and hydrological (eg. pumping) stresses. Model complexity is defined (in the groundwater flow modelling best practice guidelines being promulgated for national adoption in Australia (Middlemis et al, 2000) as the degree to which a model application resembles, or is designed to resemble, the physical hydrogeological system.

The minimum model complexity required for this study is Medium. In other words, an Impact Assessment model is required (refer to Middlemis *et al* paper in Appendix G). As the model results will also be used to set resource allocation limits, the model should achieve a High complexity (Aquifer Simulator model) standard. As described hereunder, the model achieves these aims.

The model that has been developed for this study is a significant refinement of the existing groundwater model (Rockwater, 1998). The next section outlines the review of the 1998 model, an outcome of which was the design for the refined model. The sections that follow describe the detailed features that have been incorporated into the model, and the calibration and prediction simulation results.

9.2 REVIEW OF PREVIOUS MODEL

9.2.1 Approach and Findings

The 1998 Kemerton-Bunbury regional groundwater model has been reviewed using the procedures in the Groundwater Modelling Guidelines developed recently by Aquaterra (2000) for the Murray-Darling Basin Commission. This guideline is currently being promulgated for national adoption as a best practice guide (refer Middlemis et al, 2000).

The review of the 1998 model was based on the following information:

- Rockwater report to Water Corporation dated October 1998 (Numerical Groundwater Model Kemerton-Bunbury Region Interim Report); and
- Kemerton model data files (software package PMWin v5) provided by the Water Corporation.

In summary, the 1998 model fundamentals are generally quite sound, with certain exceptions outlined below. In particular, substantial effort had been put in to adequately represent the conceptual hydrogeology and boundary conditions, and to specify abstraction from existing bores at allocated rates. The 1998 model is considered to be suitable for the purposes of providing a simple representation of the aquifer systems, and for running steady state simulations of abstraction scenarios to predict potential impacts. Steady state simulations generally represent long term average conditions, and usually over-predict the regional effects of drawdown due to abstraction. This conservative modelling approach is often used for simple environmental impact assessment purposes, when there is considerable uncertainty in regard to hydrogeological understanding and data availability, and/or where there are constraints on time/budget. However, this approach is not suited for the objectives of the Kemerton Water Study Phase 2, which is to develop a detailed water management strategy for the Estate, and justify a groundwater abstraction licence application for the Estate.

9.2.2 Refinement of 1998 Model

The review findings, and the proposed modelling approach for this study were documented in a report submitted to the WRC (Aquaterra, 2001) for review early in the modelling study.

Although the review found that the 1998 model is not suitable in its current form for the Phase 2 study, it provides a good foundation for further refinement to develop a suitable modelling tool.

Specific areas where the 1998 model needed refinement and/or further development included:

- *Model extent:* The 1998 model covered a 20 km strip of the Swan Coastal Plain from the coast to the Darling Fault, and extended from Myalup in the north to Boyanup in the south (a distance of 46 km). This extends much further south than nominally required for the Kemerton study, and detailed calibration to and prediction of conditions in the southern half of the model (ie. south from Bunbury) is outside the scope of the Kemerton study. During redevelopment of the model, its southern boundary was moved north to an alignment just south of the Collie River, and the boundary conditions were adjusted accordingly, as described in the next section.
- *Model grid:* The grid cell size in the Kemerton area was 300x300 m in the 1998 model. While this is acceptable for a semi-regional model, it is too coarse for detailed analysis of the effects of abstraction and of wetland-aquifer interaction, and too coarse to properly represent the Wellesley River and other surface drainage features. Expansion factors of 2 and 3 were used in the 1998 model when increasing the grid cell size with distance away from the detailed grid in the Kemerton area (best practice requires the use of a maximum factor of 1.5). The refined model improved and resolved these issues, which results in more accurate simulations, but at the cost of slightly longer run-times.

- *Model calibration:* The 1998 model was calibrated in steady state mode, and semi-quantitative calibration performance measures were presented (comparisons of non-synoptic measured groundwater levels and modelled levels). More detailed calibration performance assessment and sensitivity analysis was achieved for the Phase 2 study (consistent with best practice guidelines).
- *Surface-Groundwater Interaction:* The Modflow Drain package was used in the 1998 model to represent water balance losses through both surface drainage and evapotranspiration from vegetation and/or wetlands. The refinements implemented involved using the Drain package only for surface drainage features, and using the Evapotranspiration package for vegetation water use, and for evaporation from wetlands. This enables resolution of different components of the water balance, and aids with drainage system design during the water management plan stage. This required information on vegetation water use, developed during the study with input from the ATA Environmental team.
- *Wellesley River:* The river was represented in the 1998 model with the RIV package, which involves simulation of river-aquifer interaction based on differences between the river level specified in the model (assumed at 1 m water depth in the river) and the simulated water levels in adjacent aquifer cells. This is the simplest form of representing the river, but it is also the most appropriate for this study, because there is insufficient (streamflow) data to use more complex methods. However, the 1998 model grid also needed to be refined in the area of the river (see above for details on the grid). Further refinement of the river feature is possible, but is reliant on obtaining survey data of the river bed elevation, and would require the construction of a new stream gauging station upstream of the Kemerton area and several years of stream flow and height monitoring data. At this stage, such a work programme is not regarded as warranted.
- *Pumping Stresses and Transient Calibration:* Abstraction was specified in the 1998 model based on allocation volumes, which makes adequate provision in the model to account for the effects of abstraction on a regional basis for prediction purposes. This feature was generally retained in the refined model, although actual usage data was used where available (eg. for existing Kemerton industries). In addition, the refined model was calibrated in transient (time-stepping) mode, and the calibration performance was improved greatly.

9.3 CONCEPTUAL MODEL

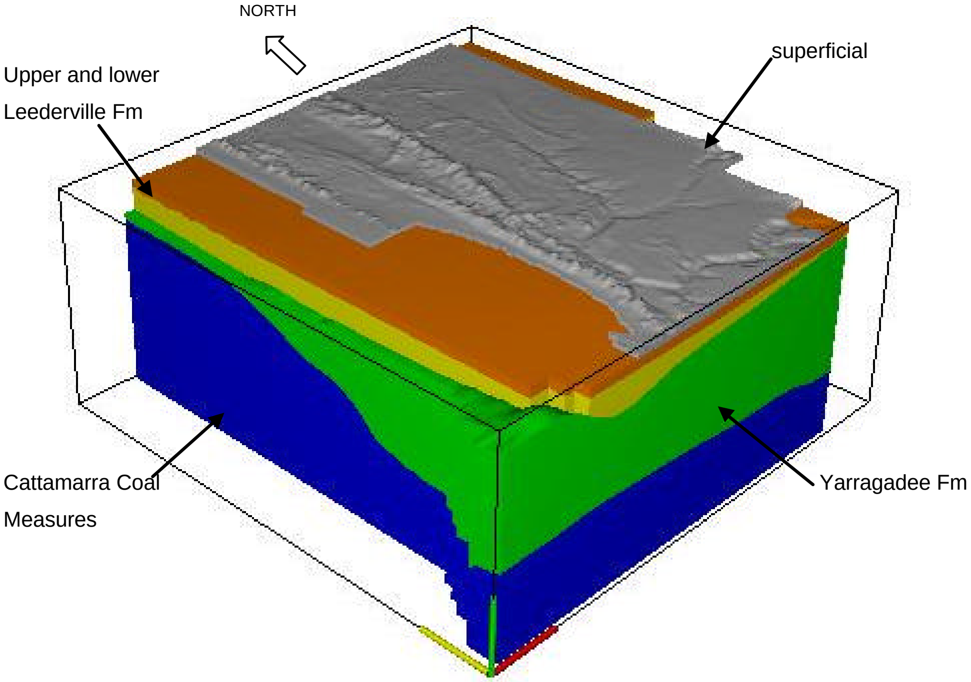
Based on the hydrogeological assessment documented in this report, and the report on the 1998 model (Rockwater, 1998), the groundwater model has been set up with five layers to represent the unconfined and confined aquifers which exist in the Kemerton area.

The five layers in the model represent the following formations:

- Layer 1 - superficial formations (unconfined);
- Layer 2 - Upper part of Leederville formation;
- Layer 3 - Lower part of Leederville formation;
- Layer 4 - Yarragadee Formation; and
- Layer 5 - Cattamarra Coal Measures.

A conceptual block model is given in Figure 9.1 below. The model grid, boundary conditions and other features for each layer are shown in Figures 9.2 to 9.5. A detailed discussion of the major features incorporated in the model is presented in the sections below, and further information is provided in Appendix F.

Figure 9.1
Conceptual Block Model



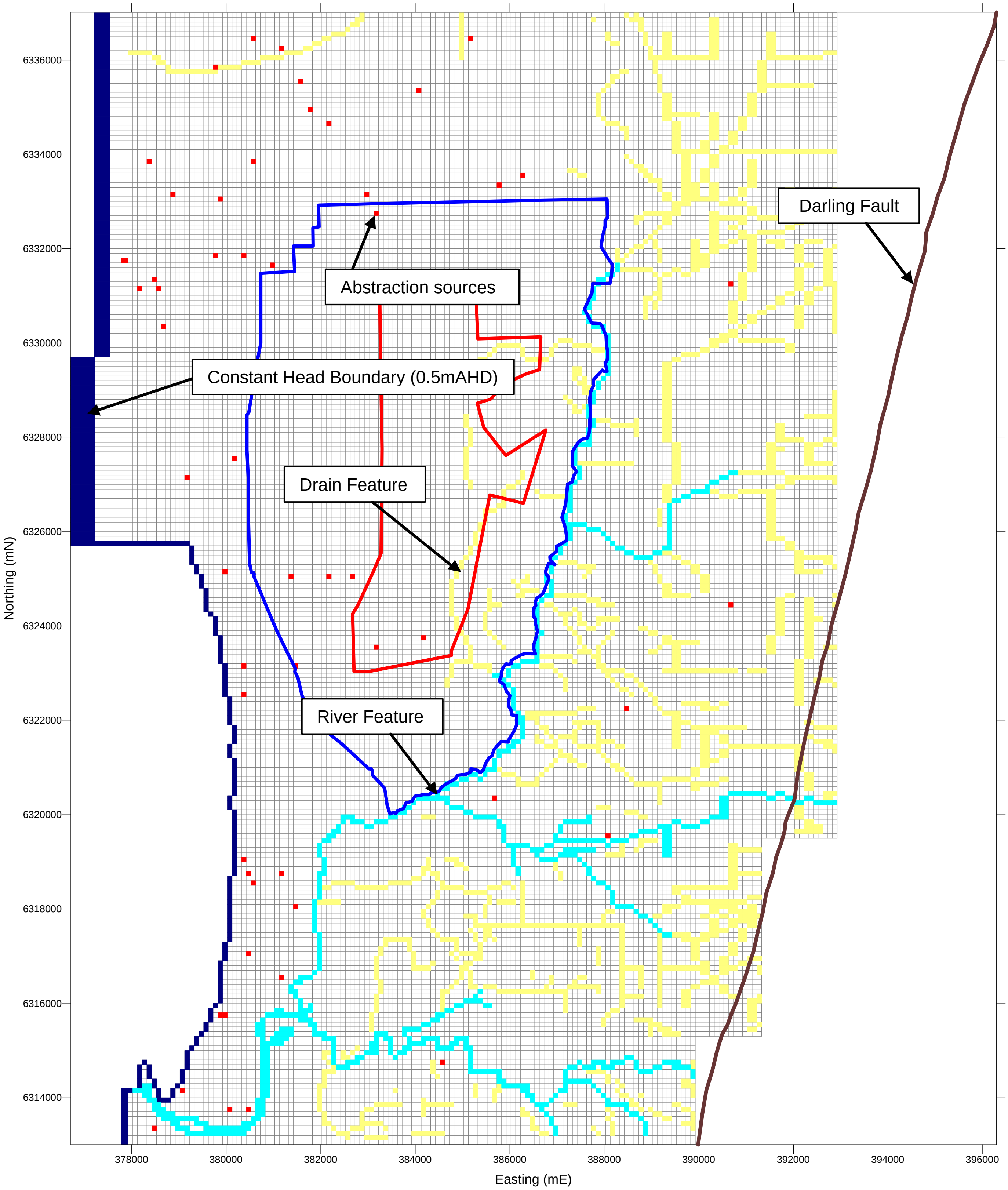
The model geometry and layer elevations are consistent with the configuration in the previous model (Rockwater, 1998). Contours of elevation for the top of each of the above layers is given in Appendix F.

In the model area, the superficial formation comprises the Safety Bay Sand, Tamala Limestone, Tamala Sand, Bassendean Sand and the Guildford Formation (GSWA, 1981 & 1982). These different units were conceptualised as different parameter zones in layer 1 of the model (see Section 9.5). The digital elevation model was used to represent the top of the superficial formations over the whole model area (refer Appendix F).

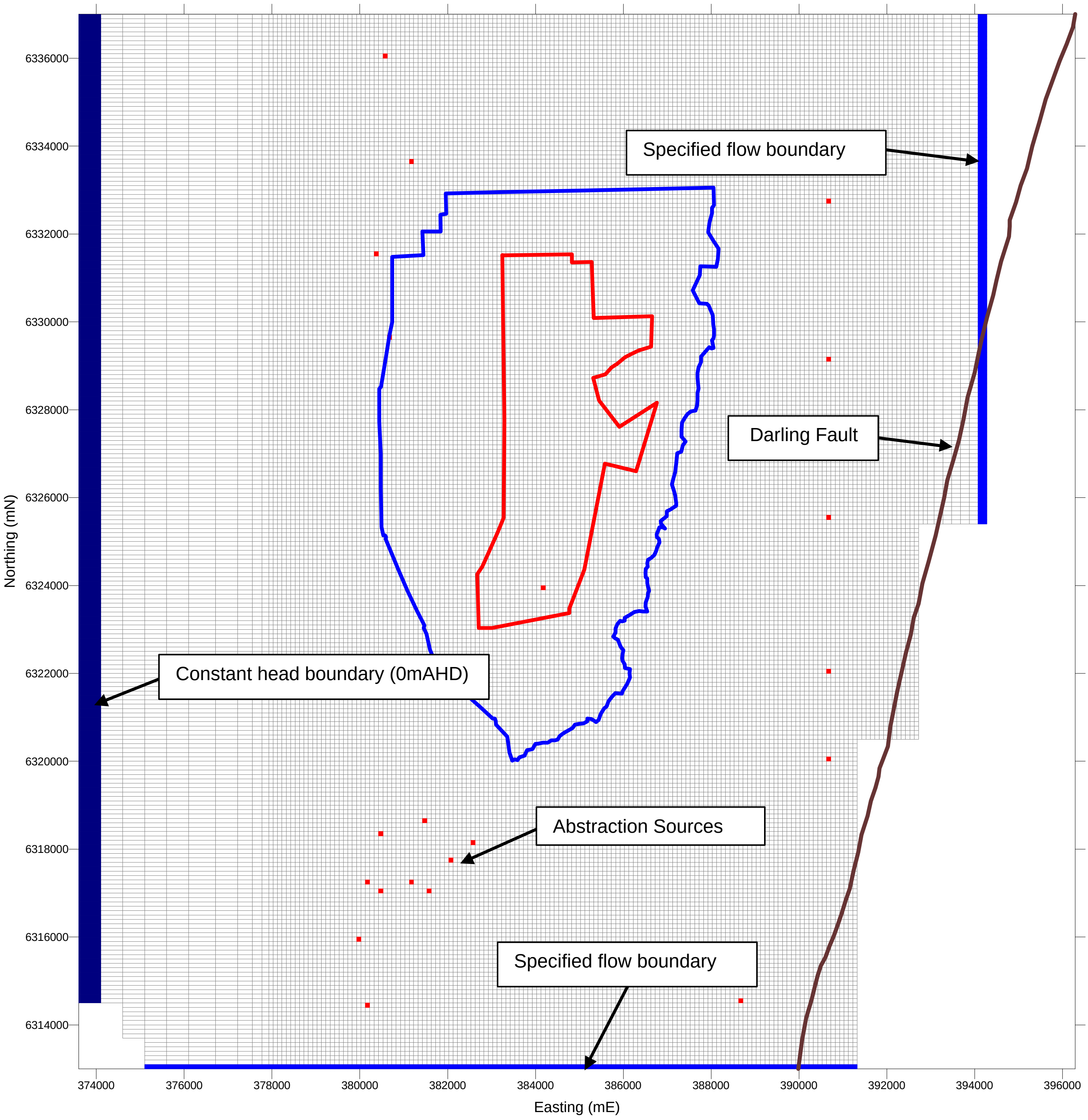
9.3.1 Model Grid and Boundary Conditions

The numerical finite difference groundwater flow modelling package MODFLOW designed by the US Geological Survey (McDonald and Harbaugh, 1988) was used for this work, operating under the PMWin Graphical User interface (version 5.1.7; Chiang and Kinzelbach, 1991-1999).

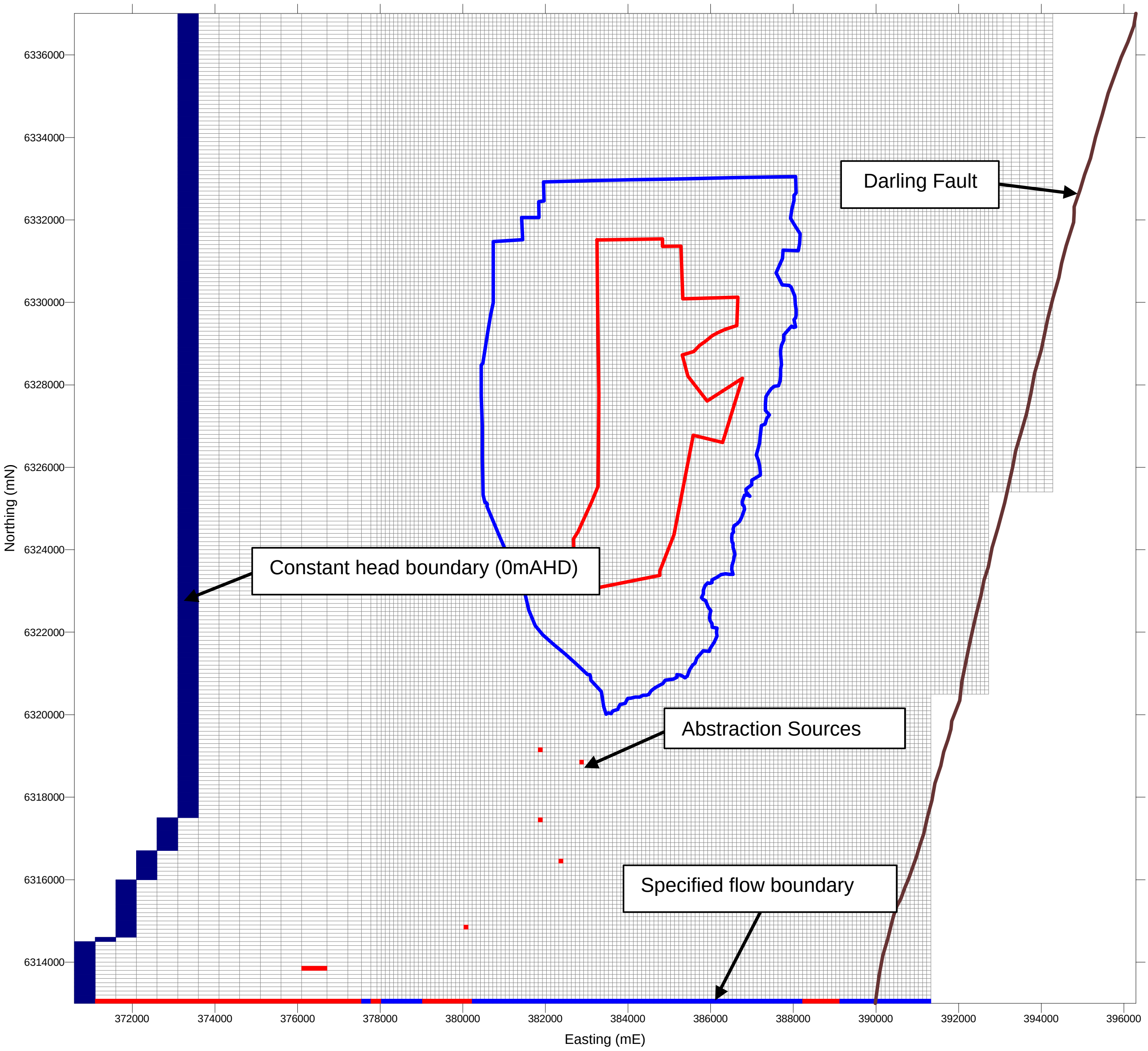
The finite difference grid consists of 176 columns x 244 rows, covering an area approximately 25 km x 25 km. The coastline serves as the western (outflow) boundary for the unconfined aquifer. The active region of the groundwater model is greater for the confined aquifers, as these aquifers extend beyond the coastline. The grid over much of the model area consists of 100 m x 100 m cells to provide more detail to accurately represent river, drainage, abstraction and evapotranspiration features in the model. The cell size increases to 500 m towards the model boundaries.



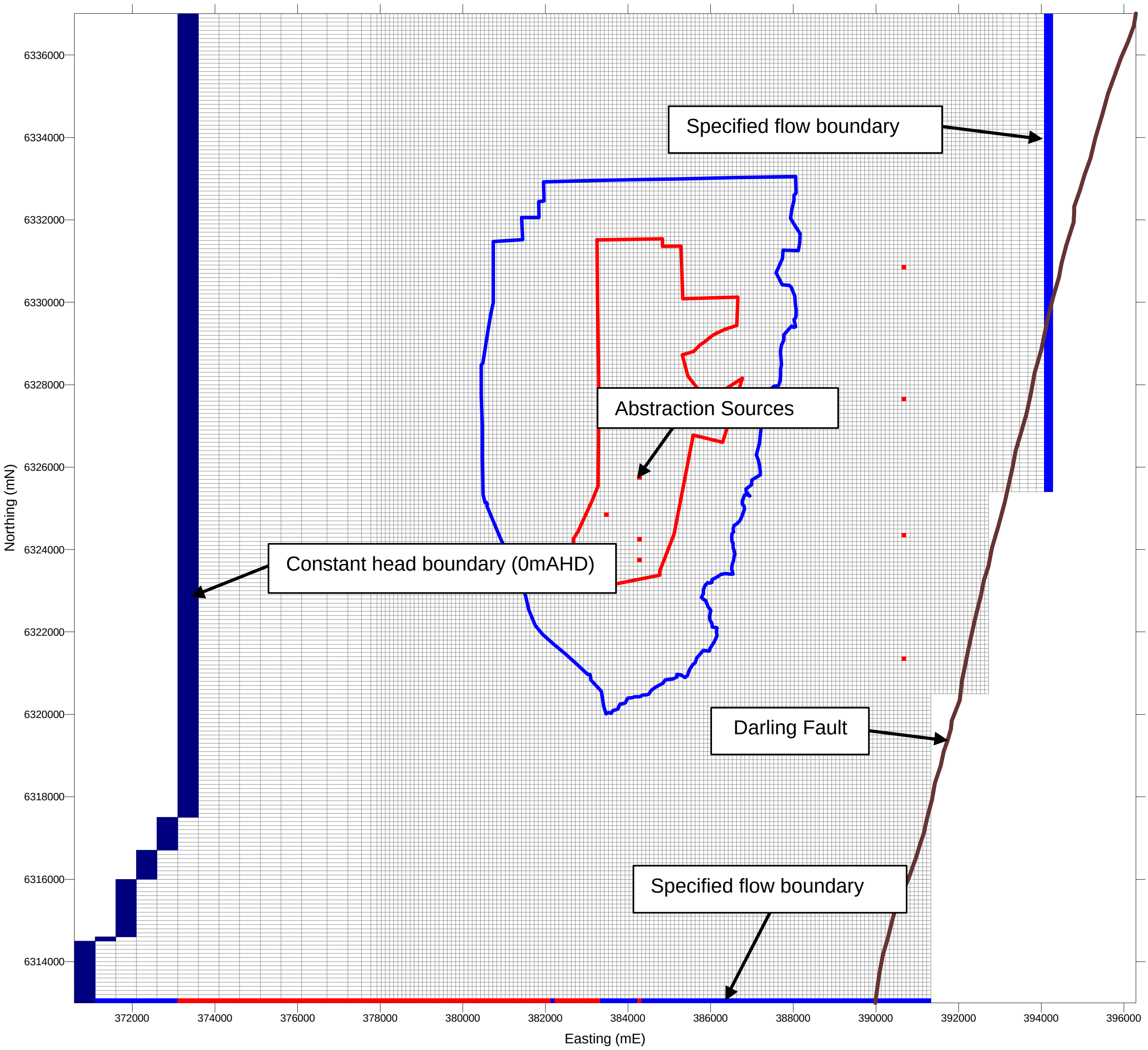
Model Boundaries - Superficial Formation
Figure 9.2



Model Boundaries - Leederville Formation
Figure 9.3



Model Boundaries - Yarragadee Formation
Figure 9.4



Model Boundaries - Cattamarra Coal Measures
Figure 9.5

9.3.2 Model Boundaries

The model developed by Aquaterra covers a smaller area than the 1998 model, extending from just south of the Collie River to north of Kemerton. Figures 9.2 to 9.5 present the boundary conditions and grid details. The northern, eastern and western boundary locations remain unchanged from the 1998 model. To accommodate moving the southern boundary of the model further north, the conditions set at the southern boundary have been changed. The flow contribution from the area south of the Collie River is now simulated by groundwater inflow. That is, the groundwater flow component from this part of the larger semi-regional model is incorporated as a boundary inflow to the new model. These modifications were made to the new Kemerton model, and steady state simulations were run to confirm that it produces results in the Kemerton area comparable with those predicted by the 1998 model.

A constant head outflow boundary was set at the western extent of the model for each layer to represent outflow to the coast. For the superficial formation, this represents the coastline and the Leschenault Estuary. The outflow boundary was set about 2.5 km off the coast for the Leederville Formation, and about 4 km off the coast for the Yarragadee Formation and Cattamarra Coal Measures. This is consistent with the 1998 model, and with hydrogeological information presented in Bulletin 142 (Davidson, 1995).

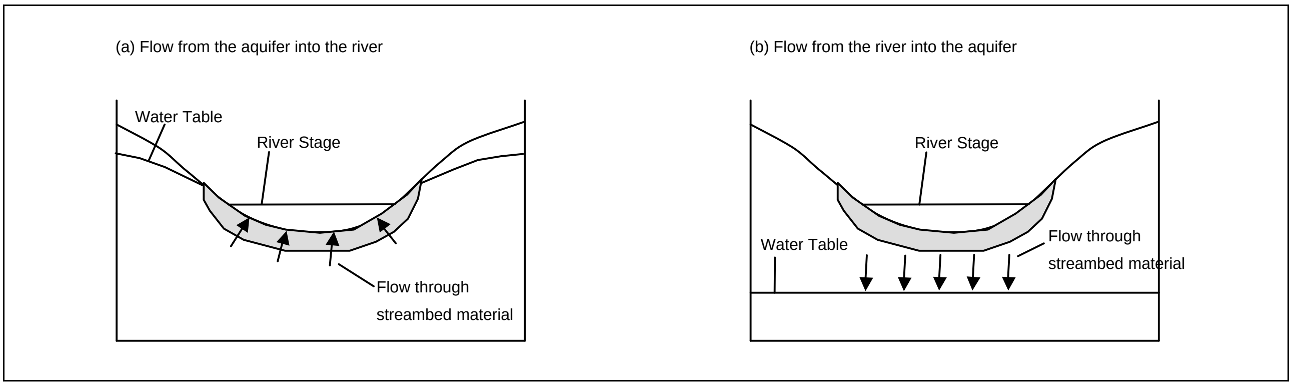
Groundwater inflow boundaries are specified on the northern parts of the eastern model boundary for the Leederville Formation and Cattamarra Coal Measures. There is no eastern inflow boundary specified for the Yarragadee Formation, as this unit is absent in the northern part of the Kemerton area.

9.4 MODEL FEATURES

9.4.1 Surface-Groundwater Interaction

The river (RIV) package in Modflow was used to simulate the Collie, Brunswick and Wellesley Rivers. This allows the simulation of flow between the rivers and the superficial aquifer. A conceptual representation of the stream-aquifer connection is given below. Flow between the river and aquifer is calculated proportional to the head difference and the conductance of the streambed material. The streambed conductance is a function of the cell dimension and the permeability of the underlying material, and is generally a parameter which is varied during model calibration (Anderson and Woessner, 1992). When the head in the river is greater than the water table, flow occurs from the river into the aquifer. If the head in the aquifer is greater than the river stage, then flow occurs from the aquifer into the river.

River Conceptual Model (Modflow)



The digital elevation model was used to define the elevation of the river bed surface. For the steady state calibration (Section 9.5), the height of flow in the river was based on average flow heights data from the gauging stations located along the Collie, Brunswick and Wellesley Rivers. Details on the transient calibration data set are provided in Section 9.6. The bed conductance parameter for both the river and drain features (see later) was 100 m^2/d.

9.4.2 Groundwater Abstraction

There are a large number of abstraction sources in the model area from the unconfined and confined aquifers. The majority of abstraction from the confined aquifers is used for industrial and public water supply purposes, whereas abstraction from the unconfined superficial aquifer is used for irrigation, gardening, domestic and industrial purposes. Licensed abstractions greater than 1,500 kL/yr were included in the model. Generally, the abstraction specified in the model was equal to the licensed allocation, with actual usage data incorporated where available. In the case of abstraction for industries within the Estate, and for water supply by the Water Corporation, the abstraction specified in the model was consistent with information obtained from annual production summaries submitted to the WRC by the industries. Actual usage surveyed by the WRC for a number of licences were also used in lieu of licensed allocations where available. Table 9.1 summarises all abstraction sources included in the model. Abstraction from the Leederville formation was equally split between layers 2 and 3.

9.4.3 Evapotranspiration

Evapotranspiration ("e/t") was applied throughout the model to represent the discharge of groundwater from wetlands and fringing vegetation. The model requires the specification of an e/t surface and maximum e/t rate, such that, if the aquifer water levels rises to the e/t surface, e/t occurs at the maximum rate, as shown in the figure below. The e/t surface was set consistent with ground levels (obtained from the digital elevation model). The extinction depth was set at a specified depth below the elevation of the e/t surface (details given below), such that if aquifer water levels fall below the e/t surface, e/t decreases linearly from the maximum e/t rate and reaches zero as the water level reaches the extinction depth.

Evapotranspiration Conceptual Model (Modflow)

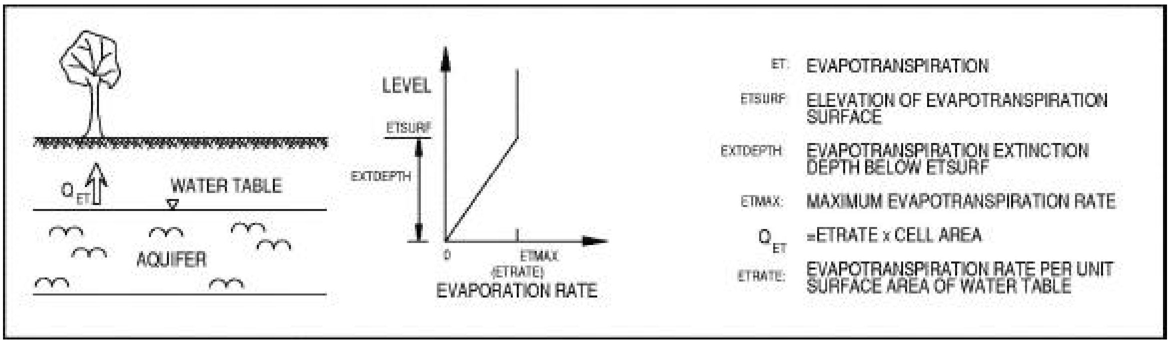


Table 9.1
Modelled Abstraction Sources

Licence No. of Source	Aquifer	Rate (kL/d)	Basis
61062	Cattamarra Coal Measures	1,540	Average of production for 1999 and 2000
61063	Leederville Formation	2,800	
61061	Yarragadee Formation	4,000	Average of production for 1998, 1999 and 2000
61185	Yarragadee Formation	550	Average of production for 1998 to 2000
61186	superficial formation	2.5	
60367	superficial formation	2,300	Average of production for Jul 97 to Jun 98 and Jul 99 to Jun 00
63542 and 97731	Leederville Formation	5,700	Average of production for Jun 98 to Jul 00
Other Users	superficial formation	13,220	Annual allocation & surveyed usage
	Leederville Formation	2,120	Annual allocation & surveyed usage
	Yarragadee Formation	625	Annual allocation & surveyed usage
	Cattamarra Coal Measures	0	Annual allocation & surveyed usage
TOTAL	superficial formation	15,525	Combination of annual allocation, actual usage and surveyed usage
	Leederville Formation	10,620	
	Yarragadee Formation	5,175	
	Cattamarra Coal Measures	1,540	

The extinction depths (Figure F8) specified in the model attempt to represent different land use and vegetation patterns. The extinction depth was set as the depth to the average annual minimum groundwater level. In areas where this depth was greater than 6m below ground (eg. along the topographic ridge), a value of 6m was assigned. The East Gnangara Water Stress Study (WAWA, 1992) suggested that dryland areas with a depth to groundwater of les than 6m were most affected by drawdown. Therefore, vegetation communities are not likely to be directly dependent on groundwater in areas where the water table is greater than 6m below the surface.

Figures F8 and F9 (Appendix F) show the extinction depth and e/t rate specified in the model, consistent with different land use and vegetation patterns in the area.

In terms of e/t rate, there is no site-specific (or even semi-regional) information available on actual water use by different types of groundwater-dependent vegetation in the area. Maximum e/t rates adopted for modelling purposes were 80% of the pan evaporation rate for (potentially) open water bodies and 50% of the pan rate for other areas (the pan rate ranges between 1.8×10^{-3} and 8.2×10^{-3} mm per day). A rate lower than pan was adopted for open water bodies, to reflect the lower water temperature, and the lack of incident side radiation, in water bodies compared to standard pan arrangements. Average quarterly pan evaporation rates were specified in the model, consistent with the transient model setup. Further details on spatial variations are provided in Section 9.6.

9.4.4 Recharge

Groundwater recharge to the superficial aquifer was specified as a percentage of actual rainfall. This was applied in annual stress periods for the steady state runs (Section 9.5), and quarterly stress periods for the transient runs (Section 9.6). The rates of recharge are consistent with the geology of the superficial formations. Table 9.2 lists the (annual) steady state rates, and Table 9.4 and Figure 9.7 show the quarterly recharge rates specified for transient runs. Indirect rainfall recharge to the underlying confined aquifers is by means of leakance across the layer boundary.

Additional recharge was specified for the prediction runs to represent the effects of the development, and to assess the potential for ASR to minimise drawdown impacts and improve water use efficiency. Further details are given later.

9.4.5 Drains

The Drain package in Modflow was used to simulate the large and complex drain network which exists mainly to the east of the Collie and Wellesley Rivers (Figure 9.2). Some of these drains direct flow from low lying sump lands towards the rivers, while others are used for irrigation purposes.

The major drains in the area are the Wellesley diversion drain, Mangosteen drain and the Harvey River diversion drain. The Wellesley diversion drain connects the upper reach of the Wellesley River to the Harvey River diversion drain. Many of the drains in the area, particularly those draining low lying areas into the Wellesley River, are likely to receive groundwater inflows from the superficial aquifer during the wetter parts of the year.

Conceptually, the drain feature in Modflow simulates the removal of water from the aquifer at a rate proportional to the difference between the head in the aquifer and the elevation of the drain, factored by the drain conductance parameter. Similarly to the river package (see above), the drain conductance is a function of the cell dimensions and the conductivity of the underlying material, and is generally a parameter which is varied during model calibration (Anderson and Woessner, 1992). The elevation of the drains was set at 0.5m below the topographic surface represented by the digital elevation model. The discharge of groundwater to the drain feature only occurs if the head in the aquifer is above the specified elevation of the drain. The drain package has no effect if the head in the aquifer falls below the elevation of the drain. The bed conductance parameter for both the rivers and drains was 100 m^2/d.

9.5 STEADY STATE CALIBRATION

The model was initially calibrated to steady state conditions using average annual rates of recharge and evapotranspiration. A number of simulations were performed until an acceptable match was achieved between calculated and observed water levels. For the unconfined and confined aquifers, the measured water levels chosen for the calibration were those measured in April to May 1996, a time when there was monitoring data available for most of the superficial monitoring bores.

The aim of the steady state calibration exercise is to obtain an appropriate set of initial heads for the transient calibration.

Generally, a good match was obtained between the calculated and observed water levels over the whole model area. A calibration plot of calculated steady state groundwater contours, together with measured head values is presented in Figures F10 to F14 (Appendix F) for each aquifer (the heads for the

Leederville formation are average heads simulated for layers 2 and 3). A root mean square (RMS) error of 0.85 m was obtained between the calibrated steady state and observed water levels. This represents a scaled RMS error (percentage of the range in observed heads) of 4.5%, within the guideline value of 5% (Middlemis et al, 2000 - Appendix G). Figure F15 (Appendix F) presents the RMS calibration plot of observed and measured groundwater levels for both the superficial and confined monitoring bores.

The calibrated aquifer parameters and recharge rates from the steady state simulations are given in Table 9.2.

Table 9.2
Aquifer Parameters from Steady State Calibration

Layer	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Steady State Recharge Rate (%)
Layer 1 - superficial			
Guildford Fm	5.5	0.5	12%
Bassendean Sand	0.5 to 25	0.05 to 1.0	30%
Tamala Sand	9.5	1.0	15%
Safety Bay Sand	8.5	1.0	30%
Tamala Limestone	30	1.0	5%
Alluvial River Sediments	15	1.0	12%
Peaty Sands	2	0.1	12%
Layers 2 & 3 - Leederville Fm	4 to 25	1×10^{-3} to 1×10^{-4}	-
Layer 4 - Yarragadee Fm	4 to 25	5×10^{-5}	-
Layer 5 - Cattamarra Coal Measures	4 to 25	5×10^{-5}	-

The steady state water balance is presented in Table 9.3, with a comparison to that achieved in the 1998 model over the same model area. Note that the removal of water from shallow groundwater areas was represented in the 1998 model using the drain package, whereas the new model utilises the evapotranspiration package of Modflow. The constant head boundaries to the south and east in the new model were changed to specified inflow boundaries for the transient calibration (see next section).

9.6 TRANSIENT CALIBRATION

9.6.1 Period of Calibration

The period of model calibration runs from January 1990 to December 2000, reflecting the availability of groundwater monitoring records. This 11 year period exhibits a number of relatively wet to relatively dry years, within an overall period (since 1970) when the average rainfall has been 10% lower than the long term average. Climate variability is addressed further in the prediction simulations (next section). The model calibration period was divided into quarterly stress periods (total of 44) to account for seasonal fluctuations in recharge and evapotranspiration.

Table 9.3
Steady State Water Balance

	1998 Model		New Model	
	Inflow	Outflow	Inflow	Outflow
Constant Head				
superficial	870	51,320	340	4,500
Upper Leederville	4,940	1,800	13,330	9,060
Lower Leederville	11,970	6,160	34,540	29,900
Yarragadee	36,340	21,370	29,110	24,620
Cattamarra Coal M.	20,390	18,040	69,480	67,920
Wells				
superficial	-	5,510	-	15,530
Upper Leederville	-	6,460	-	5,310
Lower Leederville	-	6,460	-	5,310
Yarragadee	-	13,150	-	5,175
Cattamarra Coal M.	-	2,200	-	1,540
Drains	-	41,120	-	5,790
Recharge	107,120	0	128,190	-
River Leakage	280	6,670	18,750	20,500
Evapotranspiration	-	-	-	102,350
TOTAL	**181,910**	**180,260**	**293,740**	**297,505**

Notes:
Constant head flow represents net inflow and outflow of the model through the southern, western and eastern boundaries.

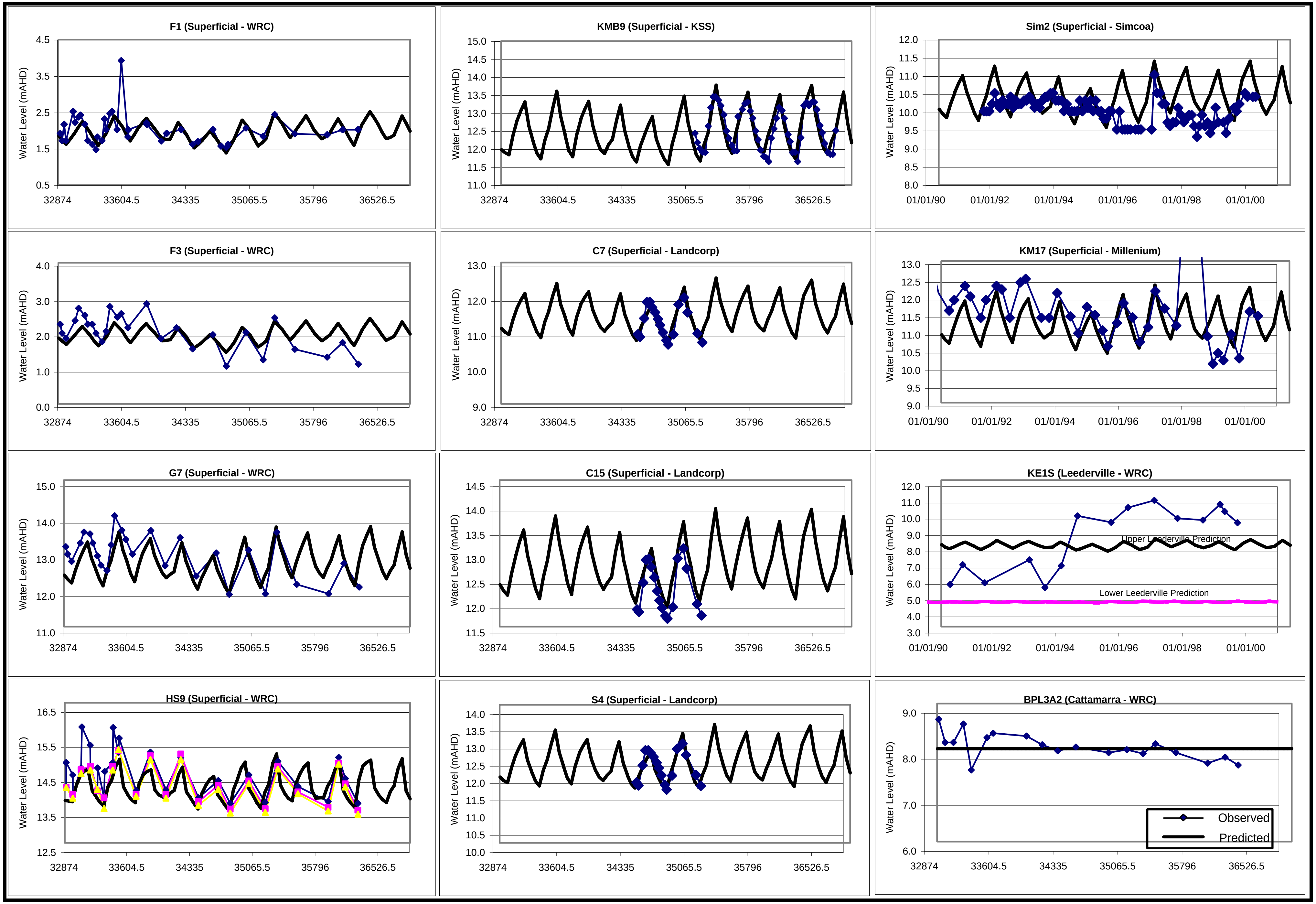
The model was calibrated to long term monitoring records available for 70 bores in the superficial aquifer, and 11 bores in the confined aquifers (Leederville and Cattamarra Coal Measures). Figure 9.6 presents calibration plots of measured versus modelled water level hydrographs for 12 selected bores, with the full set of plots presented in Figures F17 to F23 (Appendix F).

Figure F16 (Appendix F) presents the RMS calibration plot of measured versus modelled groundwater levels for the monitoring bores. A root mean square (RMS) error of 0.8m was obtained between the calibrated and observed water levels. This represents a scaled RMS error (percentage of the range in observed heads) of 3.7%, well within the guideline value of 5% (Middlemis et al, 2000 - refer Appendix G).

These results show that the model is very well calibrated to a wide range of monitoring data for the period 1990 to 2000. Climate variability issues are discussed in more detail in Section 9.7.

9.6.2 Aquifer Parameters from Transient Calibration

The calibrated aquifer parameters for each of the model layers, and the recharge rate, is summarised in Table 9.4 (for all aquifers), and Figure 9.7 (superficial aquifer only). Figures F6 to F8 (Appendix F), show the spatial distribution of these parameters for all aquifers.



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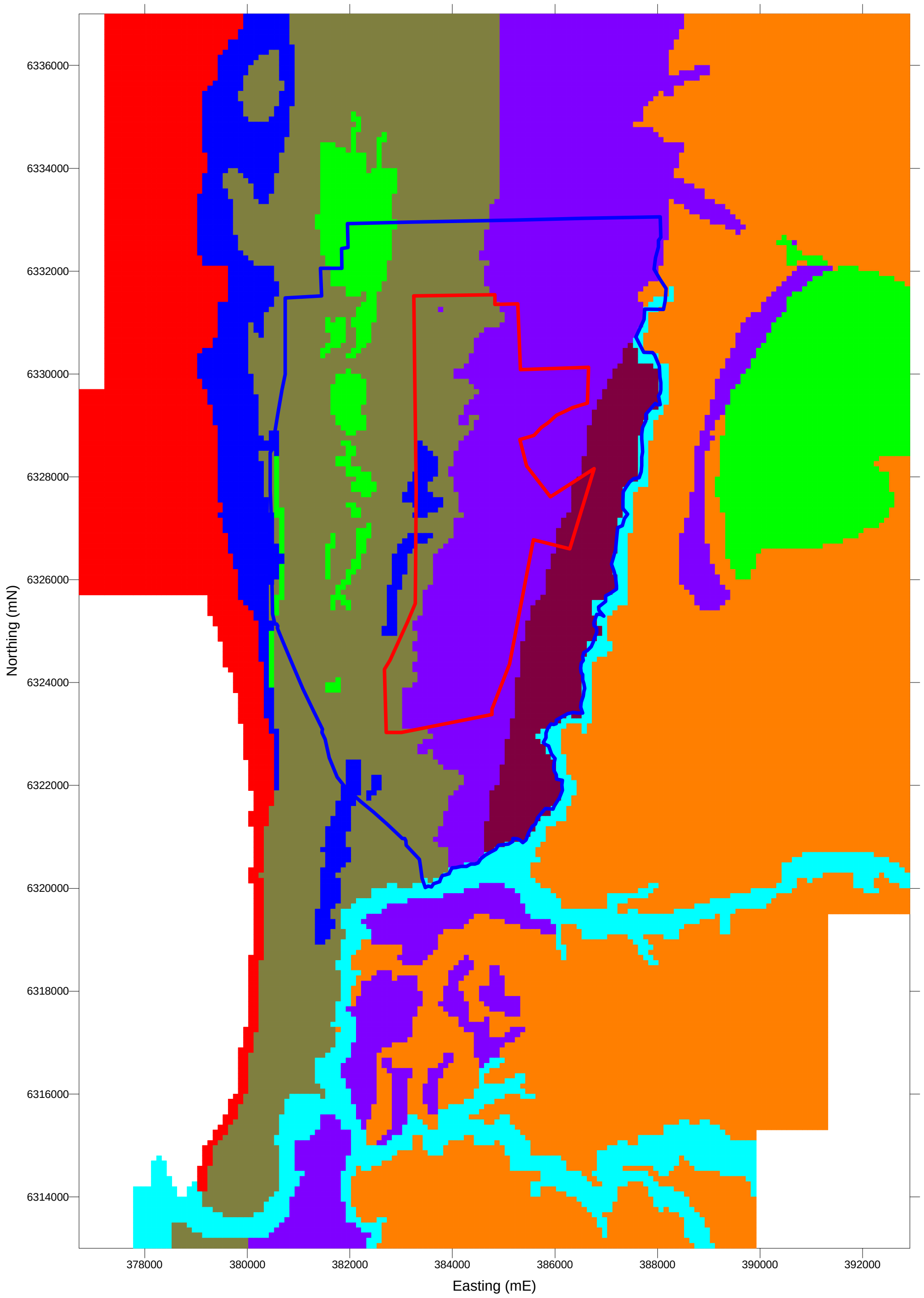
F:\jobs\211\X2\Report Figures\Word Figures\[Figure 9.6.xls]Figure 9.6

Transient Calibration

Figure 9.6



Key	Unit	Kh (m/d)	Kv (m/d)	Sy	Recharge
🟥	Safety Bay Sand	4.5	0.5	0.20	40%
🟦	Tamala Limestone	22	1.0	0.05	5%
🟪	Bassendean Sand	12.5	0.5	0.10	40%
🟫	Bassendean Sand	0.5	0.05	0.10	40%
🟨	Tamala Sand	4.5	0.5	0.10	20%
🟧	Guildford Formation	5.5	0.1	0.03	15%
■	Alluvial River Sediments	15	1.0	0.25	15%
🟩	Peaty Deposits	2	0.1	0.15	15%

Note: Recharge rate is a percentage of quarterly rainfall

Aquifer Parameters - Superficial Formation
Figure 9.7

Table 9.4
Aquifer Parameters from Transient Calibration

Layer	K_h (m/d)	K_v (m/d)	S_y	S	Recharge (%)
Layer 1 - superficial (refer Figure F6)					
Safety Bay Sand	4.5	0.5	0.20	-	40%
Tamala Limestone	22	1.0	0.05	-	5%
Bassendean Sand	0.5 to 12.5	0.05 to 0.5	0.10	-	40%
Tamala Sand	4.5	0.5	0.10	-	20%
Guildford Formation	5.5	0.1	0.03	-	15%
Alluvial River Sediments	15	1.0	0.25	-	15%
Peaty Deposits	2	0.1	0.15	-	15%
Layers 2 & 3 - Leederville Fm	4 to 25	1×10^{-3} to 1×10^{-4}	0.01	2×10^{-4}	-
Layer 4 - Yarragadee Fm	4 to 25	5×10^{-5}	1×10^{-3}	2×10^{-4}	-
Layer 5 - Cattamarra Coal Measures	4 to 25	5×10^{-5}	1×10^{-3}	2×10^{-5}	-

Notes:
Kh - horizontal conductivity; Kv - vertical conductivity; Sy - unconfined storage; S - confined storage;
Recharge specified as a percentage of quarterly rainfall.

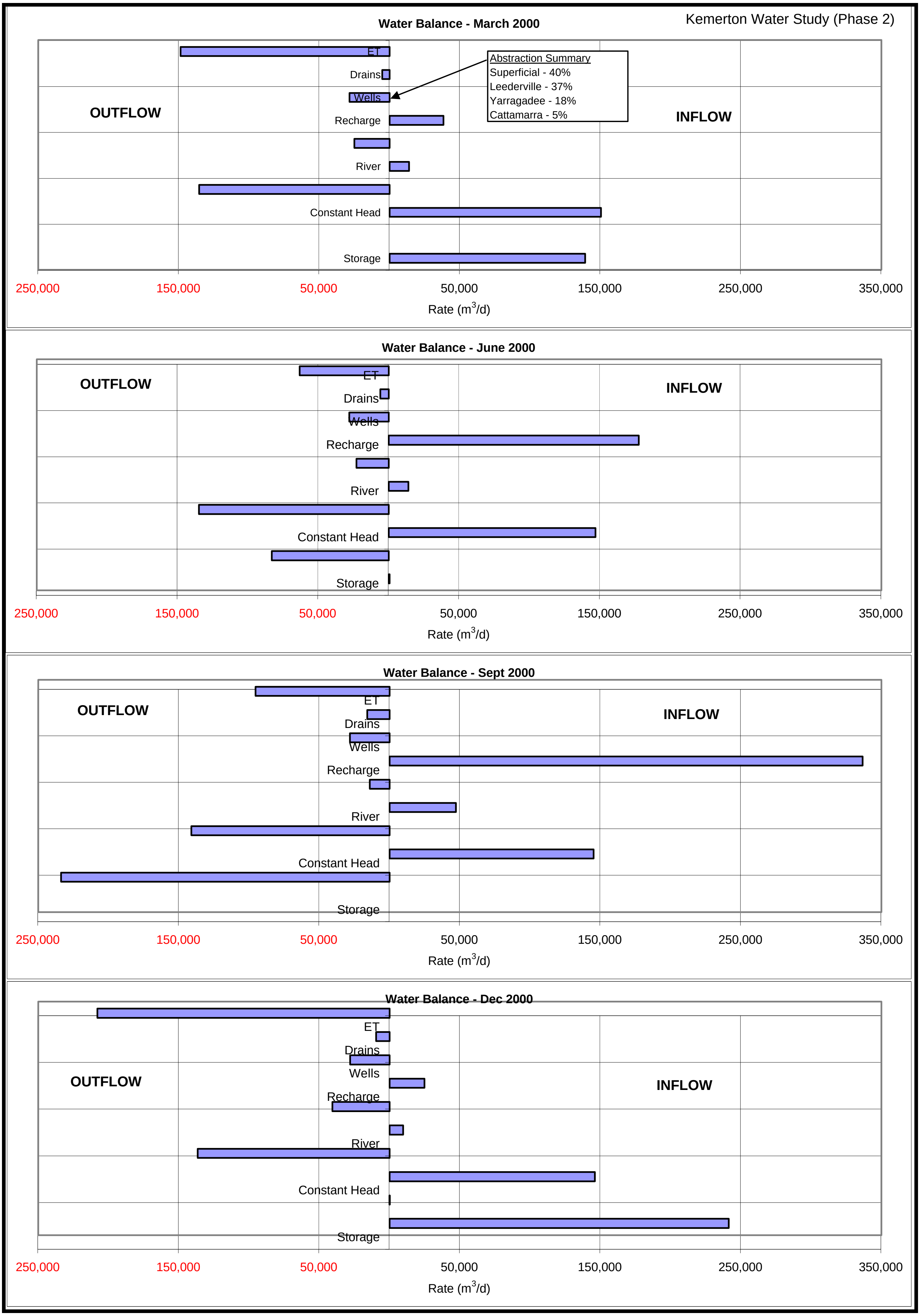
Calibration of the model using quarterly stress periods allowed the replication of seasonal fluctuations in water levels (Figure 9.6). Recharge rates varied between 5% and 40% of quarterly rainfall, based on the surface geology, vegetation patterns and topographic features (Table 9.4 and Figure 9.7). Evaporation was applied at rates of between 0.5 and 0.8 of average pan evaporation for the quarterly stress period, which ranges between 1.8×10^{-3} and 8.2×10^{-3} mm per day. The factor of 0.8 was assigned for open water bodies and 0.5 for the remainder of the model area. The zones of different e/t rates and extinction depths (Appendix F) was consistent with different land use and vegetation patterns in the area, as described in Section 9.4.3.

9.6.3 River Feature for Transient Calibration

As described in Section 9.4, the digital elevation model was used to define the elevation of the river bed surface. The height of flow in the river was based on data from the gauging stations located along the Collie, Brunswick and Wellesley Rivers. River height data was available for the whole length of the calibration period from the Brunswick and Wellesley River gauging stations, but was only available from late 1996 for the Collie station. Average flow heights were applied for the remainder of the calibration period for the Collie River. The flow height specified for each river in the model is therefore the average height measured at each of the gauging stations over the stress period (3 months). Table 9.5 summarises average seasonal flow heights recorded at each of the gauging stations.

9.6.4 Water Balance for Transient Calibration

The water balance for the transient calibration varies with time as the recharge, evapotranspiration and river leakage stresses are changed each stress period (quarterly). Table 9.6 and Figure 9.8 summarise the calibrated water balance for a typical year (2000).



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Transient Calibration Water Balance Summary

F:\jobs\211\B1\Data Processing\[Calibration Water Balance.xls]Water Balance

Figure 9.8

Table 9.5
Average Seasonal River Height

Interval	**Average River Flow Height (Range of Flow Height) in metres**		
	Wellesley (Sep 90 - Dec 00)	Brunswick (Sep 90 - Dec 00)	Collie (Sep 96 - Dec 00)
Jan - Mar	0.22 (0.08 - 0.39)	0.66 (0.32 - 0.85)	0.37 (0.28 - 0.45)
Apr - Jun	0.33 (0.09 - 0.58)	0.93 (0.70 - 1.21)	0.56 (0.47 - 0.69)
Jul - Sep	0.94 (0.58 - 1.36)	1.74 (1.16 - 2.26)	1.29 (0.58 - 2.77)
Oct - Dec	0.25 (0.12 - 0.49)	0.80 (0.44 - 1.09)	0.62 (0.36 - 0.94)

Table 9.6
Transient Calibration Water Balance - Year 2000

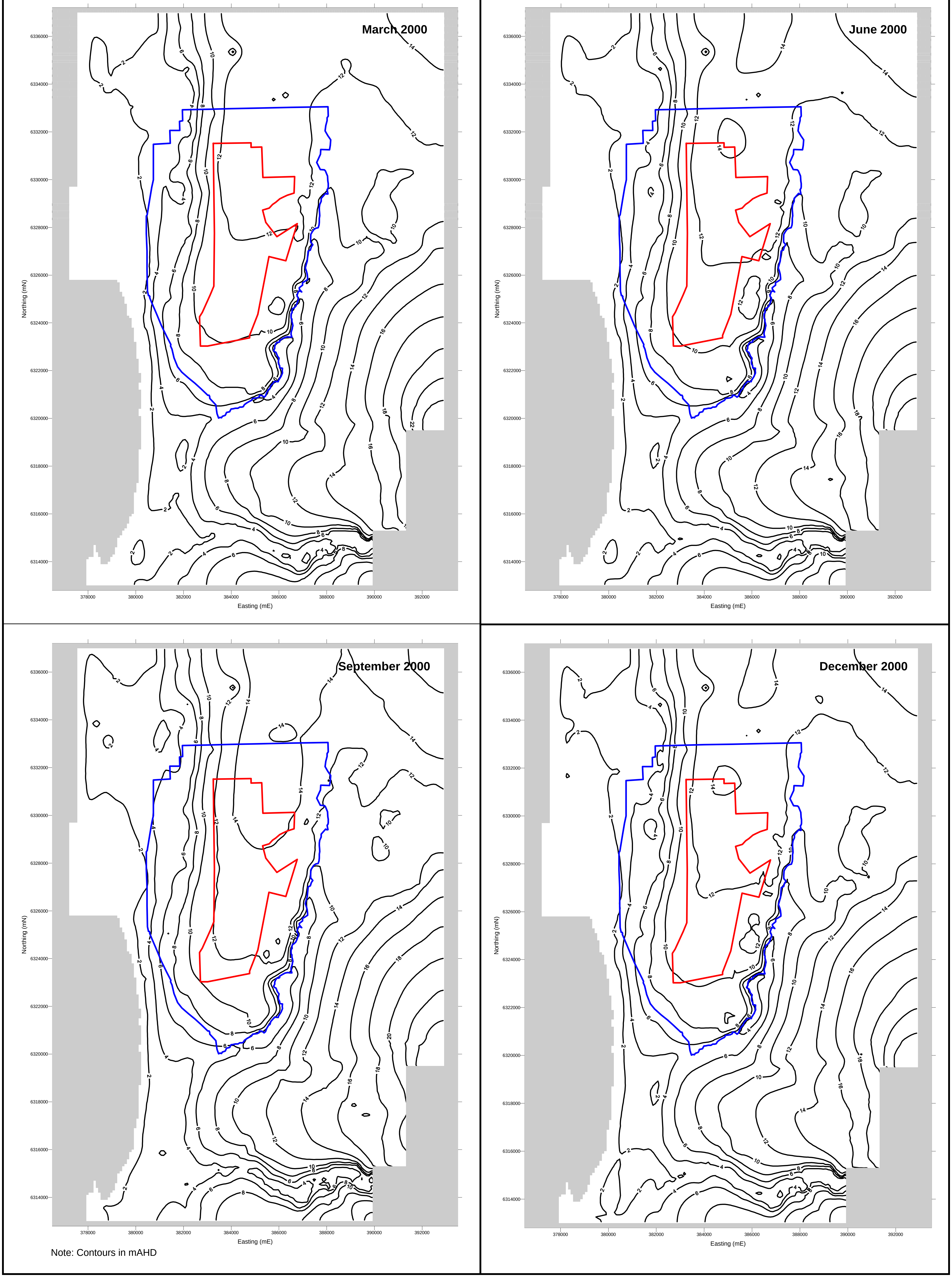
Component	**March 2000**	**June 2000**	**September 2000**	**December 2000**
Inflows (kL/d)				
Storage	139,200	700	0	241,400
Constant Head Inflow	150,400	146,900	145,200	146,100
Recharge	38,300	177,600	336,600	24,900
River Leakage Into Aquifer	13,900	14,000	47,200	9,700
Total Inflows (kL/d)	341,800	339,200	529,000	422,100
Outflows (kL/d)				
Storage	0	83,100	233,800	100
Constant Head Outflow	135,400	134,900	141,100	136,500
Groundwater Abstraction	28,100	28,100	28,100	28,100
Drains	5,300	6,000	15,900	9,500
Evapotranspiration	148,800	63,200	95,300	207,900
River Leakage out of Aquifer	25,000	22,900	14,100	40,700
Total Outflows (kL/d)	342,600	338,200	528,300	422,800

Figure 9.8 shows the dynamic changes in the major components of the water balance during different times of the year. During the winter months, recharge is dominant, and during the summer months, evapotranspiration is the dominant component. Constant head inflows and outflows do not change significantly throughout the year. Current groundwater abstraction is a relatively minor component of the water balance. Leakage from and to the river (there is spatial variation of inflows/outflows to/from the rivers), and aquifer outflow to drains, is highest during the winter period, but these flows are also a minor component of the overall water balance.

Figure 9.9 presents contour plots of modelled superficial aquifer water level for each quarter through the year 2000, showing the effect in terms of water level ranges of these seasonal changes to the water balance. Climate variability is discussed in more detail in the next section.

9.7 MODEL PREDICTIONS

The calibrated groundwater model was used to perform a number of predictive simulations to assess the impact of groundwater abstraction, climate variability and aquifer storage and recovery on aquifer water levels, environmental water requirements and the sustainability of groundwater abstractions.



Note: Contours in mAHD

Seasonal Change in Water Table
Figure 9.9

9.7.1 Model Setup for Predictions

The southern and eastern constant head boundaries used to represent inflow/outflow into the confined units during calibration were replaced with specified flow boundaries for the prediction scenarios. The flows specified were those observed across the boundary during calibration. The specified flows are summarised in Table 9.7 below. These flows remain constant for all of the predictions discussed below.

Table 9.7
Specified Boundary Flows

Aquifer	Southern Boundary		Eastern Boundary	
	Inflow (kL/d)	Outflow (kL/d)	Inflow (kL/d)	Outflow (kL/d)
Upper Leederville Fm	11,770	-	1,150	-
Lower Leederville Fm	30,350	-	4,100	-
Yarragadee Fm	25,780	13,820	-	-
Cattamarra Coal Measures	11,900	10,580	57,580	-

In order to simulate clearing for the Estate, and the increase in runoff from the paved areas of the development, the recharge rate for the industrial core was increased to 50%. This is consistent with groundwater recharge rates adopted in groundwater modelling completed for various areas on the Swan Coastal Plain, including Ellen Brook and the Alkimos-Eglinton area (Woodward Clyde, 1996).

In addition, some prediction runs (notably Pred5 - see Table 9.8) involved the specification of additional recharge during winter to simulate the effect of aquifer storage and recovery (ASR). Based on the information provided in Section 6, a total of 2GL (at 22,000 kL/d) was injected to the superficial aquifer during the winter quarter, with abstraction at the High Demand case, to simulate ASR.

9.7.2 Period of Simulation for Predictions

The groundwater model uses rainfall data to estimate recharge to the aquifer (refer Section 9.4). Figure 9.10 shows the annual rainfall for the Central Coast District, along with the long term average and the average for periods of relatively high and low rainfall (1915-34, and 1970-99, respectively).

Figure 9.10 shows that the average for the period 1970 to 1999 is 753 mm, which is around 10% less than the long term average (1913 to 1999) of 836 mm. This indicates that the model calibration period (1990 to 2000) occurs within the extended low rainfall period since about 1970. There have been periods of above and below average rainfall within the period since 1970 (compared to the average for this period). The calibration period therefore comprises an acceptable set of multiple distinct hydrological conditions (ie. it helps to address the model non-uniqueness issue) in terms of recharge. In other words, the model is calibrated to hydrological variations over a 10-year period, within an overall relatively dry period of 30 years.

Figure 9.10
Annual Rainfall (Central Coast District)

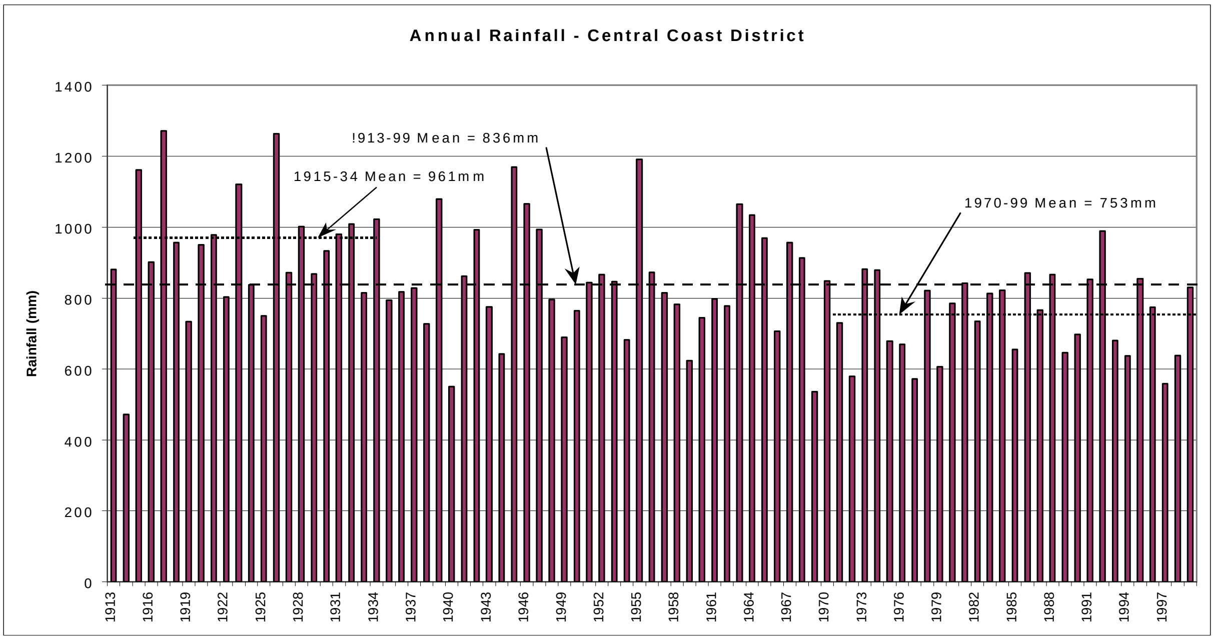


Figure 9.11 shows the residual annual rainfall plot for these periods - 1913 to 1999, 1915-34 and 1970 to 1999. Residual rainfall is a plot of the difference between the annual rainfall and the average annual rainfall (for that period), accumulated each year. A rising slope indicates above average rainfall (eg. 1915 to 1934), a flat trend indicates an average rainfall period (eg. through the 1940's to 1970), and a falling slope indicates below average rainfall (eg. 1970 to 1999).

There is a view that the lower rainfall conditions that we have experienced since 1970 could include some Greenhouse effects, but the degree cannot be quantified (J Ruprecht, *pers.comm.*). The accepted hydrological wisdom is that the rainfall conditions expected over the next 20-30 years would be similar to that since 1970.

Therefore, the base case prediction scenario will use the rainfall record since 1970 to estimate recharge for input to the model. This approach provides a degree of conservatism for this impact assessment study, as the base case run reflects relatively dry conditions, compared to the long term record through last century. As an extreme dry (Greenhouse effect) case, a sensitivity run will use the rainfall record since 1970, reduced by 10%. As a wet scenario, the modelled recharge will be based on rainfall for the period 1915 to 1934.

9.7.3 Prediction Scenarios

A summary of the predictive simulations carried out to assess the impact of groundwater abstraction is given in Table 9.8 below. It should be noted that the Pred0 base case involves existing regional abstraction (ie. including around 7,192 kL/d or 2.6 GL/yr for existing Kemerton industries - refer Table 9.1), plus the specified Kemerton Demand scenario as additional abstraction.

Figure 9.11
Residual Rainfall Plot (Central Coast District)

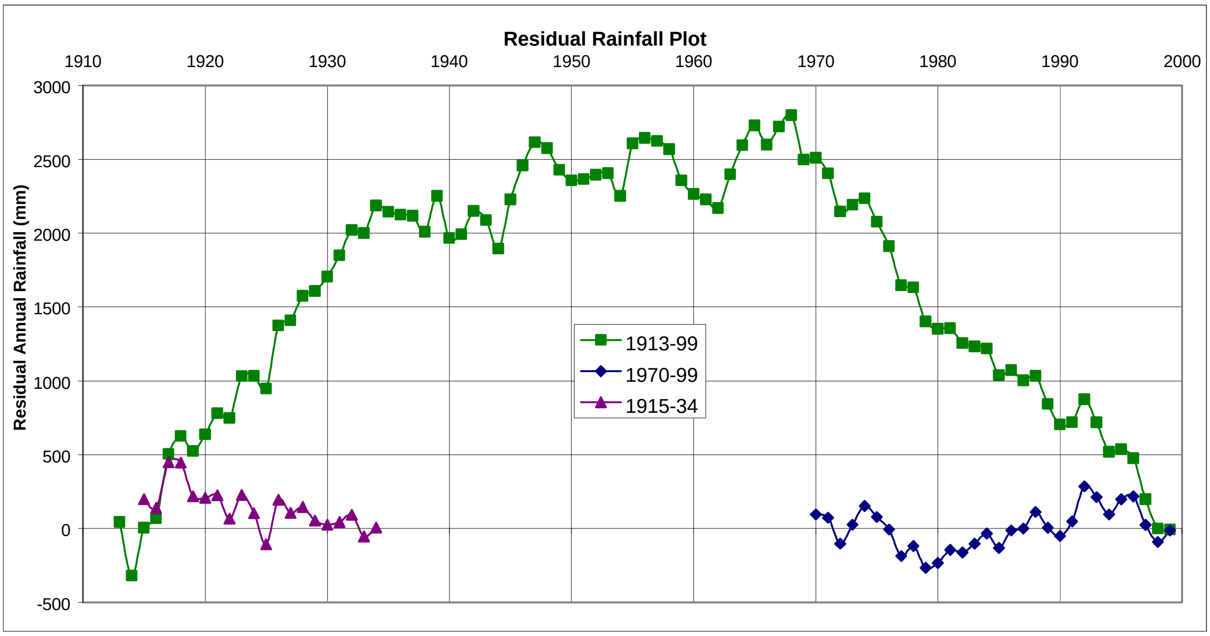
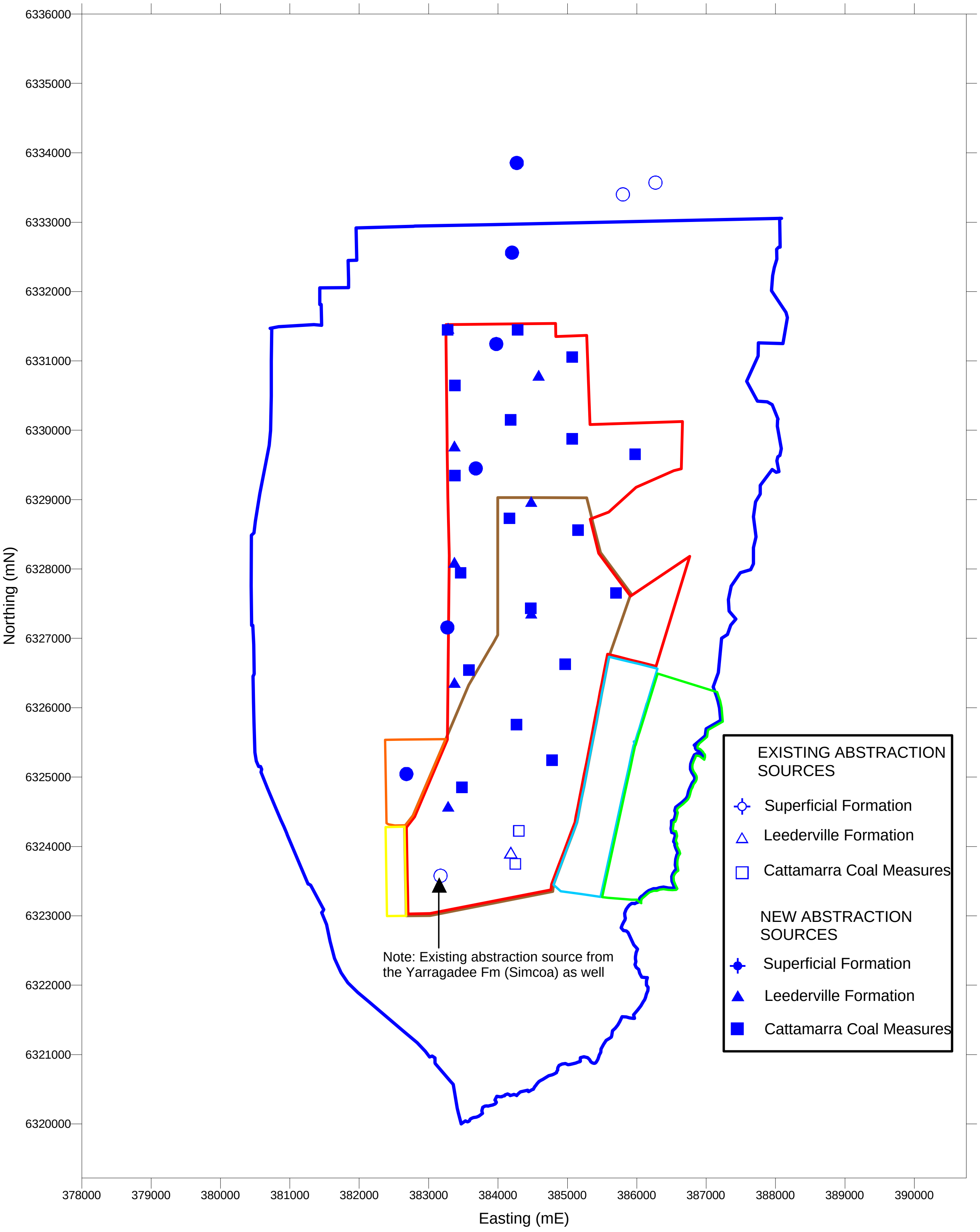


Table 9.8
Prediction Run Schedule

Run	Description
Pred0	Simulation over 30 year base case period with abstractions continuing at the current rate.
Pred1	Pred0 plus abstraction of 14 GL/yr (high growth demand scenario) from the Leederville Formation (20 bores @ 1920 kL/d each).
Pred2	Pred0 plus abstraction of 14 GL/yr (high growth demand scenario) from the Cattamarra Coal Measures (20 bores @ 1920 kL/d each).
Pred3	Pred0 plus 14 GL/yr abstraction, with 2.5 GL/yr from the superficial formation (7 bores @ 1000 kL/d each) and 11.5 GL/yr (17 bores @ 1850 kL/d each) from the Leederville Formation.
Pred4	Pred0 plus 14 GL/yr abstraction (high growth demand scenario), with 1GL/yr from the superficial formation (7 bores @ 400 kL/d each), 4 GL/yr from the Leederville Formation (9 bores @ 1200 kL/d each) and 9 GL/yr (12 bores @ 2050 kL/d each) from the Cattamarra Coal Measures. The total abstraction was increased at a rate of approximately 1 GL/yr over 14 years and then maintained at 14 GL/yr for the rest of the simulation.
Pred5	Pred1 plus the simulation of aquifer storage and recovery (ASR) by injecting 22,000 kL/d into the Leederville Fm during winter each year (this volume represents a 5% take off from the Wellesley River during winter peak flow conditions).
Pred6	Pred0 plus abstraction of 10 GL/yr (Medium demand scenario) from the Cattamarra Coal Measures.

The maximum drawdown in each aquifer for the above predictions, which occurs around the selected abstraction bore locations, is summarised in Table 9.9 below. The spatial distribution of the predicted drawdown impacts in each aquifer for the Pred4 High Demand scenario (14GL/yr) is shown in Figures 9.12 to 9.14.

Table 9.10 and Figures 9.15 to 9.17 summarise the impact of the predictions in terms of the various components of the model water balance at the end of the simulation period. Water balance impacts need to be considered because they quantify the impacts of the additional abstraction in terms of changes to flows at the model boundaries, as well as the interaction between other components of the water balance. Assessment of changes to flows at the boundaries can identify risks such as saline intrusion (eg. if what is currently an outflow boundary to the coast changes to an inflow condition under certain abstraction scenarios, then there is significant risk of saline intrusion).



Note: Existing abstraction source from the Yarragadee Fm (Simcoa) as well

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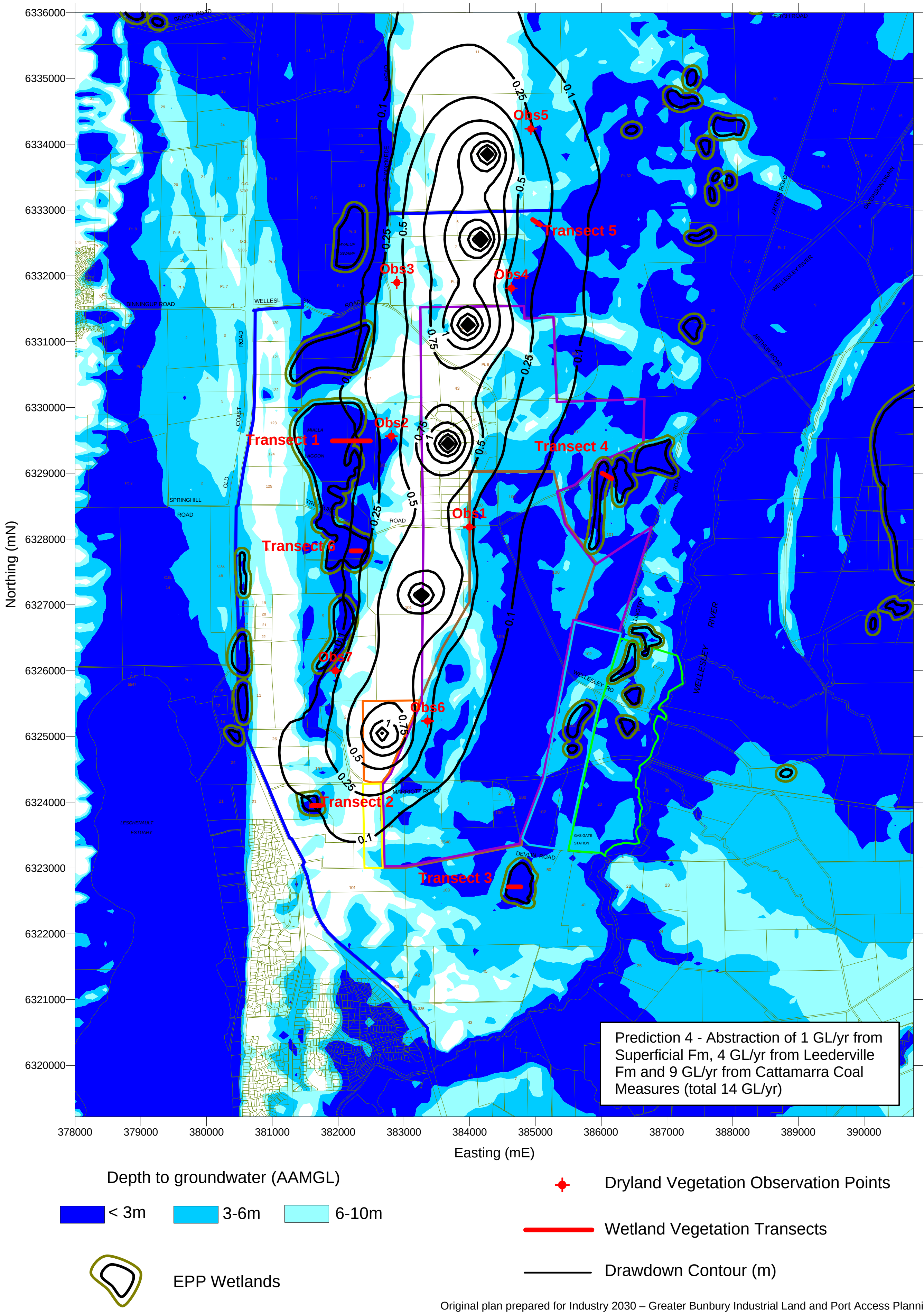
Location of Abstraction Sources
Figure 9.12a



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures (total 14 GL/yr)

Original plan prepared for Industry 2030 – Greater Bunbury Industrial Land and Port Access Planning

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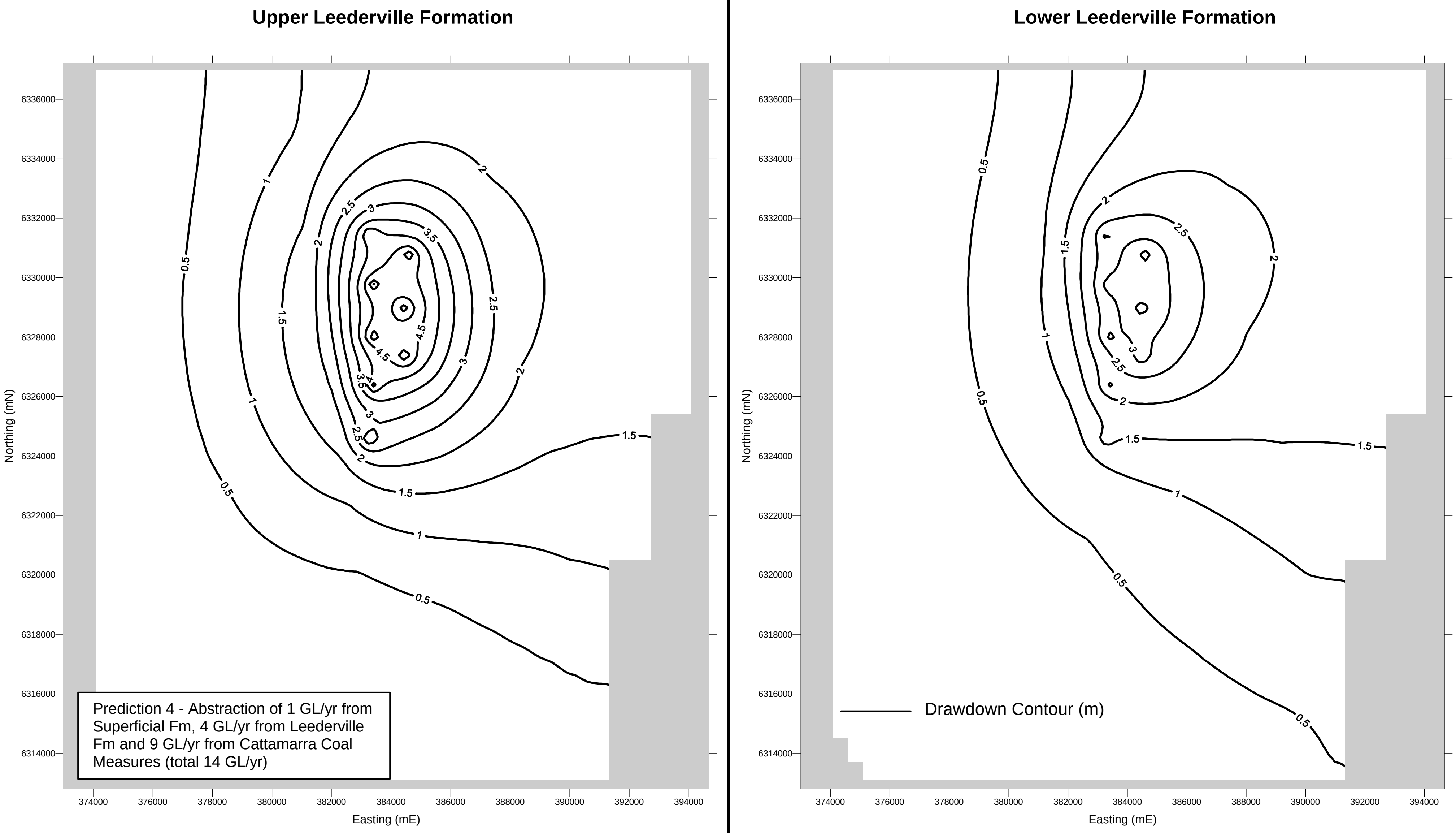
Drawdown in Superficial Fm (30 yrs) – Pred4

Figure 9.12

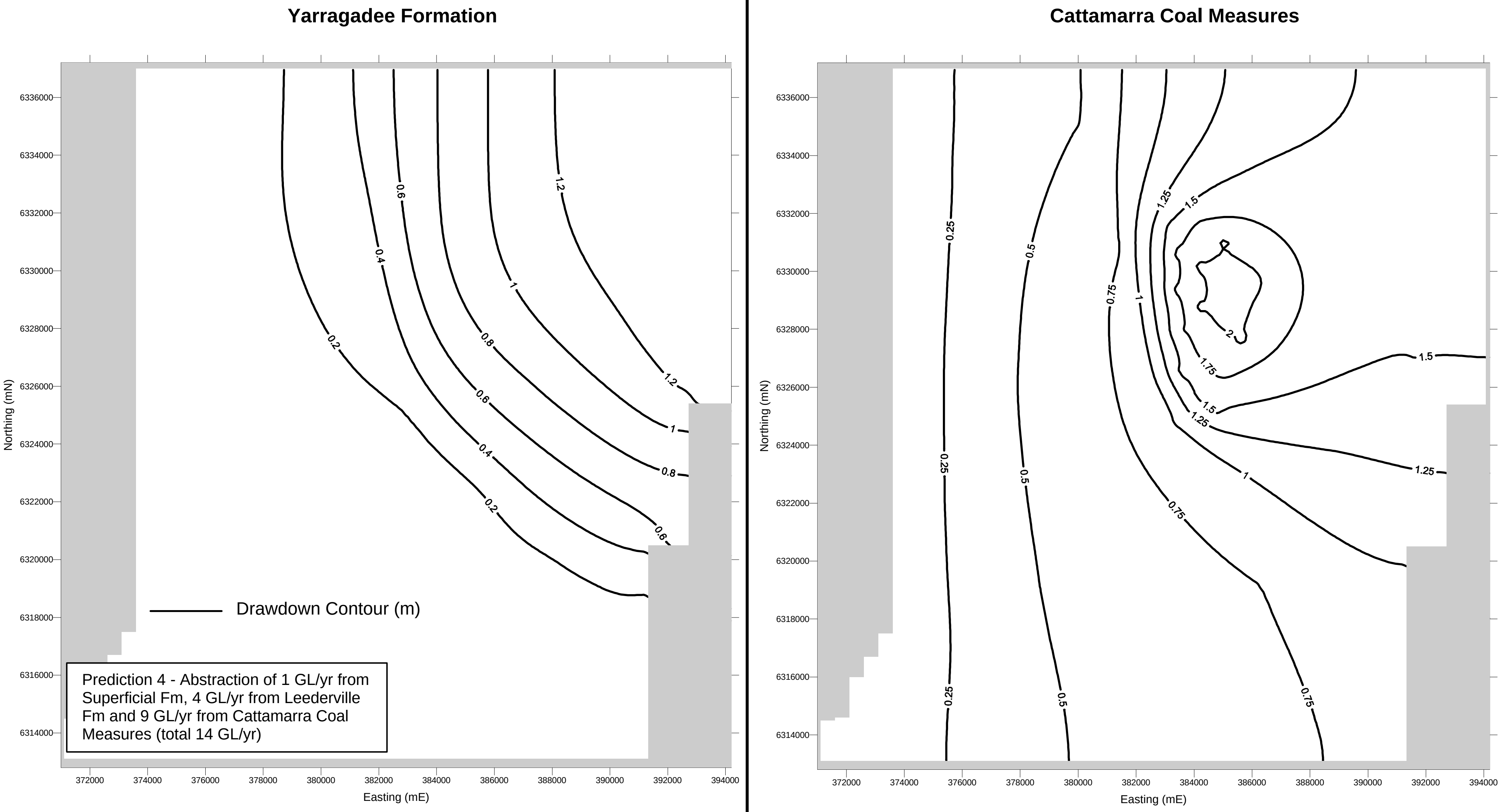


Upper Leederville Formation

Lower Leederville Formation

Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures (total 14 GL/yr)

Drawdown in Upper and Lower Leederville Fms (30 yrs) – Pred4
Figure 9.13



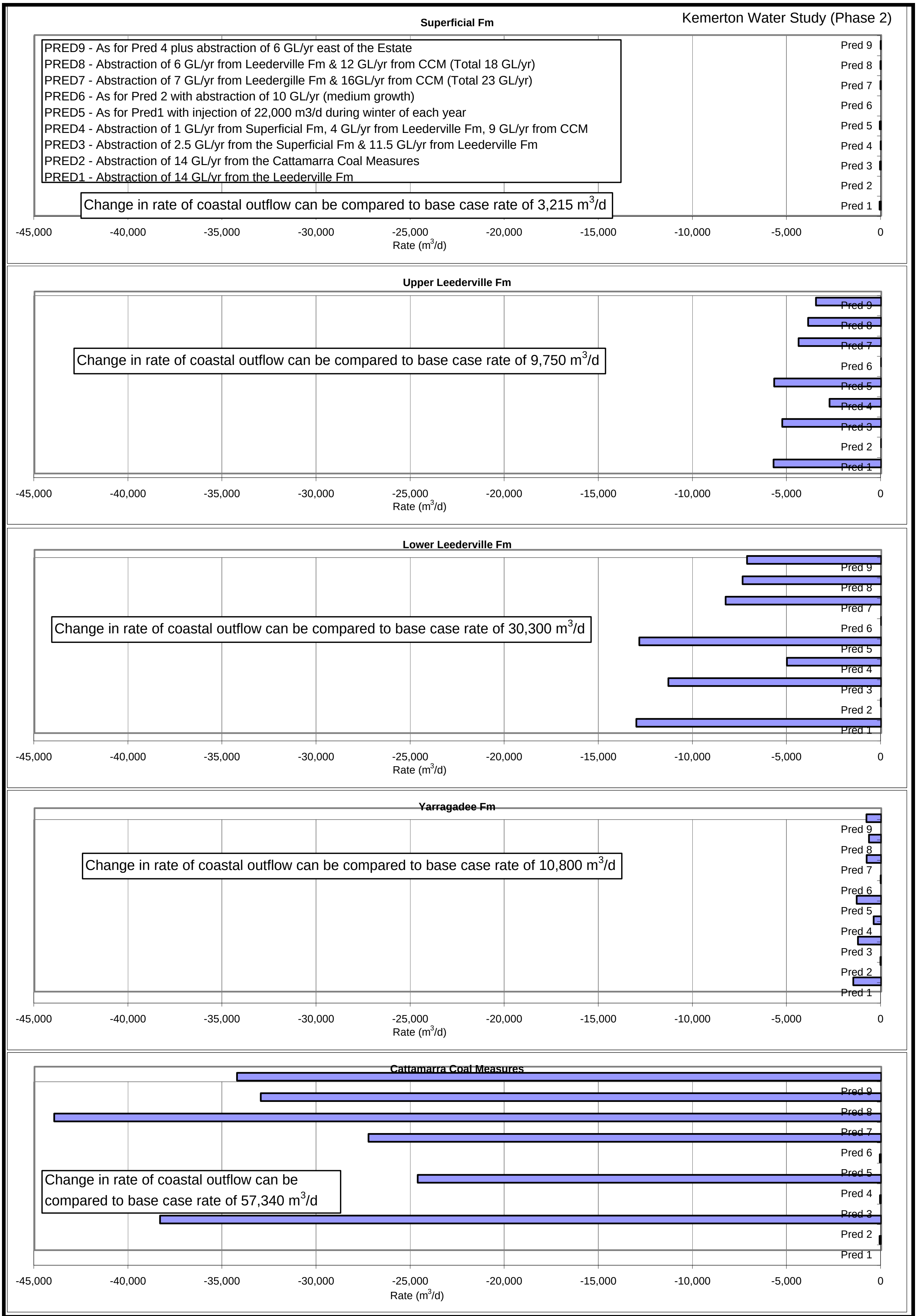
Yarragadee Formation

Cattamarra Coal Measures

Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures (total 14 GL/yr)

Drawdown in Yarragadee Fm & Cattamarra Coal Measures (30 yrs) – Pred4

Figure 9.14



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Change in Coastal Outflow

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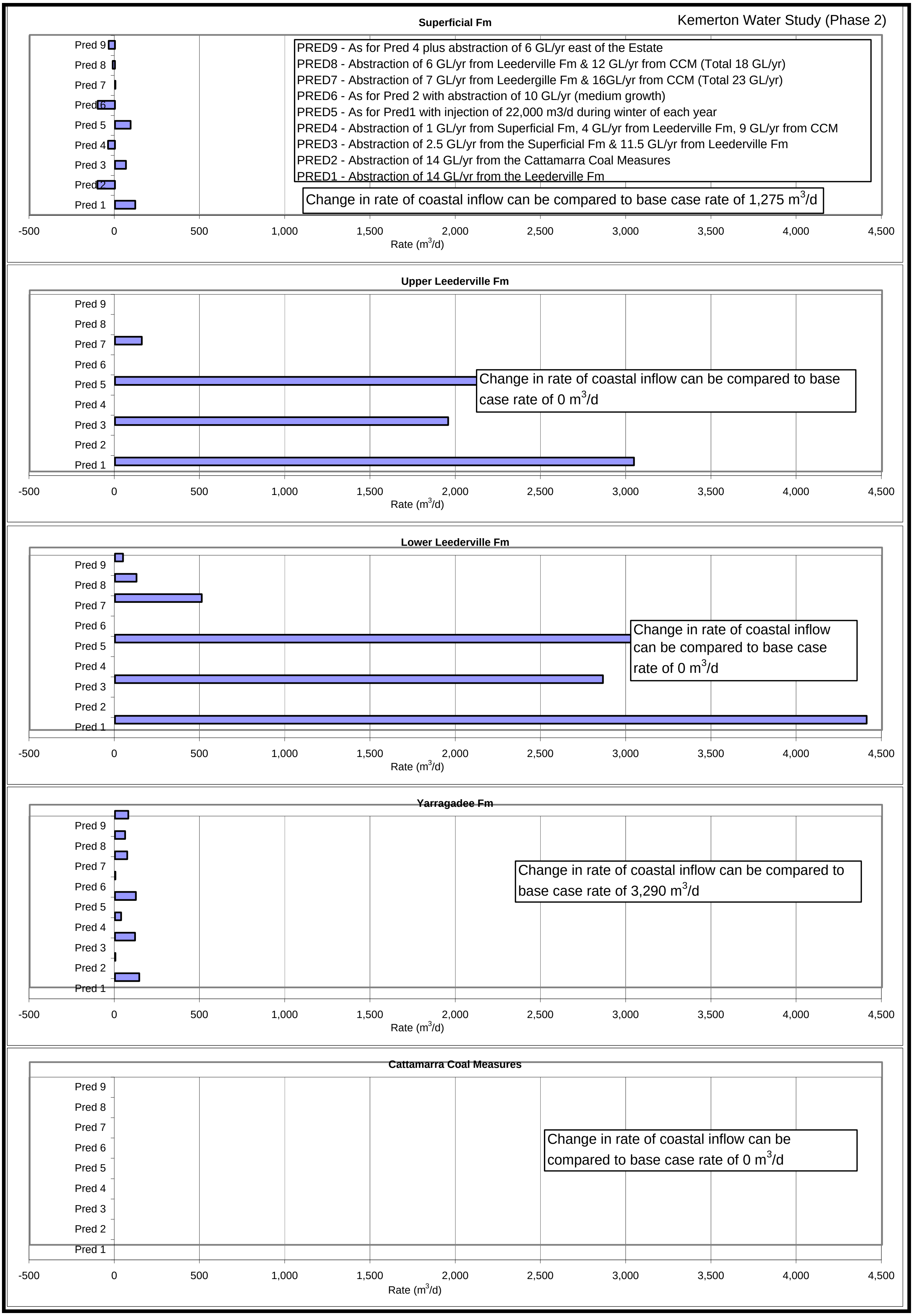
Figure 9.15

Kemerton Water Study (Phase 2)



PRED9 - As for Pred 4 plus abstraction of 6 GL/yr east of the Estate
PRED8 - Abstraction of 6 GL/yr from Leederville Fm & 12 GL/yr from CCM (Total 18 GL/yr)
PRED7 - Abstraction of 7 GL/yr from Leedergille Fm & 16GL/yr from CCM (Total 23 GL/yr)
PRED6 - As for Pred 2 with abstraction of 10 GL/yr (medium growth)
PRED5 - As for Pred1 with injection of 22,000 m3/d during winter of each year
PRED4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm, 9 GL/yr from CCM
PRED3 - Abstraction of 2.5 GL/yr from the Superficial Fm & 11.5 GL/yr from Leederville Fm
PRED2 - Abstraction of 14 GL/yr from the Cattamarra Coal Measures
PRED1 - Abstraction of 14 GL/yr from the Leederville Fm

Change in rate of coastal inflow can be compared to base case rate of 1,275 m^3/d

Change in rate of coastal inflow can be compared to base case rate of 0 m^3/d

Change in rate of coastal inflow can be compared to base case rate of 0 m^3/d

Change in rate of coastal inflow can be compared to base case rate of 3,290 m^3/d

Change in rate of coastal inflow can be compared to base case rate of 0 m^3/d

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Change in Coastal Inflow

Figure 9.16

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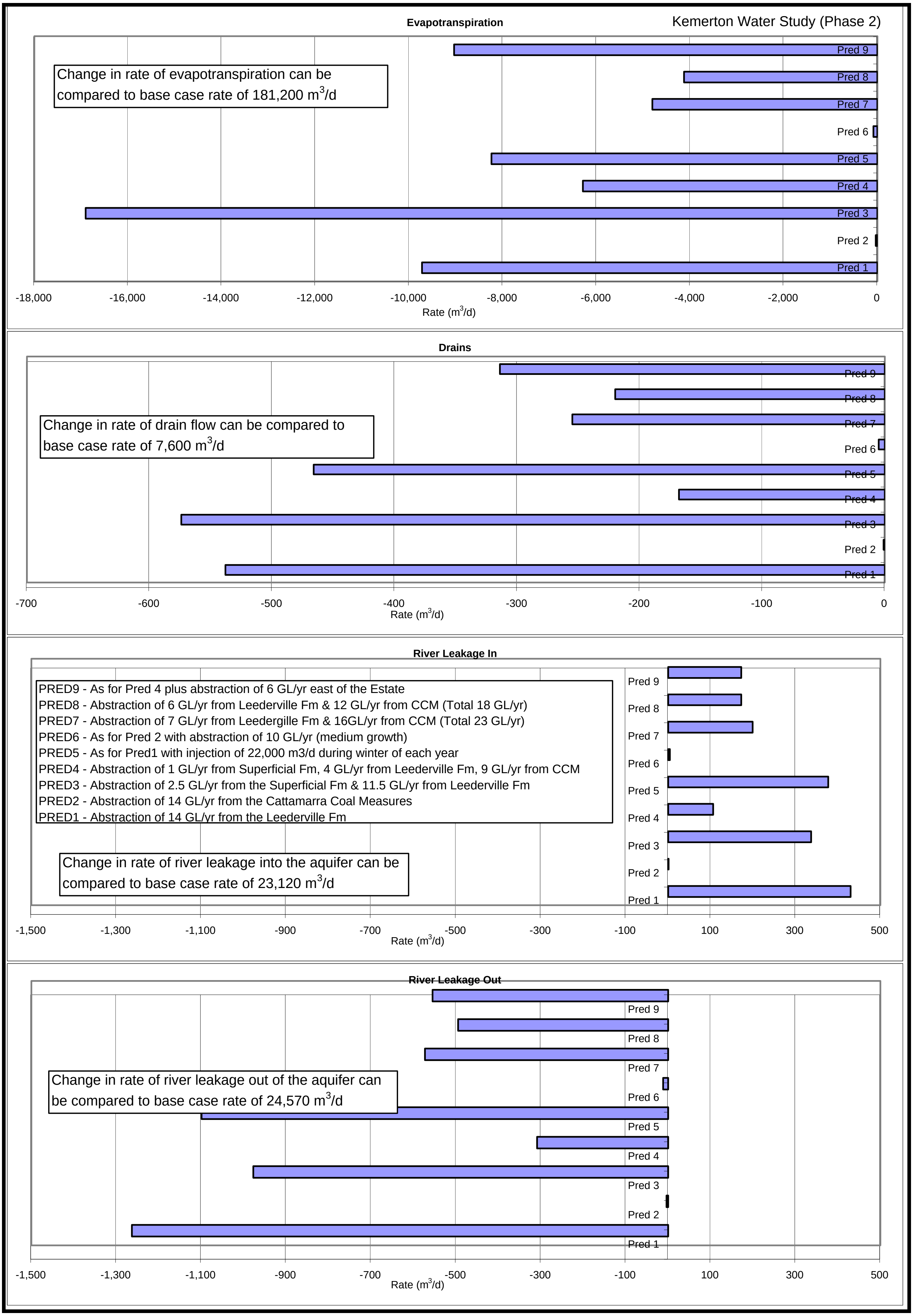
Kemerton Water Study (Phase 2)



Change in rate of evapotranspiration can be compared to base case rate of 181,200 m^3/d

Change in rate of drain flow can be compared to base case rate of 7,600 m^3/d

PRED9 - As for Pred 4 plus abstraction of 6 GL/yr east of the Estate
PRED8 - Abstraction of 6 GL/yr from Leederville Fm & 12 GL/yr from CCM (Total 18 GL/yr)
PRED7 - Abstraction of 7 GL/yr from Leedergille Fm & 16GL/yr from CCM (Total 23 GL/yr)
PRED6 - As for Pred 2 with abstraction of 10 GL/yr (medium growth)
PRED5 - As for Pred1 with injection of 22,000 m3/d during winter of each year
PRED4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm, 9 GL/yr from CCM
PRED3 - Abstraction of 2.5 GL/yr from the Superficial Fm & 11.5 GL/yr from Leederville Fm
PRED2 - Abstraction of 14 GL/yr from the Cattamarra Coal Measures
PRED1 - Abstraction of 14 GL/yr from the Leederville Fm

Change in rate of river leakage into the aquifer can be compared to base case rate of 23,120 m^3/d

Change in rate of river leakage out of the aquifer can be compared to base case rate of 24,570 m^3/d

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Change in Evapotranspiration, Drain Flow & River Leakage

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Figure 9.17

Table 9.9
Maximum Drawdown - Prediction Scenarios

Aquifer	Pred1	Pred2	Pred3	Pred4	Pred5	Pred6
Superficial formation	0.3 m	0.0 m	6.8 m	2.7 m	0.3 m	0.0 m
Upper Leederville Fm	20.6 m	0.0 m	17.4 m	6.3 m	20.6 m	0.0 m
Lower Leederville Fm	14.7 m	0.0 m	12.6 m	4.1 m	14.7 m	0.0 m
Yarragadee Fm	5.2 m	0.1 m	4.4 m	1.3 m	5.2 m	0.0 m
Cattamarra Coal Measures	0.0 m	3.6 m	0.0 m	2.2 m	0.0 m	2.5 m

Similarly, changes to other parts of the water balance allow more detailed interpretation of the effects of proposed abstractions. For example, the exchange in water (leakage) between the different layers in the model for the above predictions is summarised in Table 9.11. As expected, increased abstraction from the confining units for some scenarios induces greater leakage from the overlying unit, which then results in greater drawdown in the overlying unit, usually resulting in reduced volumes in the evapotranspiration component of the water balance, which would presumably have an associated impact on vegetation health.

A number of model simulations were run to identify the appropriate balance of abstraction between aquifers that resulted in limited drawdown in the superficial aquifer, and low risk of saline intrusion in the confined aquifers. The results of these simulations were discussed with WRC staff to identify the optimal development scenario.

Several prediction runs trialled a range of ASR scenarios, with results for the best case presented for Pred5. This run showed that the injection of 2GL/yr to the superficial aquifer during winter did not noticeably change the drawdown effect due to the High Demand abstraction case of 14 GL/yr. It may be concluded that ASR may provide benefits in terms of improved water use efficiency, but it would not significantly ameliorate drawdown effects unless a source of significant storage volumes (with appropriate quality) can be identified.

Careful consideration of the prediction results presented in Tables 9.9 to 9.11, and Figures 9.12 to 9.17, leads to the conclusion that Pred4 is the optimal scenario to meet the High Demand (14GL/yr) case. The main reason is that this scenario spreads the abstraction across the superficial and the confined aquifers, resulting in impacts that are not excessive in relation to specific issues such as wetland drawdown impacts and saline intrusion risks.

The Pred4 scenario involves concentrating the abstraction in the confined aquifers, particularly the Cattamarra Coal Measures, and, to a lesser extent, the Leederville Formation. Some abstraction is possible from the superficial formation, but the results show that this needs to be minimised to reduce environmental impacts on wetlands and dryland vegetation.

Table 9.10
Water Balance - Prediction Scenarios

Aquifer and Component	Pred0	Pred1	Pred2	Pred3	Pred4	Pred5	Pred6
Superficial							7
Coastal Outflow	3,220	3,130	3,210	3,140	3,190	3,140	3,210
Coastal Inflow	1,280	1,400	1,170	1,340	1,240	1,370	1,180
Drains	7,620	7,090	7,620	7,050	7,460	7,160	7,620
Evapotranspiration	181,200	171,470	181,160	164,290	174,910	172,960	181,110
River Leakage into aquifer	23,120	23,550	23,120	23,460	23,220	23,500	23,120
River Leakage out of aquifer	24,570	23,310	24,560	23,590	24,260	23,470	24,560
Upper Leederville Fm							
Coastal Outflow	9,740	4,020	9,740	4,480	7,000	4,060	9,740
Coastal Inflow	0	3,050	0	1,960	0	2,960	0
Lower Leederville Fm							
Coastal Outflow	30,300	17,280	30,280	18,990	25,290	17,450	30,290
Coastal Inflow	0	4,410	0	2,860	0	4,230	0
Yarragadee Fm							
Coastal Outflow	10,800	9,310	10,750	9,550	10,390	9,490	10,770
Coastal Inflow	3,290	3,440	3,300	3,410	3,330	3,420	3,300
Cattamarra Coal Measures							
Coastal Outflow	57,340	57,250	19,010	57,260	32,700	57,260	30,090
Coastal Inflow	0	0	0	0	0	0	0

Note: Flows specified in kL/day.

The optimal prediction scenario (Pred4) for the High Demand (14GL/yr) case does not impact greatly on the water balance of the superficial formation, with no significant changes to coastal, drain and river flows, and a decrease of less than 4% in the evapotranspiration discharge. Outflow to the coast is reduced by approximately 20% in the Leederville Formation and 40% in the Cattamarra Coal Measures. The abstractions do not result in inflows from the ocean within the Leederville Fm and Cattamarra Coal Measures. Due to abstraction from the Leederville Fm, downward leakage from the superficial formation is increased by approximately 30%, with a slight decrease in upward leakage from the Leederville Fm.

Table 9.11
Leakage Between Layers - Prediction Scenarios

Aquifer From	Aquifer To	Pred0	Pred1	Pred2	Pred3	Pred4	Pred5	Pred6
superficial	Upper Leederville	7,500	16,810	7,500	15,050	9,800	16,590	7,500
Upper Leederville	superficial	4,460	3,270	4,460	3,510	4,110	3,320	4,460
Upper Leederville	Lower Leederville	2,050	2,250	2,060	2,170	2,010	2,250	2,060
Lower Leederville	Upper Leederville	580	710	580	650	560	710	580
Lower Leederville	Yarragadee	710	80	740	130	470	60	730
Yarragadee	Lower Leederville	30	1,120	30	880	200	1,200	30
Yarragadee	Cattamarra	30	20	70	20	40	20	50
Cattamarra	Yarragadee	50	140	20	120	40	120	20

Note: Leakage in units of kL/day.

Figure 9.12 is a key plot, as it shows, for the optimal prediction scenario (Pred4) for the High Demand (14GL/yr) case, the spatial distribution of predicted drawdown in the superficial aquifer, in relation to a number of key features, notably the:

- Distribution of areas where the (measured) average annual minimum groundwater level lies within 6 m of the land surface - these areas represent the distribution of potential groundwater dependent vegetation, such as *Banksia ilicifolia*; and
- Locations of vegetation transects at key wetlands.

These results show that the optimal scenario has limited environmental impact by careful bore placement, and by splitting the abstraction between the aquifers to achieve an appropriate balance between the following issues:

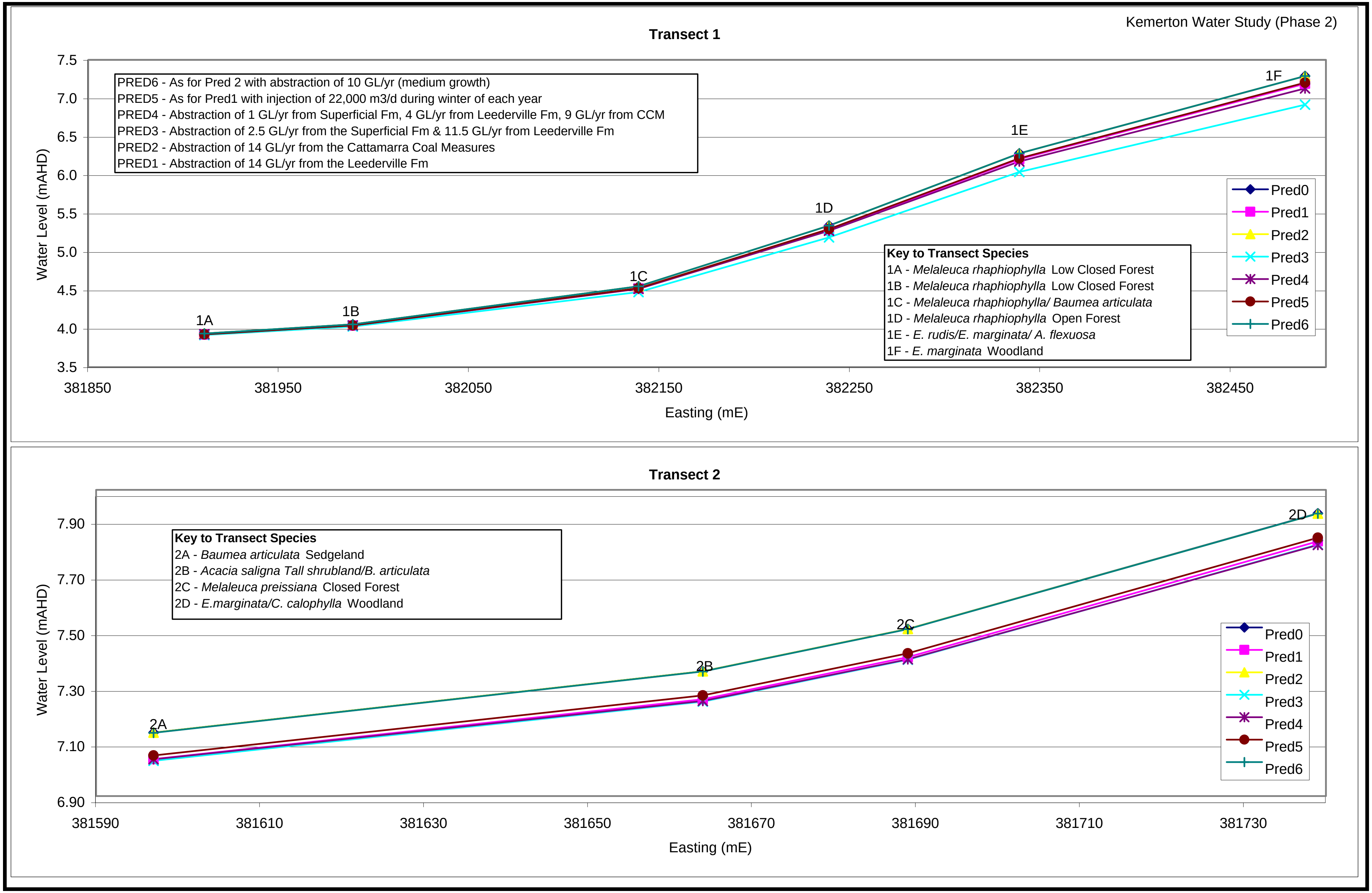
- Minimising the drawdown impacts in the superficial aquifer;
- Reducing the potential risk for saline intrusion (eg. due to drawing too much water from one aquifer); and
- Obtaining a reasonable amount of better quality water from the upper aquifers for Estate demands.

As the maximum drawdown impact occurs at the pumping bore locations, the bores must be placed near the ridge line on the western side of the Estate, as this is where the depth to the water table is greatest, and where there would be no groundwater-dependent vegetation. These impact issues are discussed in more detail in the following sections.

9.7.4 Impacts on Wetlands

Table 9.12 summarises the maximum drawdown impact at the selected wetland vegetation monitoring locations over the period of simulation, which is required to be less than 1.5m (Table 7.2). Figure 9.12 shows that the spatial distribution of the impact barely extends to the key wetlands. Cross sections of water level at the end of the simulation across each of the six wetland transects (locations for which are shown in Figure 9.12) are presented in Figures 9.18 to 9.20. The change in vegetation type along the transect is also shown on the figures. Figures 9.21 to 9.23 present hydrographs for each of the transects, showing the development of drawdown with time.

The results indicate that all scenarios, including the optimal High Demand scenario (Pred4), have a small drawdown impact on the selected wetland transects, well within the EWR constraints outlined in Section 7.6 (Table 7.3). Figure 9.12 shows that the key chain of EPP wetlands (including Mialla Lagoon) on the western side of Kemerton have a maximum drawdown of approximately 0.1 to 0.25m. Myalup Swamp and the eastern chain of EPP wetlands experience negligible drawdown (<0.1m) under this scenario. The maximum predicted drawdowns are less than the EWR criteria for the most susceptible vegetation types along the wetland “transect lines”, as shown in Figures 9.18 to 9.23, and summarised in Appendix E4.



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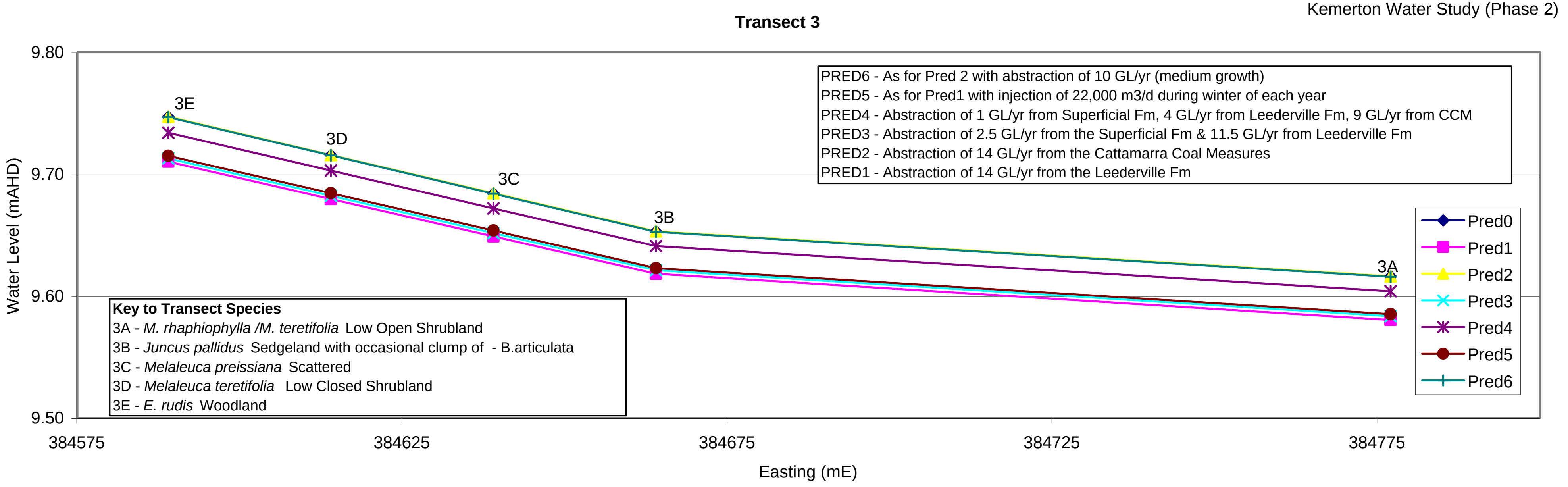
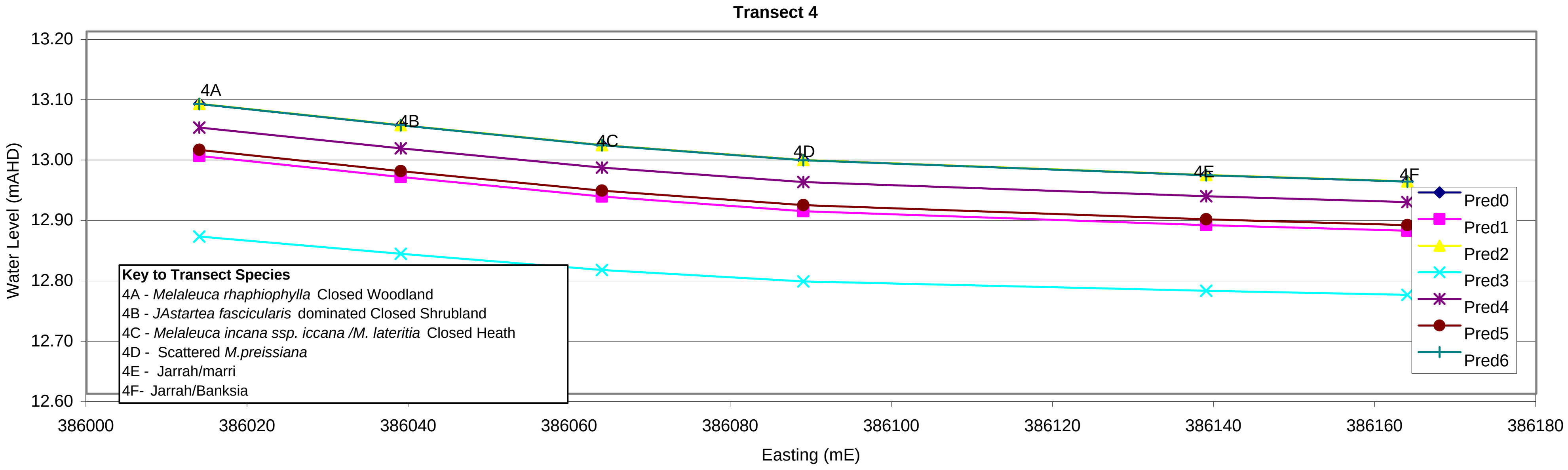
Water Level Cross Section - Transect 1 and 2

F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Figure 9.18

Kemerton Water Study (Phase 2)





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Water Level Cross Section - Transect 3 and 4

Figure 9.19

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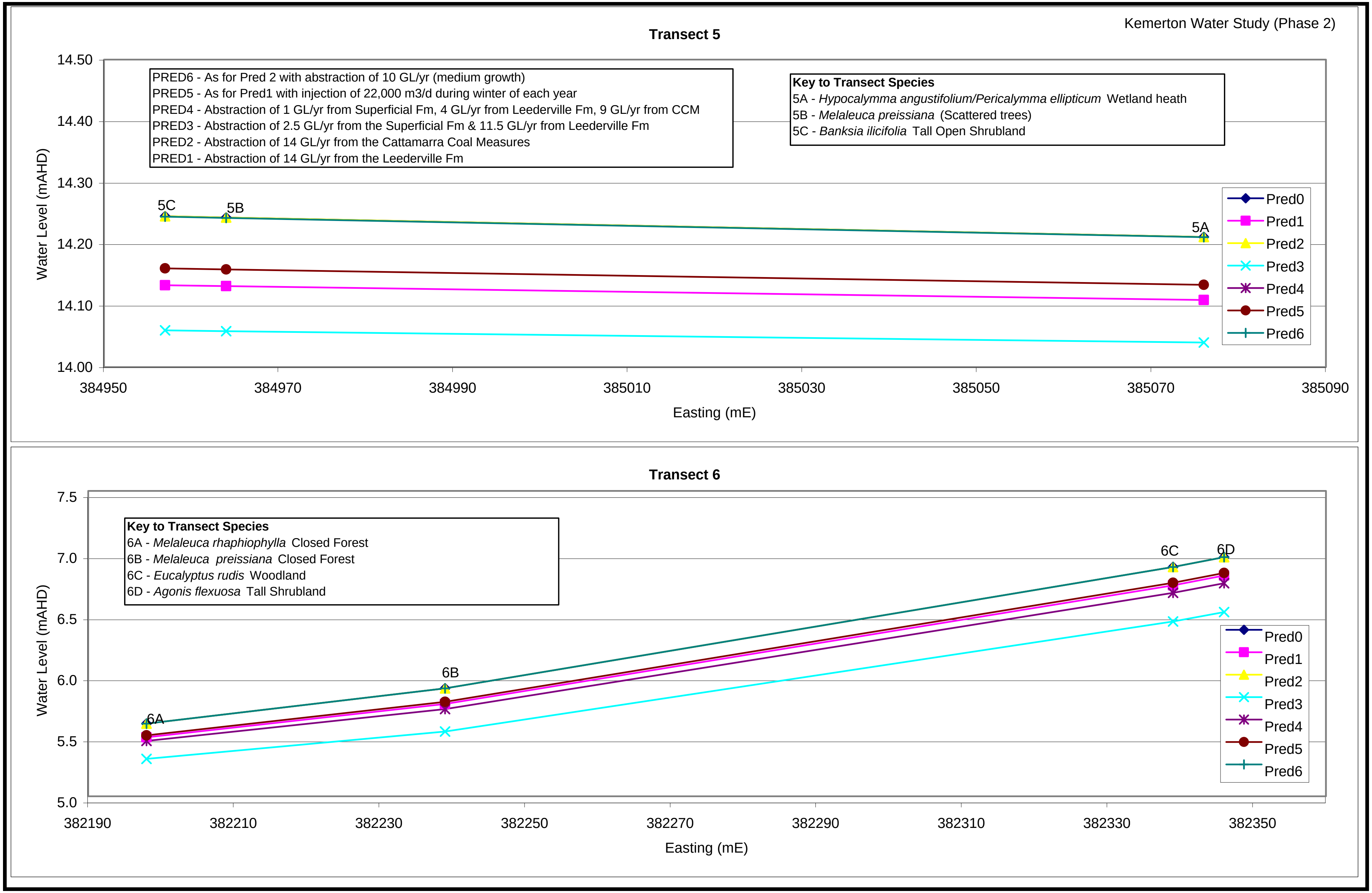

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Water Level Cross Section - Transect 5 and 6

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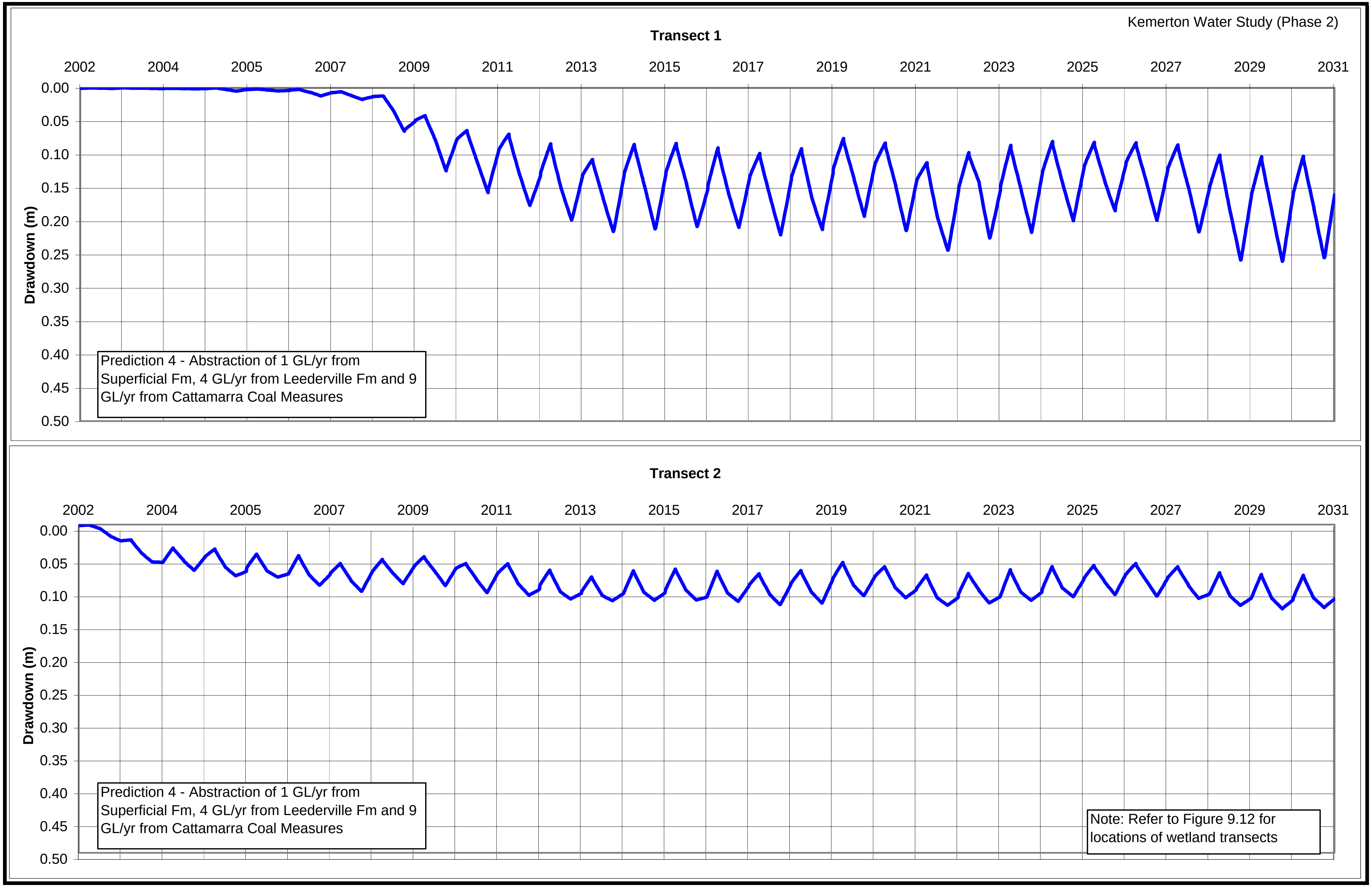
Figure 9.20

Kemerton Water Study (Phase 2)



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Note: Refer to Figure 9.12 for locations of wetland transects

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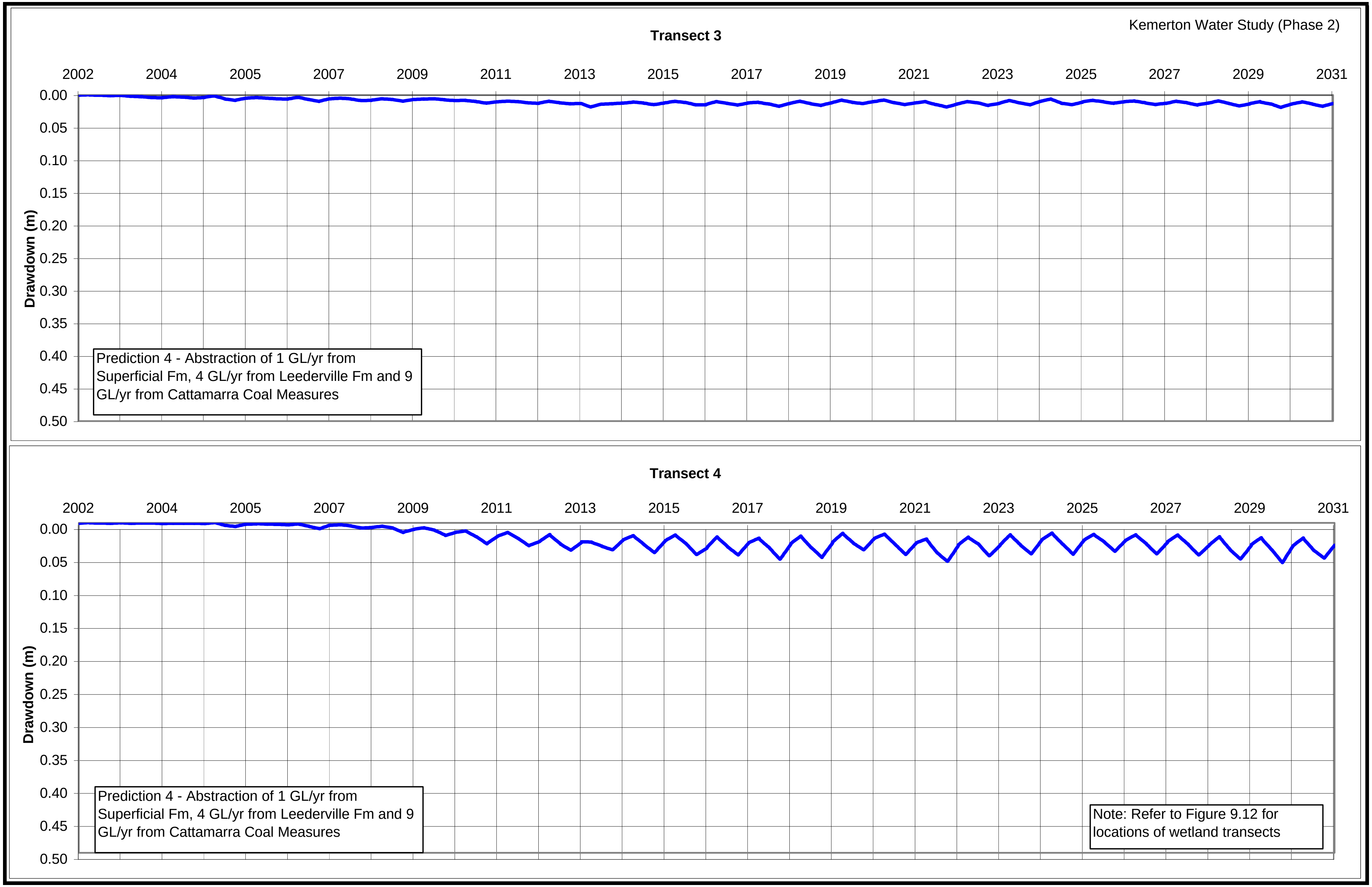
F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Predicted Drawdown - Wetland Transects

Figure 9.21

Kemerton Water Study (Phase 2)



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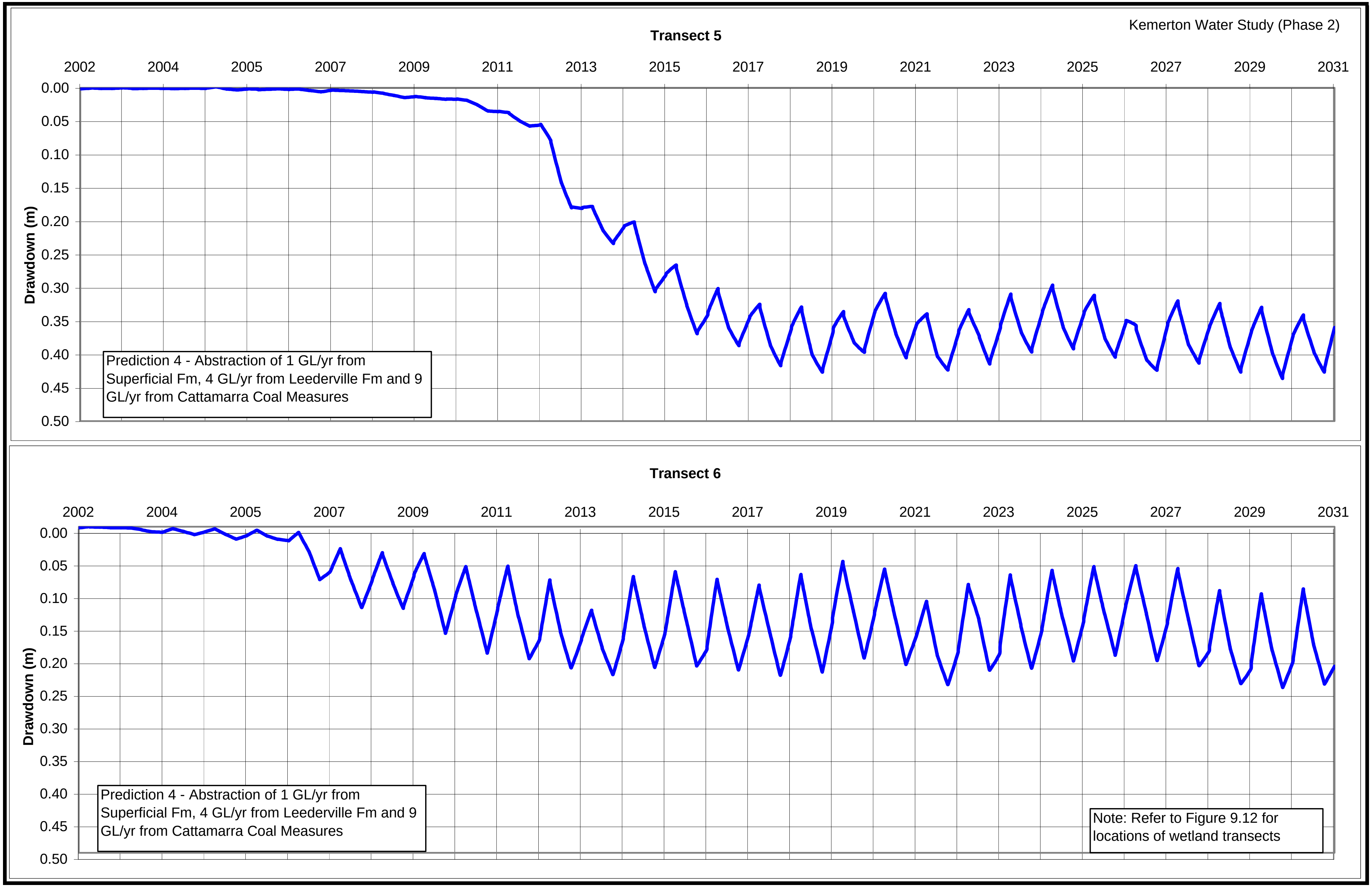
Predicted Drawdown - Wetland Transects

Figure 9.22

F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Note: Refer to Figure 9.12 for locations of wetland transects

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F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Predicted Drawdown - Wetland Transects

Figure 9.23

Table 9.12
Maximum Drawdown - Wetland Monitoring Locations

Location	Pred1	Pred2	Pred3	Pred4	Pred5	Pred6
Transect 1	0.17 m	0.01 m	0.62 m	0.26 m	0.14 m	0.01 m
Transect 2	0.11 m	0.01 m	0.13 m	0.13 m	0.10 m	0.01 m
Transect 3	0.05 m	0.01 m	0.05 m	0.02 m	0.05 m	0.01 m
Transect 4	0.14 m	0.01 m	0.39 m	0.07 m	0.12 m	0.01 m
Transect 5	0.14 m	0.00 m	0.23 m	0.44 m	0.11 m	0.00 m
Transect 6	0.17 m	0.02 m	0.57 m	0.25 m	0.14 m	0.02 m

Note: maximum long term drawdown constraint is 1.5m

The above discussion concentrates on assessing impacts on wetlands in relation to groundwater drawdown. Other wetland Ecological Water Requirements relate to surface water flooding regimes, which cannot be predicted using the groundwater model. However, the model can be used to assess impacts in relation to groundwater contributions to flows in the surface drain and river network, and to groundwater discharge through evapotranspiration, which simulates both vegetation water use and wetland (lake) evaporation. Table 9.10 shows that the predicted change in discharge via the Drain feature in the model reduces by just 2% for the optimal High Demand scenario (Pred4). Results given later for the climatic variability scenarios and the Maximum Demand scenarios indicate reduction of 3% to 4%. Similarly, predicted changes to the evapotranspiration component of the predicted water balance for the High to Maximum Demand cases lie in the range of 2% to 3%. The predicted changes to river-aquifer interaction flows are even smaller (negligible for all scenarios). This indicates very little change to the groundwater support of the surface hydrology regime for the proposed abstraction scenarios.

As outlined in Section 8, the implementation of water sensitive design principles will involve the use of existing undeveloped parts of industrial blocks to infiltrate runoff generated from the buildings and paved areas to the water table. The groundwater model has incorporated additional recharge for the prediction runs to account for these changes. In low infiltration rate areas, notably on the eastern side of the Estate where the water table is shallow, any subsequent ponding is to be directed, via shallow swale drains with inverts above the AAMGL, to existing Multiple Use wetlands, drains or creeks, resulting in minimal impacts on the surface flow support to these wetlands. The important wetland chain to the west of Kemerton is in a different catchment, and surface hydrology would not be affected.

9.7.5 Impact on Dryland Vegetation

The drawdown impact was also assessed at a number of dryland vegetation monitoring points (shown as the “obs” sites in Figure 9.12) for the prediction scenarios. These points were selected in areas which were close to the area of abstraction from the superficial aquifer (the bores are aligned along the topographic ridge), and were also in an area where the annual average minimum groundwater level was within 6 m of the surface.

The maximum drawdown at these selected dryland vegetation monitoring locations for the optimal prediction scenario (Pred4 - the High Demand case of 14GL/yr) is typically between 0.25m and 0.5m, as summarised in Table 9.13. This is well within the long term constraints which ranges between 0.75 and 1.75m (Table 7.3).

Table 9.13
Maximum Drawdown - Dryland Vegetation Monitoring Locations

Location	Pred4
Obs 1	0.33 m
Obs 2	0.45 m
Obs 3	0.47 m
Obs 4	0.51 m
Obs 5	0.34 m
Obs 6	0.34 m
Obs 7	0.24 m

Drawdown hydrographs for the selected dryland monitoring points are given in Figures 9.24 to 9.27. These figures show a stable trend in drawdown, with some seasonal variation apparent, once the rate of abstraction has stabilised at 14 GL/yr (ie. after 2015). The hydrographs show that the maximum drawdown impacts are within the critical tolerance levels for each category of water table depth (Table 7.3), and also satisfies the maximum annual drawdown criterion of 0.25m. Table 9.14 summarises the maximum level of drawdown observed for areas within the three categories of water table depth.

Table 9.14
Critical Tolerance Levels and Performance for Drawdown Impacts on Dryland Vegetation

Category	Drawdown required to be less than	Predicted maximum drawdown (over 30 years)
0 - 3m water table depth	0.75 m	0.5 m
3 - 6m water table depth	1.25 m	0.75 m
6 - 10m water table depth	1.75 m	1.0 m

The drawdown hydrographs show a seasonal variation with maximum drawdown occurring at the end of winter and minimum drawdown at the end of summer. The seasonal difference in drawdown (around 0.1 m, and not significant) is due to the combined effect of variations in evapotranspiration (due to the depth-dependent nature of e/t), and recharge variations due to seasonal rainfall changes.

9.8 SENSITIVITY ANALYSIS

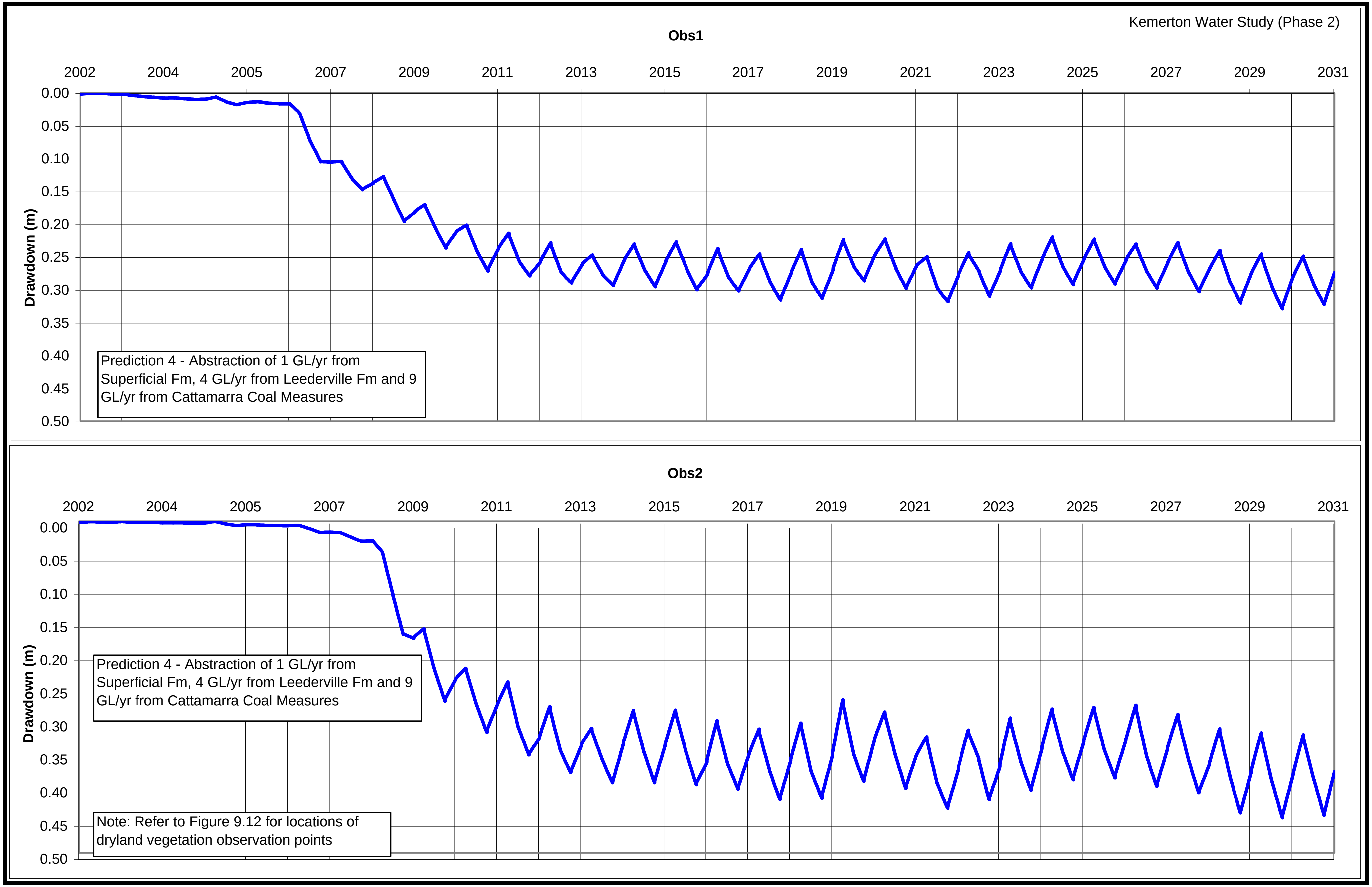
9.8.1 Sensitivity Analysis - Climate Variability

As outlined in Section 9.7, the impact of climate variability was to be assessed by running two sensitivity simulations on the optimal scenario to meet the High Demand abstraction case (Pred4 - 14 GL/yr).

The first run represents an extreme dry case, by specifying a further 10% reduction in the rainfall observed over the 1970-2000 period, which is already 10% lower than the long term average.

The second run represents a wet case, using the rainfall during the period 1914-1935, when rainfall was 15% higher than the long term average.

The approach involved running a base case scenario (ie. existing abstraction) for the appropriate climatic period, then running the prediction scenario (additional High Demand case abstraction for the Kemerton development), and assessing the differences between the runs.



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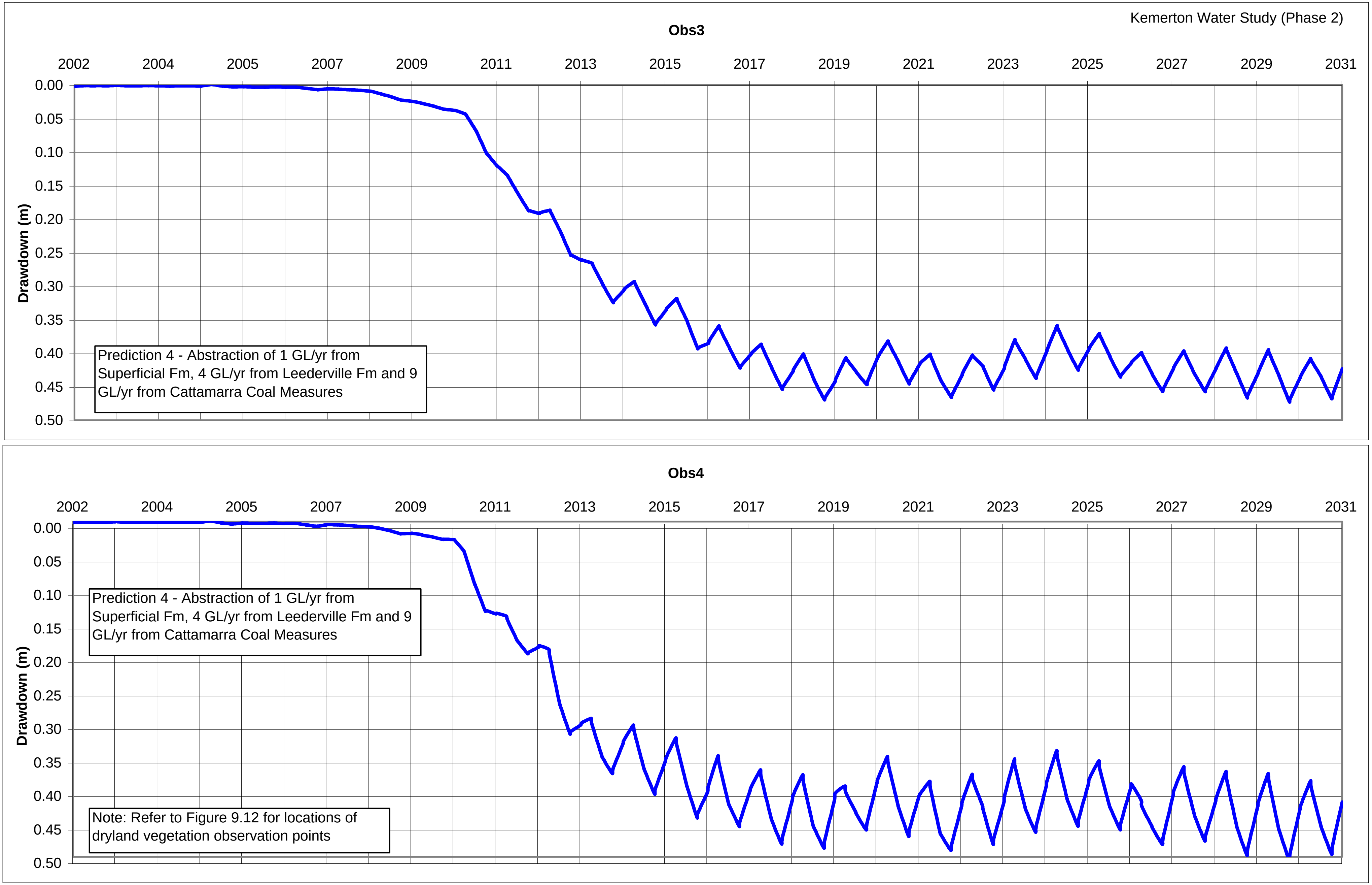
Predicted Drawdown - Dryland Vegetation Locations

F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Figure 9.24

Kemerton Water Study (Phase 2)



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Note: Refer to Figure 9.12 for locations of dryland vegetation observation points

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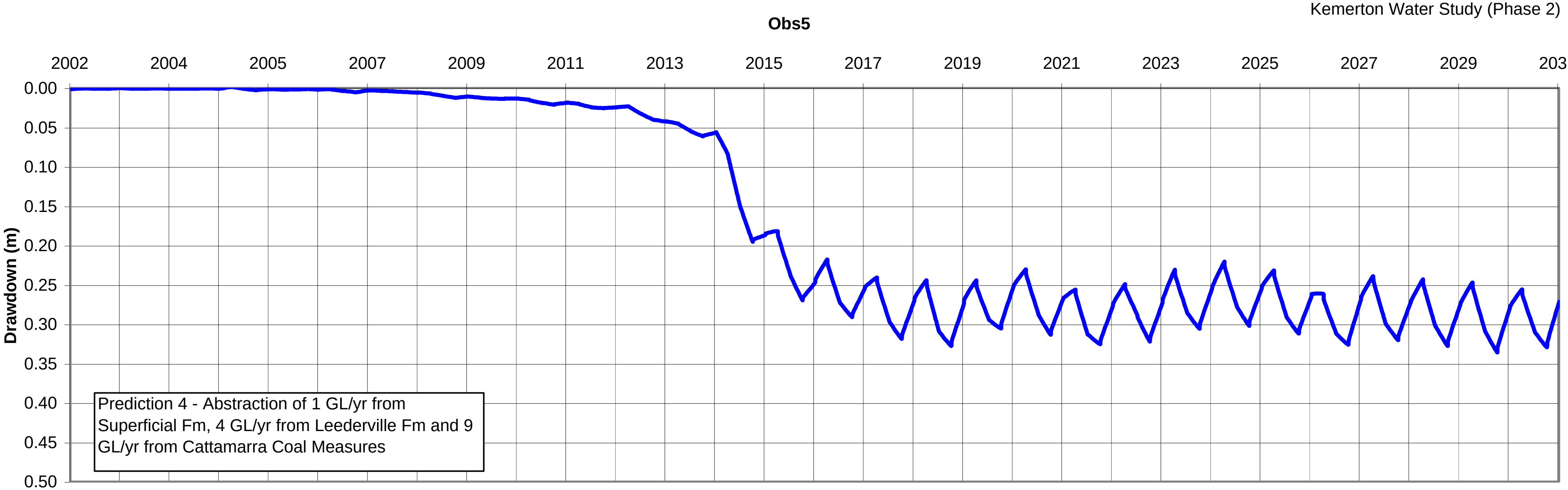
Predicted Drawdown - Dryland Vegetation Locations

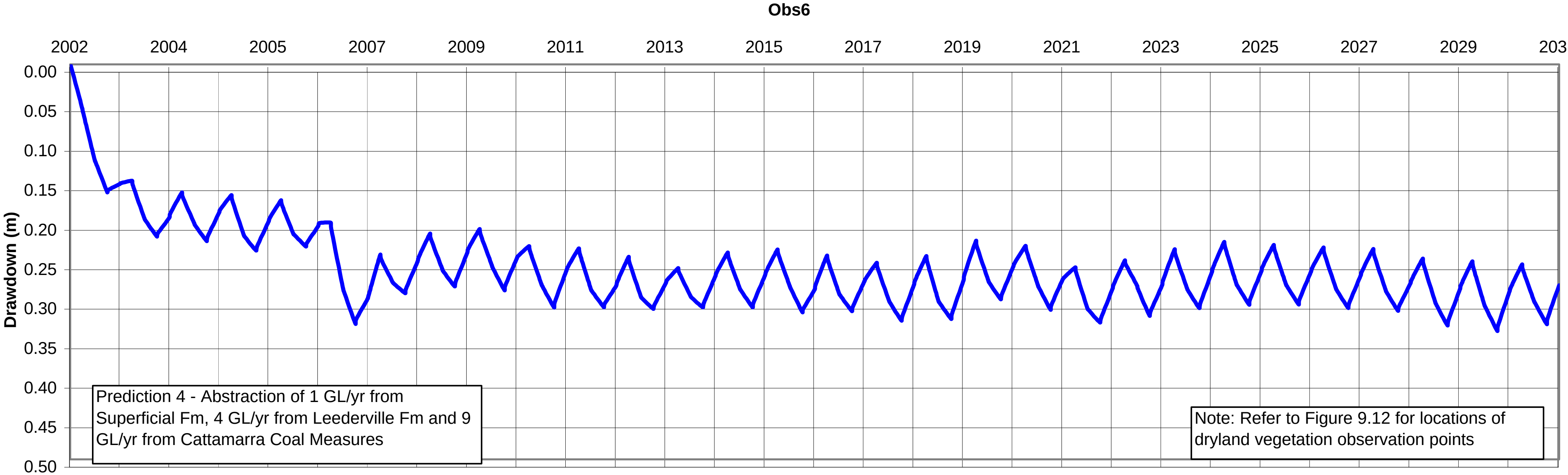
Figure 9.25

F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Kemerton Water Study (Phase 2)



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures



Prediction 4 - Abstraction of 1 GL/yr from Superficial Fm, 4 GL/yr from Leederville Fm and 9 GL/yr from Cattamarra Coal Measures

Note: Refer to Figure 9.12 for locations of dryland vegetation observation points

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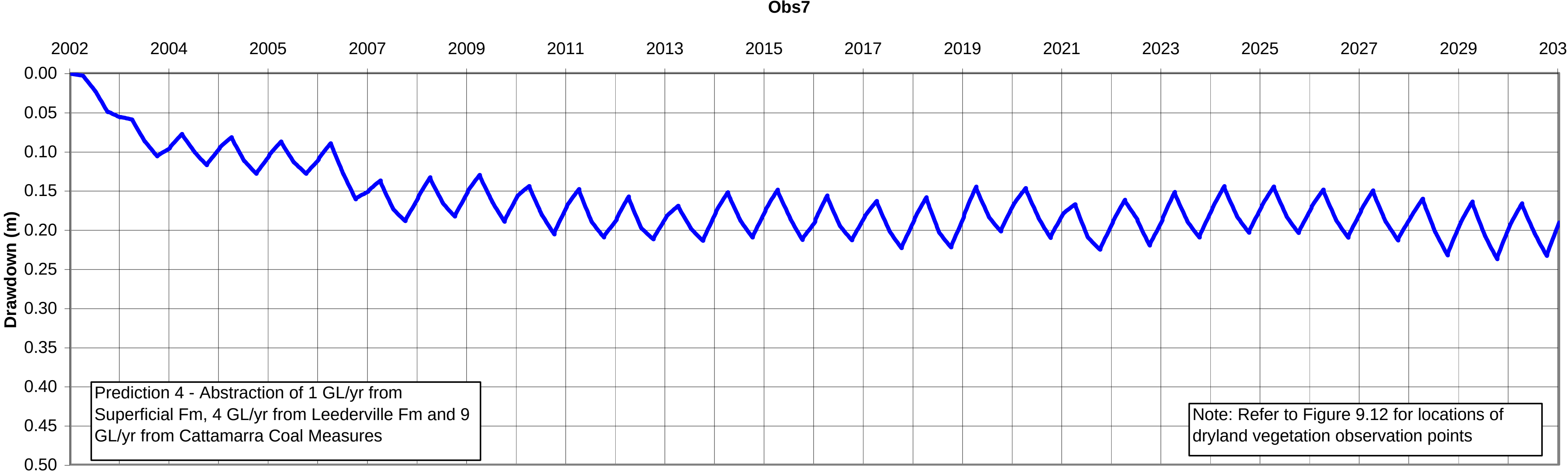
F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Predicted Drawdown - Dryland Vegetation Locations

Figure 9.26

Kemerton Water Study (Phase 2)



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Predicted Drawdown - Dryland Vegetation Locations

F:\jobs\211\B1\Predictions\[Predictions Summary.xls]Drawdown

Figure 9.27

The change in water balance as a result of the proposed abstractions at the end of the simulation for each of these predictions is summarised in Table 9.15.

Table 9.15
Impact of Climate Variability on Water Balance

Aquifer and Component	**Base Case (existing) Abstraction**		**Base Case plus Additional 14 GL/yr Abstraction (Pred4)**	
	Extreme Dry Case (Sens1)	**High Rainfall Case (Sens2)**	**Extreme Dry Case (Sens1)**	**High Rainfall Case (Sens2)**
Superficial				
Coastal Outflow	2,850	3,600	2,820	3,550
Coastal Inflow	1,450	920	1,510	970
Drains	6,860	8,000	6,700	7,810
Evapotranspiration	164,910	183,290	158,730	177,290
River Leakage into aquifer	23,670	22,440	23,780	22,530
River Leakage out of aquifer	22,960	26,330	22,640	26,050
Upper Leederville Fm				
Coastal Outflow	9,600	9,880	6,850	7,150
Coastal Inflow	0	0	0	0
Lower Leederville Fm				
Coastal Outflow	30,220	30,370	25,200	25,370
Coastal Inflow	0	0	0	0
Yarragadee Fm				
Coastal Outflow	10,790	10,810	10,390	10,400
Coastal Inflow	3,290	3,290	3,330	3,330
Cattamarra Coal Measures				
Coastal Outflow	57,340	57,340	32,700	32,700
Coastal Inflow	0	0	0	0

The results indicate that the predicted impacts for the High Demand abstraction scenario (14 GL/yr additional abstraction) are not sensitive to variations in rainfall recharge. The maximum drawdown in each aquifer is unchanged, with the exception of a slight decrease in drawdown in the superficial formation under the high rainfall scenario. The ‘dry case’ sensitivity simulation shows that a further 10% reduction in rainfall impacts greatest on the evapotranspiration component of the water balance, which decreases by almost 10%, as would be expected. This is similar to the result for the ASR run (Pred5), where an additional 2 GL/yr injection did not noticeably reduce the drawdown effect for the High Demand case.

The maximum drawdown resulting for the above climate variability scenarios are summarised in Table 9.16 below.

Table 9.16
Maximum Drawdown - Climate Variability Simulations

Aquifer	Pred4	Sens1	Sens2
superficial	2.7	2.7	2.5
Upper Leederville Fm	6.3	6.3	6.3
Lower Leederville Fm	4.1	4.1	4.1
Yarragadee Fm	1.3	1.3	1.3
Cattamarra Coal Measures	2.2	2.2	2.2

The impact of the above sensitivity simulations in terms of maximum drawdown at the selected wetland and dryland vegetation monitoring points is summarised in Table 9.17, again indicating low sensitivity to climate variability.

Table 9.17
Impact of Climate Variability on Drawdown at Wetland and Dryland Monitoring Points

Location	Pred4	Sens1	Sens2	Location	Pred4	Sens1	Sens2
Transect 1	0.26 m	0.25 m	0.28 m	Obs 1	0.33 m	0.33 m	0.33 m
Transect 2	0.13 m	0.13 m	0.13 m	Obs 2	0.45 m	0.45 m	0.44 m
Transect 3	0.02 m	0.02 m	0.02 m	Obs 3	0.47 m	0.50 m	0.43 m
Transect 4	0.07 m	0.07 m	0.06 m	Obs 4	0.51 m	0.52 m	0.49 m
Transect 5	0.44 m	0.45 m	0.41 m	Obs 5	0.34 m	0.35 m	0.31 m
Transect 6	0.25 m	0.24 m	0.26 m	Obs 6	0.34 m	0.34 m	0.36 m
				Obs 7	0.24 m	0.24 m	0.24 m

Note: Transect denotes Wetland Transect, and Obs denotes Dryland Monitoring Point

9.8.2 Sensitivity Analysis - Aquifer Parameters

A number of sensitivity simulations were performed on the optimal High Demand abstraction scenario (Pred4) to assess the impact of varying the key aquifer parameters of vertical leakance, storage and hydraulic conductivity. The sensitivity simulations are summarised below:

- Sens3 - An increase in vertical conductivity by an order of magnitude in the confined units (Leederville, Yarragadee and Cattamarra Coal Measures) - this would be expected to result in greater drawdown impacts in the superficial formation, and less in the underlying units as leakage from the superficial aquifer increases.
- Sens4 - A 25% decrease in unconfined storage in the superficial and a 50% decrease in confined storage within the Leederville, Yarragadee and Cattamarra Coal Measures - this would be expected to result in greater drawdown impacts in all aquifers.
- Sens5 - A decrease in horizontal hydraulic conductivity by 50% in both the unconfined and confined units - this would be expected to result in greater drawdown impacts in all aquifers.

The impact on the various components of the water balance resulting from the above predictions is summarised in Table 9.18.

Table 9.18
Sensitivity of Water Balance to Aquifer Parameters

Aquifer and Component	Pred4 (base case)	Sens3 (higher Kv)	Sens4 (lower storage)	Sens5 (lower Kh)
superficial				
Coastal Outflow	3,190	5,140	3,020	2,080
Coastal Inflow	1,240	530	1,510	1,350
Drains	7,460	7,860	6,890	6,910
Evapotranspiration	174,910	153,780	165,110	188,450
River Leakage into aquifer	23,220	22,200	23,760	22,350
River Leakage out of aquifer	24,260	27,460	23,040	18,510
Upper Leederville Fm				
Coastal Outflow	7,000	10,820	6,960	5,040
Coastal Inflow	0	0	0	0
Lower Leederville Fm				
Coastal Outflow	25,290	28,620	25,270	22,590
Coastal Inflow	0	0	0	0
Yarragadee Fm				
Coastal Outflow	10,390	11,790	10,390	10,140
Coastal Inflow	3,330	3,130	3,330	3,360
Cattamarra Coal Measures				
Coastal Outflow	32,700	33,580	32,700	32,690
Coastal Inflow	0	0	0	0

Note: All flows in kL/d

The maximum drawdown in each aquifer for the above sensitivity simulations are summarised in Table 9.19 below.

Table 9.19
Maximum Drawdown - Sensitivity Analysis to Aquifer Parameters

Aquifer	Pred4	Sens3	Sens4	Sens5
superficial	2.7 m	3.1 m	3.0 m	4.9 m
Upper Leederville Fm	6.3 m	4.1 m	6.3 m	11.1 m
Lower Leederville Fm	4.1 m	3.4 m	4.1 m	7.9 m
Yarragadee Fm	1.3 m	0.7 m	1.3 m	2.7 m
Cattamarra Coal Measures	2.2 m	2.2 m	2.2 m	4.5 m

The influence of the above sensitivity simulations on the leakage between model layers is summarised in Table 9.20.

An increase in the vertical conductivity of the confined aquifers (Sens3) results in more leakage from the superficial formation. This results in an increased drawdown in the superficial formation but a decreased drawdown in the Leederville and Yarragadee Fms. The predicted increase in drawdown in the superficial aquifer involves greater predicted environmental impacts, as discussed later.

Table 9.20
Leakage Between Layers - Sensitivity Simulations

Aquifer From	Aquifer To	Pred4 (base case)	Sens3 (higher Kv)	Sens4 (lower storage)	Sens5 (lower Kh)
Superficial	Upper Leederville	9,800	34,910	9,780	7,810
Upper Leederville	superficial	4,110	20,010	4,130	7,110
Upper Leederville	Lower Leederville	2,010	14,430	2,000	820
Lower Leederville	Upper Leederville	560	7,500	570	2,380
Lower Leederville	Yarragadee	470	3,240	460	480
Yarragadee	Lower Leederville	200	640	200	500
Yarragadee	Cattamarra	40	880	40	70
Cattamarra	Yarragadee	40	0	40	80

Note: All flows in kL/d

Drawdown impacts of reduced aquifer storage (Sens4) is only noticeable in the superficial aquifer. The increase in drawdown is mainly due to a decrease in the volume available for evapotranspiration. There is also a slight decrease in outflow to the coast and drain flows in the superficial formation. The drawdown in the confined units is unchanged as the model reaches a steady state condition within the time period of the simulation.

A decrease in the horizontal hydraulic conductivity (Sens5) results in increased drawdown in the unconfined and confined units, indicating that the predictions are sensitive to this parameter in terms of affecting drawdown, but not in terms of overall impacts, as described below.

As expected, the leakage between layers is most sensitive to changes in the vertical conductivity. An increase in the vertical conductivity significantly increases leakage between all layers in the model. This allows much greater volumes of water to leak down from the superficial aquifer to support abstractions from the underlying confined aquifers. In turn, this results in around a 50% increase in the predicted drawdown impact at key wetland and dryland monitoring points, as summarised in Table 9.21. It should be noted that the predicted drawdowns for the sensitivity runs are all within the EWR constraints outlined previously (Table 9.14).

A decrease in aquifer storage (Sens4) has little impact on the maximum drawdown at the wetland and dryland monitoring points. An increase in the vertical leakance results in drawdown increasing to between 0.2 m and 0.6 m at the wetland transects and between 0.4 m and 0.8 m at the dryland monitoring points. Similarly, a decrease in the horizontal hydraulic conductivity increases drawdown to between 0.1 m and 0.7 m at the wetland transects and between 0.3 m and 0.7 m at the dryland monitoring points.

The critical parameters in terms of affects on the prediction results are the horizontal and (particularly) the vertical aquifer hydraulic conductivity. It is recommended that future field programmes be charged with the task of obtaining more detailed information on these parameters. However, there is no urgent need for this work, because the predicted drawdowns for the sensitivity runs are still within the EWR constraints outlined previously (Table 9.14).

Table 9.21
Aquifer Parameter Sensitivity on Maximum Drawdown at Wetlands and Drylands

Location	Pred4 (base case)	Sens3 (higher Kv)	Sens4 (lower storage)	Sens5 (lower Kh)
Wetland Transects				
Transect 1	0.26 m	0.39 m	0.30 m	0.27 m
Transect 2	0.13 m	0.50 m	0.13 m	0.14 m
Transect 3	0.02 m	0.16 m	0.08 m	0.13 m
Transect 4	0.07 m	0.17 m	0.10 m	0.08 m
Transect 5	0.44 m	0.63 m	0.45 m	0.58 m
Transect 6	0.25 m	0.38 m	0.27 m	0.70 m
Dryland Monitoring Points				
Obs 1	0.33 m	0.56 m	0.34 m	0.47 m
Obs 2	0.45 m	0.67 m	0.47 m	0.56 m
Obs 3	0.47 m	0.70 m	0.50 m	0.55m
Obs 4	0.51 m	0.76 m	0.52 m	0.69 m
Obs 5	0.34 m	0.46 m	0.35 m	0.45 m
Obs 6	0.34 m	0.46 m	0.35 m	0.48 m
Obs 7	0.24 m	0.38 m	0.25 m	0.28 m

9.9 ADDITIONAL MODEL PREDICTIONS

A number of additional predictions were simulated to assess water demand scenarios higher than the nominal “High” case, and to assess the potential impacts of additional abstractions east of the Estate and the Wellesley River. The prediction configurations are summarised below:

- Pred7 - Pred0 (existing abstractions), plus the abstraction of 16 GL/yr from the Cattamarra Coal Measures and 7 GL/yr from the Leederville Formation (total of 23 GL/yr) - this is a Maximum demand scenario to predict the impacts of abstraction for a large industry in the Estate, in addition to the High demand case.
- Pred8 - Pred0 plus the abstraction of 12 GL/yr from the Cattamarra Coal Measures and 6 GL/yr from the Leederville Formation (total of 18 GL/yr) - this represents a Very High Demand case for Kemerton abstraction (ie. higher than the High Demand case (Pred4) of 14 GL/yr, but not as much as the Maximum Demand case (Pred7) of 23 GL/yr).
- Pred9 - Pred4 (existing abstractions, plus High demand of 14 GL/yr for Kemerton) plus the abstraction of 6 GL/yr east of the Estate and Wellesley River. This abstraction was divided between the aquifers as 0.5 GL/yr from the superficial, 2 GL/yr from the Leederville Formation and 3.5 GL/yr from the Cattamarra Coal Measures (similar ratio to that used for Pred4). This run was requested by WRC to assess the potential impacts associated with High demand abstractions at Kemerton, along with abstractions by potential future abstraction sources east of Kemerton.

The maximum drawdown in each aquifer for these predictions is summarised in Table 9.22 below. Table 9.23 summarises the impact of the additional maximum demand simulations on water balance components at the end of the simulation.

Table 9.22
Maximum Drawdown - Additional Predictions

Component	Pred4	Pred7	Pred8	Pred9
Superficial	2.7 m	0.2 m	0.1 m	2.7 m
Upper Leederville Fm	6.3 m	10.5 m	8.9 m	7.3 m
Lower Leederville Fm	4.1 m	7.4 m	6.4 m	5.1 m
Yarragadee Fm	1.3 m	2.6 m	2.2 m	3.2 m
Cattamarra Coal Measures	2.2 m	3.8 m	2.8 m	2.9 m

All three additional predictions result in a large decrease in outflow to the coast in the Leederville Fm and Cattamarra Coal Measures, which are the aquifers that are exploited to provide the demands. The three predictions also result in small inflows from the coast in the Leederville Formation. These predictions give some guide to the WRC in regard to the maximum sustainable abstractions from the Leederville Fm without inducing inflow from the coast (saltwater intrusion).

Table 9.23
Water Balance - Additional Predictions

Aquifer and Component	Pred0	Pred4	Pred7	Pred8	Pred9
Superficial					
Coastal Outflow	3,220	3,190	3,170	3,170	3,180
Coastal Inflow	1,280	1,240	1,280	1,260	1,260
Drains	7,620	7,460	7,370	7,400	7,310
Evapotranspiration	181,200	174,910	176,390	177,070	172,160
River Leakage into aquifer	23,120	23,220	23,320	23,290	23,340
River Leakage out of aquifer	24,570	24,260	24,000	24,070	24,010
Upper Leederville Fm					
Coastal Outflow	9,740	7,000	5,350	5,850	6,280
Coastal Inflow	0	0	160	0	0
Lower Leederville Fm					
Coastal Outflow	30,300	25,290	22,030	22,930	23,170
Coastal Inflow	0	0	510	130	50
Yarragadee Fm					
Coastal Outflow	10,800	10,390	10,020	10,140	10,010
Coastal Inflow	3,290	3,330	3,360	3,350	3,370
Cattamarra Coal Measures					
Coastal Outflow	57,340	32,700	13,380	24,370	23,110
Coastal Inflow	0	0	0	0	0

Note: All flows in kL/d

The Maximum and Very High Demand for Kemerton (Pred7 and Pred8) involve little drawdown impact on the superficial aquifer as there are no additional abstractions from this aquifer. Hence, there would be much less environmental impact on wetlands or dryland vegetation for these demands, compared to that already presented for the optimal High Demand case (Pred4 involved abstraction at 1GL/yr from the superficial aquifer).

Additional abstractions east of the Estate (Pred9) does not increase drawdown locally in the Kemerton area in the superficial formation, but it does result in an increase in drawdown within the confined units. Figures 9.28 to 9.30 present contours of drawdown in each aquifer for Prediction 9.

9.10 SUMMARY OF GROUNDWATER MODELLING AND OUTCOMES

A groundwater model has been established, with features to represent the superficial and confined aquifers in the Kemerton area, and detailed stream-aquifer interaction, drainage and evapotranspiration processes. The model has been well calibrated in transient mode using monitoring data on rainfall, evaporation, groundwater level and licensed abstraction over an 11 year period (1990 - 2000).

The model is capable of assessing:

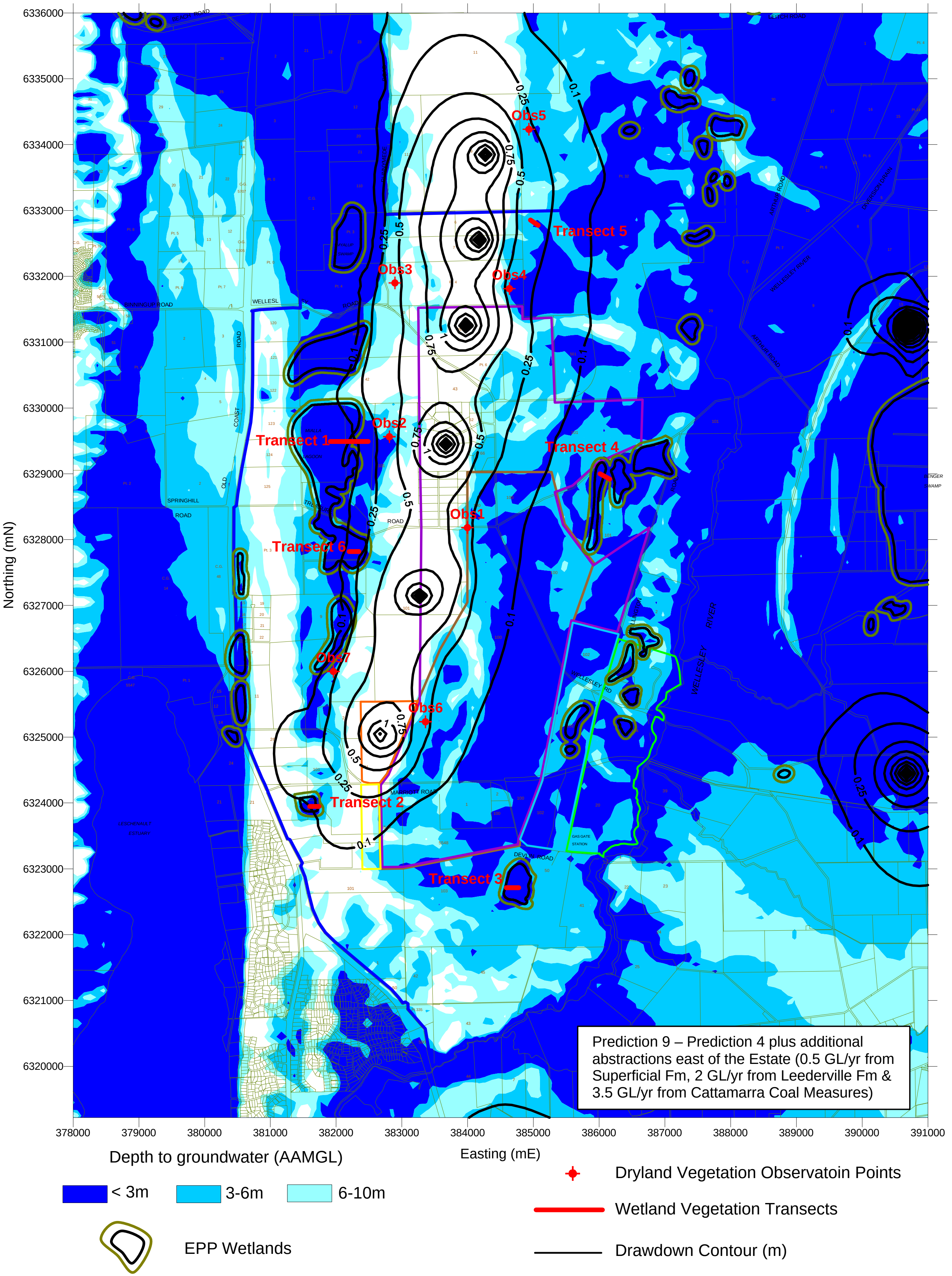
- Sustainability of proposed abstractions within the Estate;
- Drawdown impacts on nearby users and specific locations near key wetlands and groundwater dependent vegetation;
- Impacts on river and drain flows, evapotranspiration and other components of the overall water balance;
- Potential for inflows from the sea (saltwater intrusion); and
- Different wellfield design scenarios to minimise offsite impacts and optimise production.

The calibrated groundwater model has been used to model a number of abstraction scenarios from various aquifer units represented in the model. To minimise drawdown impacts and inflows from the coast, it was found that it was necessary to limit abstractions from the superficial formation, and abstract most of the demands from the Leederville formation and Cattamarra Coal Measures.

The optimal prediction scenario meets the High Demand abstraction for Kemerton (additional 14 GL/yr, plus abstractions by existing industries) over 30 years. This abstraction could be met from 6 bores in the superficial aquifer (totalling 1 GL/yr), 8 bores in the Leederville aquifer (totalling 4 GL/yr), and 18 bores in the Cattamarra Coal Measures aquifer (totalling 9 GL/yr). The quality of this water supply is summarised in Table 9.24. Note that this assessment has been based on an average water quality for each aquifer. Groundwater investigations completed as part of this study has shown that the salinity (as TDS) of the Leederville Formation and Cattamarra Coal Measures is as low as 400 mg/L and 950 mg/L respectively. The prediction also identified little risk of saline intrusion under this scenario.

Table 9.24
Abstraction and Water Quality Details of Optimal Prediction Scenario

Aquifer	No. of Bores	Total Abstraction	Average TDS
Superficial formations	6	1 GL/yr	750 mg/L
Leederville Formation	8	4 GL/yr	800 mg/L
Cattamarra Coal Measures	18	9 GL/yr	2,500 mg/L
Total	32	14 GL/yr	1,890 mg/L

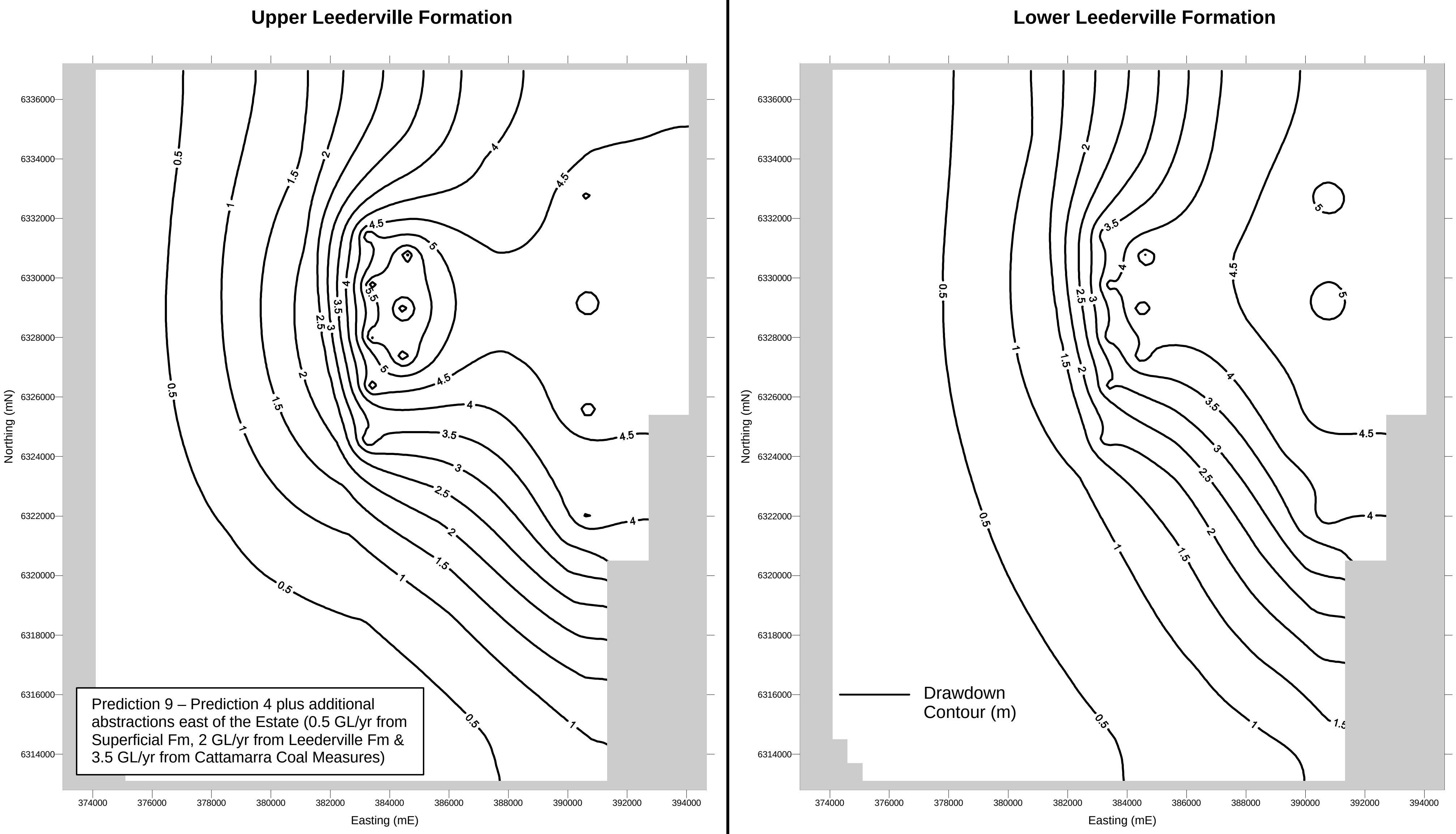


Prediction 9 – Prediction 4 plus additional abstractions east of the Estate (0.5 GL/yr from Superficial Fm, 2 GL/yr from Leederville Fm & 3.5 GL/yr from Cattamarra Coal Measures)

Original plan prepared for Industry 2030 – Greater Bunbury Industrial Land and Port Access Planning

Drawdown in Superficial Fm (30 yrs) – Pred9

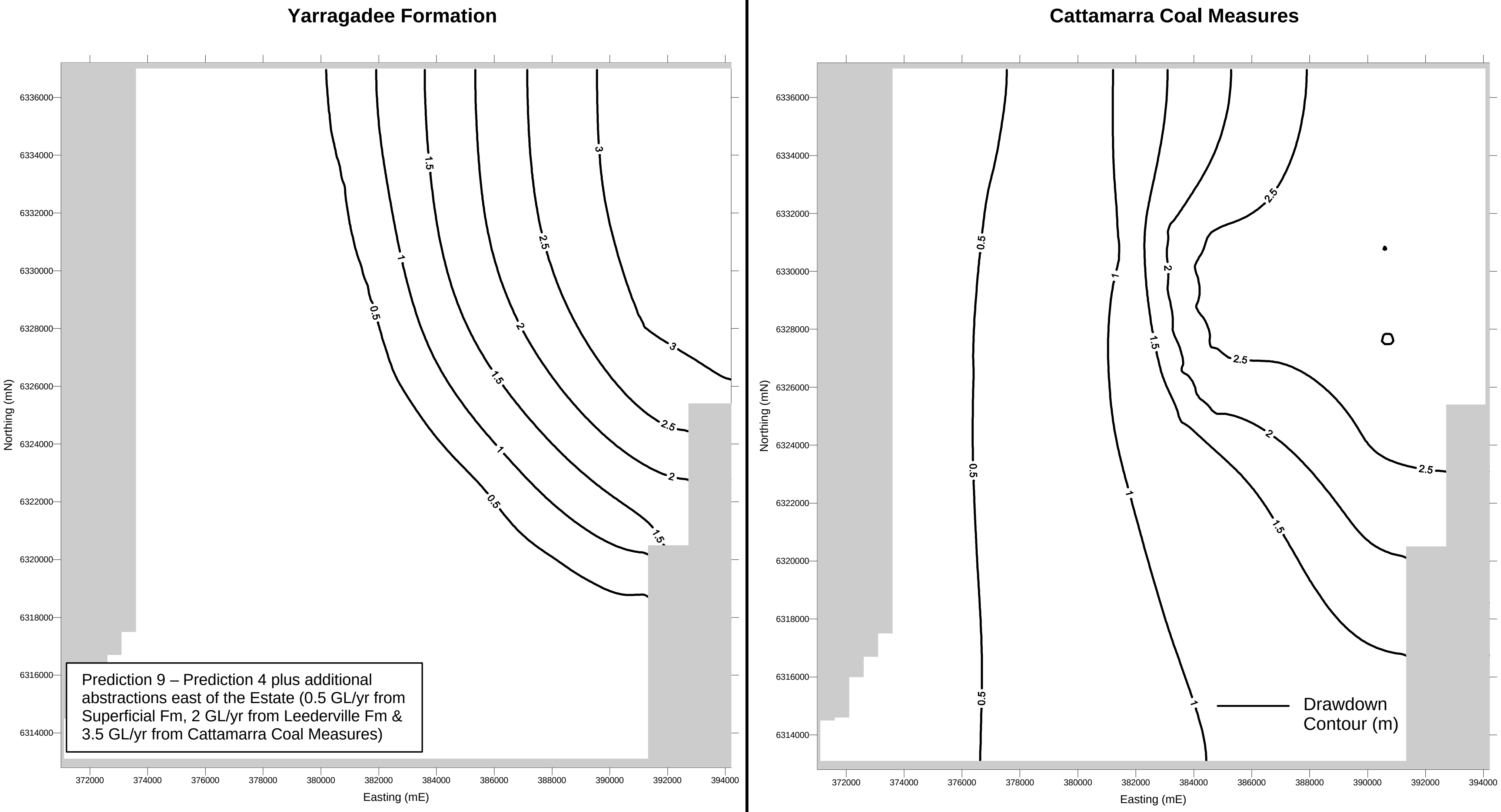
Figure 9.28



Prediction 9 – Prediction 4 plus additional abstractions east of the Estate (0.5 GL/yr from Superficial Fm, 2 GL/yr from Leederville Fm & 3.5 GL/yr from Cattamarra Coal Measures)

Drawdown in Upper and Lower Leederville Fms (30 yrs) – Pred9

Figure 9.29



Prediction 9 – Prediction 4 plus additional abstractions east of the Estate (0.5 GL/yr from Superficial Fm, 2 GL/yr from Leederville Fm & 3.5 GL/yr from Cattamarra Coal Measures)

Drawdown in Yarragadee Fm & Cattamarra Coal Measures (30 yrs) – Pred9
Figure 9.30

Abstraction from the different aquifers also allows access to water of varying quality to cater for the needs of different potential industries (generally better water quality in the superficial and Leederville aquifers, with brackish water in the Cattamarra Coal measures aquifer). To limit environmental impacts, the optimum abstraction scenario focuses abstraction in the confined aquifers, particularly the Cattamarra Coal Measures and to a lesser extent the Leederville Formation, and also allows for some abstraction from the superficial formation. The modelling indicated that abstraction sources in the superficial formation need to be located carefully (along the topographic ridge) to reduce impacts on wetland and dryland vegetation. Locations for confined aquifer bores are not similarly constrained.

For the High Demand abstraction (14 GL/yr), the groundwater model predicts limited drawdown impacts under wetlands and (groundwater-dependent) dryland vegetation. The maximum predicted drawdown for the three categories of water table depth (Table 7.3) are all within the critical tolerance levels. The maximum annual criterion of 0.25m is also not exceeded. Further modelling has shown that the Maximum Demand case (23 GL/yr) can be met without violating environmental criteria, provided there is no abstraction from the superficial aquifer.

The abstraction of the Maximum Demand for Kemerton (additional 23 GL/yr, plus abstractions by existing industries) results in a maximum drawdown of between 4m and 11m in the confined aquifers, less than 1m drawdown in the superficial aquifer, and some inflows from the coastal boundary (ie. there is the risk of saline intrusion). The Very High Demand abstraction (18 GL/yr) has a slightly lower drawdown impact and is predicted to result in little to no inflow from the coastal boundary. This indicates that the abstraction of between 18 and 23 GL/yr is possible with limited environmental impacts on wetlands or dryland vegetation, although there could be potential risks of saline intrusion. Details of abstraction and water quality for these two scenarios is summarised in Table 9.25.

Table 9.25
Abstraction and Water Quality Details – Very High and Maximum Demand Scenarios

	Very High Demand (18 GL/yr)		Maximum Demand (23 GL/yr)	
Aquifer	**Total Abstraction**	**Average TDS**	**Total Abstraction**	**Average TDS**
Superficial formations	0 GL/yr	750 mg/L	0 GL/yr	750 mg/L
Leederville Formation	6 GL/yr	800 mg/L	7 GL/yr	800 mg/L
Cattamarra Coal Measures	12 GL/yr	2,500 mg/L	16 GL/yr	2,500 mg/L
Total	18 GL/yr	1,930 mg/L	23 GL/yr	1,980 mg/L

A number of sensitivity simulations were also performed to assess the impact of climate variability and variation in aquifer parameters. The results were found to be insensitive to climate variability (‘dry case’ and ‘wet case’ scenarios), and somewhat sensitive to variations in the values of the horizontal and vertical hydraulic conductivity parameters. A higher vertical conductivity results in greater drawdown impacts in the superficial formation due to an increase in downward leakage, and reduced impact on the confined aquifers. A lower horizontal hydraulic conductivity results in an increase in drawdown within both the unconfined and confined units. However, the predicted long term drawdowns were still within the applied environmental constraints.

These results provide a sound argument to support an application for a groundwater abstraction licence for the Kemerton Industrial Estate of at least 14 GL/yr (in addition to existing abstractions), and suggest that an additional 4 to 9 GL/yr could be earmarked for the Estate for future use.

9.11 MODEL LIMITATIONS

The groundwater model developed for this study achieves a High complexity (Aquifer Simulator model - refer Appendix G for more information) standard with detailed stream-aquifer interaction, drainage and evapotranspiration features, and accurate calibration to monitoring data over an 11 year period for 70 superficial aquifer bores, and 11 confined aquifer bores.

A key objective of the modelling exercise was to adequately represent the interaction of groundwater and surface water features, such as rivers, drains, wetlands and groundwater dependent vegetation. These features, however, also rely on surface water processes such as overland flow. It is currently not possible to directly simulate these surface water processes by the groundwater model. However, the model does include features to represent the existing surface drainage network at Kemerton, which discharges to wetlands and rivers, and to represent evaporation from water bodies and vegetation. Model results are presented in terms of predicted changes to water balance components, providing the opportunity to assess the impact of various development scenarios on groundwater contributions to these systems.

The evapotranspiration model currently uses factored Class A Pan data to represent maximum evapotranspiration rates from vegetation and wetlands, as there is no site-specific data on water use through these processes. While the model calibration is shown to be accurate, the physical realism of the model could be improved if future work programmes were to obtain site- and vegetation-specific water use data on a woodlot scale.

Stream flow is also not currently simulated in the model but could be activated using the Streamflow-Routing package. This package, however, requires flow data from a number of gauging stations along the Wellesley, Brunswick and Collie Rivers at upstream and downstream locations. This data is not available, and would take several years to collate sufficient data to justify upgrading the river feature. This approach is not considered warranted.

10.1 OBJECTIVES

The overall objective of the Kemerton Water Study Phase 2 is to develop a water management strategy that is acceptable to relevant authorities, and is capable of practical implementation to maximise the development potential for the Kemerton Industrial Estate. The aims of the water management strategy are to plan for sustainable and efficient water use, and to minimise potential impacts from development and operation of the Estate, whilst maintaining environmental values of significant wetlands, watercourses and vegetation.

The Water Management Strategy is designed to be acceptable to authorities, with the water supply based on sustainable groundwater abstraction, and impacts that meet the established Environmental Water Requirements (EWR). The strategy conforms to the Environmental Water Provisions (EWP) Policy of the Water and Rivers Commission (WRC), as well as to the water sensitive drainage management policies of the WRC and local councils. The Strategy also conforms to environmental management policies of the Department of Environmental Protection (DEP), particularly regarding wetlands and vegetation.

The previous sections of this detailed report on the Kemerton Water Study Phase 2, and this Strategy, provide the technical information required by the WRC to set water allocations, consistent with their EWR/EWP and other policies. The detailed technical information presented in the report can also serve as a bore completion report for the WRC, documenting the results of the drilling programme undertaken for this Study. Other information in the report provides detail regarding environmental values and management for wetlands and vegetation, as well as for drainage management.

This Water Management Strategy is also capable of practical implementation. It provides management guidance for design, development, and management of land within the expanded core of the Estate. Proposed industrial Estate tenants can use information presented in this Strategy for detailed engineering design for their specific site. Essentially, this Water Management Strategy provides a tool for structure planning, earthworks and drainage design, consistent with the overall water, drainage and environmental management of the Estate.

The following sections outline:

- Environmental values and management objectives for wetlands, vegetation and water resources;
- EWR/EWP issues and criteria;
- Water supply abstraction scenarios, nominal bore locations and pumping rates, and predicted impacts;
- Wastewater and drainage management issues and strategies;
- Monitoring programmes for hydrology, groundwater and vegetation;
- Groundwater contamination issues and pollution control action guidelines; and
- Compliance reporting and environmental auditing.

10.2 ENVIRONMENTAL VALUES

The conservation values of the Estate were estimated during the Phase 1 Biological Assessment (Muir, 1999). Areas of inherent conservation value included those areas with high species richness and intact, unlogged forest woodland. Other areas included wetlands, particularly EPP wetlands and perched wetland sites containing Declared Rare or Priority Flora. Other areas of regional ecological significance include two floristic community types - Southern *Eucalyptus gomphocephala, Agonis flexuosa* woodland (Type 25) and *Banksia ilicifolia* woodland (Type 22). These communities are typically not well represented within National Parks or Conservation Reserves and are therefore regarded as conservation significant.

No Threatened Ecological Communities (TECs) are known from the Estate (English and Blyth, 1997).

Wetlands with the highest ecological values are those which collectively support a diverse wetland flora and are classified as Conservation Category wetlands. Within the overall buffer boundary of the Kemerton Industrial Estate this includes several wetlands assessed as part of this study, the most important of which is Mialla Lagoon (CCW1, Figures 7.1 and 7.2), which had the highest score of wetlands re-assessed using the 686 Bulletin questionnaire.

EPP wetlands were identified on the basis of their hydrological status and size in December 1991, and are not categorised as such on the basis of their ecological values.

Some areas of dryland vegetation can comprise Groundwater Dependant Ecosystems (GDEs), or ecosystems which have their species composition and their natural ecological processes determined by groundwater (Hatton and Evans, 1998). Ecosystems that occur where the depth to the groundwater is less than 6m are generally the most susceptible to any decline in the level of the groundwater table (such as in period of drought) as they have adapted to having shallow groundwater in the vicinity of their root system. The East Gnangara Water Stress Study (WAWA, 1992) suggested that dryland areas with a depth to groundwater of less than 6m were most affected by drawdown.

Banksia ilicifolia is a species that is prominent within the Jarrah/Marri/Banksia woodland and is widespread throughout the Estate. *Banksia ilicifolia* is a phreatophytic plant species (i.e accesses water from the groundwater table), that is poorly adapted to a sudden or rapid decline in the water table (Groom *et al.,* 2000a). It is a species that is restricted in its distribution by the depth to groundwater (in the range 2m to 10m) (S. Nicoski and R. Froend, ECU, unpub. data). A reduction in the vigour and structure of *B. ilicifolia* is considered to be a significant indicator of both long and short term reduction of groundwater levels on shallow aquifers on the Swan Coastal Plain.

Shallow-rooted plant species generally do not have access to a groundwater resource that is greater than 1m in depth (Dodd *et. al.,* 1984) and as a consequence are less likely to die as a direct response to significant groundwater drawdown, although excessive drawdown may exacerbate the impact (Groom *et. al.,* 2000). Only a decrease in the level of the superficial aquifer will have an impact on groundwater dependant vegetation. Drawdown in deeper aquifers has been shown to have a minimal impact on the shallow superficial aquifer and consequently will have no impact on vegetation.

10.3 WETLAND EVALUATIONS AND MANAGEMENT OBJECTIVES

A total of 10 wetlands were re-evaluated during Phase 2 of the Kemerton Water Study. This included seven wetlands with preliminary Conservation Category classifications and three with Resource Enhancement category classifications. Figure 7.2 shows the distribution of wetlands in the Kemerton area. No EPP wetlands occur within the Expanded Core Area (ECA).

The northern half of wetland CCW7 (dampland off Devlin Road, near the existing MIC site) lies within the expanded core boundary. This is the only Conservation Category Wetland which lies/partially lies within the expanded core boundary. Following re-evaluation, its classification remained unchanged. One Conservation Category wetland, located outside of the ECA and within the Kemerton Silica Sands lease, was assessed to be a Resource Enhancement category wetland (CCW4, a sumpland off Treasure Road). However, on advice from the WRC, it could not be considered for re-classification, as it is a gazetted EPP wetland.

Two of the re-evaluated Resource Enhancement Category wetlands (RE2 and RE3) are located within the Kemerton ECA. The preliminary classification assigned to these wetlands remains unchanged. One Resource Enhancement category wetland (RE1), which abuts the southeastern corner of the ECA, was downgraded to the Multiple Use Category (MU).

The primary management objectives for different wetland categories (EPA, 1993) are summarised in Table 10.1.

Table 10.1
Wetland Management Objectives and Categories

Category	**Primary Management Objectives**
EPP	These wetlands are protected from activities including draining, filling, mining, polluting or other alteration to the hydrological function of the wetland.
Conservation	Management to maintain and, wherever possible, enhance the natural attributes and functions of the wetland
Resource Enhancement	Management to maintain, and wherever possible, enhance the existing ecological function of the wetland
Multiple Use	There are generally no constraints associated with the development of MU wetlands, provided the remaining hydrological functions of the catchment are maintained

Subject to these management objectives, the Environmental Protection Policy (EPP), Conservation Category (CC) and Resource Enhancement (RE) wetlands within the Kemerton Industrial Estate need to be protected from any disturbance and surrounded by an appropriate buffer zone. This means that there should be no development activity within a 100 m buffer zone around these EPP, CC and RE wetlands.

There are no similar constraints associated with the development of Multiple Use (MU) category wetlands, which occur extensively on the eastern side of the Estate, in the area of the high water table, and (at present) commonly on grazed land.

Additional management criteria for wetlands and dryland vegetation are presented in the next section, relating to EWR/EWP issues.

10.4 EWR/EWP CRITERIA

The Water and Rivers Commission has recently released its Statewide Policy on Environmental Water Provisions (WRC, 2000a). The primary objective of the policy is to provide for the protection of water dependent ecosystems while allowing for the management of water resources for their sustainable use.

The policy document provides the following definitions:

- **Ecological Water Requirements** (EWRs) are “the water regimes needed to maintain ecological values of water dependent ecosystems at a low level of risk”
- **Environmental Water Provisions** (EWPs) are “the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts: they may meet in part or in full the EWRs”.

Criteria for Ecological Water Requirements (EWRs) of dryland as well as wetland ecosystems within the Estate have been determined, based on recent research by Edith Cowan University (Froend & Zencich, 2001). The WRC has supported these criteria on the basis that it is the best published information available. The criteria sets a maximum level of drawdown for three different categories of depth to groundwater (Table 10.2). A maximum annual allowable drawdown of 0.25m has also been specified. These levels, listed in Table 10.2, have been adopted as the EWR criteria. There are other, less critical, criteria that were also applied to certain wetland vegetation types, as described in Section 7 of the report.

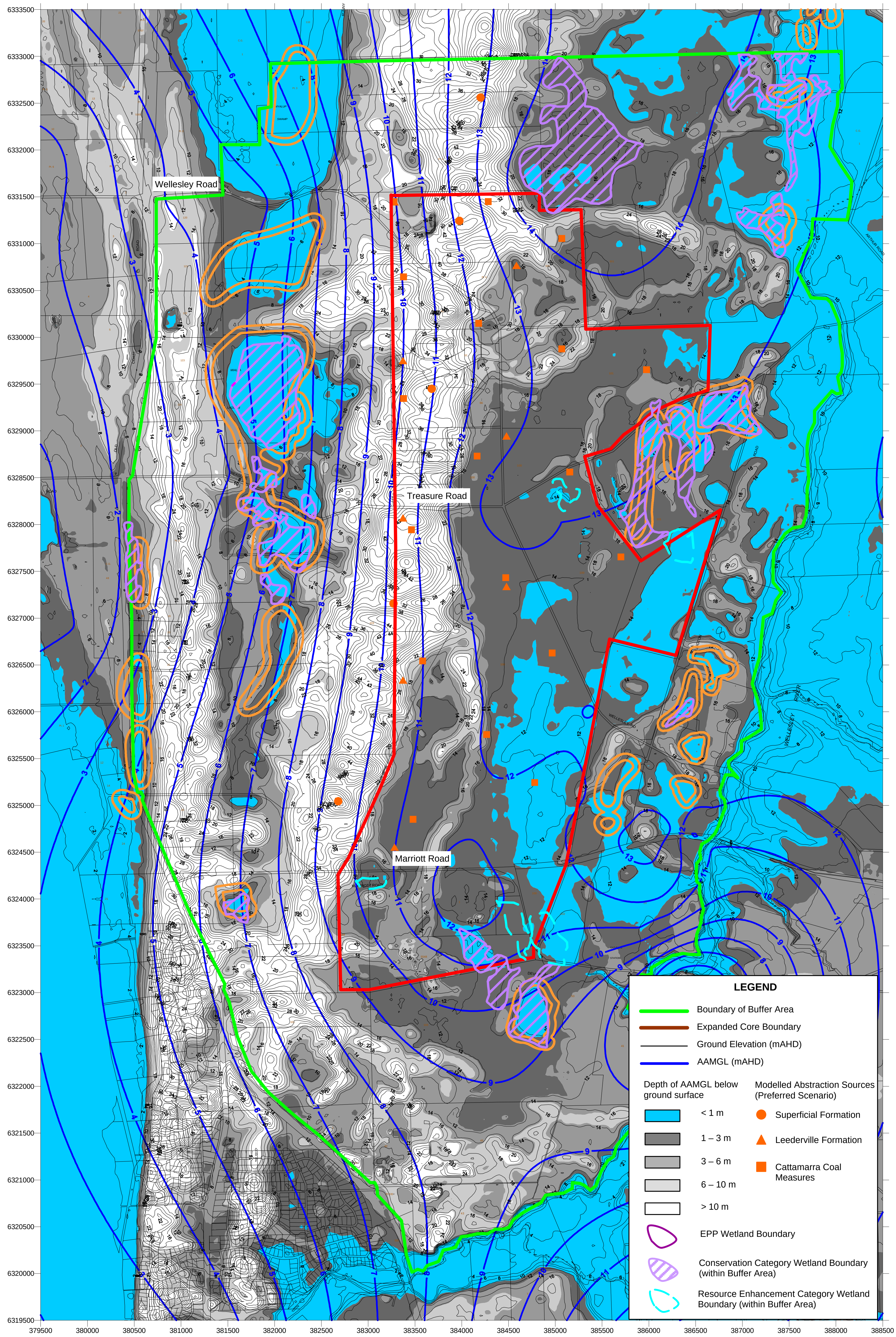
Table 10.2
Ecological Water Requirement (EWR) Criteria
Critical Tolerance Levels of Groundwater Drawdown Impact for Dryland and Wetland Vegetation

Category	Critical Levels of Drawdown
Category 1: 0 - 3m depth to groundwater	0.75 m
Category 2: 3 - 6m depth to groundwater	1.25 m
Category 3: 6 - 10m depth to groundwater	1.75 m

The impact of proposed abstractions on the vegetation was assessed to determine whether the Environmental Water Provisions (EWPs) are within the EWR criteria. In other words, if the predicted drawdown impacts of proposed abstractions to supply Kemerton water demands was within the EWR criteria, then the EWP was deemed acceptable. A summary of the predicted drawdowns at selected wetland and dryland vegetation monitoring points is presented later.

The location of the dryland vegetation monitoring points (Figure 9.12) are in areas which were close to the area of abstraction from the superficial aquifer, and were also in an area where the annual average minimum groundwater level was within 6m of the surface (Figures 8.4 and 10.1). As indicated in Section 10.2, the East Gnangara Water Stress Study (WAWA, 1992) suggested that dryland areas with a depth to groundwater of less than 6m were most affected by drawdown. The location of the wetland monitoring points (Figure 9.12) correspond to field transects where the different vegetation types along the transect were mapped to assess the drawdown impact on different vegetation species. This is required because there are different EWP criteria that need to be applied to different types of wetland vegetation.

Kemerton Water Study (Phase 2)



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Water Management Strategy Information
Figure 10.1

10.5 WATER SUPPLY OPTIONS FOR THE ESTATE

10.5.1 Water Supply Demands

A number of water supply options for the Estate have been investigated to meet the Medium, High and Maximum demands of future industry (Table 10.3) through local groundwater abstractions. Due to the requirement for high quality process water for some industries, an allowance has been made in each case for desalination to achieve the required quality.

Table 10.3
Projected Water Demand

Scenario	Demand	Comments
Low Growth	7 GL/yr	Status quo with demand dictated by the expansion of MIC and Simcoa Operations. Included also is the possibility of titanium sponge production and few small unspecified industries.
Medium Growth	10 GL/yr	Volume required is higher to meet the demands of a synthetic rutile plant, wool processing, iron briquetting plant and a pulp mill.
High Growth	14 to 18 GL/yr	Optimistic view considering the full development of Kemerton with a wide range of industries including an aluminium smelter, power station and other industries.
Maximum	23 GL/yr	High growth demand plus the introduction of a 'high water demand' industry

The quality of the groundwater in the aquifers under Kemerton range from fresh (<1,000 mg/L Total Dissolved Solids (TDS)) in the superficial aquifer, and generally for the Leederville aquifer, to brackish (generally <3,000 mg/L TDS) for the Cattamarra Coal Measures aquifer. In some areas, however, the groundwater quality in the superficial aquifer can be highly saline (10,000 to 20,000 mg/L TDS), and exploration programmes would be required to confirm water quality prior to any development.

10.5.2 Groundwater Abstraction

Groundwater modelling has indicated that the High Demand case of 14 GL/yr can be obtained from the unconfined and confined aquifers in the area with minimal environmental and groundwater impact, while meeting EWR/EWP criteria (see later). The modelled scenario involved the abstraction of 1 GL/yr from the superficial formation (~750 mg/L TDS), 4 GL/yr from the Leederville Formation (~800 mg/L TDS) and 9 GL/yr from the Cattamarra Coal Measures (~2500 mg/L TDS). Nominal bore locations are shown in Figure 10.1, along with topographic levels, and the different categories of depth to groundwater specified for the EWR/EWP criteria (this indicates potential areas of groundwater-dependent vegetation).

The spread of abstractions across the different aquifers results in environmental impacts being minimised and allows access to different quality water. Modelling has also shown that, by not abstracting from the superficial aquifer, the drawdown induced in the superficial aquifer by abstracting from the deeper, confined aquifers, is greatly reduced. The reduced drawdown impact is less than the seasonal variation in water levels.

The modelling also indicated that the abstraction of the Very High to Maximum Demand cases of 18 to 23 GL/yr is possible, but there are potential risks of saline intrusion and significant reductions in outflows to the coast. In these cases, it would be necessary to abstract from only the confined aquifers, to avoid unacceptable impacts on wetlands and vegetation.

10.5.3 Groundwater Abstraction Impacts

Figures are presented in Section 9 of the report to show the predicted drawdown along each wetland transect, along with the different vegetation types, as well as at dryland monitoring points. The maximum drawdown presented in Table 10.4 is within EWR criteria (Table 10.2), and is of the order of (and typically less than) seasonal variations in water level in the area. The maximum annual drawdown of 0.25m is also not exceeded at any of the sites.

Table 10.4
Maximum Drawdown at Wetland and Dryland Monitoring Points

Wetland Monitoring Points		**Dryland Monitoring Points**	
Transect	Drawdown (m) @ 30 yrs	Observation Point	Drawdown (m) @ 30 yrs
Transect 1	0.14	Obs 1	0.33
Transect 2	0.10	Obs 2	0.45
Transect 3	0.05	Obs 3	0.47
Transect 4	0.12	Obs 4	0.51
Transect 5	0.11	Obs 5	0.34
Transect 6	0.14	Obs 6	0.34
		Obs 7	0.24

These results demonstrate that the predicted EWPs fully meet the EWR criteria.

10.5.4 Groundwater Management Strategy

Sustainable groundwater abstraction has been demonstrated to meet Kemerton water demands and the EWR/EWP requirements, provided the following management principles are applied:

- Locate superficial formation bores in areas remote from wetlands, preferably along the topographic ridge on the western edge of Kemerton, where the maximum depth to the water table occurs;
- Confined bore locations are not constrained, as modelling has shown very little drawdown impacts in the (superficial) water table due to abstraction from the confined aquifers - confined bores should be located as close to industry as possible to minimise pipe infrastructure requirements;
- Abstract the majority of the water requirements from the Leederville and Cattamarra Coal Measures aquifers (at a volume ratio of about 1:2), with pumping rates of around 1,500 kL/d per bore, with abstractions from the superficial aquifer limited to a maximum of 1 GL/yr (at rates of around 500 kL/d per bore);
- Gradually increasing total groundwater abstraction as various industries are introduced into the Estate, and implementing adaptive management to assess impacts and adjust abstractions as appropriate; and
- If there are successive years of lower than average rainfall, higher than average temperatures and resultant poor recharge, it may be necessary to reduce summer groundwater abstraction in order to minimise the risk of death to groundwater dependant vegetation and ensure that the environmental water requirements are met.

10.5.5 Alternative Water Supplies

Although this work has shown that local groundwater systems can supply Kemerton's water demands, access to additional water resources could also be met by alternative sources, notably the transfer of water from the Wellington Dam, and wastewater reuse. The Water Corporation has indicated that it has obtained all the necessary approvals to provide a water supply by pipeline from the Wellington Dam to Kemerton. However, it needs the commitment of a major industry with a significant water demand to justify the implementation of this option, which remains a viable alternative.

There is significant potential for wastewater treatment to reduce the basic water supply demand for Kemerton. There is an existing wastewater treatment plant at the Millennium Inorganic Chemicals site, although the produced water is currently being discharged to the ocean (around 1 GL/yr of 30,000 mg/L TDS water). It is recommended that consideration be given to the further treatment of the existing wastewater volumes to a sufficient quality so that it could be reused by existing or future industries. There is construction work currently being undertaken to relocate the Australind and Eaton domestic wastewater treatment plants into Kemerton. This could provide an additional source of water (projected at 1.3 to 2.6 GL/yr from 2010 to 2040), which could be used to meet certain water requirements of industries, provided the water is of adequate quality.

Increased water usage as Kemerton is developed will also result in the generation of substantial wastewater volumes (4 to 15 GL/yr for the Low to High Demand cases). The Water Corporation is considering the potential introduction of an industrial wastewater treatment plant into the Estate (although little work has been done to date). Synergistic development of these wastewater treatment plants should be possible, to produce water with a range of quality that could be utilised by existing and/or future industries, thereby reducing the water supply demands.

Aquifer storage and recovery (ASR) was considered as an alternative method of helping to meet the groundwater abstraction demands, and possibly reducing associated environmental impacts. However, groundwater modelling has indicated that ASR does not significantly provide benefits in reducing drawdown impacts within the confined aquifers, although it may provide benefits in terms of improved water use efficiency.

10.6 WATER QUALITY OBJECTIVES

Clearing and land development for industrial activities has the potential to directly contaminate groundwater and surface water bodies by causing changes in water quality (urban and rural runoff) and recharge rates to aquifers. Ecosystem protection is the main aim of water quality criteria, specifically to:

- Protect wetlands, groundwater dependent ecosystems and downstream users from deterioration in groundwater quality; and
- Protect downstream surface water bodies including the Wellesley and Brunswick Rivers, Leschenault Inlet and the ocean from increase loads of nutrients and other contaminants.

The results of water quality analysis from designated monitoring bores, wetlands and the Wellesley River should be compared to baseline levels (documented in this Phase 2 Study report and data volume), and ANZECC Guidelines for the Protection for Aquatic Ecosystems (ANZECC, 2000). It is recommended that analysis results should also be compared to ANZECC guidelines for ‘recreational water quality and aesthetics’ and ‘marine and estuarine water quality’ (WRC, 1996). The designated sites should be discussed and agreed with the Department of Environment, Water and Catchment Protection (DEWCP - previously WRC and DEP), and documented in the environmental management plan for any site. Water quality parameters should include major ions and nutrients (notably nitrogen and phosphorous), chlorophyll-a, and salinity. Refer also to Section 10.9 (Monitoring and Assessment Programmes).

Exceedance of the water quality criteria at any designated site for two consecutive years should trigger an investigation into the cause, potential impacts and proposed remedial action. If the background water quality is already higher than ANZECC guidelines, this level should be managed with the objective of preventing further degradation of the water resource quality and enhancing the water quality. Even groundwater with TDS greater than 13,000 mg/L is of beneficial use to the ecosystem (WRC, 1996).

Further management strategies are outlined in the following sections dealing with wastewater, drainage, contamination and monitoring issues.

10.7 WASTEWATER DISPOSAL

Water quality impacts on wetlands and other surface water features should be minimised by disposing of all industrial wastewater to the common ocean outfall, or to any wastewater treatment plant for later re-use. Industries permitted in the Estate should be restricted to those whose wastewater (if any) is suitable for treatment and either disposal via the common outfall, or re-use, as determined by the regulating agencies. Efforts should be made to recycle and re-use this water within the operation to decrease the demand on groundwater resources.

It is currently proposed that domestic wastewater be used for irrigation purposes within the estate. Appropriate health and water quality guidelines must be adhered to prevent adverse health effects and degradation of waterways. Industries should be encouraged to engage in negotiations with the Water Corporation to re-use this water in the industrial process, thereby reducing demands on the groundwater resource.

10.8 DRAINAGE MANAGEMENT STRATEGY

10.8.1 Drainage Strategy

Urban and industrial development typically increases the water input to the natural hydrological system, due to enhanced runoff from extensive paved surfaces and a reduction in interception and evapotranspiration losses due to less vegetation. Traditional drainage methods involve using earthfill to create building pads, and collecting and conveying runoff via roadways, pipes and channels to receiving water bodies (with associated nutrients).

Water sensitive design principles have recently been promoted, which involve the infiltration of stormwater into the soil near its source using soakwells, shallow swale drains or sheet runoff into permeable areas such as lawns, garden beds, pervious pavements etc. This results in extra recharge to the aquifer, which is available for re-use in the development by subsequent groundwater pumping (this aspect was addressed in the groundwater modelling predictions). As water sensitive design generally relies on infiltration, it is most effective for smaller, more frequent storms. Traditional methods are often required to augment water sensitive design practices when the rates of surface runoff significantly exceed the infiltration rate (which commonly occurs in areas of high water table such as near wetlands).

The key benefits of the drainage management strategy presented below involve:

- Minimising the capital costs for development by avoiding the need for trunk drainage and extensive earthfill areas; and
- Maximising the infiltration of runoff to recharge the aquifer for later use through abstraction, which is consistent with water sensitive design principles.

The Kemerton Industrial Estate should be designed with a mix of water sensitive design and traditional design methods, as appropriate for the site-specific details for any block on the Estate. Detailed drainage plans will be required to be developed for each site, consistent with the strategy outlined below. These plans will need to use the information presented in the Phase 2 Water Study report, including:

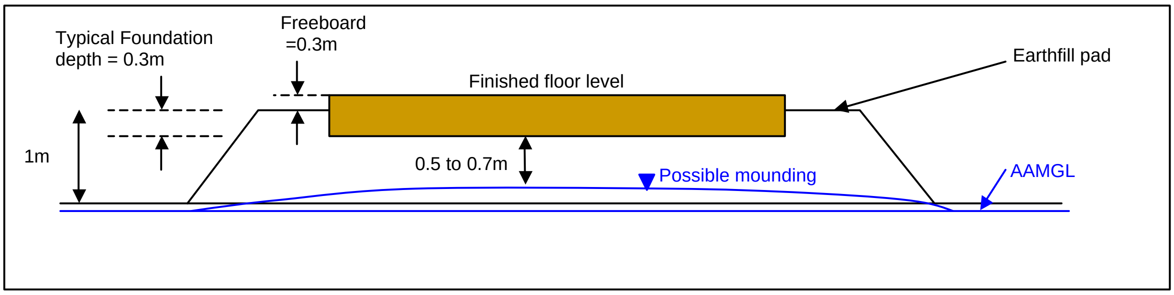
- Topographic elevations (see also Figure 10.1)
- Average annual maximum groundwater levels (AAMGL - see also Figure 10.1)
- Drainage Design Requirements (outlined below and summarised in Table 10.5).

The site stormwater drainage network should have sufficient capacity for the more frequent flooding events, up to the 2 year average recurrence interval (ARI) storm. In areas with high infiltration rates, on site storage of stormwater such as in soakwells and shallow depressions should be adopted. In areas with low infiltration rates, on site storage of stormwater should be utilised where possible, for example in summer, when groundwater levels are low. Infiltration will be limited when groundwater levels are high, and stormwater runoff will need to be conveyed away from the developed part of the site.

10.8.2 Developed Areas

Developed areas are defined as those areas of each block (or across the Estate generally) that are developed for roads, buildings, car parks, hardstand areas etc (ie. those areas with hard paved surfaces that generate more runoff than natural surfaces). Only developed portions should require earthfill to obtain the minimum clearance from the water table. The “water table” for this purpose is defined as the average annual maximum groundwater level (AAMGL), as shown in Figure 10.1.

The minimum water table clearance needs to allow for foundation depths of 0.3m and the potential for groundwater mounding of 0.2m. To provide a minimum clearance of 0.5m between the underside of foundations, and any groundwater mounding under earthfill pads, a maximum pad height of 1m may be required for certain sites. Finished floor levels should be set with a 0.3m freeboard above the earthfill level, consistent with local council requirements. This is illustrated below.



As there would be little to no infiltration under buildings or paved areas, groundwater mounding would be minimal and a clearance of up to 0.7m between the base of foundation and the AAMGL could be obtained. Some industries may have deeper foundations, and/or require greater separation distances between foundations and the water table, which would require greater depths of earthfill or relocation to more appropriate sites. Information is provided in Table 10.5 and Figure 10.1 for the detailed drainage design for any site.

In the developed areas of the block, floodways should be designed to convey flows from larger than the 10 year average recurrence interval (ARI) storm. Floodways will typically be formed from roadways or hardstand areas and should always have an outlet to either the undeveloped part of the block, or to existing drainage systems. Surcharging of roads and hardstand areas is acceptable (ie. use these features as floodways to convey the major flood flows towards undeveloped parts of the block, existing drains or natural overland flow paths) in rarer events such as the 10 year ARI storm, but is not acceptable for more frequent events.

10.8.3 Undeveloped Areas

Undeveloped areas should be used effectively as natural retention basins for larger flows that cannot be infiltrated within the developed areas. Multiple Use category wetlands could also be used as drainage basins for larger flood events. However, this must not result in changes to the hydrological and ecological regime of other EPP, Conservation Category and Resource Enhancement wetlands in the area.

As much remnant vegetation as possible should be retained on each site, and existing cleared portions that are not required for development should be revegetated. The use of existing natural drainage paths is also encouraged rather than using engineered drainage structures.

In undeveloped areas with low infiltration rates, shallow swale drains should be constructed to alleviate ponding, with inverts above the AAMGL. These shallow drains should traverse the block to convey excess water towards Multiple Use wetlands, existing drains or creeks. The potential for soil erosion in the swale drains should be reduced by constructing them on minimal grades and applying rock protection to susceptible areas such as entry points from developed areas. Where roads intercept open drains or shallow flow paths, culverts will be required to convey flows under the road.

10.8.4 Drainage Strategy Summary

A summary of the drainage design requirements in relation to the depth to AAMGL is presented in Table 10.5.

Table 10.5
Drainage Design Requirements

Drainage Design Requirement	**AAMGL Depth Below Existing Ground Level**			
	0m	0.5m	1.0m	>1.5m
Developed Areas of Blocks				
1. Minimum elevation above surrounding ground surface for earthfill pads	1 m	1 m	0.5 m	0.3 m
2. Floor level freeboard to 100 year ARI flood from local runoff	0.3 m	0.3 m	0.3 m	0.3 m
3. Floodways to convey greater than 10 year ARI flood	Yes	Yes	Yes	Yes
4. Surcharge of roads and hardstand areas for greater than 10 year ARI floods (ie. use these features to convey the major flood flows towards existing drains and natural overland flow paths)	Yes	Yes	Yes	Yes
5. Roof and pavement runoff to spoon drains or rock spalls which dissipate to the groundwater	Yes	Yes	Yes	Yes

Drainage Design Requirement	**AAMGL Depth Below Existing Ground Level**			
	0m	0.5m	1.0m	>1.5m
6. Soakwells and shallow on site storage depressions	Yes	Yes	Yes	Yes
7. Ponding in lower infiltration capacity areas	Yes	Yes	Yes	Yes
8. Invert levels of drainage structures above AAMGL	Yes	Yes	Yes	Yes
9. Pollution control devices at source (eg. oil separators)	Yes	Yes	Yes	Yes
10. Rainwater tanks for water supply	Yes	Yes	Yes	Yes
Undeveloped Areas of Blocks				
11. Shallow swale drains to convey ponded surface water to existing drains or Multiple Use wetlands (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
12. Shallow diversion swale drains around building pads (drain inverts above the AAMGL, and typically a maximum of 0.3 m deep)	Yes	Yes	No	No
13. Low flow culverts under roads that intercept sheet flow runoff	Yes	Yes	No	No
14. Culverts under roads that intercept existing open drains	Yes	Yes	Yes	Yes

10.9 MONITORING AND ASSESSMENT PROGRAMMES

A monitoring programme is necessary to facilitate the adaptive nature of groundwater and environmental management. The environmental monitoring programme has been largely based on the programmes formulated for the East Gnangara Water Provisions Plan (WRC, 1997). The programme addresses (after EA, 2001):

- Environmental conditions of groundwater dependent ecosystems and the trend in condition over time;
- Groundwater attributes relevant to ecological processes in the dependent ecosystems; and
- Allocation and usage of groundwater.

Environmental and water monitoring should be most intensive in the early years following the establishment of new industry and allocation of groundwater resources. The monitoring programme should be reviewed within 2 years of the commencement of the Water Management Strategy to determine the need for modification. The effectiveness of the monitoring plan should be evaluated by considering the extent to which the plan has been implemented and the extent to which the plan has succeeded in meeting the desired goals for protection (NWQMS, 1995b). The programme should also include a commitment from individual industries for regular professional review and reporting of data to the regulating agency.

The monitoring programme will need to be designed to include quality assurance/quality control (QA/QC) procedures throughout the sampling and analysis program to ensure that high quality data is reported (WRC, 1996).

10.9.1 Groundwater Level Monitoring

A detailed groundwater monitoring programme will need to be established to support any proposed abstractions from the Estate. Multi level piezometers should be established within the aquifer unit from which abstractions are proposed and any overlying or underlying units (but not lower than the Cattamarra Coal Measures). These bores should be located close to abstraction bores (within 50m) to allow the assessment of drawdown in each aquifer and vertical leakage from overlying/underlying units, as this was identified as a critical sensitivity parameter during groundwater modelling. The monitoring bores will need to be measured monthly to be able to correlate water levels against monthly abstractions and also detect seasonal variations in water level.

A selected number of monitoring bores from the existing regional network of superficial and confined monitoring bores should also be monitored quarterly to detect regional impacts of groundwater abstraction. This regional monitoring network should include bores located near wetlands and under dryland vegetation areas to ensure groundwater abstractions are not exceeding EWR/EWP criteria (drawdown impacts) in these areas.

The actual bores selected for this process should be discussed and agreed with the Department of Environment, Water and Catchment Protection (DEWCP - previously WRC and DEP), subject to specific details regarding the proposed groundwater abstraction.

10.9.2 Groundwater Quality Monitoring

A key component of the Phase 2 study was the sampling and analysis of a large number of superficial monitoring bores within the estate. The collation in the Phase 2 Water Study report of the historical data should be used to indicate the baseline water quality of the Estate. A summary of the range in key water quality parameters is presented in Table 10.6.

Table 10.6
Superficial Aquifer Typical Water Quality of Kemerton Industrial Estate

Parameter	Minimum	Maximum	Median	Average
pH	3.9	7.9	5.6	5.9
Electrical Conductivity (µS/cm)	95	33,000	520	1030
TDS (mg/L)	60	20,000	330	650

The frequency and extent of water quality monitoring by individual industries will be dependent on the nature of the operation. A suitable monitoring programme will need to be prepared and approved by the Department of Environmental Protection and Water and Rivers Commission. It is likely that minimum requirements for water quality monitoring will need to involve quarterly measurement of pH, TDS, major ions, and possibly other industry-specific parameters as outlined in Table 10.9.

Groundwater quality should also continue to be monitored bi-annually from a selection of monitoring bores within the industrial park to establish any deviations from baseline water quality after the establishment of new industries.

10.9.3 Groundwater Dependent Vegetation (GDV)

A number of the existing monitoring bores and new superficial monitoring bores established as part of this study are located near key wetlands and groundwater dependent vegetation (GDV). These bores should be monitored quarterly to ensure that water levels are in compliance with the determined EWPs. The critical tolerance levels which should not be exceeded for *Banksia* vegetation are summarised in Table 10.2 (Froend *et al*., 1999).

In addition to water level monitoring, regular monitoring of GDV should be undertaken, particularly vegetation that is in close proximity to abstraction sites, and especially following successive years of low rainfall (Groom *et al.,* 2000a).

It is recommended that at least two permanent transects of each GDV type represented within the Estate be established, with each transect to be monitored annually. Baseline data should be collected from each transect for two years prior to abstraction having any drawdown impact. Nominal locations are presented in Figure 9.12, with final monitoring sites subject to the actual locations of production bores.

The monitoring program should include an assessment of vegetation health and vigour, species composition, species richness and cover/abundance measurements to enable any changes in vegetation structure to be monitored. Photographic monitoring should also be undertaken from a fixed, permanent point during each monitoring period.

The issue of population dynamics may need to be addressed to determine the limits of continued recruitment (Welker, 2000). It is recommended that monitoring of vegetation transects be undertaken annually during for the first 10 years, and bi-annually once abstraction has been increased to full capacity. However, long-term predictions suggest that within the next 30 years, the Swan Coastal Plain may experience up to 10% less winter rainfall and 5% less summer rainfall. Given the possibility of this, GDV monitoring may eventually need to be undertaken annually, particularly if groundwater monitoring shows a significant decline in the water table.

10.9.4 Wetlands

There are no EPP wetlands within the industrial core, however there are a number of EPP, Conservation Category (CC) and Resource Enhancement (RE) wetlands along the eastern and western boundaries of the Estate, which have stringent management requirements. There are also many Multiple Use (MU) category wetlands on the eastern side of Kemerton, which have few constraints in terms of development.

Monitoring bores established near wetlands during this study should be monitored quarterly to ensure that development impacts are in compliance with the established EWPs. As with the monitoring of GDVs, at least one transect representative of each wetland vegetation community in the Estate should be permanently established to monitor factors including seedling recruitment, species distribution in relation to water levels and general vegetation health and vigour. Nominal locations for transects are presented in Figure 9.12, but more sites may be required in future.

It is recommended that baseline data be collected from each wetland transect over the first two years of abstraction. Abstraction over this period is not expected to result in any significant impact of drawdown on wetland vegetation. It is recommended that wetland vegetation be monitored on an annual basis while abstraction is increasing, and then bi-annually once the abstraction has stabilised. However, if groundwater monitoring indicates a significant decline in the water table (ie. low recharge as a result of below average rainfall levels), monitoring should be undertaken annually. It is also recommended that fixed-point photographic records be taken during each monitoring period.

Monitoring bores and staff gauges should be established within and adjacent to selected key wetlands, and monitored regularly (quarterly) to ensure compliance with the EWPs. These wetlands should also be sampled annually (during the winter season) for a range of organic and inorganic parameters to identify any effects from industrial activities. When industrial development occurs near these wetlands, a baseline water quality and hydrological assessment of the wetland should be undertaken, and appropriate measures incorporated to their drainage management plan to ensure the water quality and hydrological regime of these wetlands are not altered.

10.9.5 Rivers

The main rivers which are at potential risk from pollution are the Wellesley and Brunswick Rivers (and associated riparian ecosystems). Riparian ecosystems are extremely important from an ecological point of view as they generally occupy the lower parts of the landscape where there is usually more water in the vegetation and soils, and the soils are often rich in organic matter with good soil structure and nutrient supply (LWRRDC, 1996). They also have a higher abundance and diversity of plant and animal life.

Poor management of riparian vegetation will lead to increased rates of erosion and flooding, decreased water quality and degradation of the ecosystem (LWRRDC, 1996b). The retention of vegetation slows the overland movement of water causing sediments and nutrients to be deposited on land before it reaches the stream channel.

Potential horticultural and stock activities within the buffer area need to be regulated to protect the riparian ecosystem. The aim is not to exclude stock altogether, but to control the timing, duration and intensity of grazing pressure. Some means of controlling grazing pressure include fencing, constructing designated watering points and formed access points (LWRRDC, 1996c). A buffer should also be established at points where surface waters enter small river channels and in landscape depressions where flow concentrates (LWRRDC, 1996d). These buffers need to be maintained so that there is almost complete groundcover and a good height of vegetation, which will maximise their trapping potential. It is generally recommended that the minimum buffer be a combination of 10m of grass and 10m of natural vegetation (LWRRDC, 1996d), however a wider buffer may be required if there is an intense source of pollutants, steep landscapes and poor vegetation cover. This is not likely to be the case as the industry specific drainage management plans are designed to trap nutrients and contaminants at the source.

The Wellesley River is believed to have unacceptably high levels of suspended sediments, which has been linked to mining activities and uncontrolled stock access to waterways (WRC, 2000c). Moderate concentrations of nitrogen and high concentrations of phosphorus have also been recorded in the Wellesley River. A summary of background water quality from WRC monitoring data is given in Tables 4.6 and 4.7. These concentrations should be considered ‘baseline’, and appropriate management practices adopted to prevent further degradation of the waterways. These practices and procedures need to be documented in industry specific Drainage Management Plans (see above) and approved by the Department of Environment, Water and Catchment Protection (DEWCP - previously WRC and DEP).

If there is a high potential for degradation of the rivers, a detailed baseline assessment of the river should be undertaken. This assessment should include flow measurement and analysis of water quality parameters such as nutrients, temperature, chlorophyll-a and salinity at appropriate locations along the river. The proposed baseline assessment and ongoing monitoring programme will need to be integrated into the drainage management plan for the industry and approved by the WRC.

Monitoring of the Wellesley and Brunswick Rivers by the WRC should continue to be reviewed to ensure the expansion of the Estate and proposed abstractions do not impact on river flow volumes and water quality. This review should be undertaken every two years by a suitably qualified hydrologist. The exceedance of the established baseline criteria will require an investigation to be undertaken into the likely cause, potential impacts and proposed remedies.

10.9.6 Groundwater Allocation

Groundwater allocations to new and existing industries within the Estate should be reviewed annually to assess efficient use of the resource and impacts on the ecosystems. All industries with a groundwater licence will be required to measure and record monthly abstraction volumes from each production bore.

The licensee should also be required to demonstrate efficient use of the groundwater resource. This includes an assessment of whether appropriate quality water is being used for the industrial application, and to assess management practices to maximise water re-use. If water allocations are not being completely utilised, it could be made available for transfer to other industrial users within the Estate under the Transferable Water Entitlements policy of the WRC.

10.9.7 Summary of Monitoring and Assessment Programme

A summary of the monitoring and assessment programme is presented in Table 10.7. Monitoring programmes for each industry will be largely dependent on the nature of operations, and will need to be approved by relevant regulating authorities. An interim monitoring programme, which should commence as soon as possible, is presented in Table 10.8. This interim monitoring programme should be undertaken by the Estate Manager.

Table 10.7
Summary of Monitoring and Assessment Programme

Parameter	Monitoring Programme	Frequency	Responsibility
Groundwater Level	• Bores in the vicinity of abstraction. These bores should be located in the aquifer unit where abstractions are occurring, and any overlying or underlying units (but not lower than the Cattamarra Coal Measures). • Selected regional monitoring bores.	• Monthly • Six monthly	• Industry • Regulatory Authority
Groundwater Quality	• Industry specific bores for a range of physical, chemical and industry specific parameters to be agreed with the WRC and DEP (see Table 10.9 in the Groundwater Contamination Section). • Selected regional monitoring bores.	• Quarterly • Six monthly	• Industry • Regulatory Authority
Groundwater Dependent Vegetation	• Superficial groundwater bores (for water level) located near key groundwater dependent vegetation. • Monitoring and auditing of groundwater dependent vegetation and flora following successive years of low rainfall (particularly in areas close to abstraction sites). • Monitoring of two permanent transects of each groundwater dependent vegetation type represented within the Estate. Baseline data should be collected from each transect two years prior to commencement of groundwater abstraction.	• Quarterly • As required • Annual	• Estate Manager • Estate Manager/ Industry • Estate Manager/ and then Industry
Wetlands	• Superficial groundwater bores (for water level) located near key wetlands. • Annual monitoring of at least one permanent transect representative of each wetland vegetation community within the Estate. Baseline data should be collected from each transect two years prior to commencement of groundwater abstraction. • Monitoring bores and staff gauges be established within and adjacent to key wetlands, and monitored to ensure compliance with EWPs. • Sampling (during winter season) of key wetlands for a range of inorganic and organic parameters.	• Quarterly • Annual • Quarterly • Annual	• Estate Manager • Estate Manager • Estate Manager/ Industry • Estate Manager
Rivers	• Review of WRC monitoring data for the Wellesley and Brunswick Rivers.	• Two yearly	• Estate Manager
Groundwater Allocation	• Review of groundwater allocation to each industry.	• Annual	• Regulatory Authority and Estate Manager

Table 10.8
Interim Monitoring Programme

Parameter	Monitoring Programme	Frequency	Responsibility
Groundwater Level	• Estate superficial and confined aquifer monitoring bores. • Other regional superficial and confined aquifer monitoring bores.	• Quarterly • Six monthly	• Estate Manager/ Industry • Regulatory Authority
Groundwater Quality	• Estate regional superficial and confined aquifer monitoring bores. • Other regional superficial and confined aquifer monitoring bores.	• Six monthly • Six monthly	• Estate Manager • Regulatory Authority
Groundwater Dependent Vegetation & Wetlands	• Superficial groundwater bores (for water level) located near key wetlands and groundwater dependent vegetation. • Monitoring of two permanent transects of each groundwater dependent vegetation type represented within the Estate. • Monitoring of at least one permanent transect representative of each wetland vegetation community within the Estate.	• Quarterly • Annual • Annual	• Estate Manager • Estate Manager • Estate Manager

Note:
The above programme is in addition to the current monitoring being completed by existing industries MIC and Simcoa.

10.10 GROUNDWATER CONTAMINATION ISSUES

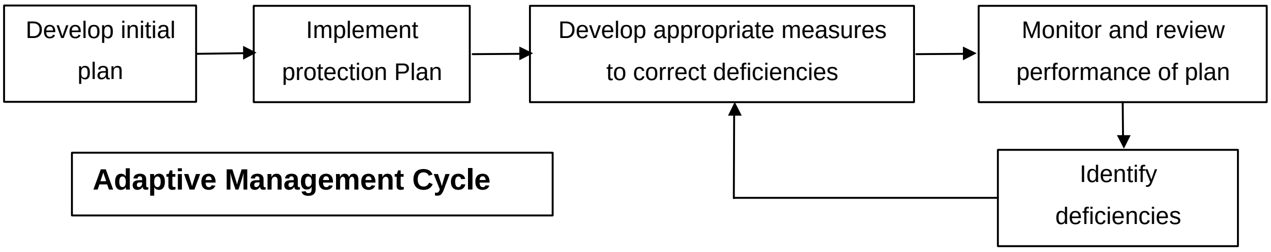
The introduction of new industries into the Estate raises the potential for contamination of the superficial groundwater aquifer from industrial activities. The eastern side of the Estate is particularly vulnerable to groundwater contamination due to a combination of shallow depth to groundwater and sandy soils. Contamination which reaches the water table has the potential to flow east to key wetlands and the Wellesley River, and west to the ocean via Myalup lake, Mialla Lagoon and Leschenault Inlet. The presence of salt contamination at Nufarm-Coogee demonstrates the potential for contamination to occur in shallow groundwater areas.

Industries with a higher potential for groundwater contamination should preferentially be located in areas with the greatest separation from the groundwater. The Spearwood soils of the ridge line is also more adsorptive than the Bassendean sand of the lowlands, and are therefore generally more suitable for industries producing many potential contaminants (BBG-Rockwater, 1998).

In areas that are contaminated, or contain potential contaminant sources, pollution control devices such as oil separators and other Best Management Practices (BMPs) should be placed at the source of the pollutant. BMPs are described in the WRC publication "A Manual for Managing Urban Stormwater Quality in Western Australia" and in other guidelines such as the WRC Water Quality Protection Note "Industrial Sites Near Sensitive Water Resources".

Potential contamination and subsequent remediation issues relating to industry specific contaminants should be addressed in a Contamination Management Plan (CMP), to be prepared by each industry. The level of detail required in the CMP is directly related to the risk of potential groundwater contamination from industrial activities. The CMP should outline potential sources of contamination and identify appropriate monitoring and contingency plans. Contingency measures may vary from simply doing nothing, to ceasing the contaminating activity, through to containing the area of contamination and clean-up action (NWQMS, 1995b). The CMP must be regularly updated through a process of Adaptive Management to reflect results of monitoring and changing industrial activities on the site.

The Adaptive Management Cycle (NWQMS, 1995b) is shown schematically below.



Potential sources of contamination will be licensed and regulated by the Department of Environmental Protection (or the new agency: Department of Environment, Water and Catchment Protection). Specific horticultural activities involving the use of pesticides and chemicals would involve some regulatory or advisory role from the Department of Agriculture.

In cases where there is a potential risk of groundwater contamination, the CMP should outline a superficial groundwater monitoring network which is to be sampled and analysed quarterly for a suite of parameters relevant to the industrial operation. This is likely to include water quality parameters, total petroleum hydrocarbons (TPH), heavy metals, BTEX and PAH compounds.

A summary of potential contaminants related to different industries is presented in Table 10.9 (after NWQMS, 1995b). Appendix H presents a detailed register of types and sources of contamination that can potentially contaminate groundwater and surface water (WRC, 1996) and a list of priority contaminants in industrial waste streams (NWQMS, 1995b). The monitoring bores should be sampled for these parameters prior to establishment of industry to allow for a baseline concentration to be set.

Table 10.9
Potential Contaminants from Industries

Industry	Activity	Contaminants
Water and Wastewater	Treatment plant floc, sewerage sludge landfill, wastewater land spreading, septic tank effluent, lagoons	Heavy metals, high organics, nutrients (P, K, N), faecal bacteria, viruses, protozoa
Solid Waste Disposal	Municipal landfill, industrial landfill	Sulphate, chloride, ammonia, TOC, high TDS, biological contaminants, fatty acids, leachates
Waste Treatment Disposal Industry	Storage of hazardous waste, waste handling	A range of mainly hazardous contaminants (refer to priority contaminant list - Appendix H)
Transport Industry	Storage of hazardous materials, fuel storage, oil and grease discharge, accidental spills	Petroleum hydrocarbons, benzene, ethylbenzene and other priority contaminants (Appendix H)
Fire Fighting	Disposal/seepage of contaminated fire fighting water	Hazardous contaminants derived from industrial fire and fire fighting water
Agriculture and Agribusiness	Cropping practices, dairies and feedlots	Pesticides, herbicides, nitrates, TDS, heavy metals, high nitrogen and phosphorus loads, biological contaminants
Electricity Generation	Fly ash ponds and landfill, waste briquettes, tars	Sulphate, heavy metals, TDS, Se, Ge, petroleum hydrocarbons, PAH
Town Gas Production	Coal tar disposal, gas scrubber waste disposal	Petroleum hydrocarbons, PAH, BTEX, phenols, sulphur compounds, cyanide, ammonia, heavy metals
Chemical and Petroleum	Hydrocarbon storage, hazardous material process, wastewater lagoons and storage, solid waste landfills, accidental spills	Petroleum hydrocarbons, PAH, BTEX, vanadium pentoxide
Mining and Mineral Industries	Mine water disposal, storage of fuel and hazardous chemicals, tailings dams, heap leaching	High TDS, iron, sulphate, heavy metals, organic flocculants, mercury cyanide, vanadium pentoxide, acidic water, petroleum hydrocarbons and hazardous materials
Manufacturing Industry	Food processing Pulp and paper manufacturing	Nutrients, nitrogen, K, P, TDS Organics such as lignins, organochlorins, sulphites, organosulphur
	Automotive industry Paint and printing Metal foundries, machinery plating and fabrication Timber mills and preserving tanneries	Organic solvents, petroleum hydrocarbons Organic solvents, resin making compounds, heavy metals Petroleum hydrocarbons, phenols, BTEX, heavy metals, cyanide, furans, organic solvents Tannins, arsenic, chromium, cresols, phenols, pesticide compounds, nutrients, sulphides, TDS, chromium
	Coke and steel manufacture	Metals, petroleum hydrocarbons

Strategies and management plans shall be developed by individual industries to deal with accidental spillages which may pose a threat to the quality of a nearby water resource. In particular, hydrocarbon storage tanks and fuelling stations will need to be bunded to contain any potential spillages. In the event of a spillage, the contaminated soil should be removed and disposed of at the regional landfill site. The WRC requires the clean up of contaminated soil where it poses a threat to water quality and may potentially affect the beneficial use of the resource. The clean up of contaminated water is also required where it is considered to pose a threat to human health and the beneficial use of the resources (WRC, 1996).

A groundwater investigation should also be undertaken to assess whether any contamination has reached the local water table and if so, the extent and nature of the contamination. In the event of groundwater contamination, a remediation programme will need to be prepared in coordination with the Department of Environmental Protection and the Water and Rivers Commission (or the new agency: Department of Environment, Water and Catchment Protection).

10.11 COMPLIANCE REPORTING

The reporting requirements of the industry will largely be dependent on the nature of the operation and licences held with the regulating authorities. Baseline monitoring should also form part of the licence requirements, to be specified by the relevant agencies. As indicated above, the level of monitoring is largely proportional to the level of risk posed to water resources. A summary of likely reporting requirements is presented in Table 10.10. The results of all monitoring and interpretation of the results should be submitted to the regulating authority in accordance with their guidelines (eg. the new agency: Department of Environment, Water and Catchment Protection or DEWCP).

Table 10.10
Compliance Reporting Requirements

Activity	Regulating Authority	Reporting Requirements
Groundwater Abstraction	Water and Rivers Commission (or the new DEWCP)	Annual Production Summary and Triennial Aquifer Review - report prepared by a qualified hydrogeologist summarising annual abstraction, water level and water quality, and comments on the impacts of current abstraction and condition of the aquifer.
Discharge of Waste and Pollution Control	Department of Environmental Protection (or the new DEWCP)	Annual Report - report which includes an analysis of environmental performance against agreed objectives and targets; progress with implementation of environmental improvement plans and summary and interpretation of monitoring results, including an annual water balance for the site. Reporting of incidents within 24hrs. The frequency of reporting may be increased (eg. quarterly) at the discretion of the DEP. A range of activities for various industries will require a DEP licence.

Note: Compliance reporting is not limited to the above, which focuses on water-related issues. A monitoring and reporting standard must be agreed with relevant regulatory agencies prior to operation.

10.12 ENVIRONMENTAL AUDITING

It is recommended that an external environmental audit be conducted at least once every three years. The audit team shall include one or more persons who are (DEP, 1998):

- Independent of the company being audited;
- Professional environmental auditors (people registered under QSA environmental auditor certification scheme would form the benchmark of required qualifications and experience); and
- Knowledgeable regarding those operations of the industry, which could have implications for the environment.

It is also recommended that the audit process and team be agreed between the licensee and the DEP (or the new agency: Department of Environment, Water and Catchment Protection). The independent auditor shall be responsible for verifying that the audit was carried out in accordance with the agreed process and the audit report is a true and fair representation of the findings (DEP, 1998). An internal environmental audit should also be completed annually to ensure compliance with environmental commitments and management plans.

The external and internal audits should also incorporate a 'water' theme, whereby the efficient and appropriate use of water resources is assessed. This will include review of an annual water balance prepared for each site, accounting for inputs, losses and transfers between different parts of the operation.

10.13 ADAPTIVE MANAGEMENT

A water management strategy has been developed for the Kemerton Industrial Estate to address water supply, drainage management and Environmental Water Provisions (EWPs) for groundwater dependent ecosystems. It is important that the strategy be adaptive, with periodic reviews allowing opportunities to adjust groundwater allocations and EWPs. It is recommended that this management strategy be reviewed after two years in operation. The review process should be participatory, involving both technical specialists and stakeholder representatives, and should include (after EA, 2001):

- An evaluation of the outcomes of environmental monitoring and any new research relating to ecosystem groundwater dependency and ecosystem response to changed water regimes;
- A review of the monitoring programmes in place with recommendations for improvement where appropriate;
- Further studies to address priority knowledge gaps and/or issues raised by environmental monitoring or new resource use developments; and
- Implementation of changes to groundwater allocation and/or EWPs that may be considered necessary.

This study has addressed in detail the Environmental Water Requirements (EWRs) of the ecosystem allowing a reasonable degree of certainty in relation to setting groundwater allocations to support large infrastructure investments. However, the implementation of changes to allocations and/or EWRs/EWPs may be required under circumstances where:

- The environmental condition of dependent ecosystems has declined to a greater level than expected under the EWP regime;
- Monitoring or research has demonstrated that dependent ecosystems are more resilient to changes in water regime than originally thought;
- The environmental significance of the ecosystem is greater than originally thought and the relative priorities between environmental and non-environmental uses has changed.

SECTION 11 - REFERENCES (ALPHABETICAL)

Anderson M.P. and Woessner W.W., 1992. Applied Groundwater Modelling - Simulation of Flow and Advective Transport. Academic Press.

AGC, 1987. Kemerton Water Supply Investigatory Production Bores, prepared by Australian Groundwater Consultants Pty Ltd for SCM Chemicals Ltd, Rep 2043/0.

AGC Woodward-Clyde, 1993. Kemerton Industrial Park Environmental Hydrogeology, prepared for LandCorp (unpublished).

AGC Woodward-Clyde, 1994. Kemerton Industrial Park - Monitoring Well Installation and Baseline Monitoring, Project No. 2652/1, prepared for LandCorp (unpublished).

AGC Woodward-Clyde, 1995. Kemerton Industrial Park - Groundwater Monitoring Annual Review (April 1994 - March 1995), Project No. 2652/1, prepared for LandCorp (unpublished).

AGC Woodward-Clyde, 1996a. Kemerton Industrial Park - Groundwater Monitoring Review (April 1994 - March 1996), Project No. 2652/1, prepared for LandCorp (unpublished).

AGC Woodward-Clyde, 1996b. Water Resource Management Plan - Alkimos Eglinton.

ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality - Aquatic Ecosystems (Volume 2), National Water Quality Management Strategy.

Aquaterra, 2000. Groundwater Flow Modelling Guidelines. Report to Murray-Darling Basin Commission by Aquaterra (ver. I, Dec., 2000).

Aquaterra, 2001. Kemerton Water Study Phase 2. Model Inception Report. Report to LandCorp, DRD, and WRC by Aquaterra.

ARMCANZ, 1996. National Principles for the Provision of Water for Ecosystems. Occasional Paper #3, Task Force on Water Reform, Commonwealth of Australia.

AS 5667.1, 1998. Australian/New Zealand Standard: Water Quality Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples.

AS 5667.11, 1998. Australian/New Zealand Standard: Water Quality Sampling, Part 11: Guidance on sampling of groundwaters.

BBG-Rockwater, 1999. Kemerton Water Study - Phase 1. Prepared by Bowman Bishaw Gorham and Rockwater Pty Ltd for LandCorp, Department of Resources Development, Water and Rivers Commission and Water Corporation.

BHP Engineering, 1992. Kemerton Industrial Park Future Water Supply Options - Preliminary Environmental Review, prepared for the Water Authority of Western Australia.

BSD, 1997, Kemerton Expansion Study - Final Draft Report, Volumes 1 & 2, prepared for Department of Resources Development, LandCorp, Western Australian Planning Commission and South West Development Corporation, BSD Consultants Pty Ltd.

Burns and Roe Worley Pty Ltd, 1998. Industrial Water Supply and Wastewater Management for the Kemerton Industrial Park, prepared for Department of Resources Development (unpublished).

Chiang W.H. and Kinzelbach W., 1999. Processing Modflow for Windows (PMWin Version 5.0.9 to 5.1.7).

Commander, D.P., 1988. Geology and Hydrogeology of the superficial Formations and Coastal Lakes Between Harvey and Leschenault Inlets (Lake Clifton Project), Geological Survey of Western Australia, pp 37-50, Professional Papers Report 23.

Commander, D.P., 1989. Results of Exploratory Drilling in the Kemerton Area, Geological Survey of Western Australia, Hydrogeology Report No. 1989/39.

Davidson, W.A., 1995. Hydrogeology and Groundwater Resources of the Perth Region, Western Australia, Western Australia Geological Survey, Bulletin 142.

Deeney, A.C., 1989a. Hydrogeology of the Binningup Borehole Line, Perth Basin, Geological Survey of Western Australia, pp 7 - 16, Professional Papers Report 25.

Deeney, A.C., 1989b. Geology and Groundwater Resources of the superficial formations Between Pinjarra and Bunbury, Perth Basin, Geological Survey of Western Australia, pp31 - 56, Professional Papers Report 26.

DEP, 1998. Best Practice Environmental Licences, Department of Environmental Protection, Perth, Western Australia, June 1998.

Dillon, P. & Pavelic, P., 1996. Guidelines on the Quality of Stormwater and Treated Wastewater for Injection into Aquifers for Storage and Reuse, Urban Water Research Association of Australia and Centre for Groundwater Studies, Research Report No 109.

Dillon, P., 1999. Environmental Values of Aquifers, in Short Course on Aquifer Storage and Recovery, Adelaide, Centre for Groundwater Studies.

Dillon, P., Harvey, D., Sibenaler, Z., Cugley, J. & Reed, J., 1999. Guidelines for Aquifer Storage and Recovery of Surface Water in South Australia, Artificial Recharge Coordinating Committee of SA (Draft).

Dodd, J., Heddle, E.M., Pate, J.S. & Dixon, K.W., 1984. Rooting patterns of sandplain plants and their functional significance. In: Kwongan: Plant Life of the Sandplain (eds J S Pate and J S Beard) University of Western Australia Press, Perth, 146-177.

Edmett, S., pers.comm., 2001 - Steve Edmett, Australian Environmental Laboratories Client Liaison Manager.

English, V and Blyth, J. 1997. Identifying and Conserving Threatened Ecological Communities in the South West Botanical Province. Project No. 702. Final Report to Environment Australia.

Environmental Protection Authority, 1993. A Guide to Wetland Management in the Perth and near Perth Swan Coastal Plain Area: An Update to Bulletin 374. Bulletin 686.

Froend, R.H., Farrell, R.C.C., Wilkins, C.F., Wilson, C.C. & McComb, A.J., 1993. Wetlands of the Swan Coastal Plain. The Effect of Altered Water Regimes on Wetland Plants. Volume 4. Water Authority of Western Australia and the Environmental Protection Authority, Perth.

Gerges, N.Z., 1999. Aquifer Storage and Recovery - Type and Selection of Aquifer, in Short Course on Aquifer Storage and Recovery, Adelaide, Centre for Groundwater Studies.

Gibson, N., Keighery, B., Keighery, G., Burbidge, A., and Lyons, M. 1994. A Floristic Survey of the Southern Swan Coastal Plain. Unpubl. Report to the Australian Heritage Commission.

Golowyn, G., pers.comm. 2001 - George Golowyn, Water Corporation Project Manager for Kemerton Estate Wastewater Treatment Plant.

Groom, P.K., Froend, R.H., Mattiske, E.M. & Koch, B., 2000b. Myrtaceous shrub species respond to long-term decreasing groundwater levels on the Gnangara Groundwater Mound, northern Swan Coastal Plain. *Journal of the Royal Society of Western Australia* **83,** 75-82.

Groom, P.K., Froend, R.H. and Mattiske, E.M., 2000a. Impact of groundwater abstraction on a Banksia woodland, Swan Coastal Plain, Western Australia. *Ecological Management and Restoration* **1,** 117-124.

Groom, P., pers. comm., 2001 - Phillip Groom, School and natural Sciences, Edith Cowan University, Joondalup.

GSWA, 1981. Urban Geology of Harvey - Lake Preston, parts of 1:50,000 sheets 2031 I and 2031 IV, Geological Survey of Western Australia.

GSWA, 1982. Urban Geology of Bunbury - Burekup, parts of 1:50,000 sheets 2031 III and 2031 II, Geological Survey of Western Australia.

Hatton and Evans, 1998. Dependence of Ecosystems on Groundwater and its Significance to Australia, Occasional Paper No 12/98, Land and Water Resources Research and Development Corporation.

Heddle, E.M., Loneragan, O.W. and Havel, J.J. 1980. Vegetation of the Darling System,. In: Atlas of Natural Resources, Darling System, Western Australia Department of Conservation and Environment, Perth, Western Australia.

Hill, A.L., Semeniuk, C.A., Semeniuk, V. & Del Marco, A., 1996. *Wetlands of the Swan Coastal Plain - Wetland Mapping, Classification and Evaluation*; Water and Rivers Commission and Department of Environmental Protection.

Hounslow, A.W., 1995. Water Quality Data Analysis and Interpretation, CRC Press Inc.

Hughes, G., pers.comm., 2001 - Graham Hughes, Water Corporation, Western Australia.

KSS, 2000. Annual Environmental Report, 2000, Kemerton Silica Sands.

LWRRDC, 1996a. Land Based Ecosystems - Riparian Management 5, Land and Water Resources Research and Development Corporation.

LWRRDC, 1996b. Streambank Stability - Riparian Management 2, Land and Water Resources Research and Development Corporation.

LWRRDC, 1996c. Managing Stock - Riparian Management 6, Land and Water Resources Research and Development Corporation.

Mattiske and Associates 1993. Gwalia Consolidated Limited - Kemerton Sand Project: Flora and Vegetation Studies. Fore John Consulting Services.

McDonald, M.G. and Harbaugh, A.W., 1988. A modular three-dimensional finite-difference ground-water flow model. USGS Techniques of Water Resources Investigations, Book 6, Chapter A1. Washington DC.

MIC, 2000a. Kemerton Shallow Groundwater Assessment, Millennium Inorganic Chemicals Pty Ltd, Environmental Department.

MIC, 2000b. Kemerton Aquifer Review, Millennium Inorganic Chemicals Pty Ltd, Environmental Department.

Middlemis, H., Merrick, N.P., Ross, J.B. and Rozlapa, K, 2000. The Development of Australian Guidelines for Groundwater Flow Modelling. Proceedings of Hydro2000, International Hydrology and Water Resources Symposium, Perth, November 2000. The Institution of Engineers, Australia.

Muir Environmental 1999. Report of Biological Survey - Phase 1: Kemerton Industrial Estate. For LandCorp

NWQMS, 1995a. Draft Guidelines for the Use of Reclaimed Water, National Water Quality Management Strategy, ARMCANZ and ANZECC, April 1995.

NWQMS, 1995b. Guidelines for Groundwater Protection in Australia, National Water Quality Management Strategy, ARMCANZ and ANZECC, September 1995.

Patt, M., pers. Comm.., 2001 - Melissa Patt, Water and Rivers Commission

Rockwater, 1996. Report on Cockleshell Gully Formation Test Bore Drilling and Conceptual Borefield Design, Rockwater Pty Ltd for SCM Chemicals Ltd, Kemerton Plant.

Rockwater, 1998. Numerical Groundwater Model, Kemerton-Bunbury Region Interim Report, produced for Water Corporation, October, 1998 by Rockwater Pty Ltd.

Ruprecht, J., pers.comm., 2001 - John Ruprecht, Water and Rivers Commission, Western Australia.

Rust PPK, 1996. Kemerton Industrial Park Water Supply - Foundation Planning Information, prepared for the Office of Water Regulation.

Scatena, M.C. & Williamson, D.R., 1999. A Potential Role For Artificial Recharge In The Perth Region: A Pre-Feasibility Study, Centre for Groundwater Studies Report No. 84.

Semeniuk, C.A. 1987. Wetlands of the Darling System - A Geomorphic Approach to Habitat Classification. J. Roy. Soc. Aus. 69:95-111.

Simcoa, 1988, Barrack Silicon Smelter Pollution Control, Kemerton, April 1988, Barrack Silicon Pty Ltd.

Simcoa, 1991. Wastewater Management Plan, June 1991, Simcoa Operations Pty Ltd.

Simcoa, 1996. Environmental Monitoring and Management Plan, May 1996, Simcoa Operations Pty Ltd.

Simcoa, 1999. Annual Environmental Report, 1999, Simcoa Operations Pty Ltd.

Simcoa, 2000. Annual Environmental Report, 2000, Simcoa Operations Pty Ltd.

Trayler, K., pers. Comm., 2001 - Kerry Trayler, Water and Rivers Commission

WAPC, 2000. Industry 2030 - Greater Bunbury Industrial Land and Port Access Planning, Western Australian Planning Commission, April 2000.

Warton, P.H., 1979. The Geology and Hydrogeology of the Picton Borehole Line, Geological Survey Western Australia (GSWA) Annual Report Professional Papers.

WAWA, 1989. South West Coastal Groundwater Area Groundwater Management Review, Water Authority of Western Australia, Report No. WG 84.

WAWA, 1992. Gnangara Mound Vegetation Stress Study. WAMA Report No. 127, February 1992, Water Authority of Western Australia.

WAWA, 1994. Bunbury Groundwater Area Groundwater Management Plan, Water Authority of Western Australia.

WAWA, 1995. Review of Proposed Changes to Environmental Conditions. Gnangara Mound Groundwater Resources (Section 46) Perth, WA, Water Authority of Western Australia.

Welker Environmental Consultancy and Streamtec Pty Ltd. 2000. Environmental Water Requirements Study: Harris River and East Branch of the Collie River to the South Branch. Prepared for the Water Corporation.

WRC, 1996. Draft Policy and Principles - Protection of Waters from Pollution in Western Australia, Water and Rivers Commission.

WRC, 1997. East Gnangara Environmental Water Provisions Plan: Public Environmental Review, Water and Rivers Commission.

WRC, 2000a. Environmental Water Provisions Policy for Western Australia, Water and Rivers Commission, Statewide Policy No. 5.

WRC, 2000b. Interim Policy on Accessing the Leederville and Yarragadee Aquifers in Perth, Water and Rivers Commission.

WRC, 2000c. Theme 7 - Waterway, Estuarine, Catchment and Landscape Health: Project 1 - Status and Trend in Surface Water Quality (Summary Report), Water and Rivers Commission and Land and Water Resources Research and Development Corporation.

WRC, 2001. Water Quality in the Leschenault Estuary and Catchment 1995 - 1999, South West Info, Leschenault Inlet Management Authority, Water and Rivers Commission, January 2001.

Warton, P.H., 1979. The Geology and Hydrogeology of the Picton Borehole Line, Geological Survey Western Australia (GSWA) Annual Report Professional Papers.

Heddle, E.M., Loneragan, O.W. and Havel, J.J. 1980. Vegetation of the Darling System,. In: Atlas of Natural Resources, Darling System, Western Australia Department of Conservation and Environment, Perth, Western Australia.

GSWA, 1981. Urban Geology of Harvey - Lake Preston, parts of 1:50,000 sheets 2031 I and 2031 IV, Geological Survey of Western Australia.

GSWA, 1982. Urban Geology of Bunbury - Burekup, parts of 1:50,000 sheets 2031 III and 2031 II, Geological Survey of Western Australia.

Dodd, J., Heddle, E.M., Pate, J.S. & Dixon, K.W., 1984. Rooting patterns of sandplain plants and their functional significance. In: Kwongan: Plant Life of the Sandplain (eds J S Pate and J S Beard) University of Western Australia Press, Perth, 146-177.

AGC, 1987. Kemerton Water Supply Investigatory Production Bores, prepared by Australian Groundwater Consultants Pty Ltd for SCM Chemicals Ltd, Rep 2043/0.

Semeniuk, C.A. 1987. Wetlands of the Darling System - A Geomorphic Approach to Habitat Classification. J. Roy. Soc. Aus. 69:95-111.

Commander, D.P., 1988. Geology and Hydrogeology of the superficial Formations and Coastal Lakes Between Harvey and Leschenault Inlets (Lake Clifton Project), Geological Survey of Western Australia, pp 37-50, Professional Papers Report 23.

McDonald, M.G. and Harbaugh, A.W., 1988. A modular three-dimensional finite-difference ground-water flow model. USGS Techniques of Water Resources Investigations, Book 6, Chapter A1. Washington DC.

Simcoa, 1988, Barrack Silicon Smelter Pollution Control, Kemerton, April 1988, Barrack Silicon Pty Ltd.

Commander, D.P., 1989. Results of Exploratory Drilling in the Kemerton Area, Geological Survey of Western Australia, Hydrogeology Report No. 1989/39.

Deeney, A.C., 1989a. Hydrogeology of the Binningup Borehole Line, Perth Basin, Geological Survey of Western Australia, pp 7 - 16, Professional Papers Report 25.

Deeney, A.C., 1989b. Geology and Groundwater Resources of the superficial formations Between Pinjarra and Bunbury, Perth Basin, Geological Survey of Western Australia, pp31 - 56, Professional Papers Report 26.

WAWA, 1989. South West Coastal Groundwater Area Groundwater Management Review, Water Authority of Western Australia, Report No. WG 84.

Simcoa, 1991. Wastewater Management Plan, June 1991, Simcoa Operations Pty Ltd.

Anderson M.P. and Woessner W.W., 1992. Applied Groundwater Modelling - Simulation of Flow and Advective Transport. Academic Press.

BHP Engineering, 1992. Kemerton Industrial Park Future Water Supply Options - Preliminary Environmental Review, prepared for the Water Authority of Western Australia. AGC Woodward-Clyde, 1993. Kemerton Industrial Park Environmental Hydrogeology, prepared for LandCorp (unpublished).

WAWA, 1992. Gnangara Mound Vegetation Stress Study. WAMA Report No. 127, February 1992, Water Authority of Western Australia.

Environmental Protection Authority, 1993. A Guide to Wetland Management in the Perth and near Perth Swan Coastal Plain Area: An Update to Bulletin 374. Bulletin 686.

Froend, R.H., Farrell, R.C.C., Wilkins, C.F., Wilson, C.C. & McComb, A.J., 1993. Wetlands of the Swan Coastal Plain. The Effect of Altered Water Regimes on Wetland Plants. Volume 4. Water Authority of Western Australia and the Environmental Protection Authority, Perth.

Mattiske and Associates 1993. Gwalia Consolidated Limited - Kemerton Sand Project: Flora and Vegetation Studies. Fore John Consulting Services.

AGC Woodward-Clyde, 1994. Kemerton Industrial Park - Monitoring Well Installation and Baseline Monitoring, Project No. 2652/1, prepared for LandCorp (unpublished).

Gibson, N., Keighery, B., Keighery, G., Burbidge, A., and Lyons, M. 1994. A Floristic Survey of the Southern Swan Coastal Plain. Unpubl. Report to the Australian Heritage Commission.

WAWA, 1994. Bunbury Groundwater Area Groundwater Management Plan, Water Authority of Western Australia.

AGC Woodward-Clyde, 1995. Kemerton Industrial Park - Groundwater Monitoring Annual Review (April 1994 - March 1995), Project No. 2652/1, prepared for LandCorp (unpublished).

Davidson, W.A., 1995. Hydrogeology and Groundwater Resources of the Perth Region, Western Australia, Western Australia Geological Survey, Bulletin 142.

Hounslow, A.W., 1995. Water Quality Data Analysis and Interpretation, CRC Press Inc.

NWQMS, 1995a. Draft Guidelines for the Use of Reclaimed Water, National Water Quality Management Strategy, ARMCANZ and ANZECC, April 1995.

NWQMS, 1995b. Guidelines for Groundwater Protection in Australia, National Water Quality Management Strategy, ARMCANZ and ANZECC, September 1995.

WAWA, 1995. Review of Proposed Changes to Environmental Conditions. Gnangara Mound Groundwater Resources (Section 46) Perth, WA, Water Authority of Western Australia.

AGC Woodward-Clyde, 1996a. Kemerton Industrial Park - Groundwater Monitoring Review (April 1994 - March 1996), Project No. 2652/1, prepared for LandCorp (unpublished).

AGC Woodward-Clyde, 1996b. Water Resource Management Plan - Alkimos Eglinton.

ARMCANZ, 1996. National Principles for the Provision of Water for Ecosystems. Occasional Paper #3, Task Force on Water Reform, Commonwealth of Australia.

Dillon, P. & Pavelic, P., 1996. Guidelines on the Quality of Stormwater and Treated Wastewater for Injection into Aquifers for Storage and Reuse, Urban Water Research Association of Australia and Centre for Groundwater Studies, Research Report No 109.

Hill, A.L., Semeniuk, C.A., Semeniuk, V. & Del Marco, A., 1996. *Wetlands of the Swan Coastal Plain - Wetland Mapping, Classification and Evaluation*; Water and Rivers Commission and Department of Environmental Protection.

LWRRDC, 1996a. Land Based Ecosystems - Riparian Management 5, Land and Water Resources Research and Development Corporation.

LWRRDC, 1996b. Streambank Stability - Riparian Management 2, Land and Water Resources Research and Development Corporation.

LWRRDC, 1996c. Managing Stock - Riparian Management 6, Land and Water Resources Research and Development Corporation.

Rockwater, 1996. Report on Cockleshell Gully Formation Test Bore Drilling and Conceptual Borefield Design, Rockwater Pty Ltd for SCM Chemicals Ltd, Kemerton Plant.

Rust PPK, 1996. Kemerton Industrial Park Water Supply - Foundation Planning Information, prepared for the Office of Water Regulation.

Simcoa, 1996. Environmental Monitoring and Management Plan, May 1996, Simcoa Operations Pty Ltd.

WRC, 1996. Draft Policy and Principles - Protection of Waters from Pollution in Western Australia, Water and Rivers Commission.

BSD, 1997, Kemerton Expansion Study - Final Draft Report, Volumes 1 & 2, prepared for Department of Resources Development, LandCorp, Western Australian Planning Commission and South West Development Corporation, BSD Consultants Pty Ltd.

English, V and Blyth, J. 1997. Identifying and Conserving Threatened Ecological Communities in the South West Botanical Province. Project No. 702. Final Report to Environment Australia.

WRC, 1997. East Gnangara Environmental Water Provisions Plan: Public Environmental Review, Water and Rivers Commission.

AS 5667.1, 1998. Australian/New Zealand Standard: Water Quality Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples.

AS 5667.11, 1998. Australian/New Zealand Standard: Water Quality Sampling, Part 11: Guidance on sampling of groundwaters.

Burns and Roe Worley Pty Ltd, 1998. Industrial Water Supply and Wastewater Management for the Kemerton Industrial Park, prepared for Department of Resources Development (unpublished).

DEP, 1998. Best Practice Environmental Licences, Department of Environmental Protection, Perth, Western Australia, June 1998.

Hatton and Evans, 1998. Dependence of Ecosystems on Groundwater and its Significance to Australia, Occasional Paper No 12/98, Land and Water Resources Research and Development Corporation.

Rockwater, 1998. Numerical Groundwater Model, Kemerton-Bunbury Region Interim Report, produced for Water Corporation, October, 1998 by Rockwater Pty Ltd.

BBG-Rockwater, 1999. Kemerton Water Study - Phase 1. Prepared by Bowman Bishaw Gorham and Rockwater Pty Ltd for LandCorp, Department of Resources Development, Water and Rivers Commission and Water Corporation.

Chiang W.H. and Kinzelbach W., 1999. Processing Modflow for Windows (PMWin Version 5.0.9 to 5.1.7).

Gerges, N.Z., 1999. Aquifer Storage and Recovery - Type and Selection of Aquifer, in Short Course on Aquifer Storage and Recovery, Adelaide, Centre for Groundwater Studies.

Dillon, P., 1999. Environmental Values of Aquifers, in Short Course on Aquifer Storage and Recovery, Adelaide, Centre for Groundwater Studies.

Dillon, P., Harvey, D., Sibenaler, Z., Cugley, J. & Reed, J., 1999. Guidelines for Aquifer Storage and Recovery of Surface Water in South Australia, Artificial Recharge Coordinating Committee of SA (Draft).

Muir Environmental 1999. Report of Biological Survey - Phase 1: Kemerton Industrial Estate. For LandCorp

Scatena, M.C. & Williamson, D.R., 1999. A Potential Role For Artificial Recharge In The Perth Region: A Pre-Feasibility Study, Centre for Groundwater Studies Report No. 84.

Simcoa, 1999. Annual Environmental Report, 1999, Simcoa Operations Pty Ltd.

ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality - Aquatic Ecosystems (Volume 2), National Water Quality Management Strategy.

Aquaterra, 2000. Groundwater Flow Modelling Guidelines. Report to Murray-Darling Basin Commission by Aquaterra (ver. I, Dec., 2000).

Groom, P.K., Froend, R.H., Mattiske, E.M. & Koch, B., 2000b. Myrtaceous shrub species respond to long-term decreasing groundwater levels on the Gnangara Groundwater Mound, northern Swan Coastal Plain. *Journal of the Royal Society of Western Australia* **83,** 75-82.

Groom, P.K., Froend, R.H. and Mattiske, E.M., 2000a. Impact of groundwater abstraction on a Banksia woodland, Swan Coastal Plain, Western Australia. *Ecological Management and Restoration* **1,** 117-124.

KSS, 2000. Annual Environmental Report, 2000, Kemerton Silica Sands.

MIC, 2000a. Kemerton Shallow Groundwater Assessment, Millennium Inorganic Chemicals Pty Ltd, Environmental Department.

MIC, 2000b. Kemerton Aquifer Review, Millennium Inorganic Chemicals Pty Ltd, Environmental Department.

Middlemis, H., Merrick, N.P., Ross, J.B. and Rozlapa, K, 2000. The Development of Australian Guidelines for Groundwater Flow Modelling. Proceedings of Hydro2000, International Hydrology and Water Resources Symposium, Perth, November 2000. The Institution of Engineers, Australia.

Simcoa, 2000. Annual Environmental Report, 2000, Simcoa Operations Pty Ltd.

WAPC, 2000. Industry 2030 - Greater Bunbury Industrial Land and Port Access Planning, Western Australian Planning Commission, April 2000.

Welker Environmental Consultancy and Streamtec Pty Ltd. 2000. Environmental Water Requirements Study: Harris River and East Branch of the Collie River to the South Branch. Prepared for the Water Corporation.

WRC, 2000a. Environmental Water Provisions Policy for Western Australia, Water and Rivers Commission, Statewide Policy No. 5.

WRC, 2000b. Interim Policy on Accessing the Leederville and Yarragadee Aquifers in Perth, Water and Rivers Commission.

WRC, 2000c. Theme 7 - Waterway, Estuarine, Catchment and Landscape Health: Project 1 - Status and Trend in Surface Water Quality (Summary Report), Water and Rivers Commission and Land and Water Resources Research and Development Corporation.

Aquaterra, 2001. Kemerton Water Study Phase 2. Model Inception Report. Report to LandCorp, DRD, and WRC by Aquaterra.

Edmett, S., pers.comm., 2001 - Steve Edmett, Australian Environmental Laboratories Client Liaison Manager.

Froend, R.H. & Zencich, S., 2001. Phreatophytic Vegetation and Groundwater Study - Phase 1, Phreatophytic Vegetation Research Review, Edith Cowan University, Western Australia.

Golowyn, G., pers.comm. 2001 - George Golowyn, Water Corporation Project Manager for Kemerton Estate Wastewater Treatment Plant.

Groom, P., pers. comm., 2001 - Phillip Groom, School and natural Sciences, Edith Cowan University, Joondalup.

Hughes, G., pers.comm., 2001 - Graham Hughes, Water Corporation, Western Australia.

Patt, M., pers. Comm.., 2001 - Melissa Patt, Water and Rivers Commission

Ruprecht, J., pers.comm., 2001 - John Ruprecht, Water and Rivers Commission, Western Australia.

Trayler, K., pers. Comm., 2001 - Kerry Trayler, Water and Rivers Commission

WRC, 2001. Water Quality in the Leschenault Estuary and Catchment 1995 - 1999, South West Info, Leschenault Inlet Management Authority, Water and Rivers Commission, January 2001.

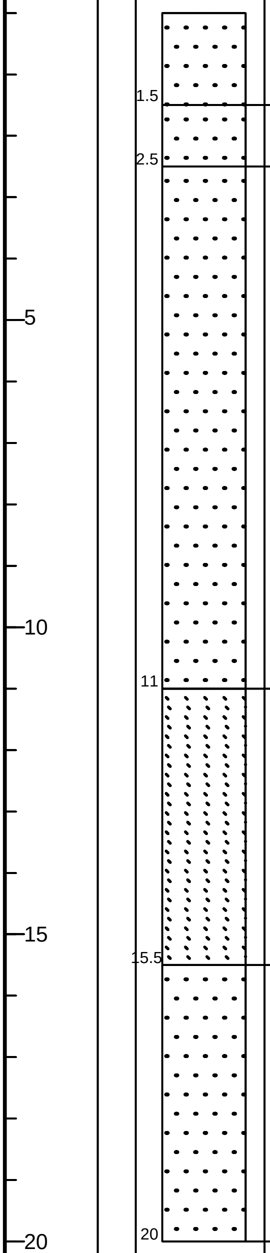
APPENDIX A

SUPERFICIAL AQUIFER BOREHOLE LOGS

BORELOG

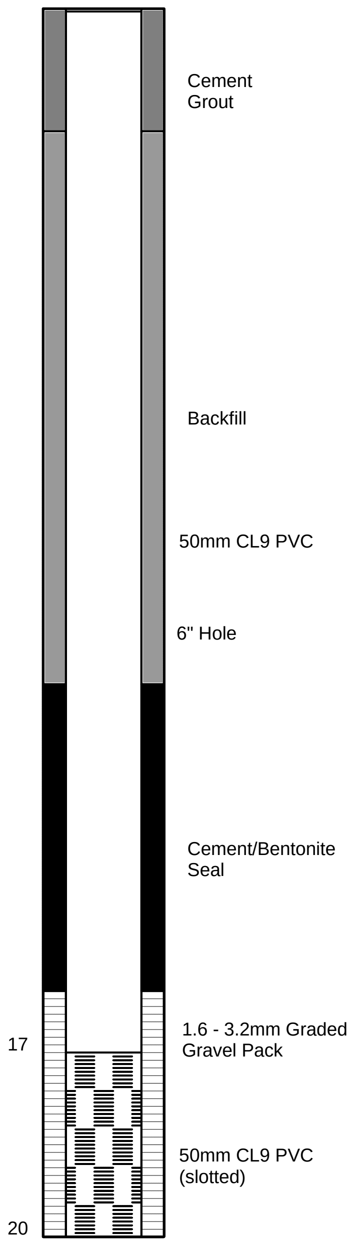
CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS1D



DEPTH (mbgl)	LITHOLOGICAL DESCRIPTION	FIELD NOTES
0 - 1.5	SAND: Grey, fine to medium grained quartz, some organic material, poorly sorted, sub angular.	
1.5 - 2.5	SAND: Brown, medium to coarse grained quartz, moderately cemented (Coffee Rock), poorly sorted.	
2.5 - 11	SAND: Light brown, fine to medium grained, minor silt horizons throughout and chips of well indurated dark brown coffee rock, poorly sorted, sub angular.	
11 - 15.5	SILTY SAND: Light brown fine to medium grained quartz sand with large amounts of silty clay in some areas, thin layers of well cemented coffee rock throughout, poorly sorted.	
15.5 - 20	SAND: Grey/brown, fine to medium grained quartz, poorly sorted, sub angular to sub rounded getting coarser and more rounded with depth.	

CONSTRUCTION INFORMATION



DATE COMMENCED: 20/03/01
DATE COMPLETED: 20/03/01
LOGGED BY: DM

STATIC WATER LEVEL: 3.34 mbgl
DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

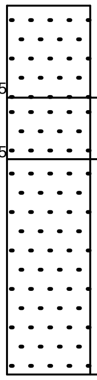
LOCATION: KIP - Track off Devlin Road
AMG CO-ORDINATES: 384363 mE 6322787 mN
TOP OF CASING: 12.78 mAHD

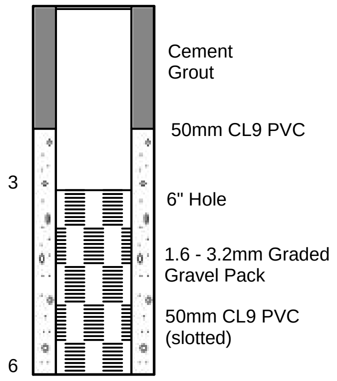
BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS1S

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
	Superficial Formation	1.5	SAND: Grey, fine to medium grained quartz, some organic material, poorly sorted, sub angular.	Lockable steel cap	
		2.5	SAND: Brown, medium to coarse grained quartz, moderately cemented (Coffee Rock), poorly sorted.		
5		6	SAND: Light brown, fine to medium grained, minor silty horizons throughout and chips of coffee rock, poorly sorted, sub angular.		
10					
15					
20					





DATE COMMENCED: 20/03/01
DATE COMPLETED: 20/03/01
LOGGED BY: DM

STATIC WATER LEVEL: 4.26 mbgl
DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-6m)

LOCATION DATA

LOCATION: KIP - Track off Devlin Road
AMG CO-ORDINATES: 384364 mE 6322787 mN
TOP OF CASING: 12.77 mAHD

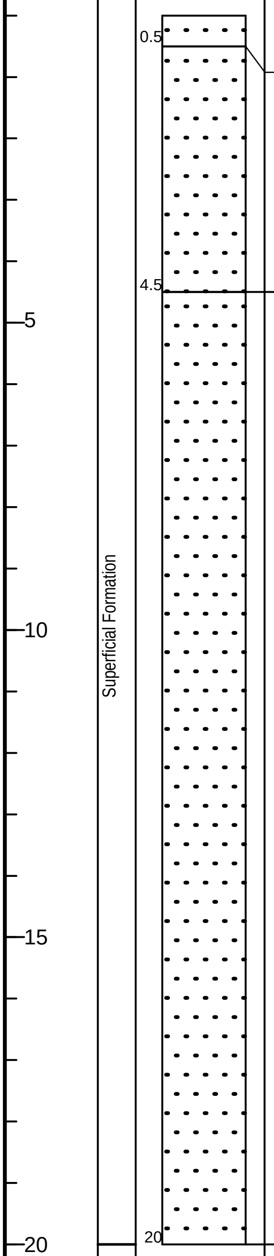
aquaterra

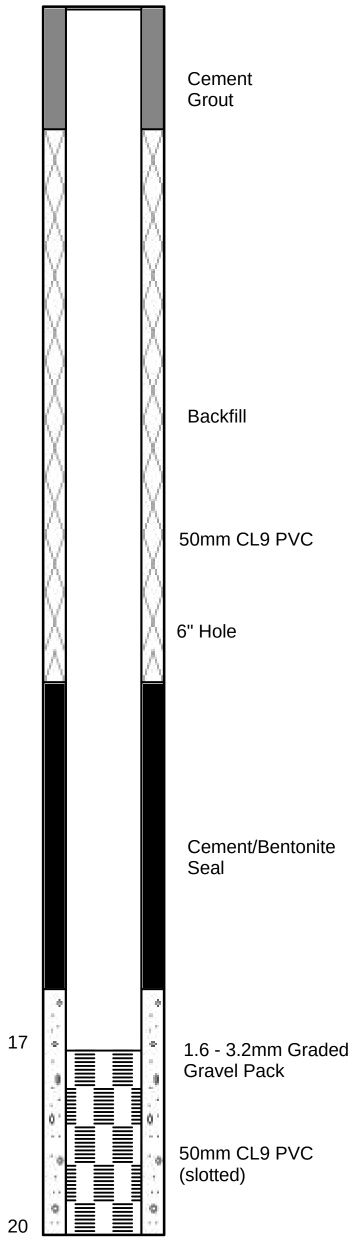
BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS2D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
0–0.5	Superficial Formation	0.5	SAND: Dark grey, fine to medium grained quartz, poorly sorted, sub angular, some organic material.	Lockable steel cap	
0.5–4.5		4.5	SAND: Grey/brown, fine to medium grained, poorly sorted, sub angular.		
4.5–20		20	SAND: Grey, fine to coarse grained, with medium to coarse grained sand present at selected intervals, varying from sub angular to rounded, generally poorly sorted, thin lenses of grey clay, present at discrete intervals.		





DATE COMMENCED: 21/03/01
DATE COMPLETED: 21/03/01
LOGGED BY: DM

STATIC WATER LEVEL: 4.63 mbgl
DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Southern track off Treasure Road
AMG CO-ORDINATES: 382405 mE 6327052 mN
TOP OF CASING: 12.48 mAHD

aquaterra

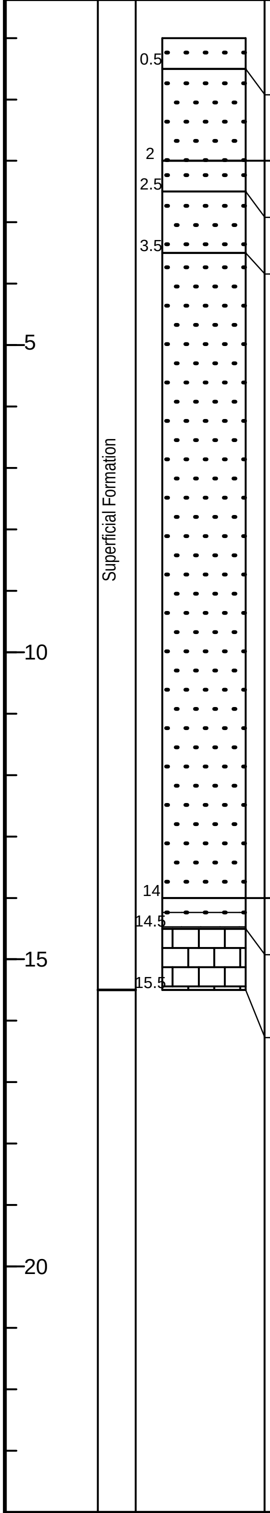
BORELOG

CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS3D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION



SAND: Black/grey, fine to medium grained, poorly sorted, sub angular, some organics present.

SAND: Grey, fine to medium grained, poorly sorted, sub angular.

SAND: Brown, fine to medium grained, poorly sorted, sub angular to sub rounded (Coffee Rock).

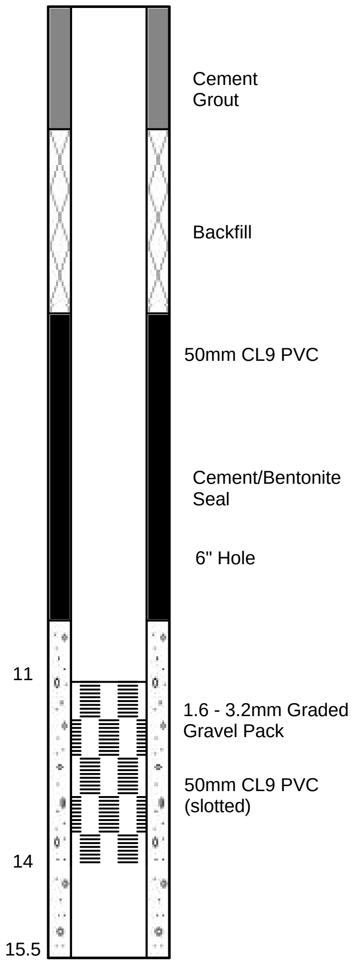
SAND: Light brown, fine to medium grained, poorly sorted, sub angular.

SAND: Grey, fine to medium grained, poorly sorted, sub angular, becoming slightly brown after 10m and becoming rounded and coarse grained between 13 - 14m.

CLAYEY SAND: Brown silty sand, medium to coarse grained sand, fine silty particles, poorly sorted.

TAMALA LIMESTONE: Pale grey, calcareous, well cemented, lenses of medium grained quartz sand, sub angular to sub rounded in a carbonate cement.

Lockable steel cap



DATE COMMENCED: 22/03/01
DATE COMPLETED: 22/03/01
LOGGED BY: DM

STATIC WATER LEVEL: 3.76 mbgl
DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-15.5m)

LOCATION DATA

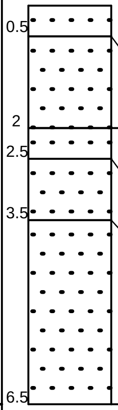
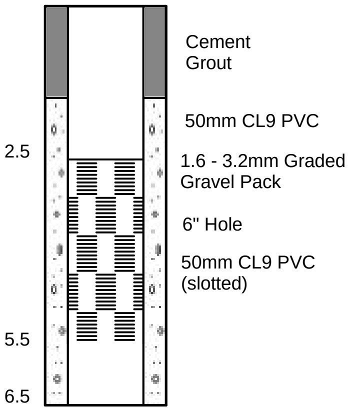
LOCATION: KIP - Northern track off Treasure Road
AMG CO-ORDINATES: 382580 mE 6329337 mN
TOP OF CASING: 8.74 mAHD

aquaterra

BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: **KEMS3S**

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
5 10 15 20	Superficial Formation		SAND: Black/grey, fine to medium grained, poorly sorted, sub angular, some organics present. SAND: Grey, fine to medium grained, poorly sorted, sub angular. SAND: Brown, fine to medium grained, poorly sorted, sub angular to sub rounded (Coffee Rock). SAND: Light brown, fine to medium grained, poorly sorted, sub angular. SAND: Grey, fine to medium grained, poorly sorted, sub angular, becoming slightly brown after 10m and becoming rounded and coarse grained between 13 - 14m.	Lockable steel cap	

DATE COMMENCED: 22/03/01
DATE COMPLETED: 22/03/01
LOGGED BY: DM
STATIC WATER LEVEL: 3.59 mbgl
DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-xxm)

LOCATION DATA

LOCATION: KIP - Northern track off Treasure Road
AMG CO-ORDINATES: 382580 mE 6329338 mN
TOP OF CASING: 8.77 mAHD

aquaterra

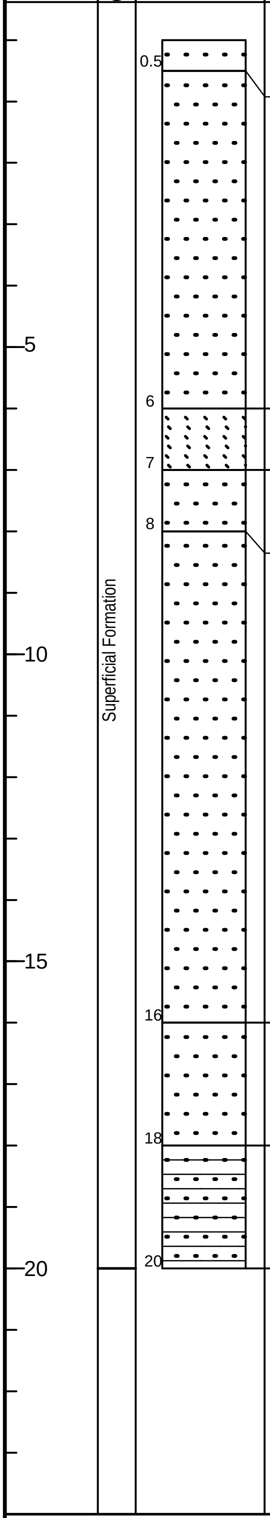
BORELOG

CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS4D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION



SAND: Brown, some organic material, fine to medium grained, poorly sorted, sub angular.

SAND: Yellow, fine to coarse grained sand, poorly sorted, sub angular to sub rounded, some thin horizons of clay throughout depth.

SILTY SAND: Yellow, fine to medium grained quartz with trace silty sand components.

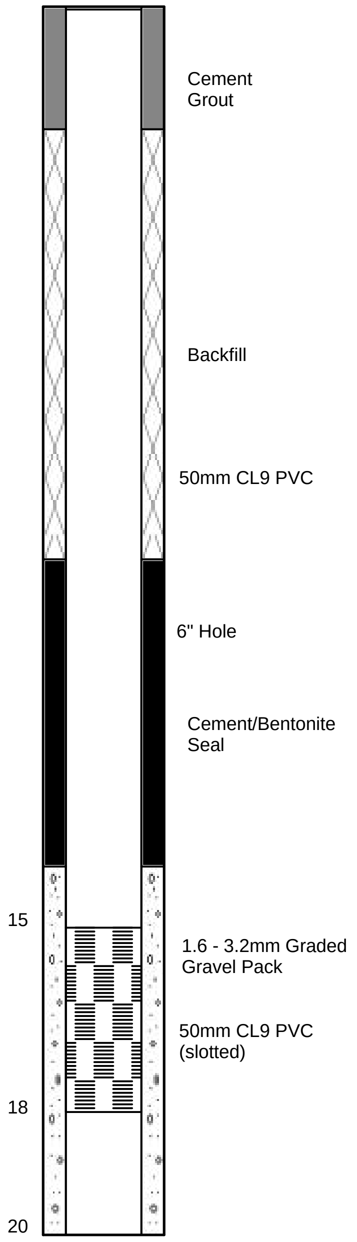
SAND: Brown, moderately cemented, fine to medium grained sand, sub rounded, moderately sorted (Coffee Rock).

SAND: Grey, med to coarse grained quartz, sub angular, getting coarser and rounded with depth, moderately sorted.

SAND: Grey, fine to meium grained quartz, as above.

CLAYEY SAND: Dark grey/green silty clay, fine to medium grained quartz, weakly cemented, poorly sorted.

Lockable steel cap



DATE COMMENCED:	23/03/01	LOGGED BY:	JEA
DATE COMPLETED:	23/03/01		

STATIC WATER LEVEL:	6.33 mbgl
DATE:	24/03/01

DRILLING INFORMATION

METHOD (DEPTHS):	Rotary Mud
FLUID (DEPTHS):	Bentonite/Guar Gum Mud
BIT RECORD:	6" (0-20m)

LOCATION DATA

LOCATION:	KIP - Off Runnymede Road			
AMG CO-ORDINATES:	382780	mE	6332801	mN
TOP OF CASING:	12.99	mAHD		

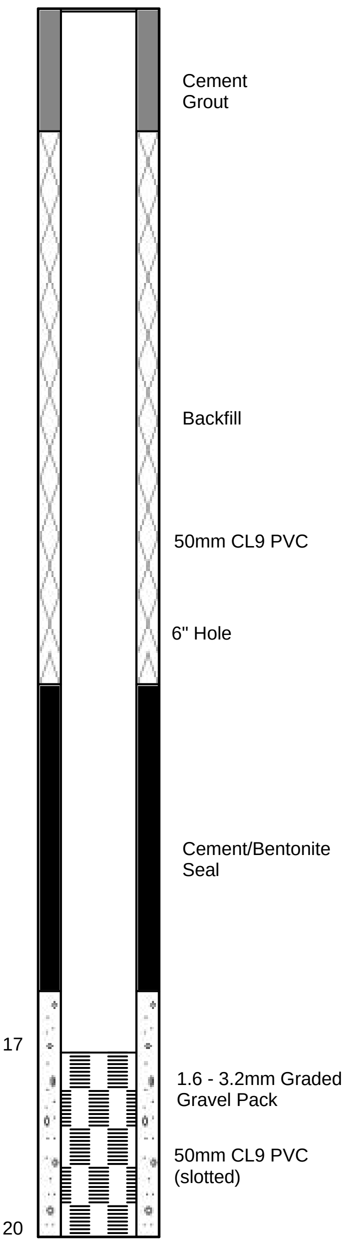
aquaterra

BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2
BORE NO: KEMS5D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES
0 - 1	Superficial Formation	1	SAND: Pale grey, fine to medium grained quartz, some organic material, poorly sorted, sub angular.	Lockable steel cap
1 - 8.5		8.5	SAND: Dark brown, fine to medium grained, silty clay horizons throughout, weakly to moderately cemented from 1 - 6m, poorly sorted (Coffee Rock).	
8.5 - 12		12	SAND: Brown, fine to medium grained quartz, sub angular, poorly sorted, chips of well indurated dark brown coffee rock from 11 - 12m.	
12 - 16		16	SAND: Grey, fine to medium grained quartz, sub angular to sub rounded, poorly sorted.	
16 - 19		19	SAND: Grey, medium to coarse grained, rounded, moderately sorted.	
19 - 20		20	SAND: Grey, fine to medium grained, poorly sorted, sub angular.	

CONSTRUCTION INFORMATION



DATE COMMENCED: 24/03/01
DATE COMPLETED: 24/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 2.65 mbgl
DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Track from WP sub station
AMG CO-ORDINATES: 384838 mE 6332790 mN
TOP OF CASING: 16.58 mAHD

BORELOG

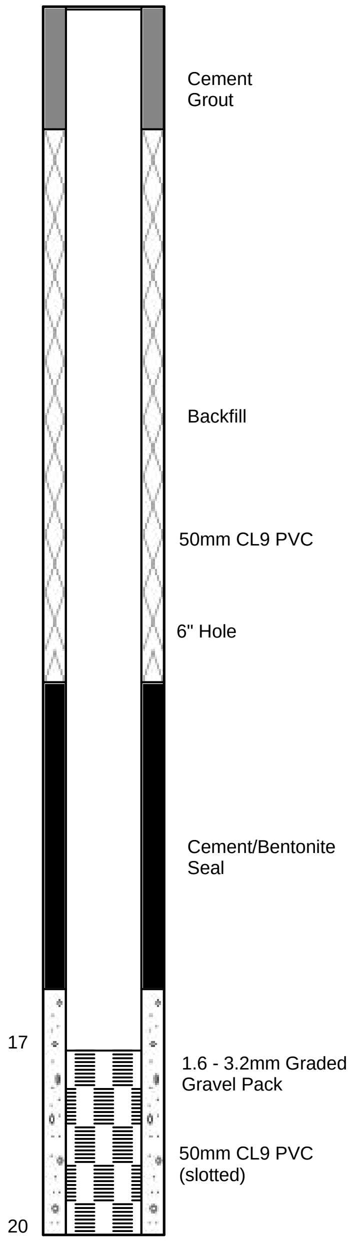
CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS6D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES
	Superficial Formation	0.5	SAND: Brown, some organic material, fine to medium grained, poorly sorted, sub angular.	Lockable steel cap
		1.5	SAND: Grey, fine grained, sub angular, poorly sorted.	
		3	SAND: Dark brown, moderately cemented, fine to coarse grained sand, sub rounded, poorly sorted (Coffee Rock).	
5		8	SAND: Light brown, fine to medium grained sand, poorly sorted, sub angular, chips of well indurated dark brown coffee rock over 7 - 8m.	
10		15	SAND: Grey, fine to coarse grained quartz, sub rounded, getting coarser and more rounded with depth.	
15		20	SAND: Grey, fine to medium grained quartz, poorly sorted, sub angular.	
20				

CONSTRUCTION INFORMATION



DATE COMMENCED: 23/03/01

DATE COMPLETED: 23/03/01

LOGGED BY: JEA

STATIC WATER LEVEL: 2.72 mbgl

DATE: 24/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud

FLUID (DEPTHS): Bentonite/Guar Gum Mud

BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Off Wellesley Road

AMG CO-ORDINATES: 384408 mE 6329496 mN

TOP OF CASING: 15.68 mAHD

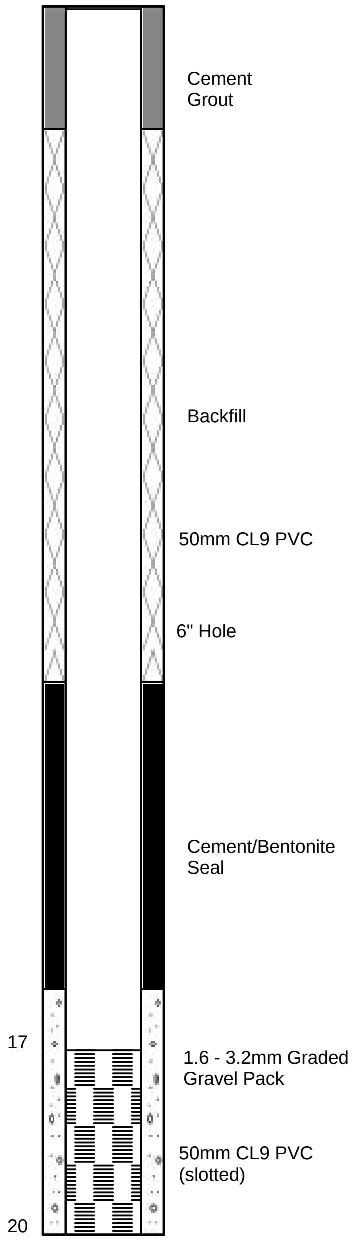
aquaterra

BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS7D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
	Superficial Formation	0.5	SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap	
		2.5	SAND: Pale grey, fine to medium grained, poorly sorted, sub angular.		
		4	SAND: Dark brown, fine to medium grained (Coffee Rock), moderately cemented, poorly sorted, sub angular.		
5		5	SAND: Pale grey, fine to medium grained, poorly sorted, sub angular.		
		6.5	SAND: Light brown, fine to medium grained, poorly sorted, sub angular.		
		8	SAND: Dark brown, fine to medium grained (Coffee Rock), well indurated chips, poorly sorted, sub angular, minor clay lenses throughout.		
10		11.5	SAND: Light brown, medium grained, poorly sorted, sub angular, coffee rock colouring and silty between 10.5 and 11.5m.		
		14	SAND: Light grey, fine to medium grained, poorly sorted, sub angular.		
15		18.5	SAND: Light brown, fine to medium grained, poorly sorted, sub angular.		
20		20	SAND: Light grey, fine to medium grained, poorly sorted, sub rounded, becoming medium to coarse grained and rounded over last 0.5m.		



DATE COMMENCED: 29/03/01
DATE COMPLETED: 29/03/01
LOGGED BY: JEA
STATIC WATER LEVEL: mbgl
DATE:

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Off KSS private road
AMG CO-ORDINATES: 386532 mE 6331229 mN
TOP OF CASING: 16.86 mAHD

aquaterra

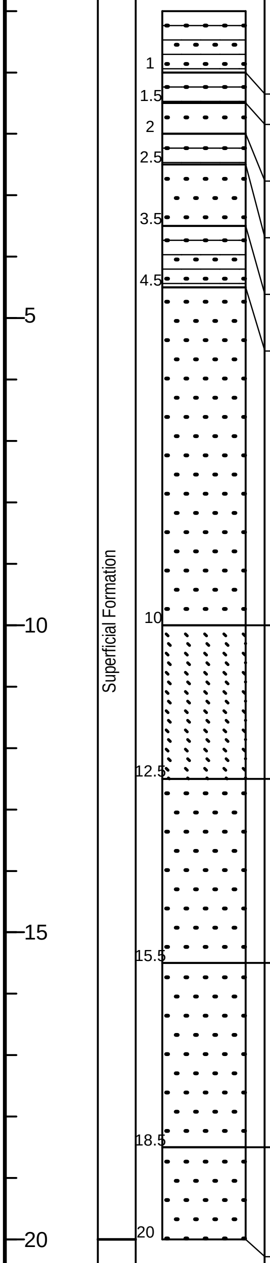
BORELOG

CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: **KEMS8D**

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION



CLAYEY SAND: Grey/brown, fine to medium grained quartz, poorly sorted, sub angular, moderately cemented.

CLAYEY SAND: As above with yellow mottled clay.

SAND: Pale grey, fine to medium grained quartz, poorly sorted, sub angular.

CLAYEY SAND: Grey, fine to medium grained, fine to medium grained, sub angular.

SAND: Grey, fine to medium grained, poorly sorted, sub angular.

CLAYEY SAND: Grey/brown, medium to coarse grained, rounded, poorly sorted.

SAND: Grey, medium to coarse grained, rounded, moderately sorted.

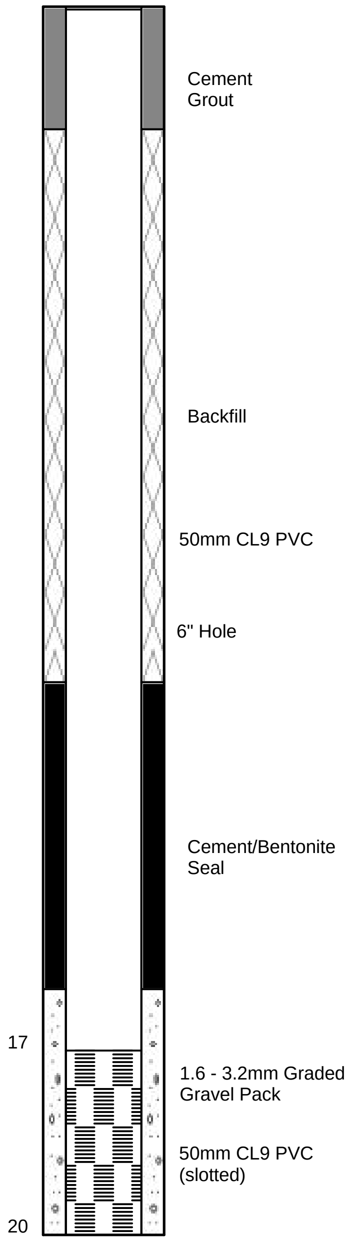
SILTY SAND: As above interbedded with clay horizons but dominantly sand.

SAND: Grey, medium grained, sub rounded, moderately sorted.

SAND: Grey, fine to medium grained quartz, poorly sorted, sub angular.

SAND: Grey, medium to coarse grained, moderately sorted, rounded with shell fragments and marine sediments (gastropods, bivalves etc), becoming fine sand over last 0.5m.

Lockable steel cap



DATE COMMENCED: 27/03/01
DATE COMPLETED: 27/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 2.79 mbgl
DATE: 28/03/01

DRILLING INFORMATION

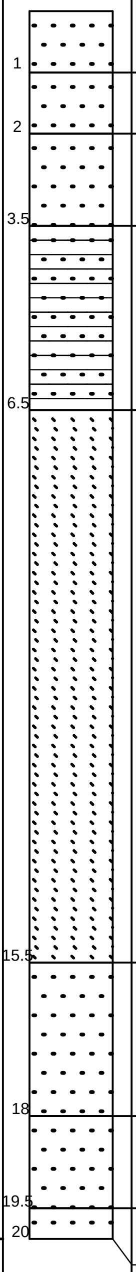
METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Easterly track off KSS road
AMG CO-ORDINATES: 387786 mE 6329599 mN
TOP OF CASING: 11.93 mAHD

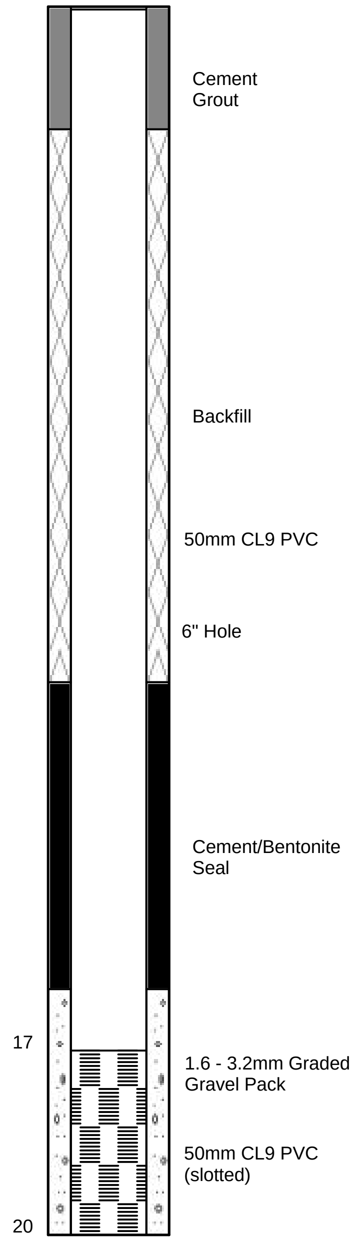
BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2
BORE NO: KEMS9D



DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES
	Superficial Formation	1	SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap
		2	SAND: Grey, fine to medium grained, poorly sorted, sub angular.	
		3.5	SAND: Brown (Coffee Rock), weakly cemented, fine to medium grained sand, poorly sorted, sub angular.	
5		6.5	CLAYEY SAND: Light brown, fine grained sand interbedded with lenses of weakly cemented grey clay.	
10 15		15.5	SILTY SAND: Light brown, fine to medium grained, poorly sorted, sub angular with silt horizons.	
		18	SAND: Grey, medium to coarse grained, rounded, moderately sorted.	
		19.5	SAND: Grey, fine to medium grained, poorly sorted, sub rounded.	
20		20	SAND: As above with chips of shell fragments and marine sediments.	

CONSTRUCTION INFORMATION



DATE COMMENCED: 27/03/01
DATE COMPLETED: 27/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 3.45 mbgl
DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Easterly track off KSS road
AMG CO-ORDINATES: 386832 mE 6329443 mN
TOP OF CASING: 14.97 mAHD

aquaterra

BORELOG

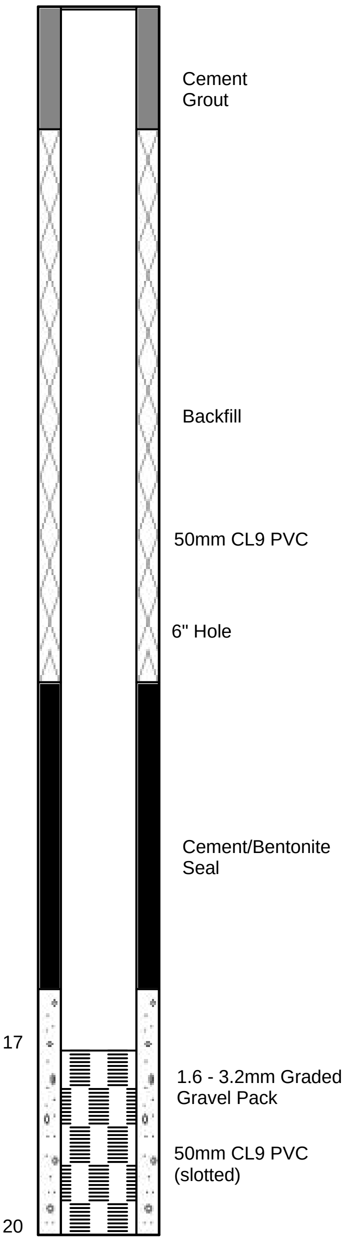
CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS10D

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES
0 - 1.5	Superficial Formation	1.5	SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap
1.5 - 3.5		3.5	SAND: Dark brown, fine to medium grained quartz (Coffee Rock), poorly sorted, sub angular, moderately cemented for first 0.5m, chips of well indurated coffee rock.	
3.5 - 10		10	SAND: Light brown, fine to medium grained, poorly sorted, sub angular, dark grey silty clay band between 4 - 5.5m and 9 - 10m.	
10 - 11.5		11.5	SAND: Dark brown, fine to medium grained quartz (Coffee Rock), poorly sorted, sub angular, weakly cemented, minor lenses of silty clay throughout.	
11.5 - 20		20	SAND: Grey/brown, fine to coarse grained, poorly sorted, sub rounded, getting more rounded and coarser with depth, layer of dark grey silty clay from 16.5 to 17m.	

CONSTRUCTION INFORMATION



DATE COMMENCED:	28/03/01	LOGGED BY:	STATIC WATER LEVEL: 3.32 mbgl
DATE COMPLETED:	28/03/01	JEA	DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Off KSS road
AMG CO-ORDINATES: 386045 mE 6329190 mN
TOP OF CASING: 14.76 mAHD

aquaterra

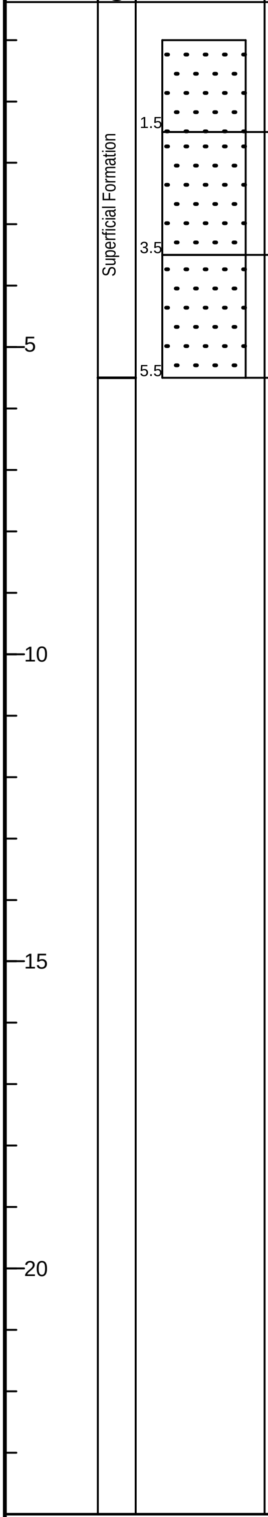
BORELOG

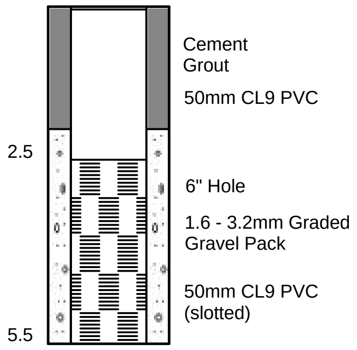
CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS10S

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
0 - 1.5	Superficial Formation		SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap	
1.5 - 3.5			SAND: Dark brown, fine to medium grained quartz (Coffee Rock), poorly sorted, sub angular, moderately cemented for first 0.5m, chips of well indurated coffee rock.		
3.5 - 5.5			SAND: Light brown, fine to medium grained, poorly sorted, sub angular, dark grey silty clay band between 4 - 5.5m and 9 - 10m.		





DATE COMMENCED: 28/03/01

DATE COMPLETED: 28/03/01

LOGGED BY: JEA

STATIC WATER LEVEL: 3.11 mbgl

DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud

FLUID (DEPTHS): Bentonite/Guar Gum Mud

BIT RECORD: 6" (0-5.5m)

LOCATION DATA

LOCATION: KIP - Off KSS road

AMG CO-ORDINATES: 386045 mE 6329191 mN

TOP OF CASING: 14.77 mAHD

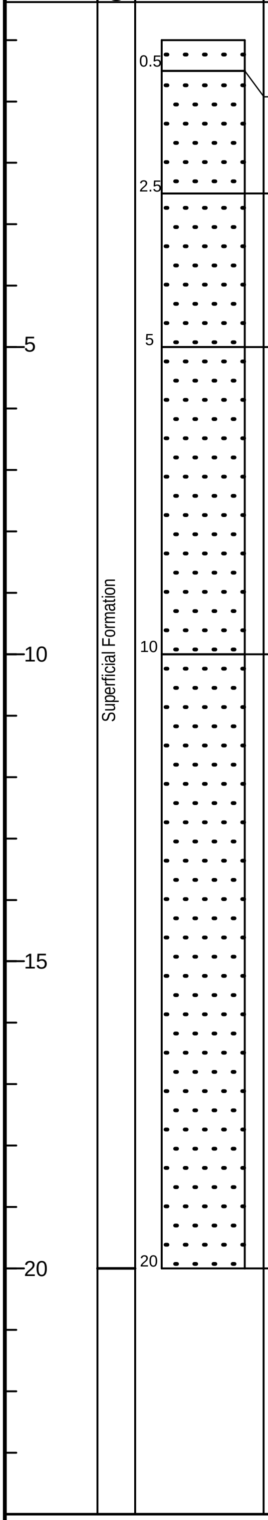
aquaterra

BORELOG

CLIENT: Landcorp / DRD / WRC

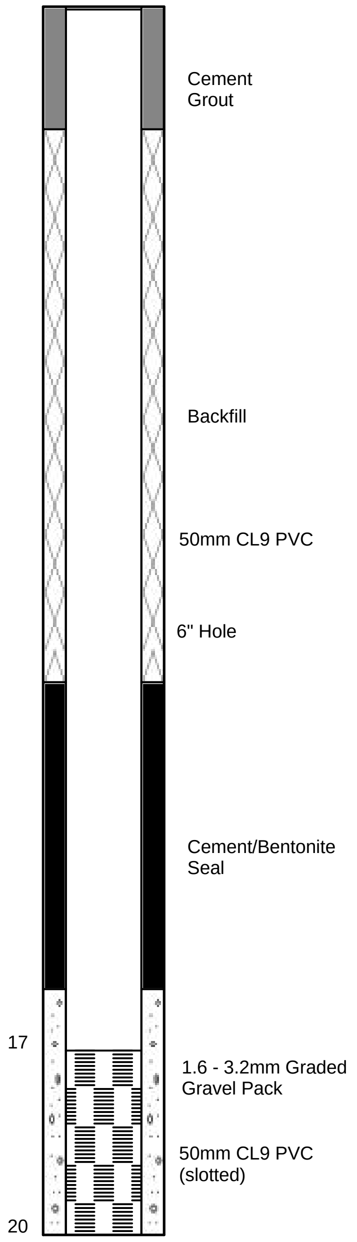
PROJECT: Kemerton Water Study - Phase 2

BORE NO: **KEMS11D**



DEPTH (mbgl)	LITHOLOGICAL DESCRIPTION	FIELD NOTES
0.5	SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap
2.5	SAND: Pale grey, fine to medium grained, poorly sorted, sub angular.	
5	SAND: Light brown, as above.	
10	SAND: Brown, as above.	
20	SAND: Light brown/grey, fine to medium grained, poorly sorted, sub angular.	

CONSTRUCTION INFORMATION



DATE COMMENCED: 29/03/01
DATE COMPLETED: 29/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 2.63 mbgl
DATE: 29/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Track near WP sub station
AMG CO-ORDINATES: 384967 mE 6331408 mN
TOP OF CASING: 15.40 mAHD

BORELOG

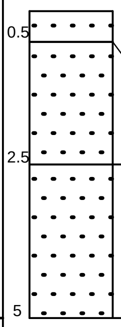
CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

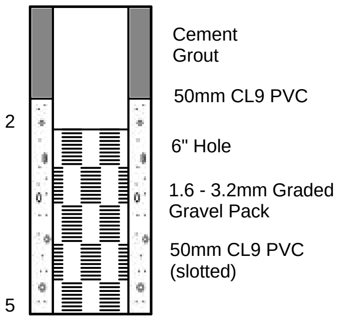
BORE NO: KEMS11S

DEPTH (mbgl)	Geology	LITHOLOGICAL DESCRIPTION	FIELD NOTES
0.5	Superficial Formation	SAND: Dark grey, fine to medium grained, some organics, poorly sorted, sub angular.	Lockable steel cap
2.5		SAND: Pale grey, fine to medium grained, poorly sorted, sub angular.	
5		SAND: Light brown, as above.	

GRAPHIC LOG



CONSTRUCTION INFORMATION



DATE COMMENCED:	30/03/01	LOGGED BY:	JEA
DATE COMPLETED:	30/03/01		
STATIC WATER LEVEL:	2.67 mbgl	DATE:	29/03/01

DRIDRILLING INFORMATION

METHOD (DEPTHS):	Rotary Mud
FLUID (DEPTHS):	Bentonite/Guar Gum Mud
BIT RECORD:	6" (0-5m)

LOCATION DATA

LOCATION:	KIP - Track near WP sub station			
AMG CO-ORDINATES:	384967	mE	6331409	mN
TOP OF CASING:	15.42	mAHD		

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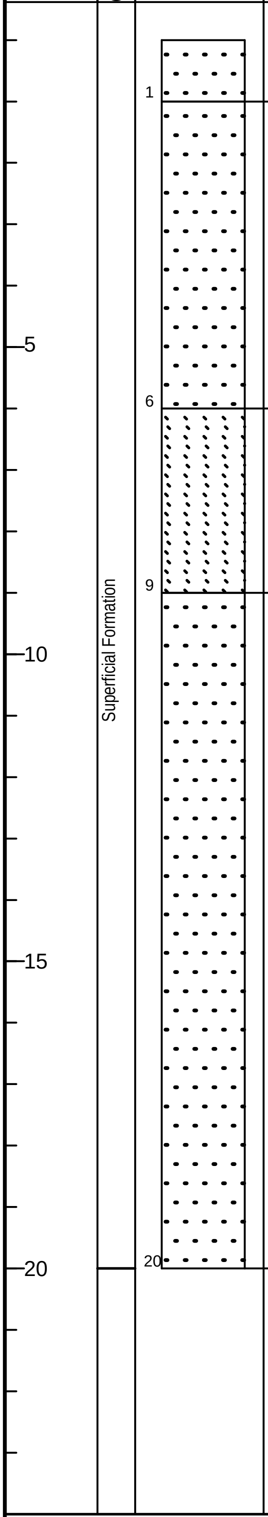
BORELOG

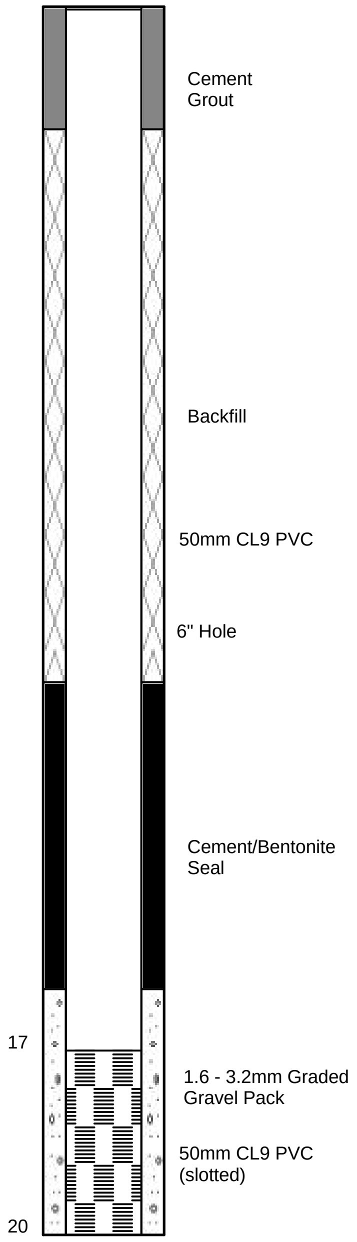
CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS12D



LITHOLOGICAL DESCRIPTION	FIELD NOTES
SAND: Grey, fine to medium grained quartz, poorly sorted, sub angular.	Lockable steel cap
SAND: Brown, fine to medium grained (Coffee Rock), poorly sorted, sub agular, nodules of well indurated dark brown coffee rock over 5 - 6m.	
SILTY SAND: Tan, fine to medium grained, poorly sorted, nodules of well indurated dark brown coffee rock throughout.	
SAND: Grey, fine to medium grained, sub angular to sub rounded, poorly sorted, ilmenite present over 15.5 - 20m, horizons of coarse rounded fractions over 11.5 - 12.5, 15 - 16 and 18.5 - 20.	

CONSTRUCTION INFORMATION



DATE COMMENCED: 24/03/01
DATE COMPLETED: 24/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 2.81 mbgl
DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-20m)

LOCATION DATA

LOCATION: KIP - Off Wellesley Road
AMG CO-ORDINATES: 384785 mE 6327503 mN
TOP OF CASING: 14.51 mAHD

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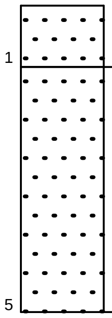
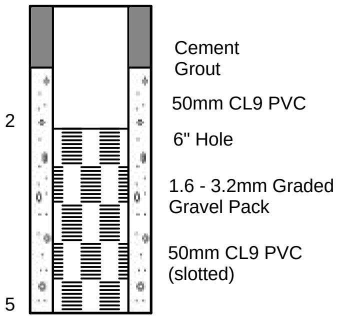
BORELOG

CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMS12S

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
	Superficial Formation		SAND: Grey, fine to medium grained quartz, poorly sorted, sub angular.	Lockable steel cap	
			SAND: Brown, fine to medium grained (Coffee Rock), poorly sorted, sub angular, nodules of well indurated dark brown coffee rock over 5 - 6m.		
5 10 15 20					

DATE COMMENCED: 26/03/01
DATE COMPLETED: 26/03/01
LOGGED BY: JEA

STATIC WATER LEVEL: 2.45 mbgl
DATE: 28/03/01

DRILLING INFORMATION

METHOD (DEPTHS): Rotary Mud
FLUID (DEPTHS): Bentonite/Guar Gum Mud
BIT RECORD: 6" (0-5m)

LOCATION DATA

LOCATION: KIP - Off Wellesley Road
AMG CO-ORDINATES: 384785 mE 6327503 mN
TOP OF CASING: 14.51 mAHD

aquaterra

APPENDIX B

CONFINED AQUIFER BOREHOLE LOGS

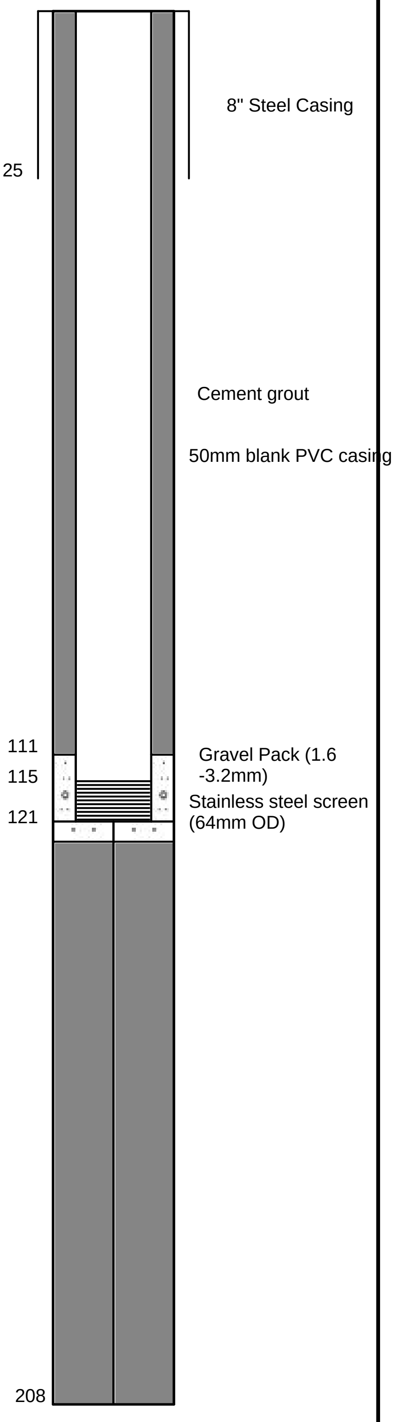
BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEML1

DEPTH (mbgl)	Geology	LITHOLOGICAL DESCRIPTION	FIELD NOTES
	Superficial Formation	SAND: Light Tan, quartz, fine to medium grained with peat horizons and minor shell grits at-24m	
24	Leederville Formation	SAND: Grey, quartz with common feldspar, fine, medium and coarse grained with ocasional 1 m thick shale horizons	
40		SHALE: Grey/black, carbonaceous, with micaceous sheen (graphitic? biotite?)	
47		SAND: Grey, quartz with common feldspar, fine, medium and coarse grained 10m thick sand beds, interbeded with 1 to 4 m thick shale horizons	
128		SHALES: Grey/black, carbonaceous, with micaceous sheen (graphitic? biotite?)	
137	Cattamarra Coal Measures	SANDS: Light tan, quartz with occasional pink (fe) quartz (garnet?), and rare feldspar, generally medium to coarse grained, with ocasional thin shale horizons	
203		CLAYS: Grey-black weakly mottled, soft with minor thin medium grained sand horizons	
208			

CONSTRUCTION INFORMATION



DATE COMMENCED: 20/04/01
DATE COMPLETED: 30/04/01
LOGGED BY: PAH

STATIC WATER LEVEL: 12.29 mTOC
DATE: 10/05/01

DRILLING INFORMATION

METHOD (DEPTHS): Mud Rotary
FLUID (DEPTHS): Mud
BIT RECORD: 8" (0 - 25m), 6.5" (24 - 208m)

LOCATION DATA

LOCATION: KIP - Off Devlin Road
AMG CO-ORDINATES: 384817.0 mE 6323382.0 mN
TOP OF CASING: 12.269 mAHD

aquaterra

BORELOG

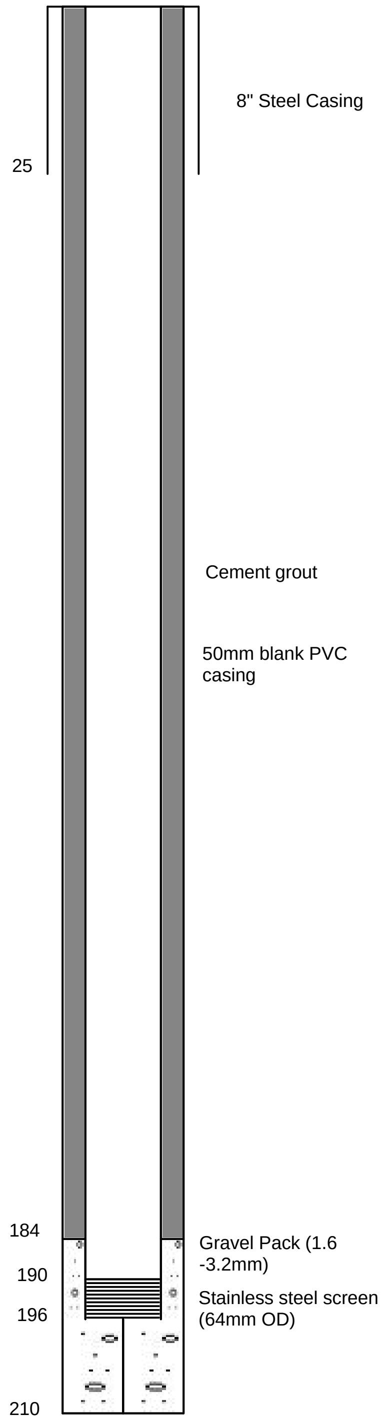
CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMC1

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES
	Superficial Formation		SAND: Light Tan, quartz, fine to medium grained with peat horizons and minor shell grits at-24m	
	Leederville Formation	24	SAND: Grey, quartz with common feldspar, fine, medium and coarse grained with ocasional 1 m thick shale horizons	
		40	SHALE: Grey/black, carbonaceous, with micaceous sheen (graphitic? biotite?)	
		47	SAND: Grey, quartz with common feldspar, fine, medium and coarse grained 10m thick sand beds, interbeded with 1 to 4 m thick shale horizons	
		128	SHALES: Grey/black, carbonaceous, with micaceous sheen (graphitic? biotite?)	
	Cattamarra Coal Measures	137	SANDS: Light tan, quartz with occasional pink (fe) quartz (garnet?, and rare feldspar, generally medium to coarse grained, with ocasional thin shale horizons	
		203	CLAYS: Grey-black weakly mottled, soft with minor thin medium grained sand horizons	
		210		

CONSTRUCTION INFORMATION



DATE COMMENCED:	20/04/01	LOGGED BY:	PAH
DATE COMPLETED:	30/04/01		
STATIC WATER LEVEL:	11.66 mTOC	DATE:	10/05/01

DRILLING INFORMATION

METHOD (DEPTHS):	Mud Rotary
FLUID (DEPTHS):	Mud
BIT RECORD:	8" (0 - 25m), 6.5" (24 - 208m)

LOCATION DATA

LOCATION:	KIP - Off Devlin Road			
AMG CO-ORDINATES:	384817.0	mE	6323382.0	mN
TOP OF CASING:	12.269	mAHD		

Lithological Log, KEMC1 and KEML1

Depth	Colour	Description
0 - 3	Grey	SAND: Quartz, fine grained, well sorted
3 – 9	Tan Brown	SAND: Quartz fine grained well sorted sand with minor peat horizons
9 – 12	Tan Brown	CLAYS/SAND: Dark clays with fine/medium grained quartz sand with minor peat
12 – 18	Tan	SAND: Quartz, fine to medium, MR with minor shell fragments
18 – 24	Grey	SAND: Fine to coarse GR quartz sand with grey clays. Qtz gravels at base of unit, poorly sorted, angular
24 - 30	Grey	SAND: Quartz medium grained with minor feldspar, sub angular
30 - 36	Grey	SAND: Medium – Coarse quartz sands, sub-angular with minor feldspar
36 - 42	Grey, black	CLAYS: Silty, micacaeous (graphitic?), carbonaceous with thin horizons coarse quartz feldspar sands
42 - 48	Dark Grey	CLAYS: Soft, dark, carbonaceous with micaceous sheen
48 - 57	Grey	CLAYS – SANDS: Clays as above, sand medium to coarse quartz with lesser feldspar and rare pyrite.
57 - 63	Grey	SAND: Quartz with minor feldspar, medium to coarse grained, sub-angular, with minor grey clay matrix
63 - 69	Grey/Black	CLAYS: Carbonaceous, soft micaceous clays
69 - 75	Grey	SANDY CLAYS: Quartz with minor feldspar, fine to very coarse, sub-angular, clays dark grey, silty
75 - 78	Light Grey	SAND/SILT/CLAYS: Silty clays with fine to very coarse grained quartz with minor feldspar, sub-angular
78 - 81	Dark Grey	SILT: With minor coarse angular quartz sands with minor feldspar.
81 - 90	Grey	SILT/SANDS: Silt with fine to coarse quartz with minor feldspar, subangular
90 - 93	Light Grey	SANDS: Quartz with lesser feldspar medium to very coarse, sub-angular, poorly sorted
93 - 102	Grey	SAND/SILT/CLAYS: Clay grey soft, quartz fine to coarse with rare gravels sub-angular, sub-rounded
102 – 105	Black	CLAYS: Soft, carbonaceous, micaceous, (graphitic?)
105 - 108	Grey	CLAYS: Clays as above with horizons of medium to coarse angular quartz with minor feldspar.
108 - 120	Grey	SILT/SAND: With clayey micaceous matrix, sands fine to medium grained poorly sorted, SA
120 - 123	Dark Grey	SILT/ CLAYS /SAND: Quartz with minor feldspar, fine to medium grained sands sub-rounded
123 - 129	Grey/Black	CLAYS: Micaceous/ glauconitic (green tinge) mottled with minor silty clays
129 - 138	Black	CLAYS/SHALE: Soft, carbonaceous, micaceous, (graphitic?)
138 - 141	Black	SANDY CLAYS: clays as above with medium grained poorly sorted quartz with minor feldspar.
141 - 144	Grey	SAND: Quartz, medium to coarse grained, sub-rounded, with minor lighter grey clays,
144 - 147	Light Tan	SAND: Quartz, with occasional pink (fe) quartz or garnet, medium to coarse grained, sub-rounded,
147 - 150	Black Grey	SANDY CLAYS: Sand medium grained, moderately sorted, rounded quartz as above. Clays black soft.
150 - 153	Light Tan	SAND: Quartz as above, medium grained, well sorted, with grey clay horizons.
153 - 156	Light Tan	SAND: Quartz as above fine to medium grained, moderately sorted, sub-rounded,
156 - 159	Light Tan	SAND: Quartz as above, fine to medium grained, moderately sorted,sub-rounded, , with minor grey clays
159 - 165	Light Grey	SANDY CLAYS: Quartz as above, coarse grained moderately sorted, angular with mottled white – grey clays
165 - 174	Light Tan	SANDS: Quartz with minor pink quartz (or garnet?), fine to medium

		grained with minor clay matrix
174 - 180	Light Tan	SAND: Quartz as above, medium grained, sub-rounded, well sorted
180 - 183	Light Tan	SAND: Quartz, medium grained as above, sub-rounded, well sorted with minor light grey clay matrix
183 - 189	Light Tan	SANDY CLAYS: Quartz, medium to coarse grained as above, sub-angular, moderately sorted, with minor black and grey clays
189 - 198	Light Tan	SANDS: Quartz, medium to coarse grained moderately sorted, sub-angular with occasional pink quartz (garnet?)
198 - 201	Light Tan	SAND: Quartz as above, medium grained, moderately sorted, sub-angluar with light grey clays
201 -204	Light Grey	CLAY: Soft, with minor fine to medium sands
204 - 208	Light Grey	CLAYS: Soft, grey- tan mottled with minor sands as above

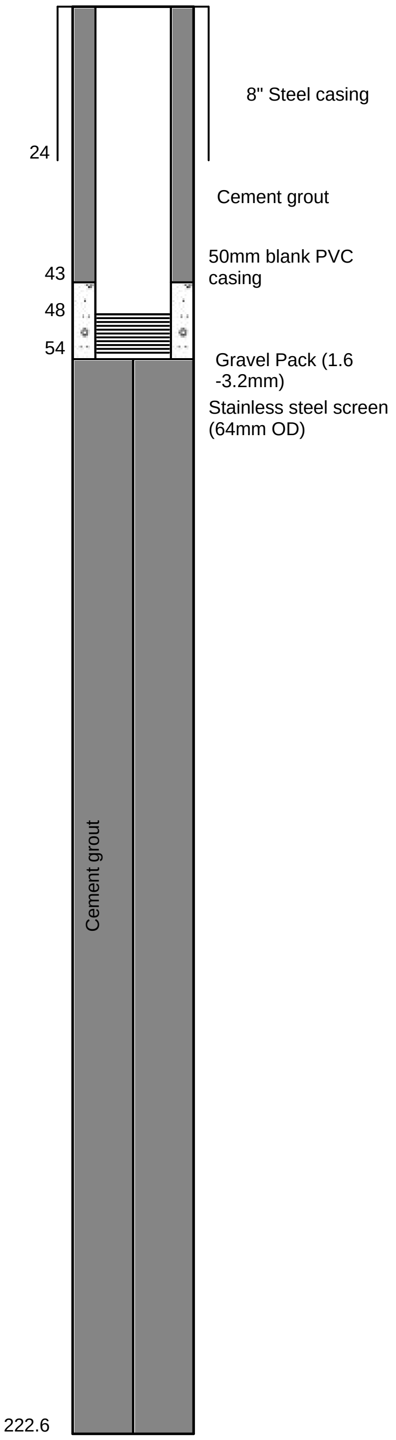
BORELOG

CLIENT: Landcorp / DRD / WRC

PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEML2

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION
24	Superficial Formation		SAND: Light Tan, quartz, fine to medium grained with peat horizons and shell grits at 21 -24m		
66	Leederville Formation		SAND: Grey,quartz with minor feldspar, fine,medium and coarse grained with shales and silts 44 - 48m		
85			SAND/SHALES/SILTS: Grey, interbedded 1 to 2 meter sand, shale and silts. Quartz with lesser feldspar		
108			SHALES: Carbonaceous, dark grey/black clays (unconsolidated)		
222.6	Cattamarra Coal Measures		SANDS: Light tan, quartz with occasional pink (fe) quartz (garnet?), and rare feldspar, generally medium to coarse grained, with minor very thin shale horizons		



DATE COMMENCED: 6/04/01

DATE COMPLETED: 20/04/01

LOGGED BY: PAH

STATIC WATER LEVEL: 9.11 mTOC

DATE: 10/05/01

DRILLING INFORMATION

METHOD (DEPTHS): Mud Rotary

FLUID (DEPTHS): Mud

BIT RECORD: 8" (0 - 24m), 6.5" (24 - 222.6m)

LOCATION DATA

LOCATION: KIP - Off Wellesley Road

AMG CO-ORDINATES: 384923.0 mE 6327210.0 mN

TOP OF CASING: 14.751 mAHD

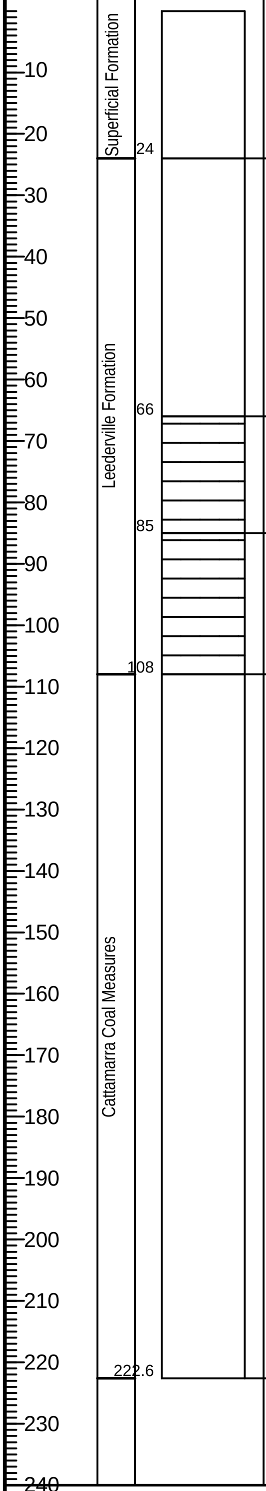
aquaterra

BORELOG

CLIENT: Landcorp / DRD / WRC
PROJECT: Kemerton Water Study - Phase 2

BORE NO: KEMC2

DEPTH (mbgl)	Geology	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	FIELD NOTES	CONSTRUCTION INFORMATION



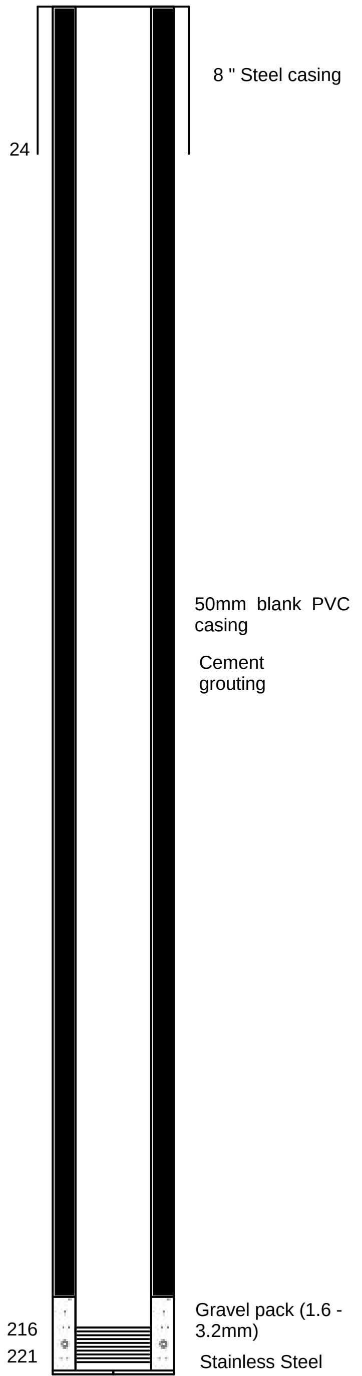
SAND: Light Tan, quartz, fine to medium grained with peat horizons and shell grits at 21 -24m

SAND: Grey,quartz with minor feldspar, fine,medium and coarse grained with shales and silts 44 - 48m

SAND/SHALES/SILTS: Grey, interbedded 1 to 2 meter sand, shale and silts. Quartz with lesser feldspar

SHALES: Carbonaceous, dark grey/black clays (unconsolidated)

SANDS: Light tan, quartz with occasional pink (fe) quartz (garnet?),and rare feldspar, generally medium to coarse grained, with minor very thin shale horizons



DATE COMMENCED: 6/04/01
DATE COMPLETED: 20/04/01
LOGGED BY: PAH

STATIC WATER LEVEL: 13.02 mTOC
DATE: 10/05/01

DRILLING INFORMATION

METHOD (DEPTHS): Mud Rotary
FLUID (DEPTHS): Mud
BIT RECORD: 8" (0 - 24m), 6.5" (24 - 222.6m)

LOCATION DATA

LOCATION: KIP - Off Wellesley Road
AMG CO-ORDINATES: 384923.0 mE 6327210 mN
TOP OF CASING: 14.751 mAHD

Lithological Log, KEMC2 and KEML2

Depth	Colour	Description
0 - 3	grey	SAND, quartz medium grained, moderately sorted, with minor peat horizons
3 - 9	Brown	SAND/PEAT, quartz sand as above with abundant peat
9 - 21	Tan	SAND, quartz fine to medium grained, moderately sorted and rounded
21 - 24	Grey	SAND, quartz, medium to coarse grained, moderately rounded with common shell fragments and minor glauconitic clays
24 – 33	Grey	SAND, quartz with common feldspar, medium grained, sub rounded, with minor grey clays/shales
33 - 36	Grey	SANDY CLAY, quartz with common feldspar, medium to coarse, angular to subrounded
33 - 39	Grey/black	CLAYS/SHALES, carbonaceous with minor fine to coarse quartz sands
39 – 45	Dark Grey	SANDY CLAY, quartz, with common feldpar, fine to coarse poorly sorted
45 - 51	Dark grey	CLAYS/SHALES, carbonaceous, with common quartz sand, fine to med poorly sorted, sub angular, with minor feldspar
51 - 60	Grey	SAND, quartz with common feldpar, fine to coarse grained, poorly sorted, sub angular. Minor clays
60 - 69	Grey	SAND, quartz with common feldspar, fine to coarse grained poorly sorted, sub angular.
69 – 72	Grey	SAND- SHALE, quartz sands with feldspar, fine to medium angular to sub angular, weakly micaceous,
72 - 84	Grey	SHALE with SANDS, micaceous carbonaceous shales/clays (graphitic) with poorly sorted fine to coarse quartz and feldspar sands.
84 - 87	Grey	SANDS, quartz with common feldspar, fine to coarse, poorly sorted, anglular
87 - 105	Dark Grey	SHALES CLAYS, weakly carbonaceous (and graphitic?) dark grey soft unconsolidated clays
105 - 111	Grey	SAND/SHALE, quartz fine to medium grained, subrounded
111- 120	Light grey/tan	SAND, quartz with very minor feldspar and cherty grains, med grained, sub rounded
120 – 129	Lt Grey	SAND, with fine dark grey, weakly consolidated , thin shale interbeds, quartz fine to coarse with very minor quartz pebbles, minor pink quartz? garnet?
129 - 141	Tan	SANDS, quartz with very minor feldspar, jasper and pink quartz? garnet? grains
141 - 153	Light Tan	SANDS, quartz with minor feldspar, fine to medium grained
153 – 180	Light Tan	SANDS, quartz, with pink Fe quartz? garnet? and minor feldspar, medium grained moderately sorted, sub angular to sub rounded.
180 – 186	Grey	SHALES, grey, waxy, weakly cemented with minor fine quartz sands
186 – 189	Grey	SANDS, fine grained- silty , dominantly quartz
189 – 195	Light Grey	SANDS, quartz, medium grained, moderately sorted and rounded
195 - 210	Light Grey	SANDS, quartz, medium to coarse grained, moderately sorted and rounded
210 - 223	Light Grey	SANDS, quartz, medium to coarse grained, moderately sorted and rounded, with minor silts and thin shale horizons

APPENDIX C

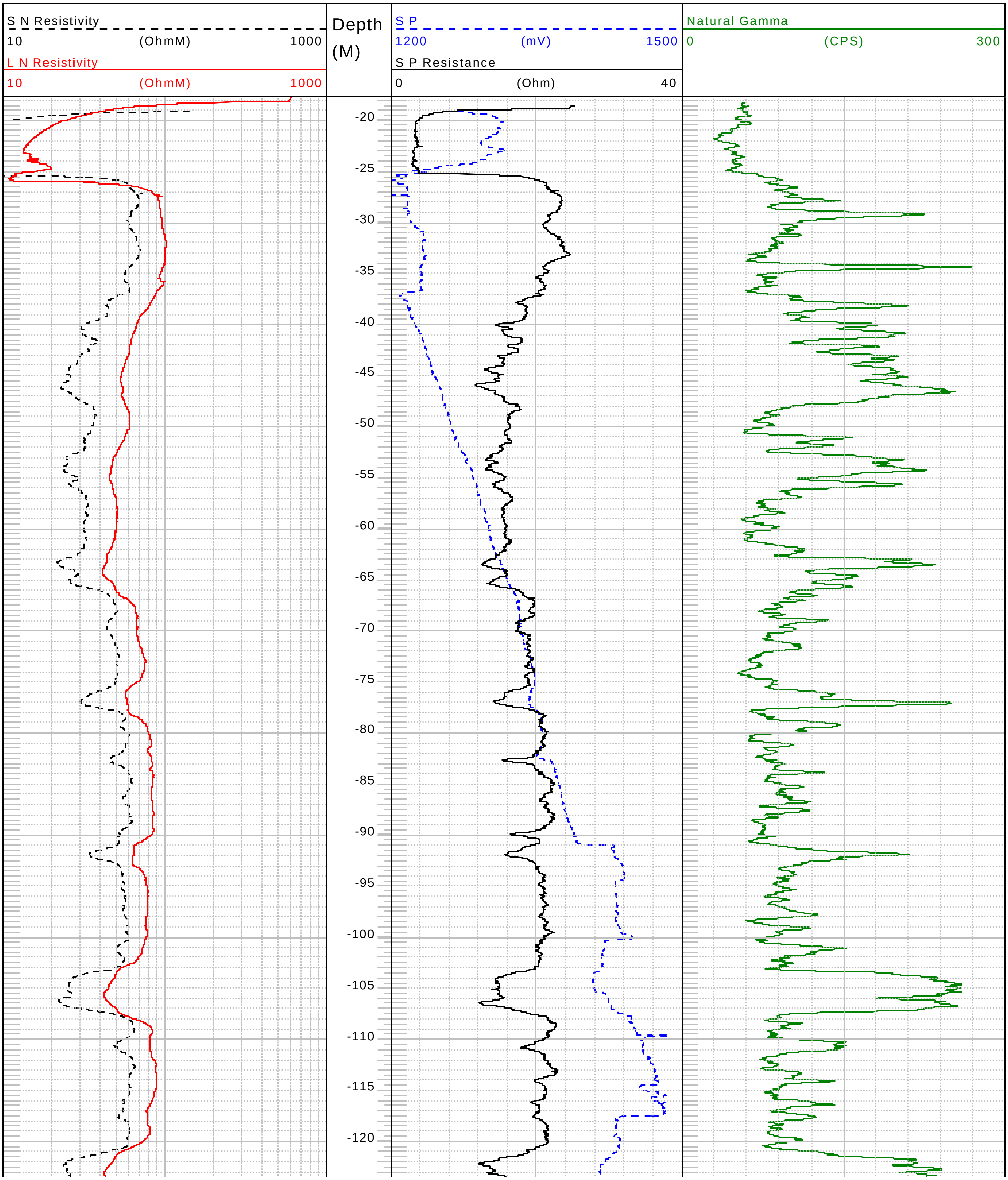
GEOPHYSICAL LOGGING PROFILE OF CONFINED AQUIFER BORES

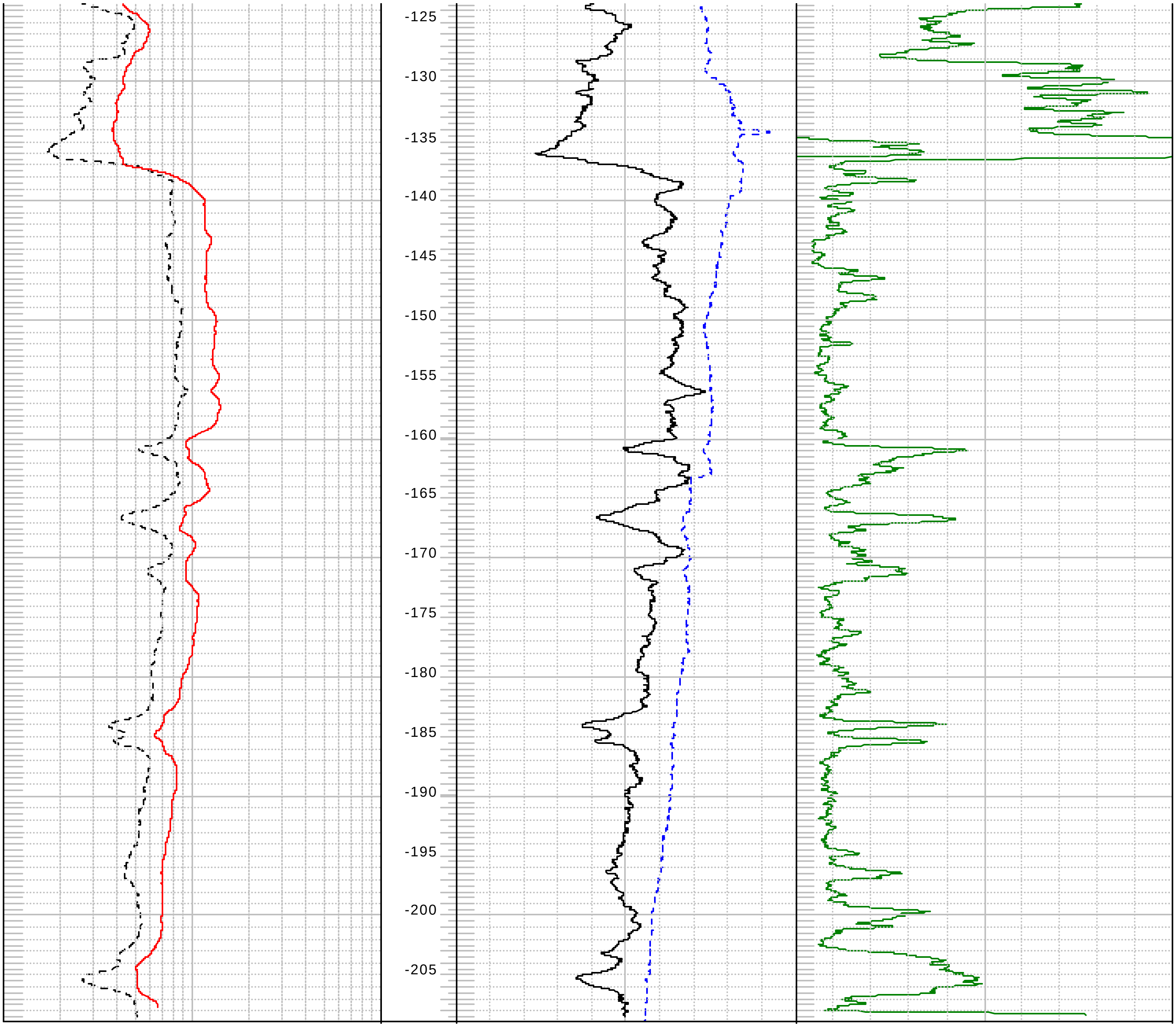
Well Name: KEM 1

File Name: C:\WinLogger\Data\elxgkem1.HDR

Location:

Elevation: 0 Reference: Ground Surface




-125
-130
-135
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-170
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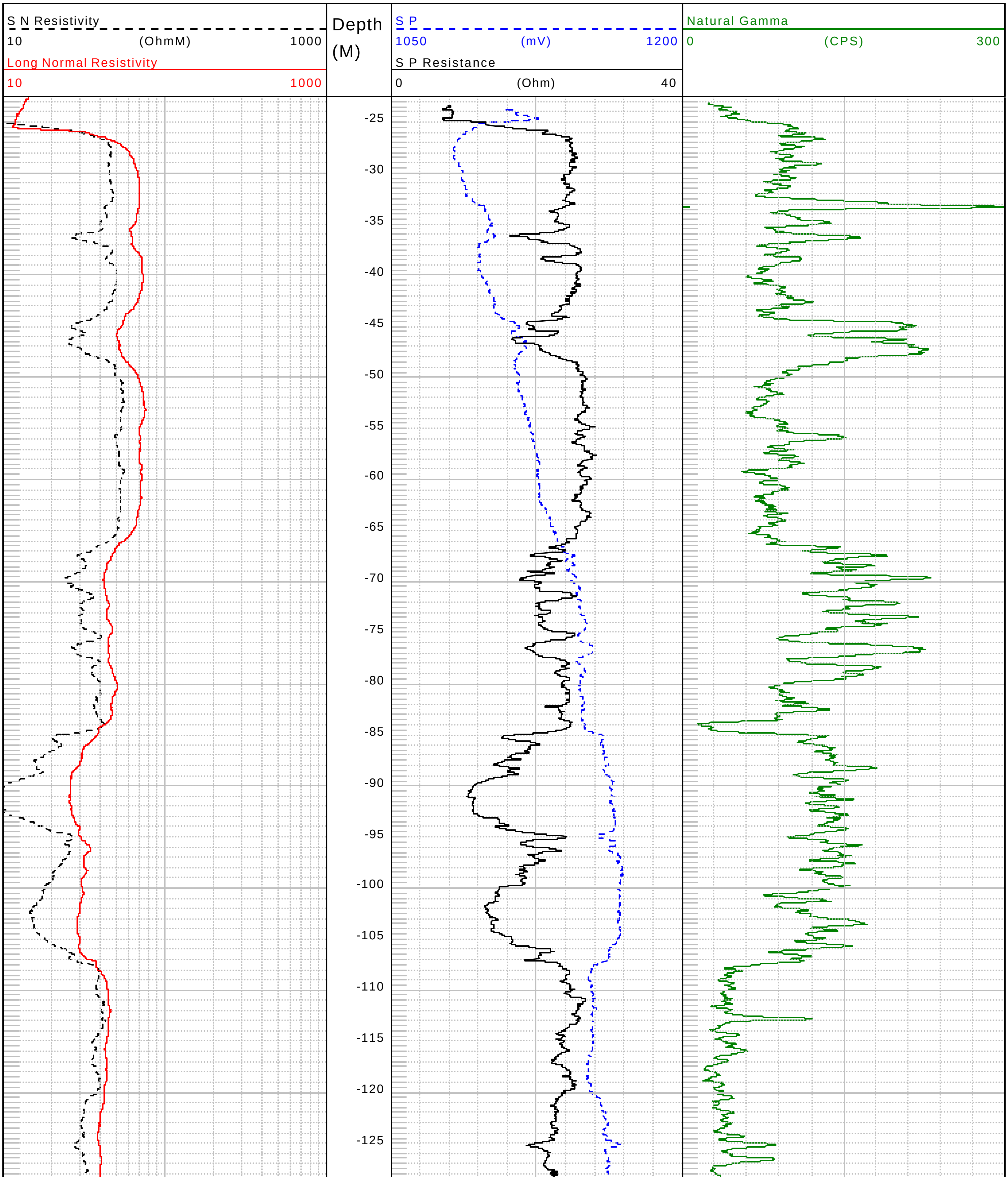
-200
-205

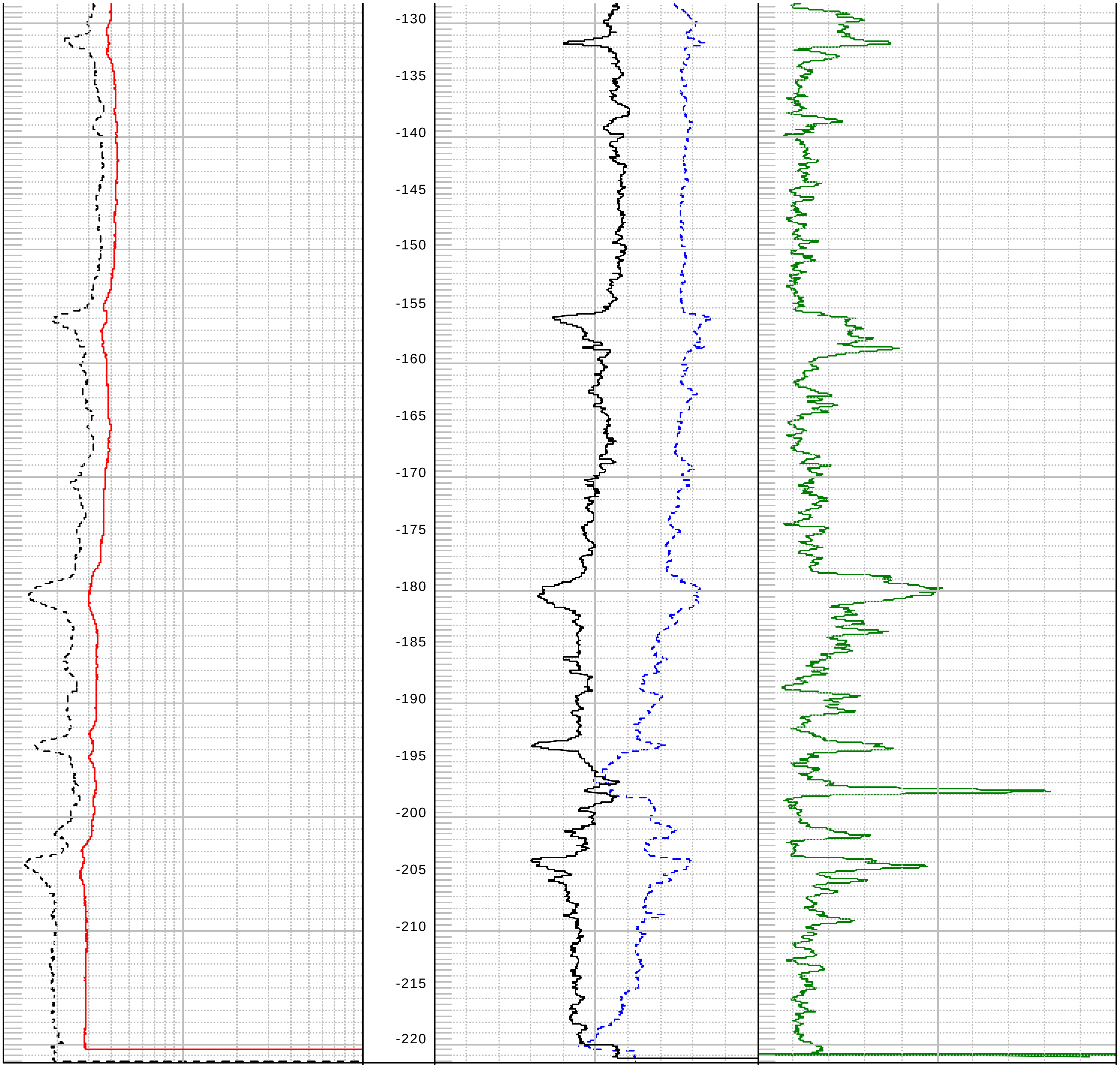
Well Name: KEM 2

File Name: C:\WinLogger\Data\ELXGKEM2.HDR

Location:

Elevation: 0 Reference: Ground Surface

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-215
-220

APPENDIX D

PALYNOLOGY REPORT

Backhouse Biostrat Pty Ltd

Report BB33

Palynology Report on samples from Kemerton 1 and 2

by

John Backhouse

Prepared for
Aquaterra **May 2001**

INTRODUCTION

Well name and samples: Kemerton 1
Kemerton 2

Location: No details provided

Client: Aquaterra (Paul Hamer)

Table 1. Summary of samples.

Well	**Depth m**	**Sample type**	**Organic yield***	**Lithology (if known)**
Kemerton 1	147-150	DC	0.022	Sst, with dark grey clay
Kemerton 1	186-189	DC	0.013	Claystone, sandy, m. grey
Kemerton 1	205-208	DC	0.011	Claystone, sandy, medium to light grey
Kemerton 2	183-186	DC	0.024	Claystone, sandy, medium to light grey
Kemerton 2	203-206	DC	0.024	Claystone/ Sst, m. grey
Kemerton 2	219-222	DC	0.020	Claystone/ Sst, m. grey

* Estimated organic yield provided by Laola Pty Ltd

ORGANIC YLD=VOL(cc)/WGHT(g)
<0.01 : EXTREMELY LOW
0.01 - 0.10 : LOW
0.1 - 0.5 : MODERATE
>0.5 : HIGH

PALYNOSTRATIGRAPHY

The comments of the assignment to stratigraphic units (formations) are made in the context of the southern Perth Basin. Because formations are essentially lithostratigraphic units, these comments are not considered to be definitive. The zones used in this report are based on Helby et al. (1987).

Kemerton 1 borehole

Palynomorph yields: High.

Preservation: Excellent.

Zone assignment:

147-150 m & 186-189 m: Probably *C. turbatus* Zone (but see comments below).
205-208 m: *C. turbatus* Zone.

Age: Bajocian to Toarcian.

Environment: No evidence for marine deposition, except possibly in caved Cretaceous.

Formation: Cockleshell Gully Formation for 205-208 m sample, possibly also for other samples.

Comments: The two highest samples from the Kemerton 1 borehole produced similar palynomorph assemblages dominated by *Corollina torosa*, *Araucariacites australis, Baculatisporites* spp. and bisaccate pollen. There are unequivocal Cretaceous species present, but these are assumed to be caved from the overlying unit. However, the wide range of species present and the mixing of assemblages through caving has clouded the results.

The presence of *Callialasporites turbatus* as a more common form in the lowest sample suggests that at least this sample is clearly in the *C. turbatus* Zone. The two higher samples may be in the upper part of the *C. turbatus* Zone, or may be in the lower part of the overlying sequence (*D. complex/ C. cooksonii* Zones), or they may be from the Cretaceous. The abundance of *C. torosa* suggests the samples are from the Early Jurassic, though the species can be common in the Cretaceous.

Kemerton 2 borehole

Palynomorph yields: High.

Preservation: Excellent.

Zone assignment:

183-186 m to 219-222 m *C. turbatus* Zone or top of *C. torosa* Zone.

Age: Probably Aalenian to Pliensbachian (Early Jurassic).

Environment: No evidence for marine deposition.

Formation: Cockleshell Gully Formation.

Comments: All three samples contain abundant *C. torosa* with other species constituting only a small percentage of the total assemblage. The presence of *C. turbatus* in the highest sample and the presence of possible *Exesipollenites tumulus* suggest the samples are still possibly in the *C. turbatus* Zone, but they could also belong in the *C. torosa* Zone.

The section appears to be somewhat older than the section in Kemerton 1.

REFERENCE

Helby, R., Morgan, R., and Partridge, A. D., 1987, A palynological zonation of the Australian Mesozoic. In P. A. Jell (ed.) Studies in Australian Mesozoic Palynology, Assoc. of Australasian Palaeontologists, Memoir 4, 1–85.

APPENDIX E

WETLAND ASSESSMENT PROCEDURE

Plate 1 Western side of Conservation Category wetland 1 (CCW), with *Juncus pallidus/Baumea articulata* dominated Sedgeland and scattered *Melaleuca preissiana* and *M. teretifolia* in foreground.

Plate 2 Eastern side of CCW1 with *Melaleuca rhaphiophylla* over *Baumea articulata* Sedgeland.

Plate 3 Eastern side of Conservation Category wetland 2 (CCW2) with *Baumea articulata* Sedgeland with *Eucalyptus rudis* fringe.

Plate 4 Eastern side of Conservation Category wetland 3 (CCW3) with *Juncus pallidus* sedgeland fringe surrounded by scattered *Melaleuca preissiana* trees and *M. teretifolia* Low Closed Shrubland.

Plate 5 Northern side of Conservation Category wetland 4 (CCW4) species rich dampland Closed Heath dominated by *Astartea fascicularis*, with scattered *M. preissiana* in background.

Plate 6 Western side of Conservation Category wetland 5 (CCW5) Species rich dampland Closed Heath dominated by *Pericalymma ellipticum*/*Hypocalymma angustifolium.*

ATA Environmental
environmental scientists

Plate 7 Eastern fringe of Conservation Category wetland 6 (CCW6) showing *Melaleuca preissiana* Forest over weed infested understorey.

Plate 8 Southern fringe of Conservation Category wetland 7 (CCW7) showing scattered *Melaleuca preissiana* tree with species rich tall shrubland understorey.

Plates 9 & 10 Western view of Resource Enhancement Category wetland 1 (RE1) off Devlin Rd (reclassified as a Multiple Use wetland – see Appendix 1) which is predominantly a pine plantation with parkland cleared *Corymbia calophylla*.

Plate 11 Eastern view of Resource Enhancement Category wetland 2 (RE2) off Devlin Rd with *Melaleuca* sp. tall shrubland/open woodland.

Plate 12 Eastern view of Resource Enhancement Category wetland 3(RE3) with *Melaleuca* rhaphiophylla Low woodland over a species rich dampland heath.

Appendix E2
WETLAND ASSESSMENT PROCEDURE

Wetland categories are assigned as the result of a re-evaluation and assessment based on the questionnaire and score system set out in the Guide to Wetland Management in the Perth and Near Perth Swan Coast Plain EPA Bulletin 686)

Wetland categories are based on the following score system, derived from graphs 1 and 2 from the 686 Bulletin.

CATEGORY	WETLANDS WITH WELL DEFINED BOUNDARIES	WETLAND WITH POORLY DEFINED BOUNDARIES
Natural attribute scores:		
Multiple use:	0-22 (transition zone 22-27)	0-9 (transition zone 9-12)
Resource enhancement	27-40(transition zone 22-27, 35-40)	12-15 (transition zones 9-12, 15-18)
Conservation	40+ (transition zone 35-40)	18 (transition zone 14-18)
Human use scores		
Multiple use:	0-8 (transition 8-12)	0-9 (transition zone 9-12)
Resource enhancement	12+ (transition 8-12)	12+ (transition zone 9-12)

WETLAND ASSESSMENT: CCW1 (MIALLA LAGOON – 41S)

A	**RESOURCE DATA**	
	Wetland Name: Mialla Lagoon (Sumpland) 41S	
	Location: off Treasure Rd, Kemerton	
	Map Reference: Wetlands Atlas Sheet 2031IV SE (Lake Preston)	
	Aerial Photograph: see attaches	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Well Defined	
	Assessment Type: Part IIA assessment	
	Wetland Atlas **Wetland Classification: C**	

B	**NATURAL ATTTRIBUTES**	**SCORE**
1	**Environmental Geology Classification:** Bassendean Sand White to pale grey	**1**
2	Adjacent Wetlands: Wetlands are present within a 2km radius	**0**
3	**Habitat Diversity:** Habitat composition and structure similar to other wetlands	**3**
4	**Drought Refuge Value:** Minor	**2**
5	**Area of Wetland**: 10-25 ha	**2**
6	**Habitat Type(s):** Habitats visible from aerial photo: 3 Paperbarks in dense clumps Low Thickets of *Melaleuca, Kunzea* Paperbark Fringe Extensive "clumps " of sedges Fringing woodland or heath Scattered paperbarks	**5.5**
7	**Emergent Vegetation:** % of emergent vegetation: 80-90%	**2**
8	**Adverse Water Quality:** None known	**5**
9	**Drainage:** No Drains	**5**
10	**Adjacent Nutrient Sources:** None known	**5**
11	**Area of Wetland Modified:** 11-20%	**4**
12	**Reserve Area:** Area of land allocated to wetland: 0 With 50m buffer (less 1 road boundary	**3**
13	**Native Vegetation Buffer:** Perimeter of wetland ~4000m Perimeter covered with nat. veg.: 90-100%	**10**

C	**HUMAN USE**	**SCORE**
1	**Aesthetics:** Little if any artificial noise Understorey mostly intact Few or no roads or buildings obvious from wetland A section of wetland where few people visit	**5**
2	**Historical/Archaeological features:** None known	**0**
3	Security of wetland Total Number of Owners: Owner Type: Private Reserve Type: System 6 Recommendation: MRS Zoning:	**1**

4	**Protection Groups:** None active	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**
7	**Other Human uses:** Agriculture	**1**
E	**PRESENCE OF RARE SPECIES:** None known	**No**
F	**PRIVATE HUMAN USE:** Grazing	**Yes**

SCORE:

Natural attributes: 47.5
Human use: 7

CATEGORY: Conservation

WETLAND ASSESSMENT: CCW2 (35S)

A	**RESOURCE DATA**	
	Wetland Name: CCW2 (35S) Sumpland	
	Location: Off Marriot Rd	
	Map Reference: Wetlands Atlas 2031 IV SE (Lake Preston SE)	
	Aerial Photograph: see attached	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly Defined	
	Assessment Type: Part IIB	

B	NATURAL ATTTRIBUTES	SCORE
1	**Environmental Geology Classification:** Bassendean Sand	**1**
2	**Adjacent Wetlands : No**	**1**
3	**Habitat Diversity:** Habitat composition similar to other wetland	**1**
6	**Habitat Type(s):** Habitats visible from aerial photo:2/3	
	Large paperbarks in dense clumps	**1**
	Paperbark Fringe	**1**
	Extensive intake bed of sedges	**1**
	Scattered ‘clumps’ or rushes or sedges	**1**
	Fringing sedges or rushes	**1**
	Flooded grasslands in winter/spring	**1**
	Fringing woodland or heath	**1**
	Scattered paperbarks	**0.5**
9	**Drainage:** No drains noted	**5**
11	**Area of Wetland Modified:** 11-20%	**4**
12	**Reserve Area:** 0-10ha	**1**

C	**HUMAN USE**	
1	**Aesthetics:** Understorey mostly intact	**1**
2	**Historical/Archaeological features:** None	**0**
3	**Security of wetland** **Total Number of Owners** **Owner Type** **Reserve Type** **System 6 Recommendation** **MRS Zoning**	**1**
4	**Protection Groups:** None known	**0**
5	**Passive Recreation:** None known	**0**
6	**Active Recreation:** None known	**0**
7	**Other Human uses:** 4WD/Trail Bikes	**1**
E	**PRESENCE OF RARE SPECIES:** None known	**0**
F	**PRIVATE HUMAN USE:** None known	**0**

SCORE:

Natural attributes: 21.5
Human use: 3

CATEGORY: Conservation

WETLAND ASSESSMENT: CCW3 (29S)

A	**RESOURCE DATA**	
	Wetland Name: CCW3 (29S)	
	Location: Off Devlin Rd, Kemerton (CCW, southern portion)	
	Map Reference: Wetlands map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph: see attached	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Well Defined	
	Assessment Type: Part IIA	

B	NATURAL ATTTRIBUTES	SCORE
1	**Environmental Geology Classification:** Bassendean Sands	**1**
2	**Adjacent Wetlands** : Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** habitat composition and structure similar to other wetlands	**3**
4	**Drought Refuge Value:** Minor	**2**
5	**Area of Wetland:** 10-25ha	**2**
6	**Habitat Type(s):** Habitats visible from aerial photo: 3/4 Large paperbarks in dense clumps Scattered ‘clumps’ or rushes or sedges Fringing rushes and sedges Flooded grasslands in winter/spring Fringing woodland or heath Scattered Paperbarks	 **1** **1** **1** **1** **1** **0.5**
7	**Emergent Vegetation:** % emergent Vegetation: <10%	**1**
8	**Adverse Water Quality:** None known	**5**
9	**Drainage:** No drains	**5**
10	**Adjacent Nutrient Sources:** None known	**5**
11	**Area of Wetland Modified:**31-40%	**2**
12	**Reserve Area:** Area of land allocated to wetland: With 50m buffer	**3**
13	**Native Vegetation Buffer:** Perimeter of wetland ~ 3000m Perimeter covered with nat. veg: 90-100%	**10**

C	**HUMAN USE**	
1	**Aesthetics:** Little or no artificial noise Understorey mostly intact Few Roads or building obvious from wetland A section of wetland where few people visit	**1** **1** **1** **1**
2	**Historical/Archaeological features:** None known	**0**
3	**Security of wetland** Total Number of Owners Owner Type Reserve Type System 6 Recommendation MRS Zoning	**1**
4	**Protection Groups:** None active	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**

7	**Other Human uses:** Nil	**0**
E	**PRESENCE OF RARE SPECIES:** None recorded	**0**
F	**PRIVATE HUMAN USE:** Evidence of Grazing	**1**

SCORE:

Natural attributes: 37.5
Human use: 6

CATEGORY: Conservation

WETLAND ASSESSMENT: CCW4 (61S)

A	**RESOURCE DATA**	
	Wetland Name: CCW4 (61S)	
	Location: Off Treasure Rd, Kemerton (north of intersection with Wellington Rd)	
	Map Reference: Wetlands map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph: Kevron Aerial Survey 16/01/01	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly Defined	
	Assessment Type: Part IIB	

B	**NATURAL ATTTRIBUTES**	**S1CORE**
1	**Environmental Geology Classification:** Bassendean Sands	**1**
2	**Adjacent Wetlands:** Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** habitat composition and structure similar to other wetlands	**3**
6	**Habitat Type(s):** Habitats visible from aerial photo: 2/3 Low thickets of *Melaleuca, Kunzea* or *Astartea* spp. Paperbark Fringe Fringing woodland or heath Scattered Paperbarks	 **1** **1** **1** **0.5**
9	**Drainage:** No drains	**5**
11	**Area of Wetland Modified:** 11-20%	**4**
12	**Reserve Area:** 10-25ha	**2**

C	**HUMAN USE**	
1	**Aesthetics:** Understorey mostly intact A section of wetland where few people visit	**1** **1**
2	**Historical/Archaeological features:** None known	**0**
3	**Security of wetland** **Total Number of Owners:** 1 **Owner Type:** Government Department **Reserve Type** **System 6 Recommendation** **MRS Zoning**	**5**
4	**Protection Groups:** None active	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**
7	**Other Human uses:** Nil	**0**
E	**PRESENCE OF RARE SPECIES:** None recorded	**0**
F	**PRIVATE HUMAN USE:** None	**0**

SCORE:

Natural attributes: 18.5
Human use: 6

CATEGORY: Resource Enhancement*

WETLAND ASSESSMENT: CCW5 (130S)

A	**RESOURCE DATA**	
	Wetland Name: CCW5 (130S)	
	Location: Off Boonilup Rd, Kemerton	
	Map Reference: Wetlands map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph: Kebvon Aerial Survey 01/2001	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Well Defined	
	Assessment Type: Part IIA	

B	**NATURAL ATTTRIBUTES**	**SCORE**
1	**Environmental Geology Classification:** Bassendean Sands	**1**
2	**Adjacent Wetlands** : Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** habitat composition and structure similar to other wetlands	**3**
4	**Drought Refuge Value:** None	**0**
5	**Area of Wetland:** 25-50ha	**3**
6	**Habitat Type(s):** Habitats visible from aerial photo: 2/3 Low thickets of *Melaleuca, Kunzea, Astartea* or *Pericalymma* sp. Paperbark fringe Fringing woodland or heath Scattered Paperbarks	 **1** **1** **1** **0.5**
7	**Emergent Vegetation:** % emergent Vegetation: <10%	**1**
8	**Adverse Water Quality:** None known	**5**
9	**Drainage:** No drains	**5**
10	**Adjacent Nutrient Sources:** None known	**5**
11	**Area of Wetland Modified:** 0-10%	**5**
12	**Reserve Area:**	**5**
13	**Native Vegetation Buffer:** 89-90%	**9**

C	**HUMAN USE**	
1	**Aesthetics:** Little if any artificial noise Understorey mostly intact A section of wetland where few people visit	**1** **1** **1**
2	**Historical/Archaeological features:** None known	**0**
3	**Security of wetland** **Total Number of Owners** **Owner Type** **Reserve Type** **System 6 Recommendation** **MRS Zoning**	**1**
4	**Protection Groups:** None known	**0**
5	**Passive Recreation:** None known	**0**
6	**Active Recreation:** None known	**0**
7	**Other Human uses:** Existing SEC service corridor adjacent	**1**

E	**PRESENCE OF RARE SPECIES:** None recorded	**no**
F	**PRIVATE HUMAN USE: No**	**no**

SCORE:

Natural attributes: 44.5
Human use: 5

CATEGORY: Conservation

WETLAND ASSESSMENT: CCW6 (45S)

A	**RESOURCE DATA**	
	Wetland Name: CCW6 (45S)	
	Location: Off Treasure Rd Rd, Kemerton (South of CCW1)	
	Map Reference: Wetlands map Sheet 2031 IV SE (Lake Preston SE)	
	Aerial Photograph: Kevron Aerial Survey 01/2001	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Well Defined	
	Assessment Type: Part IIA	

B	NATURAL ATTTRIBUTES	SCORE
1	**Environmental Geology Classification:** Bassendean Sands	**1**
2	**Adjacent Wetlands**: Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** habitat composition and structure different to other wetlands	**3**
4	**Drought Refuge Value:** None	**0**
5	**Area of Wetland:** 10-25ha	**3**
6	**Habitat Type(s):** Habitats visible from aerial photo: 1/2	
	Large paperbark in dense clumps.	**1**
	Scatterer 'clumps' of rushes or sedges	**1**
	Scattered Paperbarks	**0.5**
7	**Emergent Vegetation:** % emergent Vegetation: <10%	**1**
8	**Adverse Water Quality:** None known	**5**
9	**Drainage:** No drains	**5**
10	**Adjacent Nutrient Sources:** None known	**5**
11	**Area of Wetland Modified:** 0-10%	**5**
12	**Reserve Area:**	**5**
13	**Native Vegetation Buffer:** 89-90%	**9**

C	**HUMAN USE**	
1	**Aesthetics:** Little if any artificial noise	**1**
	Understorey mostly intact	**1**
	A section of wetland where few people visit	**1**
2	**Historical/Archaeological features:** None known	**0**
3	**Security of wetland** **Total Number of Owners** **Owner Type** **Reserve Type** **System 6 Recommendation** **MRS Zoning**	**1**
4	**Protection Groups:** None known	**0**
5	**Passive Recreation:** None known	**0**
6	**Active Recreation:** None known	**0**
7	**Other Human uses:** Existing SEC service corridor adjacent	**1**
E	**PRESENCE OF RARE SPECIES:** None recorded	**no**
F	**PRIVATE HUMAN USE: No**	**no**

SCORE

Natural attributes

Human use:

CATEGORY: Conservation

WETLAND ASSESSMENT: CCW7(10D)

A	**RESOURCE DATA**	
	Wetland Name: Un-named Dampland (10D) (Plate 8)	
	Location: Off Devlin Rd, on Millenium Minerals Site	
	Map Reference: Wetlands Map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph: see attached	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly defined	
	Assessment Type: Part IIB assessment	
B	**NATURAL ATTTRIBUTES**	**SCORE**
1	**Environmental Geology Classification:** Bassendean Sands White to pale grey	**1**
2	Adjacent Wetlands: Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** Habitat composition and structure similar and to other wetlands	**1**
6	**Habitat Type(s):** Habitats visible from aerial photo: 2 Large paperbarks in dense clumps Low Thickets of *Melaleuca, Kunzea, Astartea* Paperbark fringe Scattered Paperbarks	**1** **1** **1** **0.5**
9	**Drainage:** No Drains noted	**5**
11	**Area of Wetland Modified:** 0-10%	**5**
12	**Reserve Area:** 10-25ha	**2**

C	**HUMAN USE**	
1	**Aesthetics:** Little if any artificial noise Understorey mostly intact Few or no roads or buildings obvious from wetland A section of wetland where few people visit	**2** **1** **2** **1**
2	**Historical/Archaeological features:** None	**0**
3	Security of wetland Total Number of Owners:1 Owner Type: Private (Millenium Minerals) Reserve Type System 6 Recommendation MRS Zoning	**1**
4	**Protection Groups:** None Known	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**
7	**Other Human uses: Industry**	**1**
E	**PRESENCE OF RARE SPECIES:** None known	**0**
F	**PRIVATE HUMAN USE:** None known	**0**

SCORE

Natural attributes: 17.5

Human use: 8

CATEGORY: Conservation

WETLAND ASSESSMENT: RE1 (29S)

A	**RESOURCE DATA**	
	Wetland Name: Un-named (29S) , north of CCW3 (Plates 9&10)	
	Location: Off Devlin Rd, on Millenium Minerals Site	
	Map Reference: Wetlands Map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph: see attached	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly defined	
	Assessment Type: Part IIB assessment	
B	**NATURAL ATTTRIBUTES**	**SCORE**
1	**Environmental Geology Classification:** Bassendean Sands White to pale grey	**1**
2	Adjacent Wetlands: Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** Habitat composition and structure similar and to other wetlands	**1**
6	**Habitat Type(s):** Habitats visible from aerial photo: 1 (Pine Plantation)	**0**
9	**Drainage:** Drains into and out noted (open, from adjacent rural land)	**0**
11	**Area of Wetland Modified:**>40%	**1**
12	**Reserve Area:** >10%	**1**

C	**HUMAN USE**	
1	**Aesthetics:** Little, no artificial noise	**2**
2	**Historical/Archaeological features:** None	**0**
3	Security of wetland Total Number of Owners:1 Owner Type: Private Reserve Type System 6 Recommendation MRS Zoning	**1**
4	**Protection Groups:** None Known	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**
7	**Other Human uses:** Pine Plantation Over Site	**0**
E	**PRESENCE OF RARE SPECIES:** None known	**0**
F	**PRIVATE HUMAN USE:** None known	**0**

SCORE

Natural attributes: 4

Human use: 3

CATEGORY: Multiple Use

WETLAND ASSESSMENT: RE2 (13D)

A	**RESOURCE DATA**	
	Wetland Name: Un-named (13D) (Plate 11)	
	Location: Off west off Devlin Rd Rd, Kemerton, on Millenium Minerals Site	
	Map Reference: Wetlands Map Sheet 2031 I SW (Harvey SW)	
	Aerial Photograph:	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly Defined	
	Assessment Type: Part IIB assessment	
	Current Classification: Resource Enhancement	

B	NATURAL ATTTRIBUTES	SCORE
1	**Environmental Geology Classification**: Bassendean Sands White to pale grey	**1**
2	**Adjacent Wetlands** : Wetlands are present within 2km radius	**0**
3	**Habitat Diversity:** Habitat composition and structure similar and to other wetlands	**1**
4	**Habitat Type(s):** Habitats visible from aerial photo: 2 Low Thickets of *Melaleuca, Kunzea, Astartea* Paperbark fringe Scattered Paperbarks	**1** **1** **0.5**
5	**Drainage:** Open drains noted (probably from Millennium Minerals)	**0**
6	**Area of Wetland Modified:** 11-20%	**4**
7	**Wetland Size:** 10-25ha	**2**

C	**HUMAN USE**	
1	**Aesthetics:** Understorey mostly intact A section of wetland where few people visit	**2** **1**
2	**Historical/Archaeological features:** None	**0**
3	Security of wetland Total Number of Owners:1 Owner Type: Private (Millenium Minerals) Reserve Type System 6 Recommendation MRS Zoning	**1**
4	**Protection Groups:** None Known	**0**
5	**Passive Recreation:** Nil	**0**
6	**Active Recreation:** Nil	**0**
7	**Other Human uses:** Industry (Millennium Minerals)	**1**
E	**PRESENCE OF RARE SPECIES:** None known	**0**
F	**PRIVATE HUMAN USE:** None known	**0**

SCORE

Natural attributes: 10.5

Human use: 5

CATEGORY: Resource Enhancement

WETLAND ASSESSMENT: REW3 (49D)

A	**RESOURCE DATA**	
	Wetland Name: REW3 (49D) (Plate 12)	
	Location: Marriot Rd	
	Map Reference: Map Sheet 2031 IV SE (Lake Preston SE)	
	Aerial Photograph: Kevron Aerial Survey 01/2001	
	Local Government Authority: Shire of Harvey	
	Boundary Definition: Poorly Defined	
	Assessment Type: Part IIB	

B	NATURAL ATTTRIBUTES	SCORE
1	**Environmental Geology Classification:** Bassendean Sands	1
2	**Adjacent Wetlands** : Wetlands are present within 2km radius	0
3	**Habitat Diversity:** Habitat composition and structure similar and to other wetlands	1
6	**Habitat Type(s):** Habitats visible from aerial photo: 2/3	
	Large paperbarks (>2.5m tall) in dense clumps	1
	Low Thickets of *Melaleuca, Kunzea, Astartea*	1
	Paperbark fringe	1
	Scattered Paperbarks	0.5
9	**Drainage:** No Drains	5
11	**Area of Wetland Modified:** 0-10%	5
13	**Wetland Size:** 0-10ha	1

C	HUMAN USE	
1	**Aesthetics:** Understorey mostly intact A section of wetland where few people visit	2 1
2	**Historical/Archaeological features:** None	0
3	**Security of wetland** **Total Number of Owners** **Owner Type** **Reserve Type** **System 6 Recommendation** **MRS Zoning**	1
4	**Protection Groups:** None	0
5	**Passive Recreation:** None	0
6	**Active Recreation:** None	0
7	**Other Human uses:** None	0
E	**PRESENCE OF RARE SPECIES:** None	0
F	**PRIVATE HUMAN USE:** None	0

SCORE

Natural attributes:16.5
Human use:4

CATEGORY: Resource Enhancement

APPENDIX E3
KEMERTON WATER STUDY – PHASE 2
MONITORING SITES FLORA LISTS

Site 13	**Site 31**
Acacia pulchella	*Agonis flexuosa*
Acacia semitrullata	*Aira caryophylea*
Adenanthos meissneri	*Arctotheca calendula*
Asteridea pulverulenta	*Banksia attenuata*
Banksia attenuata	*Bossiae eriocarpa*
Banksia ilicifolia	*Brachyloma preissii*
Burchardia umbellata	*Briza maxima*
Bossiae eriocarpa	*Burchardia umbellata*
Caladenia flava ssp. *flava*	*Caladenia flava* ssp. *flava*
Calytrix fraseri	*Calytrix flavescens*
Conostephium pendulum	*Calytrix fraseri*
Dasypogon bromeliifolius	*Comesperma virgatum*
Drosera paleacea ssp. *paleacea*	*Conostephium pendulum*
Eriostemon spicatum	*Conostylis juncea*
Elythranthera. brunosis	*Corymbia calophylla*
Eucalyptus marginata	*Dasypogon bromeliifolius*
Gompholobium tomentosum	*Daviesia physodes*
Hibbertia hypericoides	*Drosera pallida*
Hibbertia subvaginata	*Eucalyptus marginata*
Hovea trisperma	*Hibbertia hypericoides*
Hypochaeris glabra	*Hibbertia racemosa*
Jacksonia furcellata	*Hypochaeris glabra*
Kunzea ericifolia	*Lepidosperma squamatum*
Lepidosperma squamatum	*Leucopogon polymorphus*
Lyginia barbata	*Macrozamia fraseri*
Macrozamia fraseri	*Melaleuca thymoides*
Melaleuca thymoides	*Petrophile linearis*
Nuytsia floribunda	*Phyllanthus calycinus*
Petrophile linearis	*Philotheca spicatus*
Rhodanthe cotula	*Pinus radiata*
Stirlingia latifolia	*Rhodanthe cotula*
Stylidium brunonianum	*Sowerbaea laxiflora*
Stylidium piliferum	*Stirlingia latifolia*
Thysanotus manglesianus	*Stylidium brunonianum*
Thysanotus multiflorus	*Ursinia anthemoides*
Ursinia anthemoides	*Xanthorrhoea brunonis*
Watsonia bulbilifera	*Xanthorrhoea preissii*
Xanthorrhoea preissii	*Xanthosia huegelii*
Xanthosia huegelii	
Site 303	**Site 230**
Acacia saligna	*Arctotheca calendula*
Baumea articulata	*Baumea articulata*
Baumea vaginalis	*Caladenia flava* ssp. *flava*
Briza maxima	*Lepidosperma longitudinale*
Caladenia flava ssp. *flava*	*Melaleuca lateritia*

Site 303	**Site 230**
Centella asiatica	*Senecio vulgaris*
Conostylis setigera	*Ursinia anthemoides*
Lobelia alata	
Melaleuca preissiana	**Site 175**
Ursinia anthemoides	*Agonis flexuosa*
Ely. brunosis	*Banksia ilicifolia*
	Caladenia flava ssp. *flava*
Site 172	*Corymbia calophylla*
Aira caryophyllea	*Dampiera linearis*
Arctotheca calendula	*Dasypogon bromeliifolius*
Baumea articulata	*Drosera pallida*
Cassytha racemosa	*Hibbertia hypericoides*
Centalla asiatica	*Hibbertia racemosa*
Cirsium vulgare	*Lepidosperma squamatum*
Hypochaeris glabra	*Macrozamia fraseri*
Lolium rigidum	*Melaleuca preissiana*
Melaleuca tertifolia	*Melaleuca thymoides*
Orobanche minor	*Patersonia occidentalis*
Villarsia albiflora	*Persoonia longifolia*
Ursinia anthemoides	*Pilotheca spicatus*
	Podolepis sp.
Site 140	*Rhodanthe cotula*
Acacia pulchella	*Thysanotus manglesianus*
Acacia stenoptera	*Ursinia anthemoides*
Aira caryophyllea	*Xanthorrhoea brunonis*
Anigozanthus manglesii	*Xanthosia huegelii*
Astroloma pallidum	
Banksia attenuata	**Site 247**
Bossiaea eriocarpa	*Acacia pulchella*
Briza maxima	*Agrostocrinum scabrum*
Burchardia umbellata	*Banksia attenuata*
Caladenia flava ssp. *flava*	*Bossieae eriocarpa*
Calytrix flavescens	*Caladenia flava* ssp.*flava*
Comesperma virgatum	*Comesperma virgatum*
Conostephium pendulum	*Conostephium pendulum*
Conostylis aculeata	*Corymbia calophylla*
Conostylis juncea	*Dampiera linearis*
Dampiera linearis	*Dasypogon bromeliifolius*
Dasypogon bromeliifolius	*Desmocladus flexuosa*
Daviesia physodes	*Eucalyptus marginata*
Dianella revoluta	*Gompholobium tomentosum*
Drosera pallida	*Hibbertia hypericoides*
Eucalyptus marginata	*Hovea trisperma*
Gompholobium tomentosum	*Lepidospermq squamatum*
Hemiandra punguns	*Macrozamia fraseri*
Hibbertia hypericoides	*Melaleuca thymoides*
Hibbertia racemosa	*Opercularia hispidula*
Hychchaeris glabra	*Petrophile linearis*
Jacksonia furcellata	*Philotheca spicatus*
Kennedia prostrata	*Pteridium esculentum*

Site 140	**Site 247**
Leucopogon propinquus	*Rhodanthe cotula*
Leucopogon polymorphus	*Senna occidentalis*
Levenhookia stipitata	*Stylidium brunonianum*
Macrozamia fraseri	*Taraxicum officinale*
Melaleuca thymoides	*Xanthosia huegelii*
Nemcia capitatum	*Ursinia anthemoides*
Patersonia occidentalis	
Petrophile linearis	
Philotheca spicatus	
Rhodanthe cotula	
Stirlingia latiflora	
Stylidium brunonianum	
Tetratheca hirsuta	
Thysanotus arbuscula	
Ursinia anthemoides	
Xanthorrhoea brunosis	

APPENDIX E4

MAXIMUM PREDICTED GROUNDWATER DRAWDOWN IMPACT ON VEGETATION TYPES ALONG TRANSECT LINES (PRED4: 14GL/YEAR)

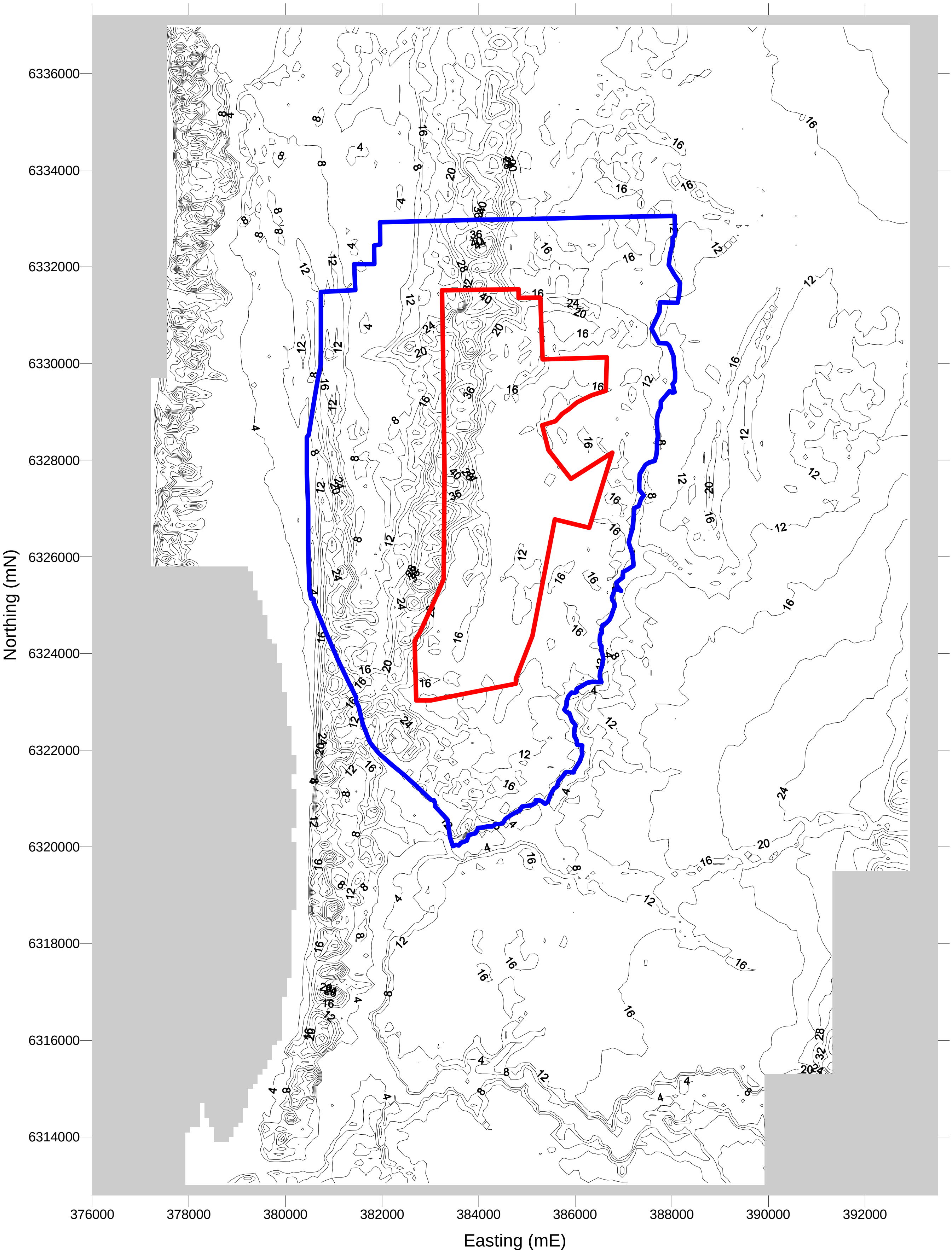
Transect Point	**Vegetation Type**	**Maximum Drawdown (annual) (Metres)**	**Maximum Drawdown (30YR) (Metres)**
1A	*Melaleuca rhaphiophylla* Low Closed Forest	0.016	0.024
1B	*Melaleuca rhaphiophylla* Low Closed Forrest	0.032	0.036
1C	*Melaleuca rhaphiophylla/ Baumea articulata*	0.072	0.088
1D	*Melaleuca rhaphiophylla* Open Forest	0.098	0.135
1E	*E. rudis/E. marginata/ A. flexuosa*	0.127	0.188
1F	*E. marginata* Woodland	0.157	0.260
2A	*Baumea articulata* Sedgeland	0.056	0.109
2B	*Acacia saligna* Tall shrubland over *B. articulata*	0.064	0.119
2C	*Melaleuca preissiana Closed Forest*	0.061	0.122
2D	*E. marginata/C. calophylla* Woodland	0.051	0.128
3A	*M. rhaphiophylla/ M. teretifolia* Low Open Shrubland	0.007	0.018
3B	*Juncus pallidus* Sedgeland with occasional clumps of *B.articulata*	0.006	0.017
3C	*Melaleuca preissiana* Scattered	0.008	0.018
3D	*Melaleuca teretifolia* Low Closed Shrubland	0.008	0.018
3E	*E. rudis* Woodland	0.008	0.019
4A	*Melaleuca rhaphiophylla*	0.038	0.066

	Closed Woodland		
4B	*Astartea fascicularis* dominated Closed Shrubland	0.039	0.065
4C	*Melaleuca incana ssp. incana /M. lateritia* Closed Heath	0.039	0.064
4D	Scattered *M.preissiana*	0.039	0.063
4E	Jarrah/Marri	0.038	0.061
4F	Jarrah/Banksia	0.038	0.060
5A	*Hypocalymma angustifolium/ Pericalymma ellipticum* dampland heath	0.089	0.372
5B	*Melaleuca preissiana* (Scattered trees)	0.086	0.423
5C	*Banksia ilicifolia* Tall Open Shrubland	0.093	0.429
6A	*Melaleuca rhaphiophylla* Closed Forest	0.116	0.166
6B	Melaleuca preissiana *Closed Forest*	0.117	0.187
6C	*Eucalyptus rudis* Woodland	0.141	0.242
6D	*Agonis flexuosa* Tall Shrubland	0.151	0.247

APPENDIX F

DETAILED INFORMATION RELATING TO GROUNDWATER MODEL

Kemerton Water Study (Phase 2)



Note: Contours of Surface Topography in mAHD

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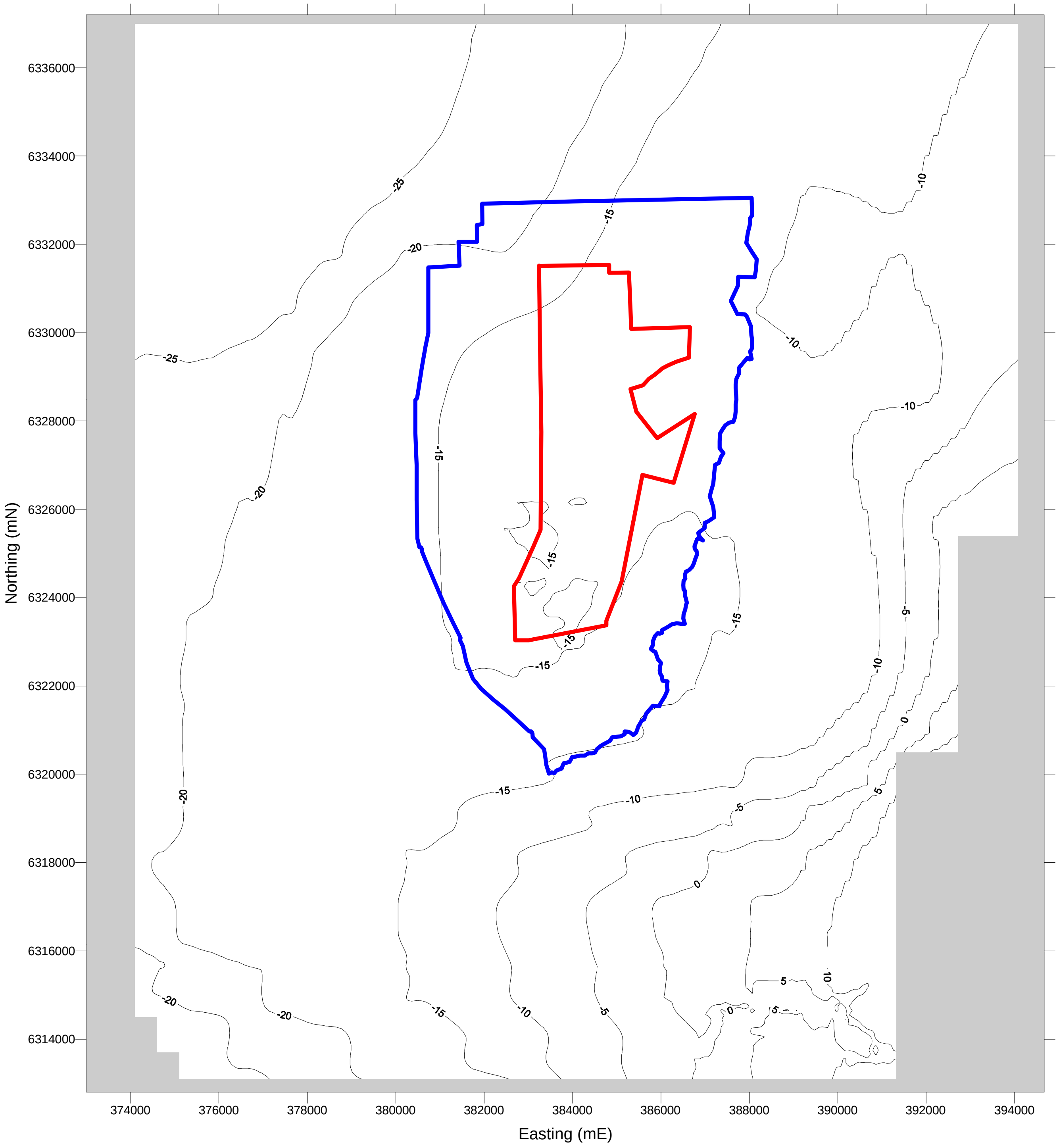
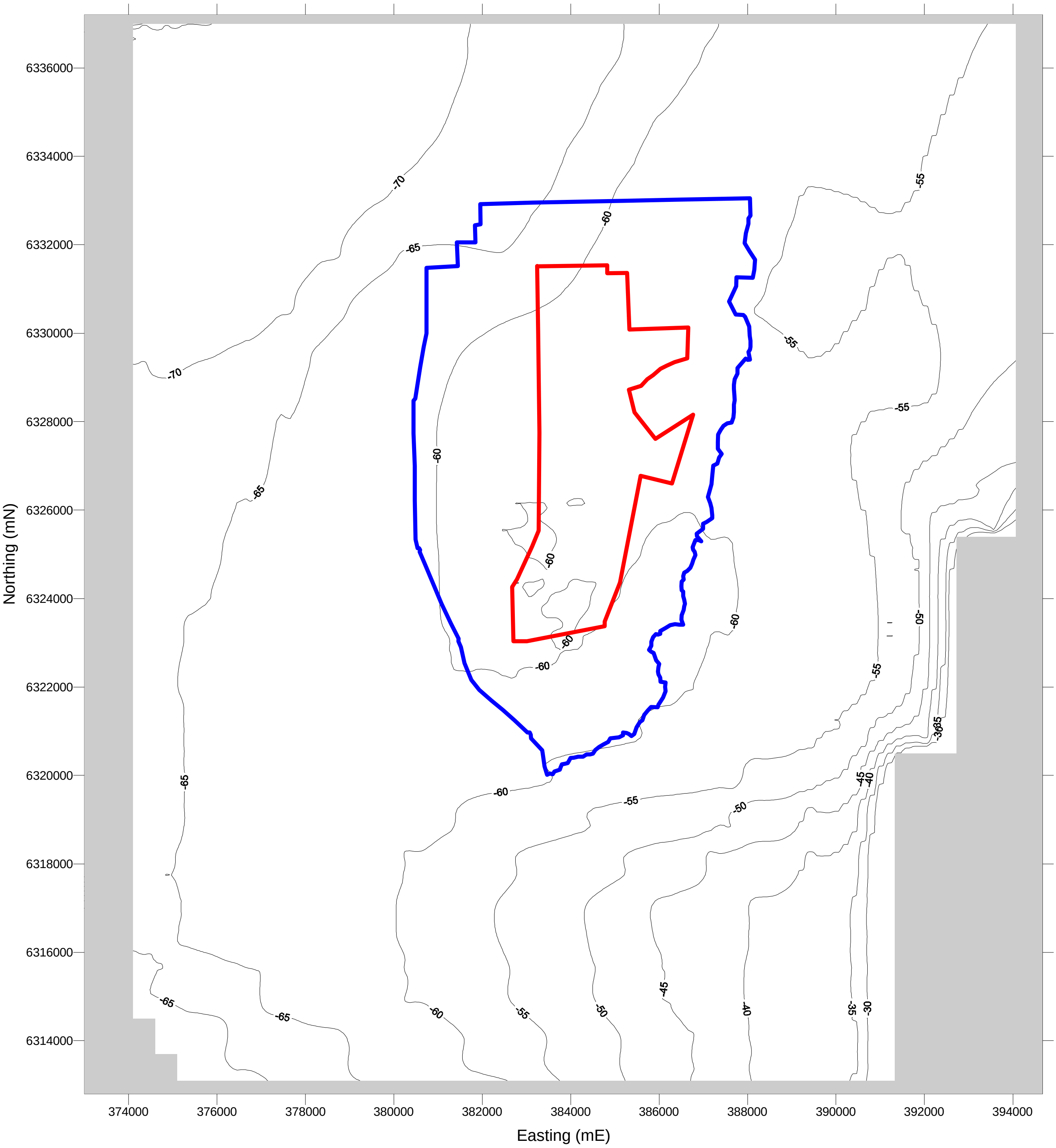
Top of Superficial Fm - Layer 1

Figure F1



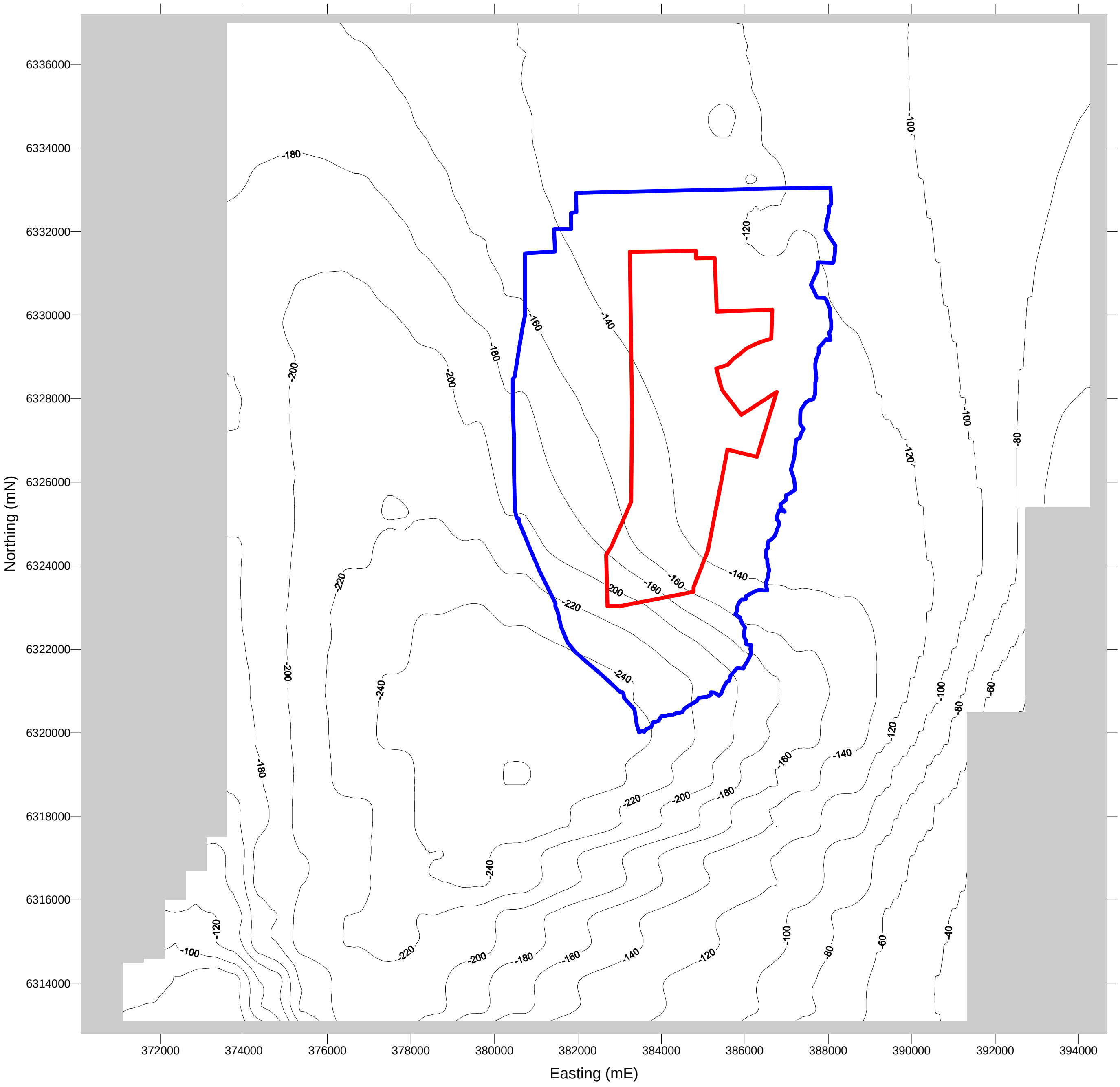
Note: Contours in mAHD

Top of Upper Leederville Fm - Layer 2
Figure F2



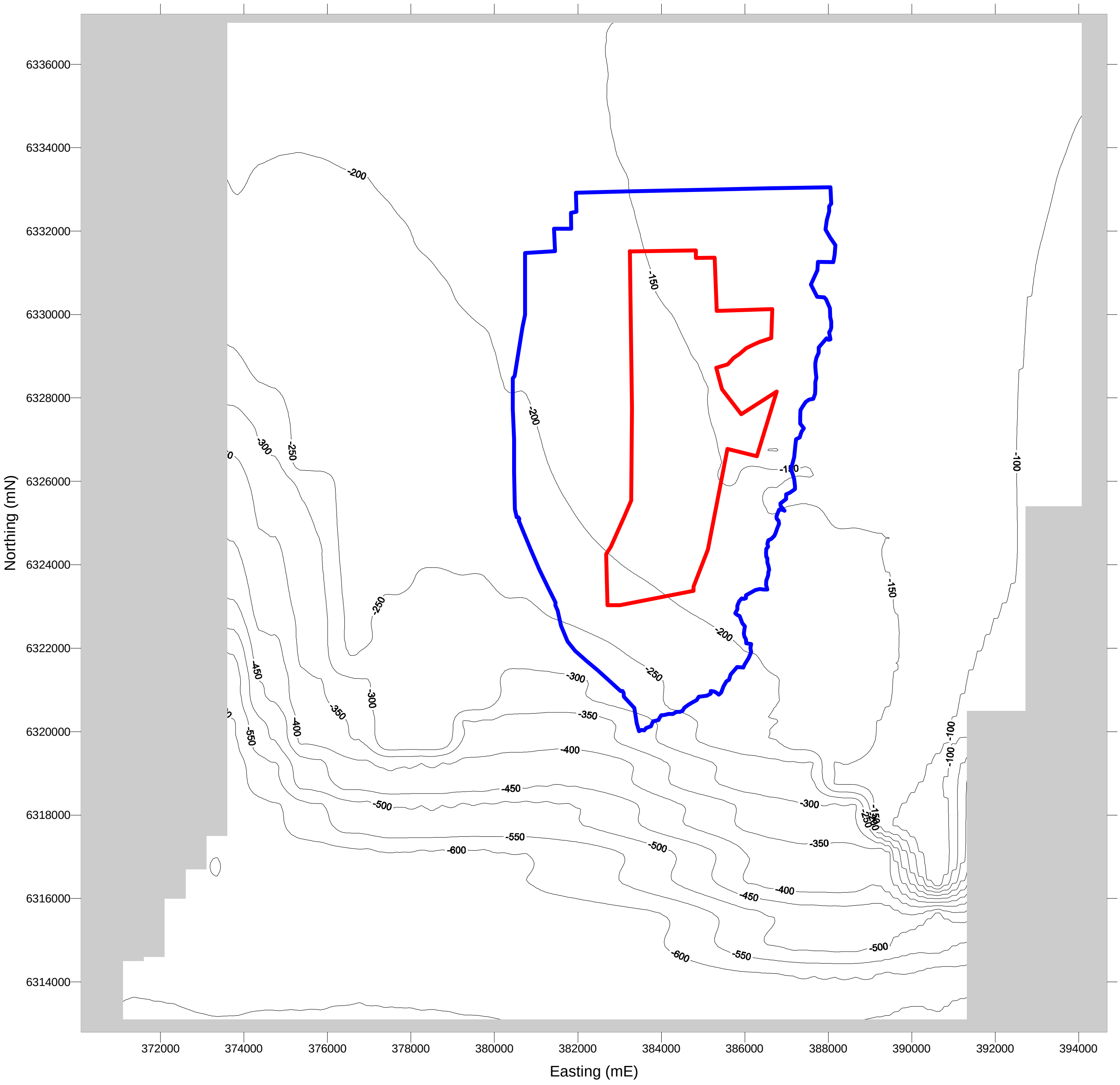
Note: Contours in mAHD

Top of Lower Leederville Fm - Layer 3
Figure F3



Note: Contours in mAHD

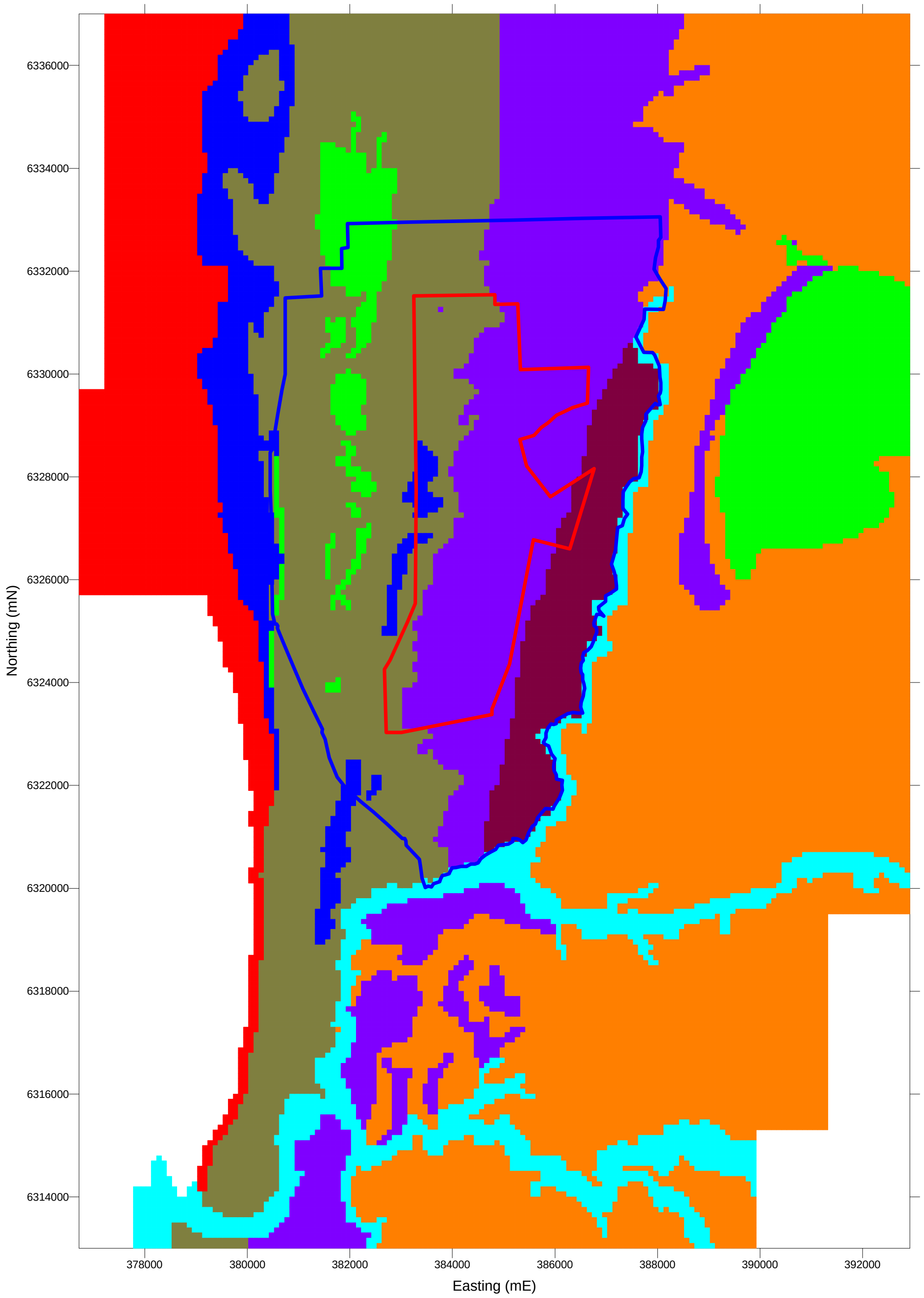
Top of Yarragadee Fm - Layer 4
Figure F4



Note: Contours in mAHD

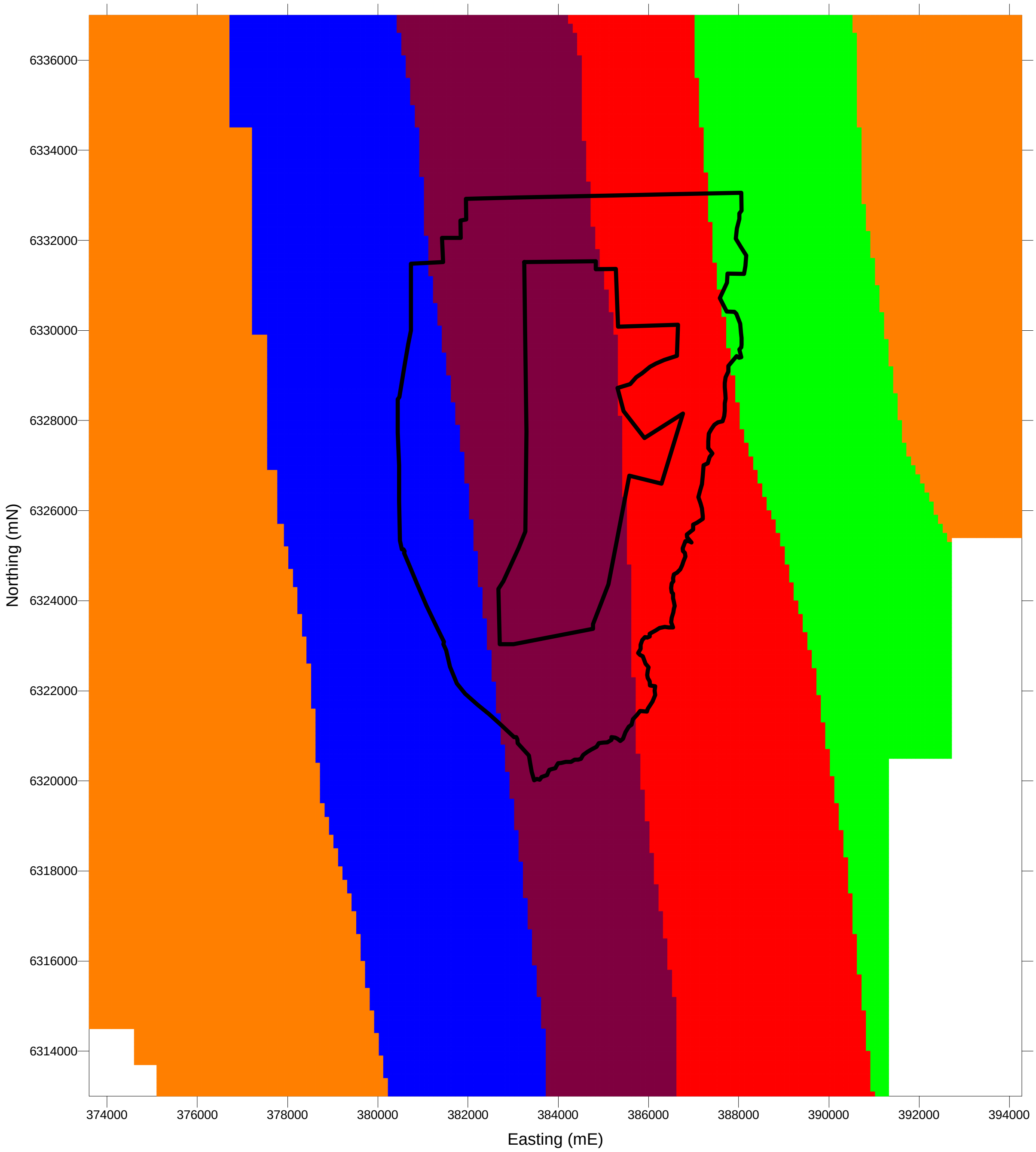
Top of Cattamarra Coal Measures - Layer 5

Figure F5



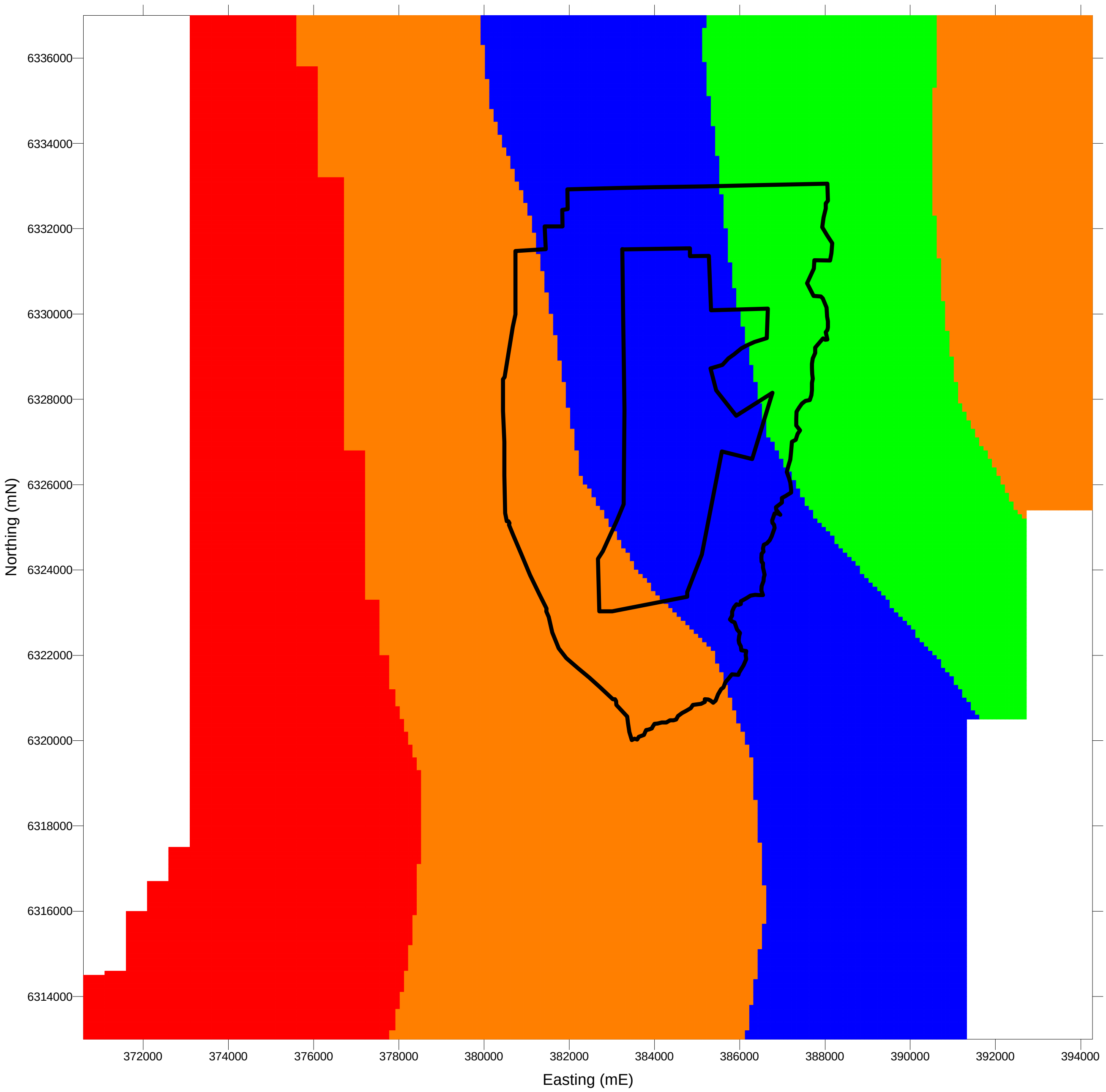
Key	Unit	Kh (m/d)	Kv (m/d)	Sy	Recharge
🟥	Safety Bay Sand	4.5	0.5	0.20	40%
🟦	Tamala Limestone	22	1.0	0.05	5%
🟪	Bassendean Sand	12.5	0.5	0.10	40%
🟫	Bassendean Sand	0.5	0.05	0.10	40%
🟫	Tamala Sand	4.5	0.5	0.10	20%
🟧	Guildford Formation	5.5	0.1	0.03	15%
🟦	Alluvial River Sediments	15	1.0	0.25	15%
🟩	Peaty Deposits	2	0.1	0.15	15%

Aquifer Parameters - Superficial Formation
Figure F6



Key	Kh (m/d)	Kv (m/d)	Sy	S
🟧	25	1 x 10^{-3} to 1 x 10^{-4}	0.01	2 x 10^{-4}
🟩	9.5			
🟥	4			
🟫	5.5			
🟦	16			

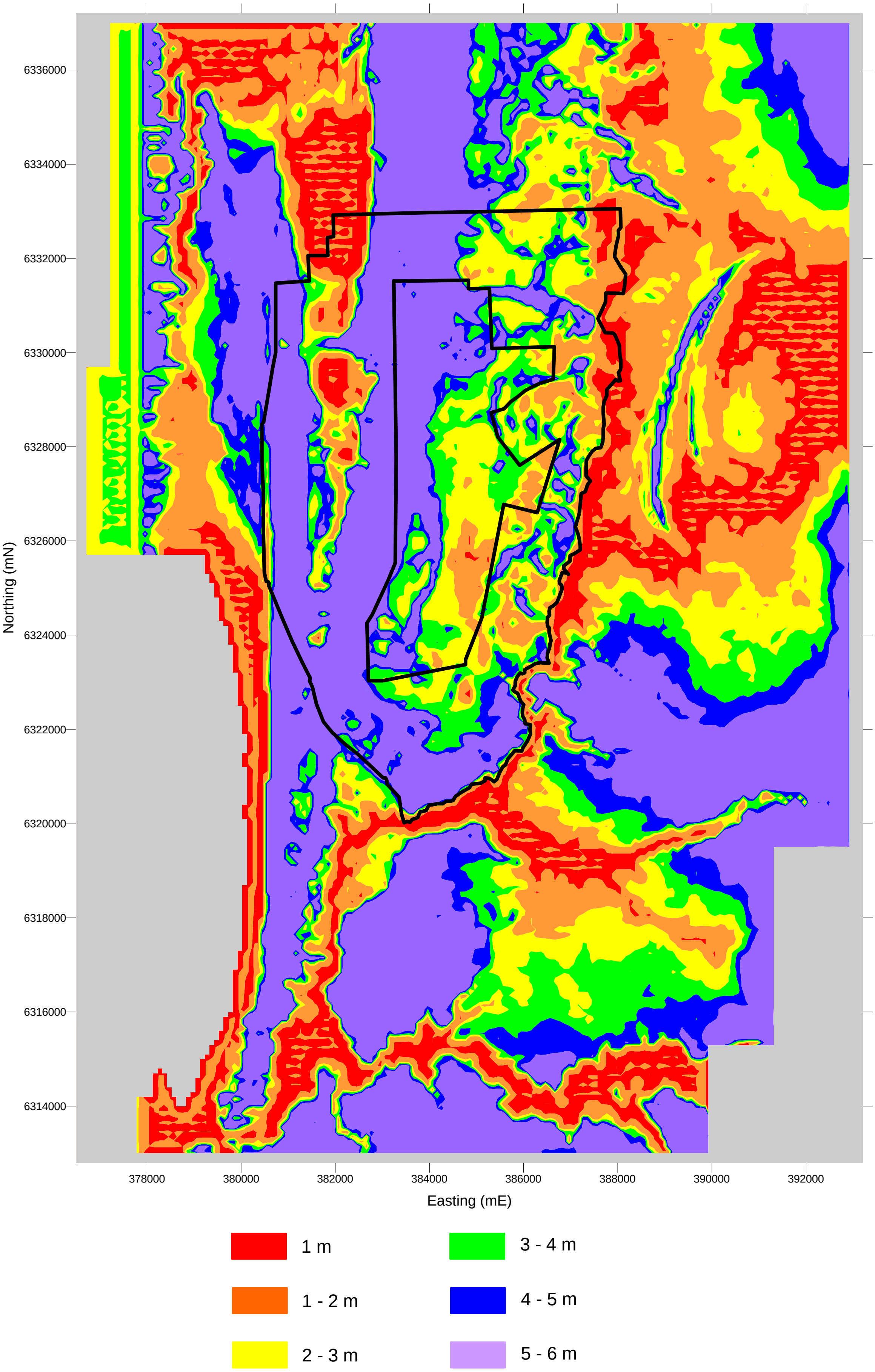
Aquifer Parameters - Leederville Formation
Figure F7



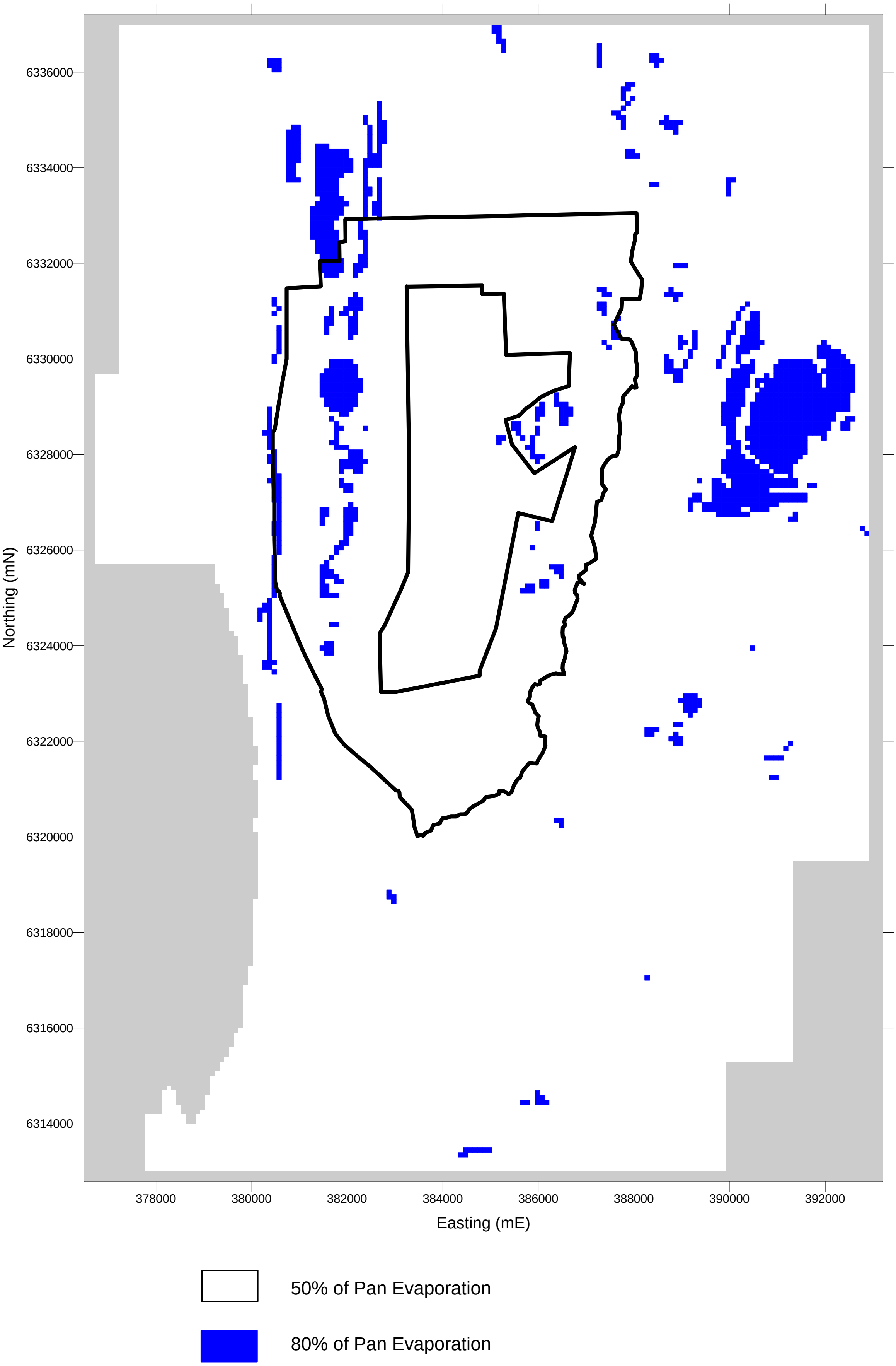
Key	Kh (m/d)	Kv (m/d)	Sy	S
🟧	25	5×10^{-5}	1×10^{-3}	2×10^{-4} to 2×10^{-5}
🟩	4			
🟥	4.5			
🟫	15			

Note: Confined storage of 2 x 10-4 for Yarragadee Fm and 2 x 10-5 for Cattamarra Coal Measures

Aquifer Parameters - Yarragadee Formation and Cattamarra Coal Measures
Figure F8

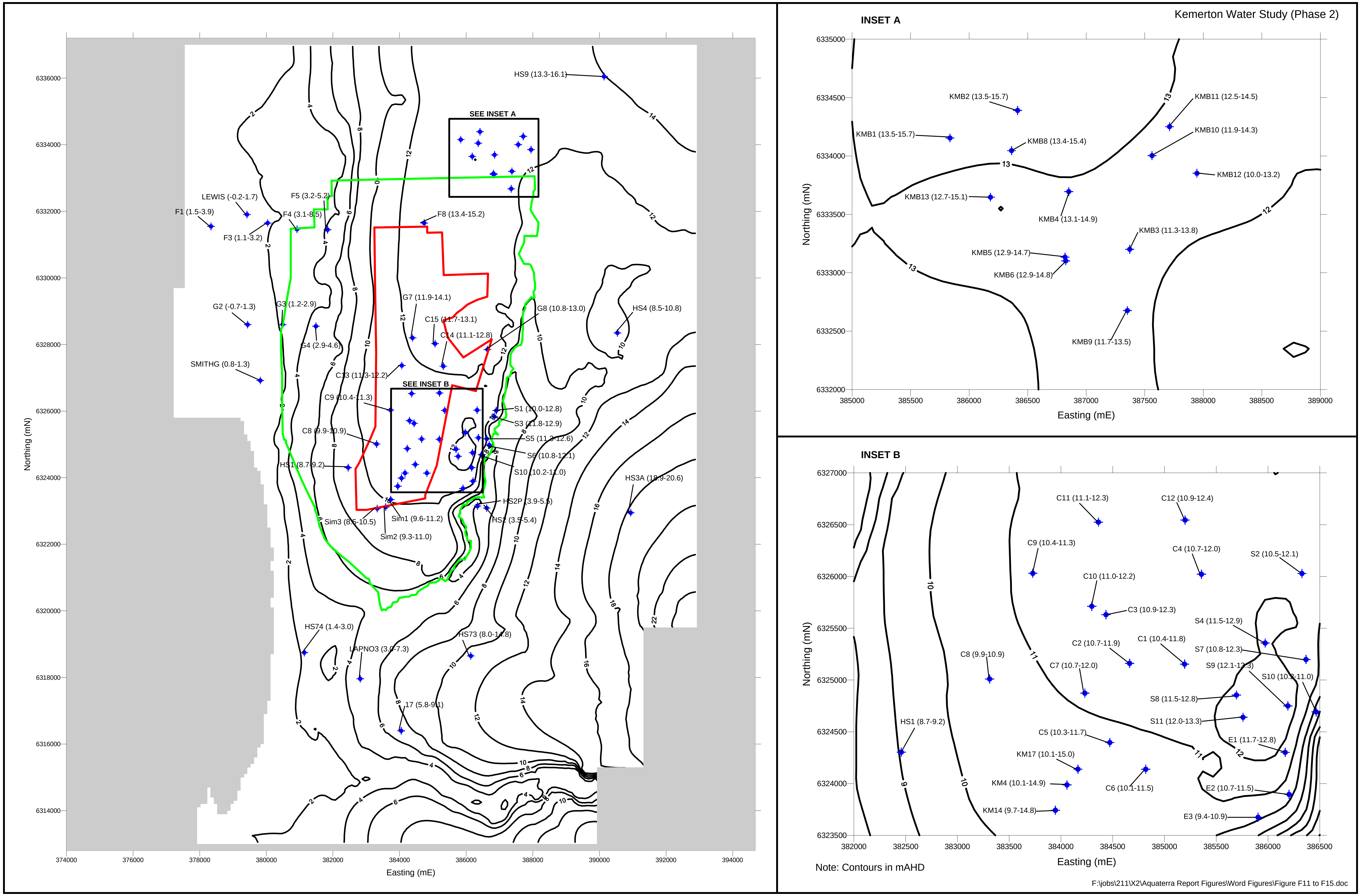


Evapotranspiration Extinction Depth
Figure F9



Evapotranspiration Rate
Figure F10

Kemerton Water Study (Phase 2)



Note: Contours in mAHD

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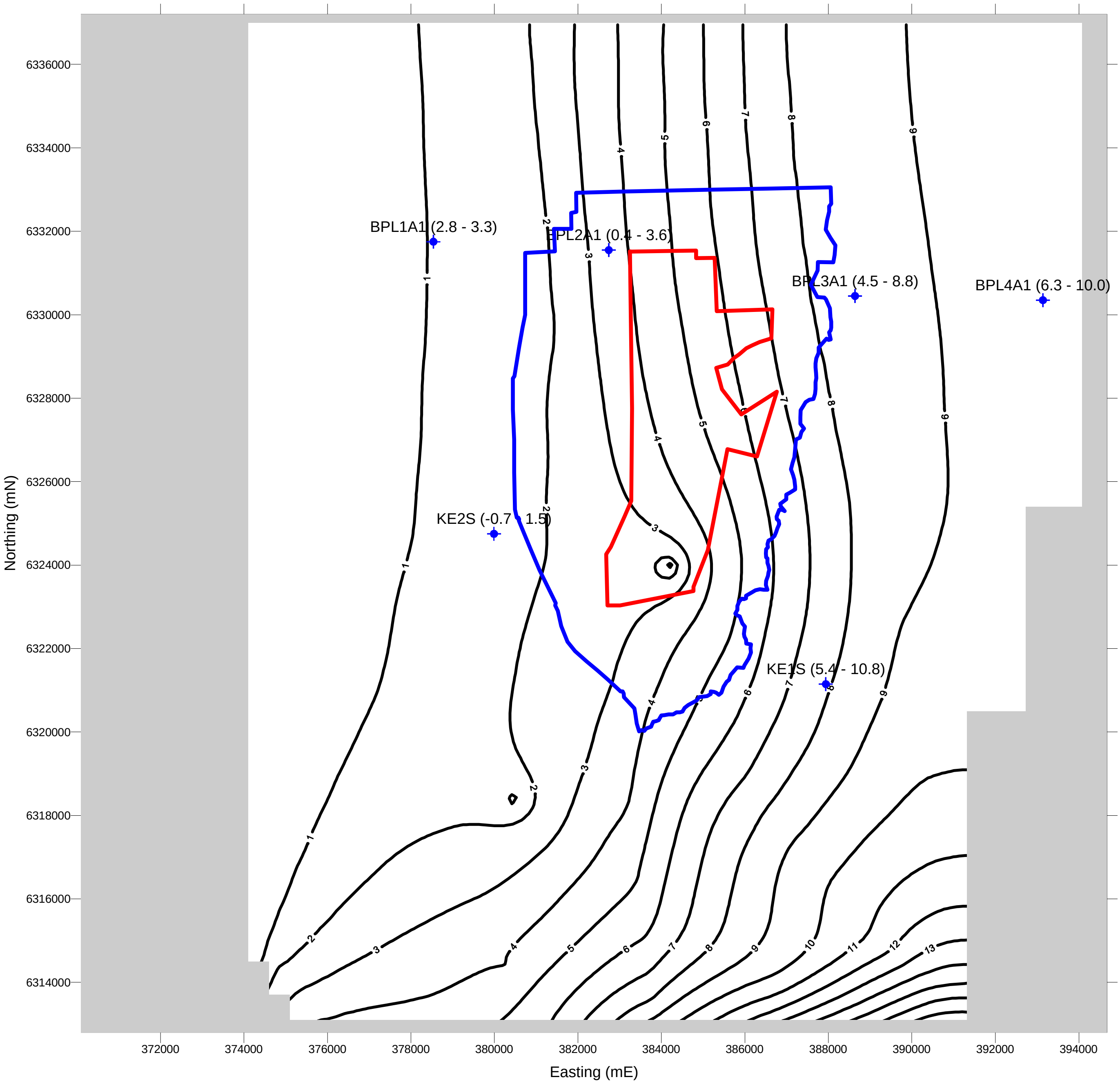
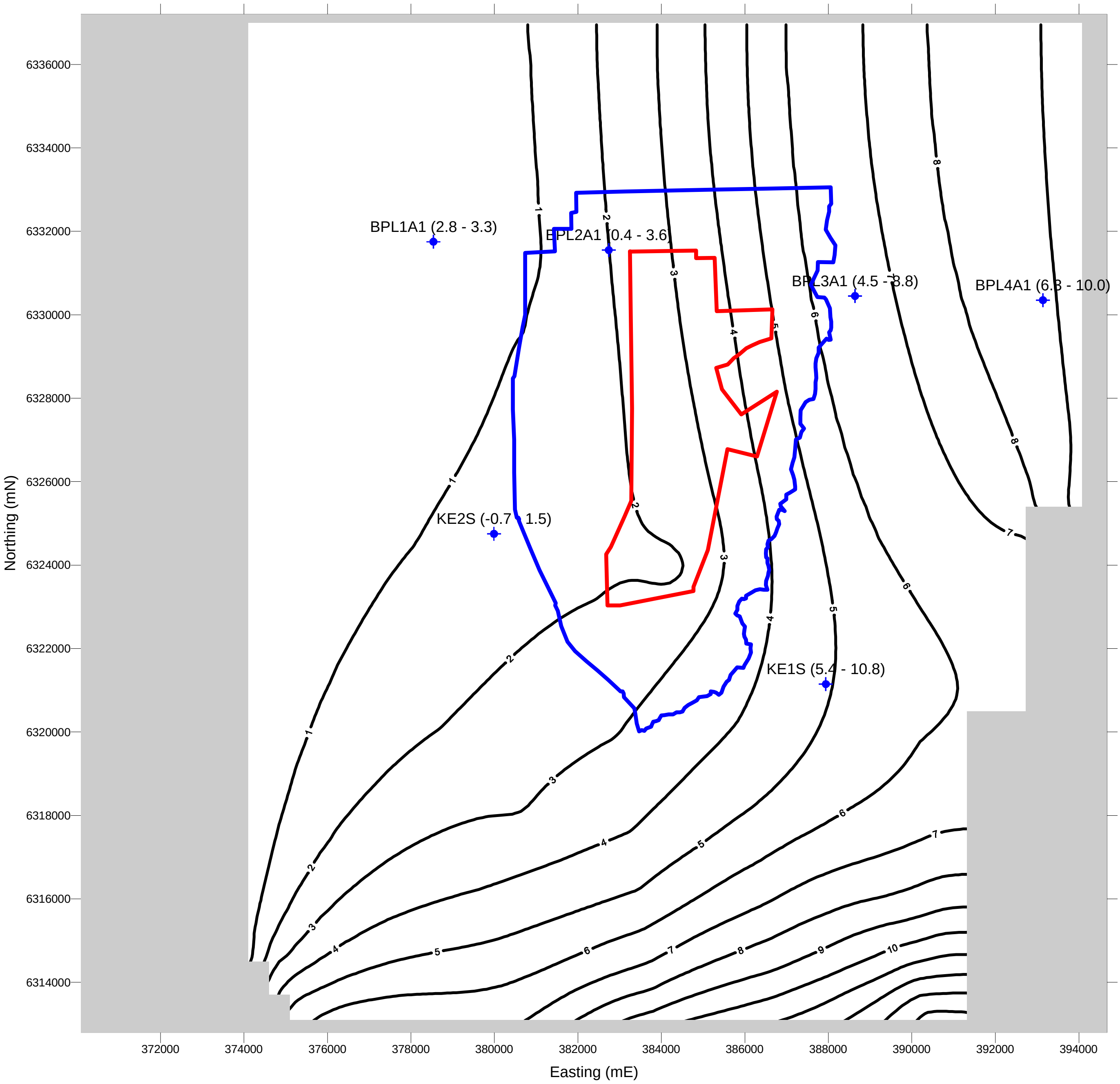
Steady State Heads and Range in Observed Heads (mAHD) - Superficial Formation (Layer 1)
Figure F11



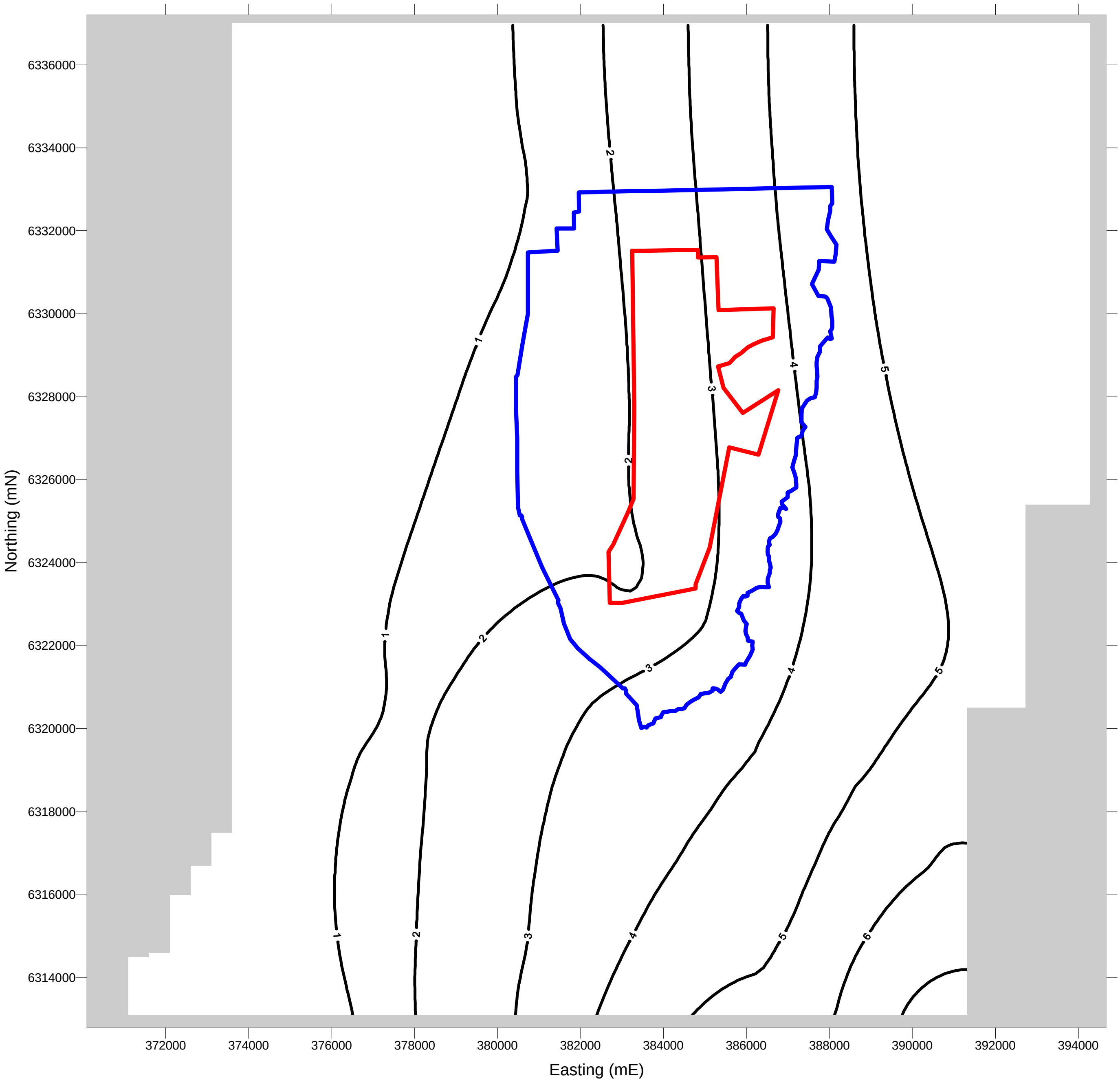
Note: Contours in mAHD

Steady State Heads and Range in Observed Head (mAHD)
Upper Leederville Formation (Layer 2)
Figure F12



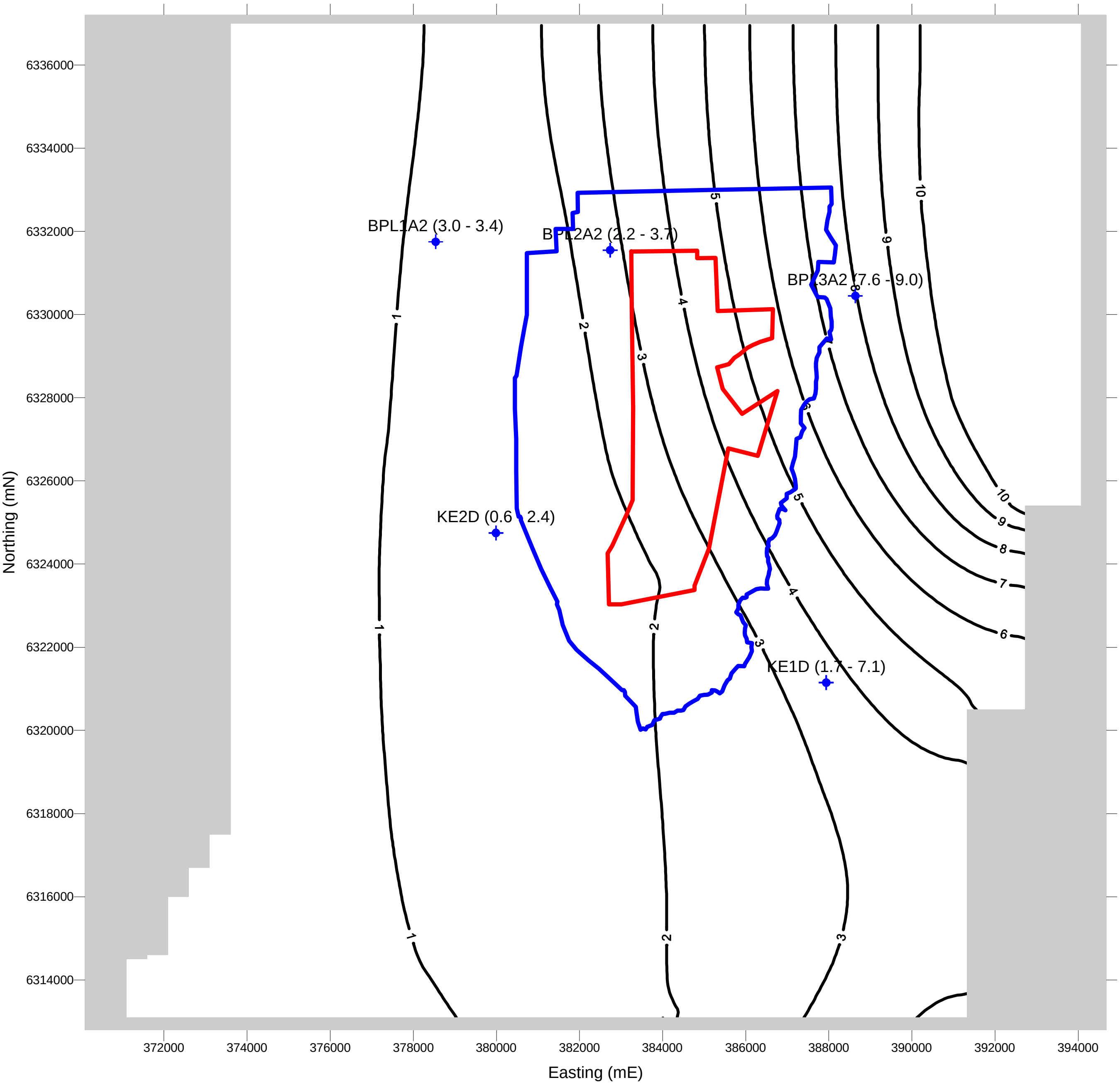
Note: Contours in mAHD

Steady State Heads and Range in Observed Head (mAHD)
Lower Leederville Formation (Layer 3)
Figure F13



Note: Contours in mAHD

Steady State Heads (mAHD)
Yarragadee Formation (Layer 4)
Figure F14



Note: Contours in mAHD

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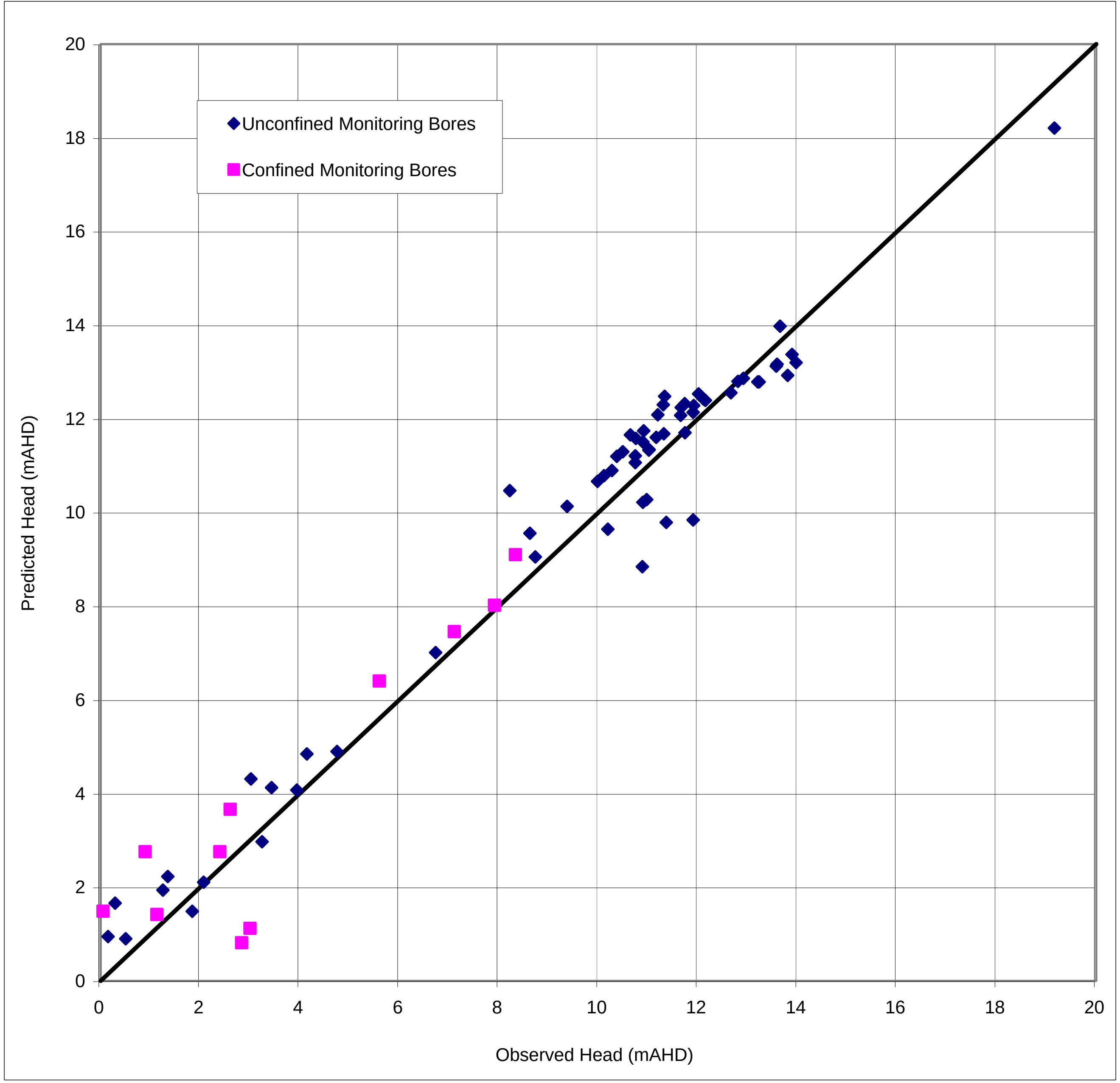
Steady State Heads and Range in Observed Head (mAHD)
Cattamarra Coal Measures (Layer 5)
Figure F15



Number of Unconfined Monitoring Bores	63
Number Confined Monitoring Bores	11
RMS Error	0.85m
Scaled RMS Error (Within guideline of 5%)	4.50%

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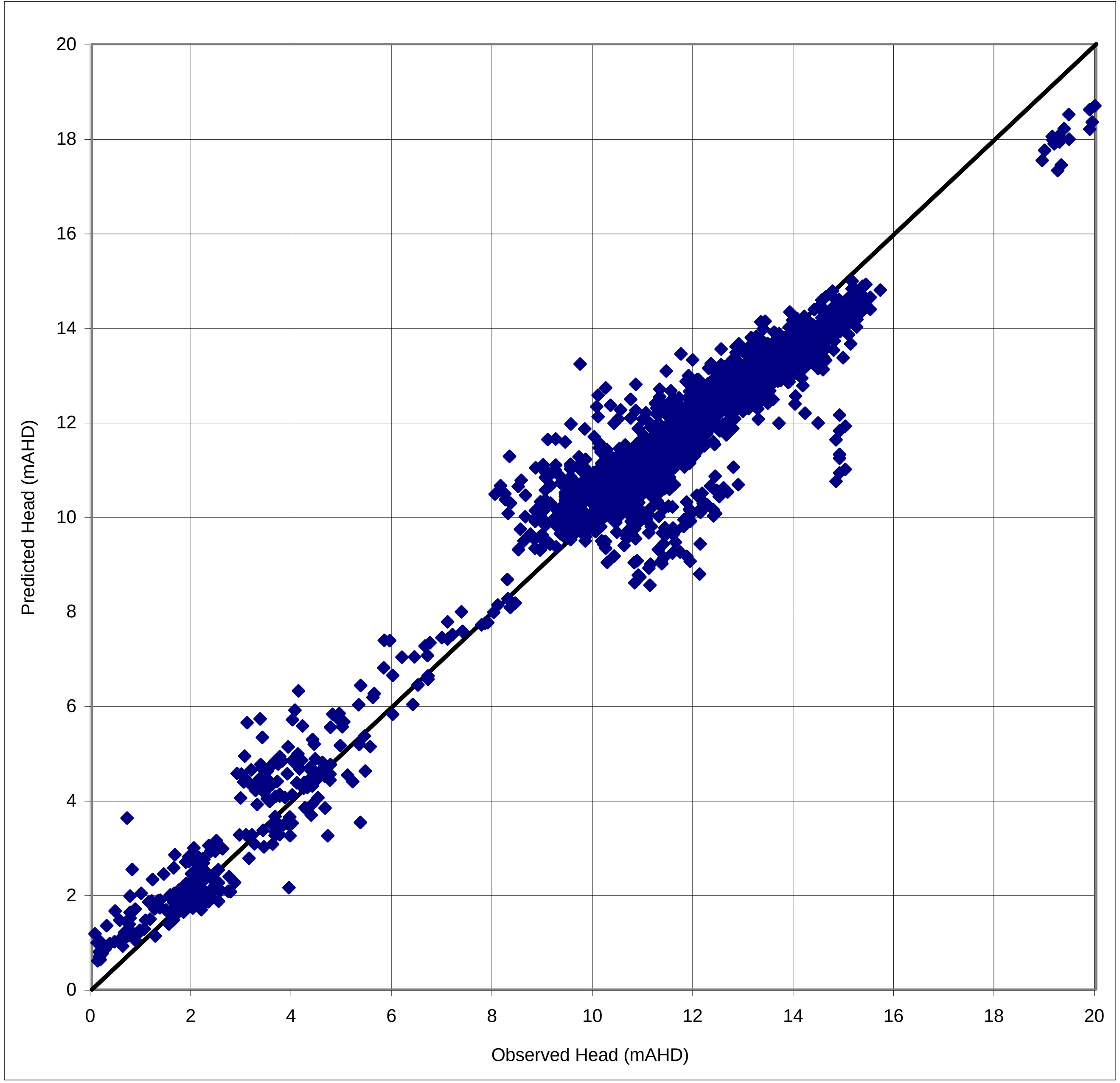
F:\jobs\211\B1\Data Processing\[Steady State Calibration.xls]Calibration Plot

Steady State RMS Calibration Plot

Figure F16



Number of Superficial Monitoring Bores	70
Number of Monitoring Data	2083
RMS Error	0.8m
Scaled RMS Error (within guideline of 5%)	3.70%

Note: Every measured data point from each superficial fm monitoring bore in transient calibration hydrographs was used in this plot

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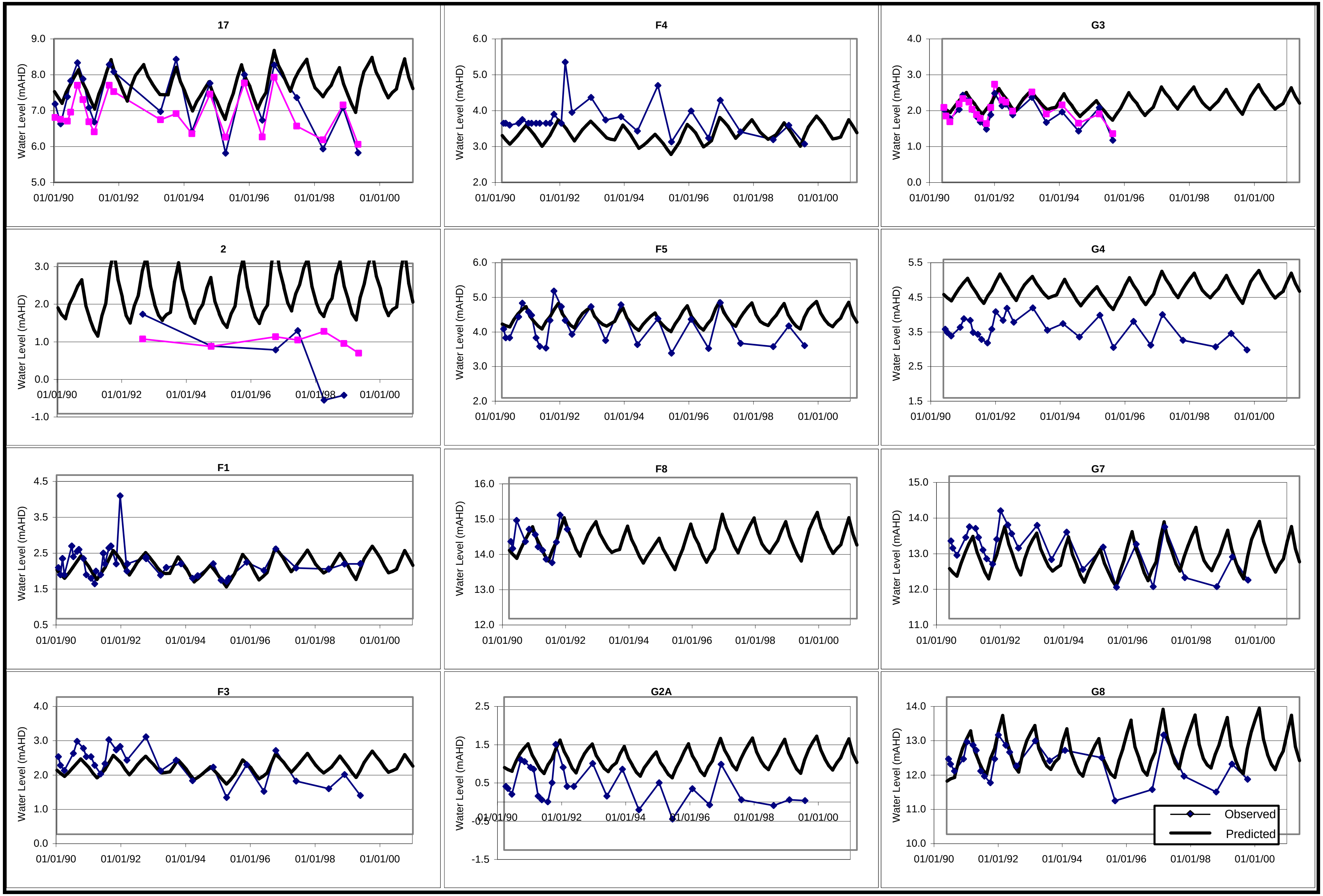
F:\jobs\211\B1\Data Processing\[Transient Calibration.xls]Calibration

Transient RMS Calibration Plot

Figure F17



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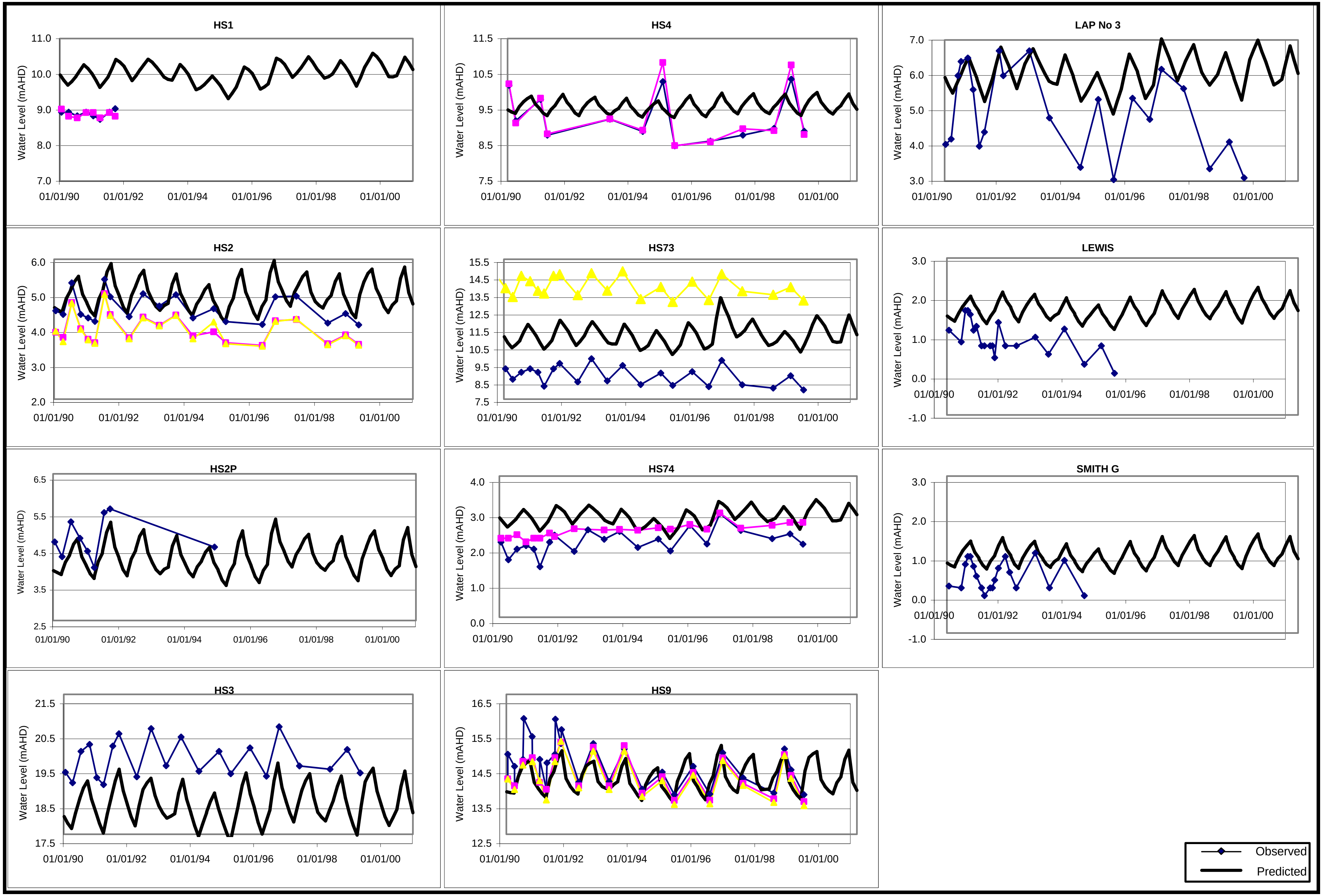
Transient Calibration - Superficial Aquifer Monitoring Bores

Figure F18

F:\jobs\211\B1\Data Processing\[Transient Calibration.xls]Calibration



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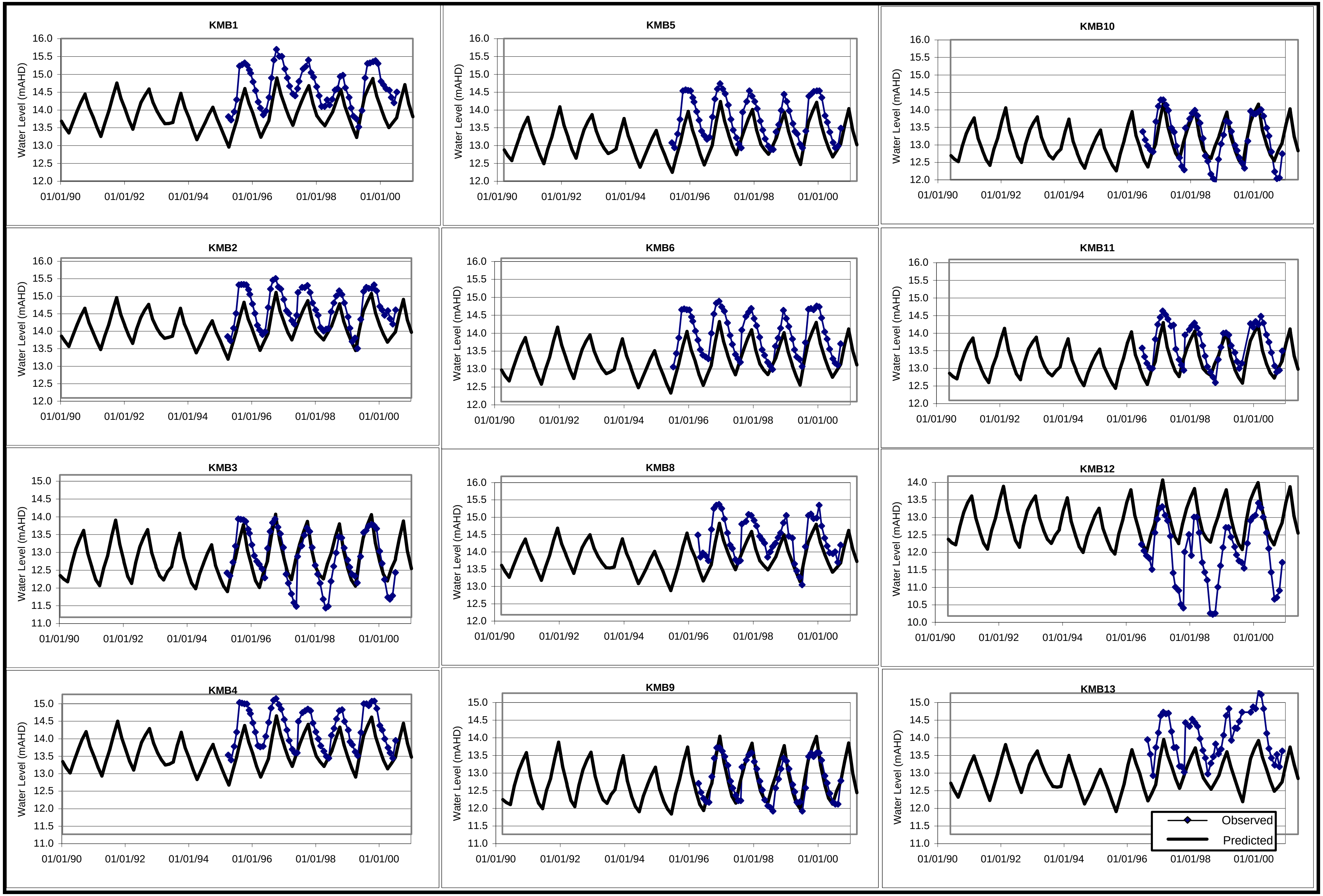
F:\jobs\211\B1\Data Processing\[Transient Calibration.xls]Calibration

Transient Calibration - Superficial Aquifer Monitoring Bores

Figure F19



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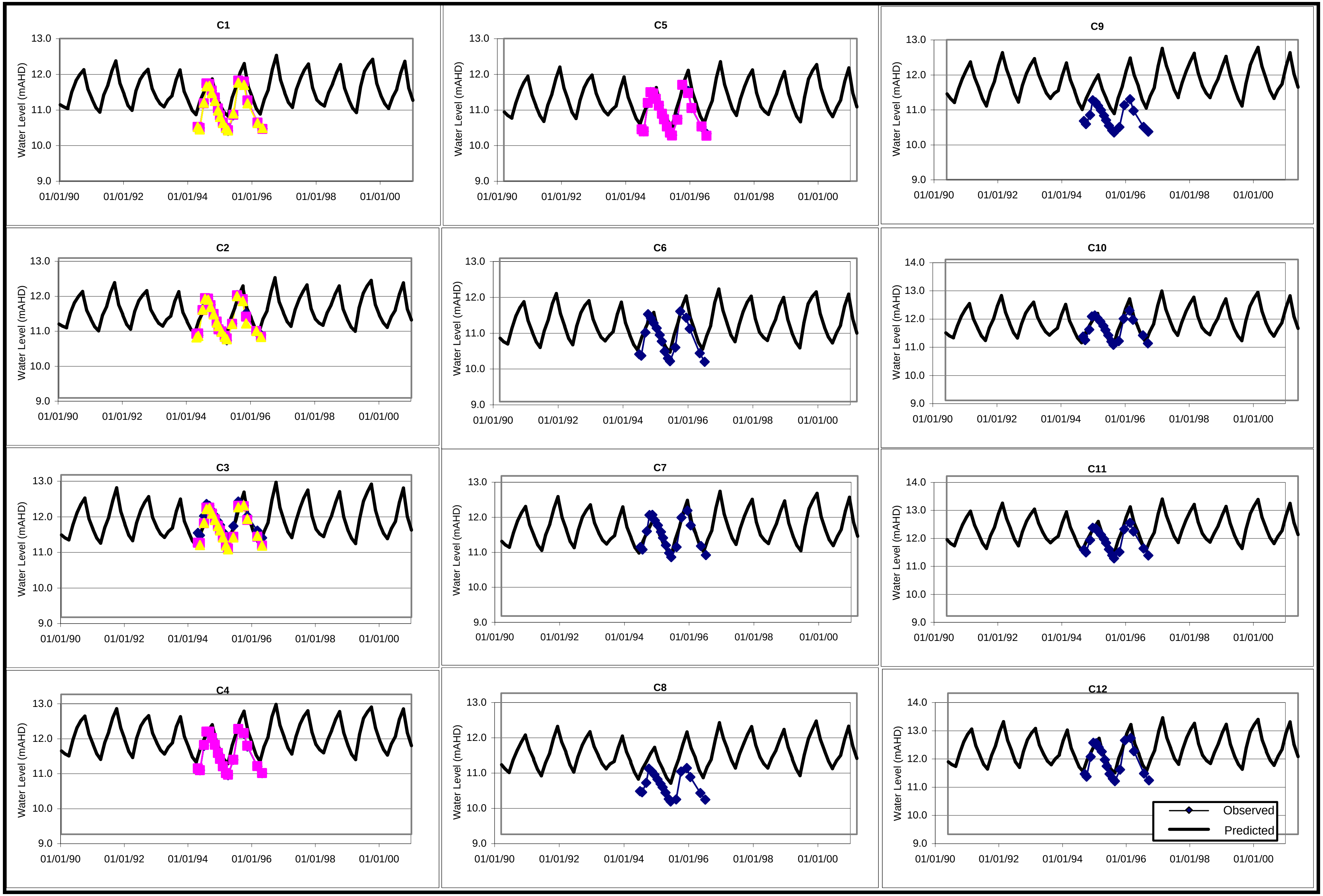
F:\jobs\211\B1\Data Processing\[Transient Calibration.xls]Calibration

Transient Calibration - Superficial Aquifer Monitoring Bores

Figure F20



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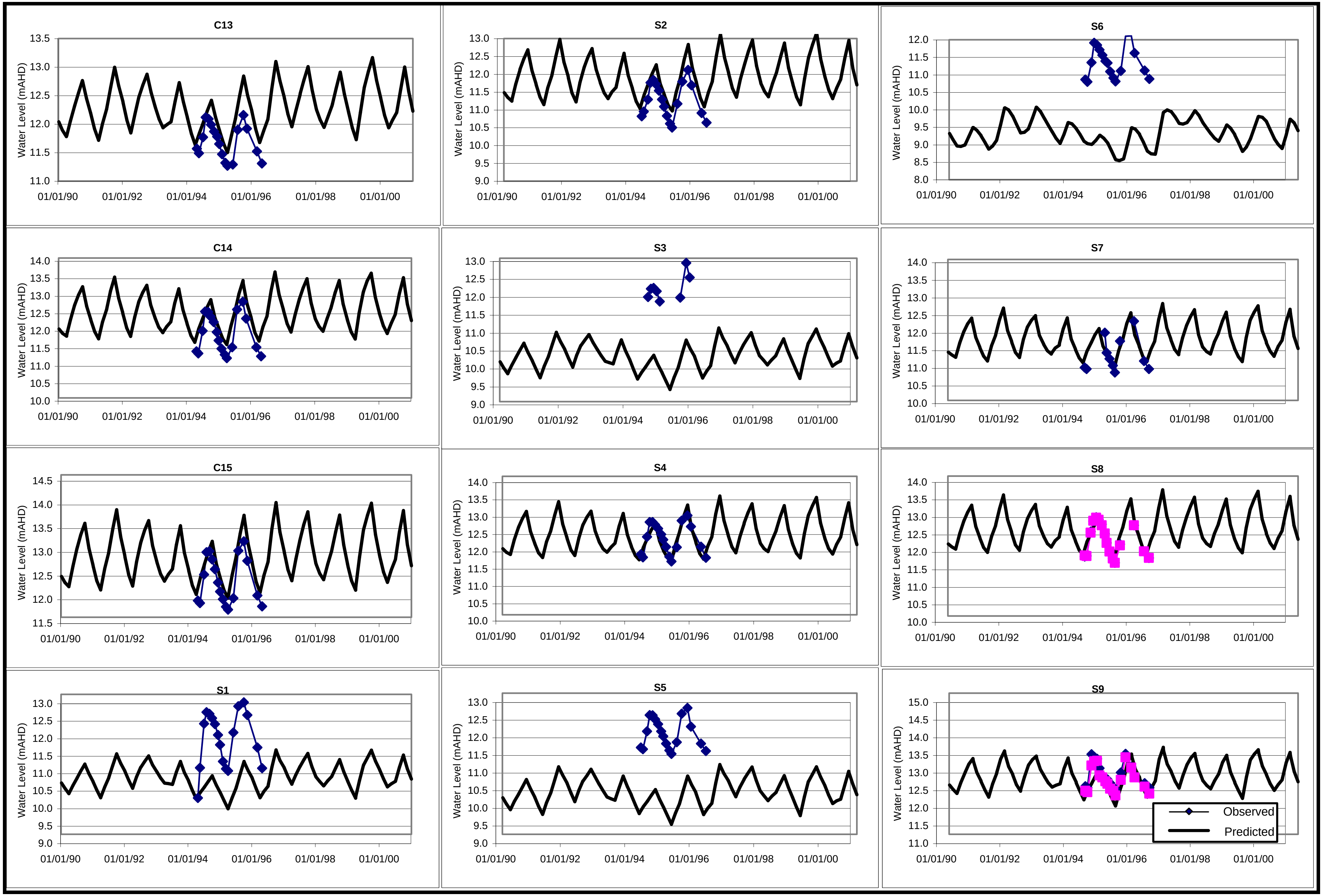
Transient Calibration - Superficial Aquifer Monitoring Bores

F:\jobs\211\B1\Data Processing\[Transient Calibration.xls]Calibration

Figure F21



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Transient Calibration - Superficial Aquifer Monitoring Bores

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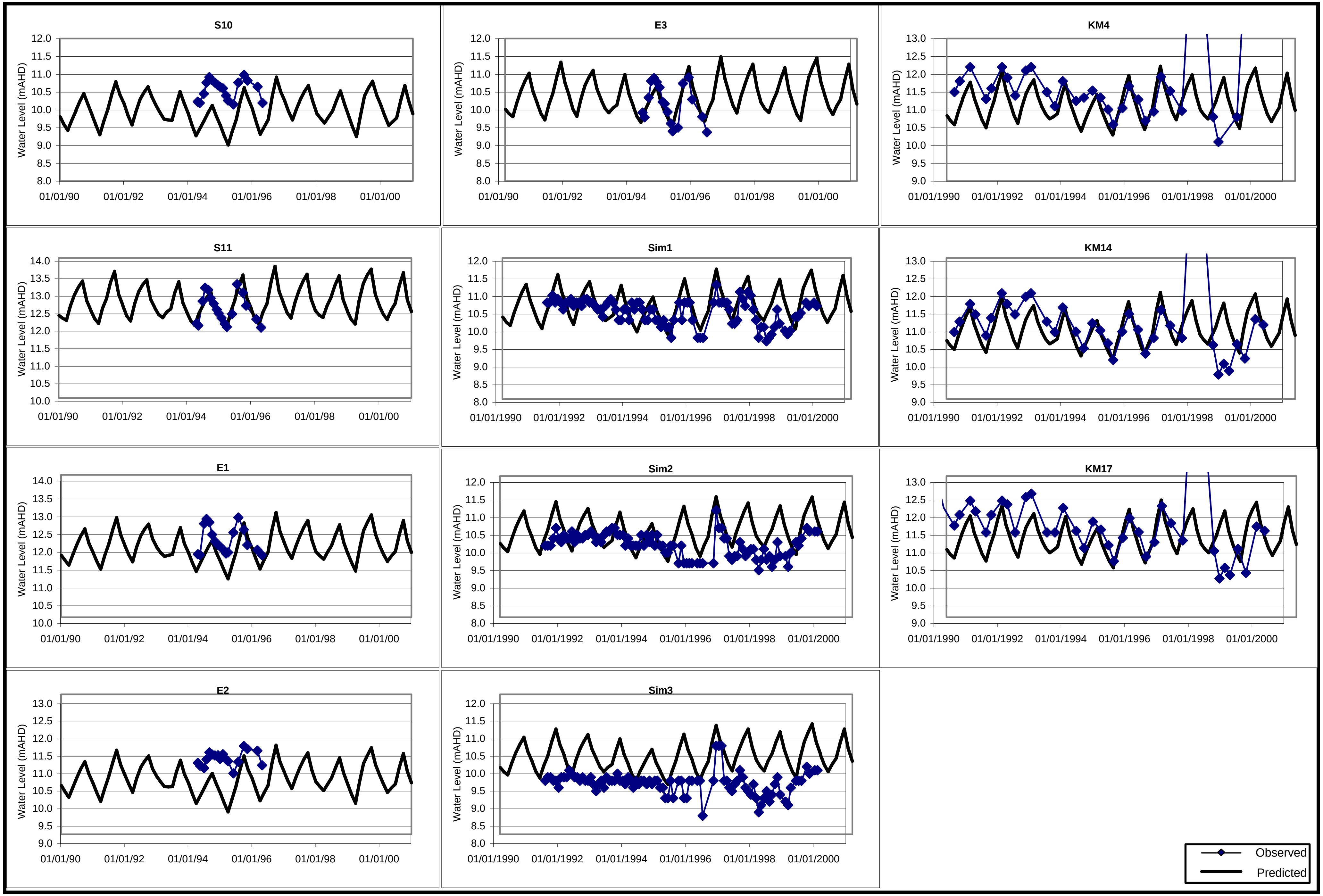
Figure F22



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Transient Calibration - Superficial Aquifer Monitoring Bores

Figure F23

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Transient Calibration - Confined Aquifer Monitoring Bores

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Figure F24

APPENDIX G

GROUNDWATER MODELLING GUIDELINES

International Hydrology and Water Resources Symposium, HYDRO 2000, Perth, Western Australia, November 20-23, 2000.

The development of Australian guidelines for groundwater flow modelling.

Hugh Middlemis [1], Noel P. Merrick[2], John M. Ross[3] and Kathryn L. Rozlapa[1].

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Abstract

Management strategies for resource allocation and control of resource degradation are increasingly dependent on the credibility of models. In a project sponsored by the Murray-Darling Basin Commission, best practice guidelines have been developed for application to groundwater flow modelling projects. The project was undertaken to address concerns, often from community groups, about the consistency and suitability of modelling methodologies being applied to a range of natural resource management projects. The guidelines are designed to encourage consistency and transparency in model development, and to provide guidance to modellers and end-users to assess whether models are fit for purpose, calibrated to agreed targets, and adequately documented and reviewed. A detailed model review methodology (with checklists), and a model study brief structure, are presented in the guide. Compliance with the guidelines will encourage best practice and reduce the level of uncertainty for decision-makers relying on model results. Solute transport methods and unsaturated zone modelling are not within the scope. A national workshop process was undertaken to review the draft guide, and achieve consensus regarding practical and implementable guidelines. Consultants, government agencies, academics, and community representatives from rural and regional Australia provided workshop input. Negotiations are in progress for the national adoption of the best practice guidelines to be applied to the process of groundwater flow model design, calibration, prediction, uncertainty management, reporting and review.

1.0 Scope of Guidelines

In a project sponsored by the Murray-Darling Basin Commission (MDBC), best practice guidelines have been developed for application to groundwater flow modelling projects in the Basin, although the approaches are suitable for application to flow modelling projects generally. A national workshop process was undertaken to review the draft guide, and achieve consensus regarding practical and implementable guidelines. The guide is designed to be applied with flexibility to simple, small scale, small budget groundwater flow modelling jobs, as well as much larger and more complex regional modelling studies with substantial resource management implications. There has been a particular emphasis on producing best practice guidelines that provide technical support to modellers, and are also meaningful and useful to the community. A “plain English” summary guide is also being developed specifically for use by the community.

The guidelines are to be applied to new groundwater flow modelling studies and reviews of existing models. Solute transport and unsaturated zone modelling methodologies are not within the scope. Some specialised aspects are also not addressed comprehensively in the guide, notably detailed methodologies for dealing with recharge, evapotranspiration from shallow water tables, and associated links between agricultural activity and these processes, although general aspects are addressed.

This paper cannot document all aspects of the guidelines, and it is intended to present summaries of only the key issues. The reader is referred to the MDBC website (mdbc.gov.au), where a full copy of the guideline will be available in late 2000.

2.0 Resource Management Process

The development and evaluation of resource management strategies for sustainable water allocation, and for control of land and water resource degradation, are heavily dependent on groundwater model predictions. Models are also used at a range of scales to assess salinity and drainage strategies, simulate effects on groundwater dependent ecosystems, evaluate irrigation development and drainage impacts, optimise salt interception schemes and disposal basins, and investigate dryland salinity processes. Models are also used to quantify impacts and develop management plans for the water supply, dewatering, discharge and waste management aspects of projects such as feedlots, effluent re-use, residential and commercial property development, and mining developments.

In this context, groundwater models provide a relevant and useful scientific tool for predicting impacts and developing management plans. At the workshop to review the draft guidelines, it was clearly acknowledged that groundwater models should be seen as an integral part of the water resource management process. This is a developing area as models are increasingly being used to demonstrate the effects of proposed developments and alternative policies to stakeholders and communities, for the purposes of gaining consensus on improved allocation distributions and management plans. This is regarded as a valuable process, and its continued success depends substantially on the ability of modelling teams to communicate the results of modelling in terms that are meaningful to the communities that are affected by the decisions based on the model findings.

3.0 Need for Guidelines

There is a perception amongst end-users of model studies in the Murray-Darling Basin that model capabilities may have been "over-sold". There is also a lack of consistency in approaches, communication and understanding among and between modellers and end-users, which often results in considerable uncertainty for decision-making on resource management. The decision-making uncertainty applies at all stages throughout model studies:

- at the initiation of a modelling study, when objectives and study purpose may have been poorly considered or specified, or data availability, integrity and reliability was uncertain;
- during the study, when poor communication may result in models being developed that are not fit for purpose;
- at the end of a study, when the modelling results may not have been well presented to, or understood by, clients.

There is a need for guidelines to reduce the level of uncertainty for model study clientele, including resource management decision makers and the community, by promoting transparency in modelling methodologies and encouraging consistency and best practice. Guidance is needed for non-specialist clientele to outline the steps involved in scoping, managing and evaluating the results of groundwater modelling studies. Guidance is also needed for modelling specialists to indicate the technical standards expected to be achieved for a range of project scopes.

4.0 Application of Guidelines

The main user group for these guidelines is land and water management planning groups, and resource and technical staff in government agencies, engineering and hydrogeological consultancies, and the Murray-Darling Basin Commission (MDBC), the sponsor for this work. The integration of modelling into the water resources management process has commonly required multi-layer numerical models to be developed at the semi-regional or regional scale. The guidelines are, therefore, particularly relevant and applicable to regional scale water resources studies of that type, although they have been designed for the application of a flexible approach to a wide range of study scopes and hydrogeological conditions.

The guide should be seen as a best practice reference point for framing modelling projects, developing appropriate models, and assessing model performance. The intention is not to provide a prescriptive step-by-step guidance, as the site-specific nature of each modelling study renders this impossible, but to provide overall guidance and to de-mystify the complex modelling process. As is the case with the ASTM guidelines (see Literature Review section), the guide offers an organised collection of a series of options and does not recommend a rigid course of action. The guide must be used in conjunction with experienced professional judgment, and it does not replace the standard or duty of care of professional service.

This guide is intended for use in raising the minimum standard of practice, without limiting the creativity required for good modelling practice, or rigidly specifying standard methods. The guidelines also should not limit the ability of modellers to use simple or advanced techniques, appropriate for the study purpose. All aspects of the guide would not necessarily be applicable to every study. It should also be acknowledged that standardisation of modelling methods will not preclude the need for some subjective (and preferably experienced) judgment during the model development process (Ritchey and Rumbaugh, 1996).

There is much value associated with plans to use the guidelines in specialist training courses for modellers, and also in using the guide in training courses for the community on scoping, managing and reviewing modelling projects.

5.0 Literature Review

To develop the guideline document, the best and most applicable aspects of the published guides and standard text books have been identified from a literature review (documented in the full guide), and adapted for application to Australian conditions and to resource (flow) modelling issues on a range of project scopes. In addition to outlining these best practice standards, a number of innovative methods and performance indicators have been developed for the evaluation of model calibration and prediction accuracy, uncertainty assessment, and review protocols.

The notable international guideline is the suite of Standard Guides from the American Society for Testing and Materials (ASTM), which are reasonably well accepted standard practice guidelines. However, the ASTM guides, and most other guideline documents and text books, are intended for application by specialist modellers to flow and solute transport modelling. They are therefore not directly applicable to this guideline, which is restricted to groundwater flow modelling methodologies, and which must also take account of the need for community involvement in the modelling study.

Published guidelines and texts are quite consistent in regard to the accepted general approach to groundwater modelling, represented by the flow chart in Figure 1. There may be greater or lesser emphasis on certain aspects, depending on the application of the guideline/text, but there is an identified need for substantial iteration/feedback between the various steps in the approach (refer next section). This accepted approach has been adopted for these guidelines, with modification where considered appropriate to suit the conditions under which the guidelines may be implemented in Australia, and expansion in certain areas to encourage improvements to modelling practice. Every modelling study involves the iterative development of a model, including the conceptual model foundation. Model refinements are based on upgrades to the data quality and volume, hydrogeological understanding, and clientele/community expectations, as indicated by the various feedback loops in Figure 1.

6.0 Best Practice Methodology

In summary, the literature review identified the following strategic approach for achieving modelling study best practice, which has been used to design the guidelines:

- Clearly state, at the outset, the model study objectives and the model complexity required.
- Adopt a level of complexity that is high enough to meet the objective, but low enough to allow conservatism where needed.
- Develop a conceptual model that is consistent with available information and the project objective.
- If possible, an experienced hydrogeologist/modeller should undertake a site visit at the conceptualisation stage.
- Model development should be undertaken in three main stages, as indicated in Figure 1, with a check point for reporting and review at the end of each stage:
  - Conceptualisation
  - Calibration and verification, and
  - Prediction.
- Address the non-uniqueness problem by using measured hydraulic properties in the model, and calibrating to data sets collected from multiple distinct hydrologic conditions (if possible).
- Perform an assessment of the model uncertainty by undertaking application verification, and sensitivity or uncertainty analysis of calibration and prediction simulations, as appropriate for the study.
- Provide adequate documentation of the model development and predictions.
- Undertake peer review of the model at various stages throughout its development, and to a level of detail appropriate for the model study scope and objectives.
- Maintain effective communication between all parties involved in the modelling study through regular progress reporting (technical issues and project management) and review.

The definition of the study objectives and the model complexity (see next section), and the development of an adequate conceptual model are acknowledged as the vital first steps in a modelling programme. A conceptual model is a simplified representation of the key features of the physical system, and its hydrological behaviour. It forms the basis for the site-specific computer model, but is itself subject to some simplifying assumptions. The assumptions are required partly because a complete reconstruction of the field system is not feasible, and partly because there is rarely sufficient data to completely describe the system in full detail.

The conceptual model should be developed using the principle of *parsimony*. In other words, the model should be kept as simple as possible, while retaining sufficient complexity to adequately represent the physical elements of the system, and to reproduce hydrological behaviour. However, the model features must be designed so that it is possible for the model to predict system responses that range from desired to undesired outcomes. In other words, the model must not be configured or constrained such that it artificially produces a restricted range of prediction outcomes. The integration of peer review at several critical stages through the project is another important method of improving modelling practice. The Australian guide proposes that reviews need to range from simple *model appraisal* using a checklist for simple models, through to more comprehensive *peer reviews* and complete *model audits* for more challenging complex models.

7.0 Complexity

The introductory ASTM guide (D5880) introduces the term *model fidelity*, with the scale from low to high fidelity being borrowed from the audio electronics field. The Australian guidelines prefer the term *model complexity*, but adopt the same definition as the degree to which a model application resembles, or is designed to resemble, the physical hydrogeological system. The main reason to adopt the term *complexity* rather than fidelity, is to try to avoid the assumption that a high fidelity model is somehow better than a low fidelity model (Frans Kalf, pers.comm.). The community representatives at the workshop also disliked the moral overtones associated with “fidelity”. It is important for modellers to remember that we must engage in valid communication with our clientele, and that communication is a two-way street. This means that we must use terms that are meaningful to clients, and we must not dilute the message regarding resource management by using terms that are not understood or are misunderstood.

Three main model purposes have also been adapted for this Australian guide from the ASTM guide. They are Basic, Impact Assessment and Aquifer Simulator models, in order of increasing complexity (compared to Screening, Engineering Calculation and Aquifer Simulator terms from the ASTM guide). The relationship between these concepts is outlined in Table 1. It is clear that the study purpose and objectives must be carefully considered and clearly stated at the outset of any modelling study to develop an adequate tool with the appropriate complexity consistent with the study objective and resources available.

Table 1 - Scoping a Modelling Study

Complexity	**Model Purpose** • Typical Characteristics	**Examples of Specific Objectives**	**Typical Data Requirements**	**Typical Budget**	**Typical Schedule**
Basic	**Simple Model** • Rough calculations • Simple assessment • Simple groundwater systems • Often uses analytical modelling approach	• Determine the observation bore network to suit a pumping test • Predict the long term drawdown due to abstractions from a proposed water supply bore • Determine the preliminary dewatering requirements for an excavation or mine • Assess the preliminary effects of discharge from wastewater plants or stormwater detention basins	• Can be completed with limited site-specific data • Parameters often obtained from literature review • Requires application of experienced judgment	$2,000 to $8,000	<1 month
Moderate	**Impact Assessment Model** • Specific question posed • Prediction of impacts of proposed development • Conservative assumptions adopted where data or understanding is lacking, such that model predictions are conservative • Usually requires numerical modelling approaches, but analytical methods may be suitable	• Determine the abstractions required for water supply developments (eg. for towns, remote communities) or dewatering (eg. for mines, construction, or salinity drainage), and predict the associated impacts • Design groundwater management schemes (eg. irrigation, aquifer storage & recovery, or salinity mitigation) and predict the effects on aquifers, rivers and GDE's* • Define source protection zones for public water supply borefields	• Some site specific data required, especially in more developed areas • Dewatering problems require good data on aquifer geometry and parameters • Water supply problems require good data on hydrological variability • Conservative approach where data limited	$10,000 to $100,000	1 month to 6 months
Complex	**Aquifer Simulator** • Suitable for predicting the response of the system to arbitrary changes in hydrologic conditions • Required for reliable water resource allocation and optimisation, assessment of stream-aquifer interaction, GDE's*, etc. • Usually requires numerical modelling approach (complex analytical methods may suit)	• Determine the sustainable yield of a groundwater system, and define optimal resource allocations and GDE* impacts • Evaluate the major flow processes causing dryland salinity in a catchment, predict and assess options for lowering water tables in a specified time frame • Determine the long term water balances and impacts within intensive irrigation areas • Assess the performance of groundwater interception schemes.	• Detailed and comprehensive data required, with ongoing monitoring and interpretation • Staged development recommended, with monitoring being guided by model results • Uncertainty assessment may be used where data availability is limited	>$50,000	>6 months

GDE = groundwater-dependent ecosystem

In simple terms, model complexity can be described by the "quick-cheap-good" paradox. The end-user can readily obtain a model with one or two of these three attributes, but not all three. If a model is required to be done quickly, it can also be done cheaply, but the results may not be good enough on which to base important resource development or management decisions. Such a low complexity model may be good enough for rough calculations to guide a field programme, or to assess the broad impacts of a certain proposal, but would usually not be sufficient for project approval or licensing purposes. Alternatively, if a good, reliable model is required, then it is not likely to be able to be developed quickly or cheaply.

8.0 Calibration and Performance Measures

The guide recommends that the success of model calibration should be evaluated in both quantitative (statistical) and qualitative (pattern-matching) terms, to evaluate the degree of correspondence between a simulation and site-specific information. Quantitative measures usually involve mathematical and graphical comparisons between measured and simulated aquifer heads, and the calculation of statistics regarding residuals (the difference between measured and simulated aquifer heads). Quantitative measures can also include comparison of simulated and measured components of the water budget, notably surface water flows, groundwater abstractions and evapotranspiration estimates. Qualitative assessment of calibration is commonly undertaken by comparing patterns of groundwater flow (based on contour plans of aquifer heads), and considering the justification for adopting model aquifer properties in relation to measured ranges of values and associated non-uniqueness issues. Qualitative assessment is undertaken with due consideration for the adopted conceptual model, particularly relating to surface-groundwater interaction.

The *non-uniqueness* problem arises because many different possible sets of model inputs can produce nearly identical model outputs (and this also applies to automated calibrations). In other words, multiple calibrations of the same system are possible using different combinations of boundary conditions and aquifer properties, because exact ("unique") solutions cannot be computed when many variables are involved in the calibration approach. It can be shown that any combination of groundwater flow rates and hydraulic conductivities in the model that has the same ratio as the actual flow rates and hydraulic conductivities in the aquifer will produce nearly identical hydraulic head distributions (Ritchey and Rumbaugh, 1996).

The main two methods that should be employed in conjunction to reduce the non-uniqueness problem involve calibrating the model using hydraulic conductivity (and other) parameters that are consistent with measured values; and, calibrating to multiple distinct hydrological conditions with that parameter set. The first method is designed to restrict the possible range of parameters to values that are consistent with the actual ("unique") values of the aquifer. The second method provides an indication of the predictive performance of a model by demonstrating that a given set of input model parameters (consistent with field measurements) are capable of reproducing system behaviour through a range of distinct hydrological conditions. The variation in hydrological conditions should not just relate to natural conditions, but also to induced stresses (eg. pumping, river regulation, etc.).

The guide recommends that the acceptability of a calibration can be assessed by judging whether each of the performance measures listed in Table 2 conform to specified criteria. The criteria or targets for calibration should be discussed and agreed between the project manager and the modeller and model reviewer before undertaking model calibration, and may be modified later, subject to negotiation. It is not possible to anticipate how successful model calibration will be, even when best practice is followed. A range of statistical performance measures (relating to item 4 in Table 2) are also detailed in the guide, but are omitted here for brevity.

9.0 Model Review Methodology

A model review framework is another key element of the guideline, with reviews recommended at all stages throughout the study, consistent with the objectives, scope, scale and budget of the project. A model review provides a process by which the end-user can check consistently that a model meets the project objectives. It also provides the model developer with a specification against which the modelling study will be evaluated. The level of review undertaken will depend on the nature of the project. The lower the complexity of a model, the less detailed a review is required. The undertaking of a review necessarily adds expense to the modelling process. The client and contractor must be clear at the outset as to which party is to bear the cost of each review.

The review itself ranges from simple *model appraisal* using a checklist for simple models, through to more comprehensive *peer reviews* and complete *model audits* for more complex models. An appraisal and a peer review would usually involve a review of a modelling study report, while an audit would also require an in-depth review of the model data files, simulations and outputs. A model appraisal is made by a professional person, not necessarily with modelling skills, but preferably with training and/or experience in undertaking reviews, who represents the contractor's clientele (eg. a government agency or contract hydrogeologist or the Technical Steering Group). A peer review or a model audit should only be done by an experienced groundwater modeller, different from the person who has developed the model. A post-audit is usually performed by the person who originally developed the model, but it could be done by a different professional modeller who has access to the model software and archived files.

Attributes of suitable experienced model reviewers may be summarised as:

- Level of local hydrogeological knowledge (or access to such knowledge)
- General experience as a modelling specialist, and experience as a modelling team leader
- Numbers of models developed of various degrees of complexity
- Expert skills in specific modelling packages (especially the one to be used in the study) and/or specific model types (eg. finite difference/finite element; 3D/quasi-3D/2D; flow/solute transport/heat/density coupled)
- Experience of modelling a range of hydrological and hydrogeological conditions (eg. arid, tropical, temperate, irrigation, mine dewatering, dryland salinity, complex river-aquifer interaction).

Table 2 - Calibration Acceptance Measures

Item	Performance Measure	Criterion	Comment
1	**Water balance** Difference between total inflow and total outflow, including changes in storage, divided by total inflow or outflow, expressed as a percentage.	Less than 1% for each stress period and cumulatively for the entire simulation.	For some very complex models, it may be acceptable to relax this criterion to around 2% for some stress periods.
2	**Iteration residual error** The calculated error term is the maximum change in heads (for any node) between successive iterations of the model.	Iteration convergence criterion should be one to two orders of magnitude smaller than the level of accuracy desired in the model head results. Commonly set in the order of millimetres or centimetres.	The criterion value must be consistent with the method used by the particular model to calculate the residual error term.
3	**Qualitative measures** Patterns of groundwater flow (based on modelled contour plans of aquifer heads). Patterns of aquifer response to variations in hydrological stresses (hydrographs). Distributions of model aquifer properties adopted to achieve calibration.	Subjective assessment of the goodness of fit between modelled and measured groundwater level contour plans and hydrographs of bore water levels and surface flows. Justification for adopted model aquifer properties in relation to measured ranges of values and associated non-uniqueness issues	Should take into consideration the adopted conceptual model, particularly relating to surface-groundwater interaction, model discretisation effects, and interpolation effects (on observed and simulated data).
4	**Quantitative measures** Statistical measures of the differences between modelled and measured head data. Mathematical and graphical comparisons between measured and simulated aquifer heads, and system flow components.	Residual head statistics criteria are detailed in the full guideline. Consistency between modelled head values (in contour plans and scatter plots) and spot measurements from monitoring bores. Comparison of simulated and measured components of the water budget, notably surface water flows, groundwater abstractions and evapotranspiration estimates.	A range of quantitative measures that are relevant to the model study, and the data availability and quality, should be selected from methods detailed in the full guideline.

10.0 Other Modelling Issues

The full guideline also documents a range of other modelling issues and methodologies, which must be omitted here for brevity. The issues include Data Collation; Code Selection; Model Design and a resulting Model Study Plan; Initial Conditions; Prediction Scenarios; Uncertainty Analysis (sustainable yield, system stresses, aquifer properties, sensitivity analysis, optimal groundwater management); Reporting; Glossary; Annotated Bibliography.

11.0 Conclusion

Best practice guidelines have been developed in a project sponsored by the Murray-Darling Basin Commission (MDBC) for application to the process of groundwater flow model design, calibration, prediction, uncertainty management, reporting and review. There has been a particular emphasis on producing best practice guidelines that provide support to modellers, and are meaningful and useful to the community. A national workshop process was used to develop concensus, and a “plain English” summary guide is also being developed, specifically for use by the community. Detailed model review methodologies, with review checklists, and an outline of a modelling study brief, are presented in the guide. The guideline should be made available on the MDBC website (mdbc.gov.au).

12.0 References

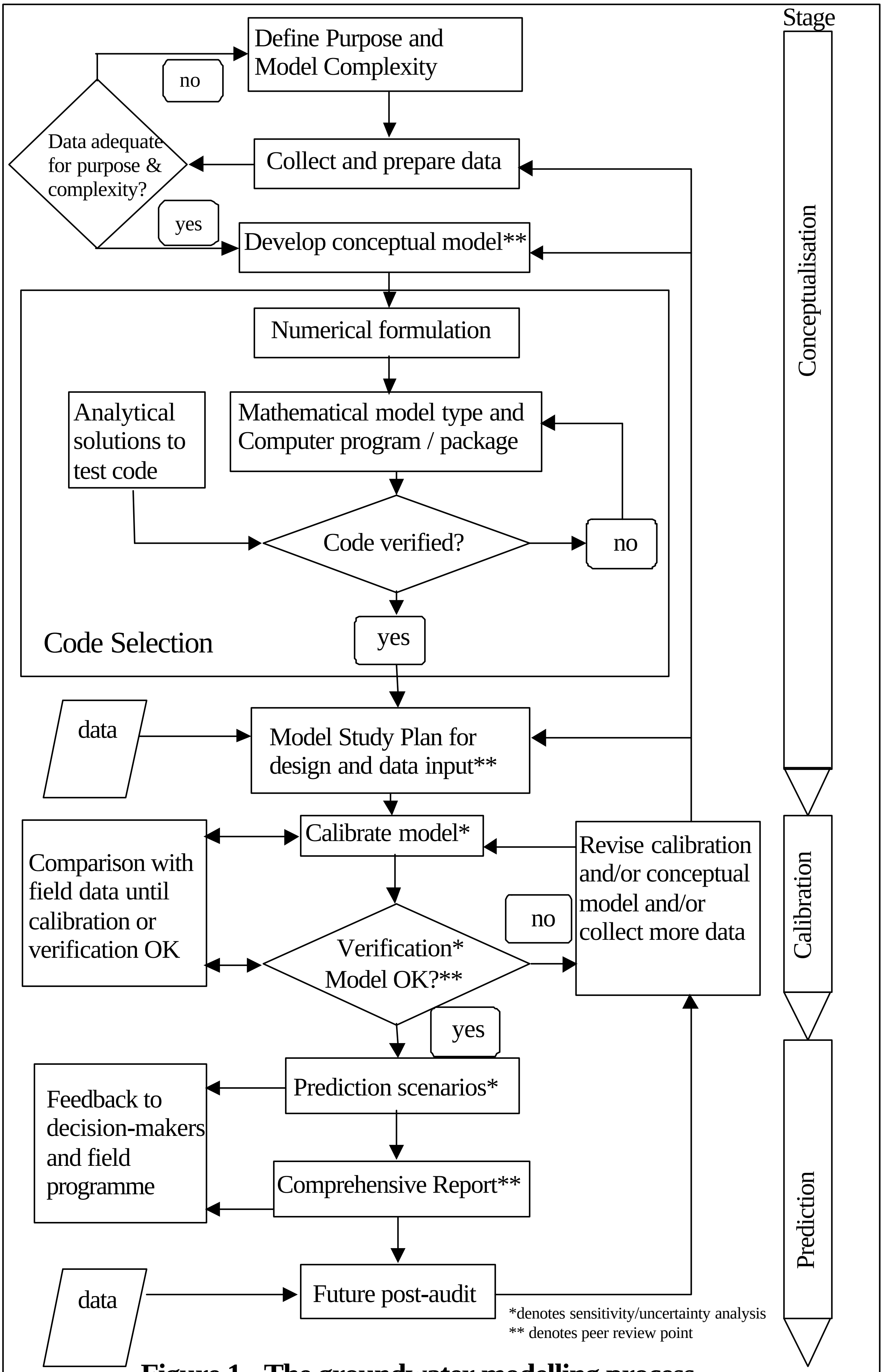
Anderson M.P. and Woessner W.W. (1992). Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic Press. San Diego, 381pp.

ASTM D5880-95 - Standard Guide for Subsurface Flow and Transport Modelling.

Murray-Darling Basin Commission (2000, in press). Groundwater Flow Modelling Guideline. Report to MDBC by Aquaterra project team, including UTS and PPK, 125pp.

Ritchey J.D. and Rumbaugh J. O. (eds.) (1996). Subsurface fluid flow (ground-water and vadose zone) modeling. ASTM Special Technical Publication 1288.

Spitz K and Moreno J (1996). A Practical Guide to Groundwater and Solute Transport Modeling. Wiley. New York, 461pp.



*denotes sensitivity/uncertainty analysis
** denotes peer review point

Figure 1 - The groundwater modelling process

(after Anderson and Woessner (1992), and Spitz and Moreno (1996))

APPENDIX H

POTENTIAL SOURCES AND REGISTER OF CONTAMINANTS

Table H1

Types and Sources of Contamination that Potentially can Contaminate Groundwater and Surface Water (WRC, 1996)

Activity	Type of Chemical	Contaminants
Agricultural/horticultural activities		See fertiliser, insecticides, fungicides, herbicides under Chemicals manufacture and use
Airports	Hydrocarbons	Aviation fuels
	Metals	Particularly aluminium, magnesium, chromium
Asbestos production and disposal		Asbestos
Battery manufacture and recycling	Metals	Lead, manganese, zinc, cadmium, nickel, cobalt mercury, silver, antimony
	Acids	Sulphuric acid
Breweries/distilleries	Alcohol	Ethanol, methanol, esters
Chemicals manufacture and use	Acid/alkali	Mercury (chlor/alkali), sulphuric, hydrochloric and nitric acids, sodium and calcium hydroxides
	Adhesives/resin	Polyvinyl acetate, phenol, formaldehyde, acrylates, phthalates
	Dyes	Chromium, titanium, cobalt, sulphur and nitrogen organic compounds, sulphates, solvents
	Explosives	Acectone, nitric acid, ammonium nitrate, pentachlorophenol, ammonia, aulphuric acid, nitroglycerine, calcium cyanamide, lead, ethylene glycol, methanol, copper, aluminium, bis(2-ethylhexyl) adipate, dibutyl phthalate, sodium hydroxide, mercury, silver
	Fertiliser	Calcium phosphate, calcium sulphate, nitrates, ammonium sulphate, carbonates, potassium, copper, magnesium, molybdenum, boron, cadmium
	Flocculants	Aluminium
	Foam Production	Urethane, formaldehyde, styrene
	Fungicides	Carbamates, copper sulphate, copper chloride, sulphur, chromium
	Herbicides	Ammonium thiocyanate, carbamates, organochlorines, organophosphates, arsenic, mercury
	Paints	
	Heavy Metals	Arsenic, barium, cadmium, chromium, cobalt, lead, manganese, mercury, selenium, zinc
	General	Titanium dioxide
	Solvent	Toluene oils natural (eg pine oil) or synthetic
	Pesticides Active ingredients	Arsenic, lead, organochlorines, organophosphates, sodium, tetraborate, carbamates, sulphur, synthetic pyrethroids
	Solvents	Xylene, kerosene, methyl isobutyl ketone, amyl acetate, chlorinated solvents
	Pharmacy	
	General	Dextrose, starch
	Solvents	Acetone, cyclohexane, methylene chloride, ethyl acetate, butyl acetate, methanol, ethanol, isopropanol, butanol, pyridine methyl ethyl ketone, methyl isobutyl ketone, tetrahydrofuran
	Photography	Hydroquinone, sodium carbonate, sodium sulphite, potassium bromide, monomethyl para-aminophenol sulphates, ferricyanide, chromium, silver, thiocyanate, ammonium compounds, sulphur compounds, phosphate, phenylene diamine, ethyl alcohol, thiosulphates, formaldehyde
	Plastics	Sulphates, carbonates, cadmium, solvents, acrylates, phthalates, styrene

Activity	Type of Chemical	Contaminants
Chemical manufacture and use (Contd)	Rubber	Carbon black
	Soap/detergent	
	General	Potassium compounds, phosphates, ammonia alcohols, esters, sodium hydroxide, surfactants (sodium lauryl sulfate), silicate compounds
	Acids	Sulphuric acid and stearic acid
	Oils	Palm, coconut, pine, teatree
	Solvents	
	General	Ammonia
	Hydrocarbons	Eg BTEX (benzene, toluene, ethylbenzene, xylene)
	Chlorinated organics	Eg Trichloroethane, carbon tetrachloride, methylene chloride
Defence Works		See Explosives under Chemicals manufacture and use, foundries, engine works, service stations
Drum reconditioning		See Chemicals manufacture and use
Dry cleaning		Trichlorethylene and ethane Carbon tetrachloride Perchlorethylene
Electrical		PCBs (transformers and capacitors), solvents, tin, lead, copper
Engine works	Hydrocarbons	
	Metals	
	Solvents	
	Acids/alkalis	
	Refrigerants	
	Antifreeze	Ethylene glycol, nitrates, phosphates, silicates
Foundries	Metals	Particularly aluminium, manganese, iron, copper, nickel, chromium zinc, cadmium and lead and oxides, chlorides, fluorides and sulphates of these metals
	Acids	Sulphuric and phosphoric Phenolics and amines Coke/graphite dust
Gas Works	Inorganics	Ammonia, cyanide, nitrate, sulphide thiocyanate
	Metals	Aluminium, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, vanadium, zinc
	Semi volatiles	Benzene, ethylbenzene, toluene, total xylenes coal tar, phenolics and PAHs
Iron and steel works		Metals and oxides of iron, nickel, copper, chromium, magnesium and graphite
Landfill sites		Methane, hydrogen sulphide, heavy metals, complex acids
Marinas		See Engine works, Metal treatments electroplating
	Antifouling paints	Copper, tributyletin (TBT)
Metal treatments	Electroplating	
	Metals	Nickel, chromium, zinc, aluminium, copper, lead, cadmium, tin
	Acids	Sulphuric, hydrochloric, nitric, phosphoric
	General	Sodium hydroxide, 1,1,1-trichloroethane, tetrachloroethylene, toluene, theylene glycol, cyanide compounds
	Liquid carburising baths	Sodium, cyanide, barium, chloride, potassium chloride, sodium chloride, sodium carbonate, sodium cyanate
Mining and extractive industries		Arsenic, mercury and cyanides, also refer to explosives

Activity	Type of Chemical	Contaminants
Power stations		Asbestos, PCBs, fly ash metals
Printing shops		Acids, alkalis, solvents, chromium
Railway yards		Hydrocarbons, arsenic, phenolics (creosote), heavy metals, nitrates and ammonia
Scrap yards		Hydrocarbons, metals, solvents
Service stations and fuel storage facilities		Aliphatic hydrocarbons BTEX (ie benzene toluene, ethylbenzene, xylene) PAHs (eg benzo(a)pyrene) Phenols, lead
Sheep and cattle dips		Arsenic, organochlorides and organophosphates, carbamates, and synthetic pyrethoids
Smelting and refining		Metals and the fluorides, chlorides and oxides of copper, tin, silver, gold, selenium, lead, aluminium
Tanning and associated trades	Metals General	Chromium, manganese, aluminium Ammonium sulphate, ammonia, ammonium nitrate, phenolics (Creosote), formaldehyde, tannic acid
Wood preservation	Metals General	Chromium, copper, arsenic Naphthalene, ammonia, pentachlorophenol, dibenzofuran, anthracene, biphenyl, ammonium sulfate, quinoline, boron, creosote, organochlorine pesticides

Source: Draft Australian Standard for “The Sampling of Potentially Contaminated Soil, April 1994”

Table H2

Priority Contaminants in Industrial Waste Streams (NWQMS, 1995b)

Metals and Inorganics:

Antimony
Arsenic
Asbestos
Beryllium
Cadmium
Chromium
Copper
Metal cyanide complexes
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Thallium
Zinc

Halogenated aliphatics:

Carbon tetrachloride
Chloroform
Dichlorobromomethane
1,2-dichloroethane
1,2-trans dichloroethylene
Methylene chloride
1,1,2,2-Tetrachloroethylene
1,1,1-trichloroethane
Trichloroethylene

Phthalates:
Bis (2-ethylhexyl) phthalate
di-n-butyl phthalate
Diethyl phthalate
Dimethyl phthalate

Pesticides and metabolites:

Aldrin
a-BHC
Lindane
Dieldrin
DDT
Chlordane
4,4'-DDE
4,4'-DDD
a-endosulfan
b-endosulfan
Endosulphan sulphate
Heptachlor
Heptachlor epo
Isophorone
2,,4 .- D
2,4,5 - T

Polycilic aromatic hydrocarbons (PAH):

Acenaphthylene
Acenaphthene
Anthracene
Benzo (a) pyrene
Chrysene
Fluoranthene
Fluorene
Napthalene
Phenanthrene
Pyrene

Radionuclides:
Radon
Radium
Uranium

Aromatics:

Benzene -
1,2-dichlorobenzene
1,4-dichlorobenzene
Ethylbenzene
Toluene
Xylene

Phenols and cresols:
2-chlorophenol
2,4-dichlorophenol
2,4-dinitrophenol
2,4-dimethylphenol
Phenol
4,6-dinitro-o-cresol
Parachlorometa cresol

Polychlorinated biphenyls and related compounds (PCB):
Aroclor 1242

Aroclor 1248
Aroclor 1254
Aroclor 1260

Biological:
Escherichia coli

Others:
Nitrates
Cyanide
Dioxins (chlorinated)

Source: Adapted from US EPA (1985)[2]

RPS

APPENDIX 2

PRI Sampling Results

ARL
Analytical Reference Laboratory

LABORATORY REPORT

ARL Lab No: 11-3427
Date: 01 June 2011

CLIENT: RPS
Po Box 465
SUBIACO WA 6904

ATTENTION: Joanne Tierney

SAMPLE DESCRIPTION: Fifteen soil samples as received for analysis of phosphorus retention index.

DATE RECEIVED: 25 April 2011

JOB NO: D10542

LOCATION: Kemerton

METHOD REFERENCES:

Phosphorus Retention Index — Subcontracted to CSBP, Report No. 262287

Kim Rodgers
Laboratory Manager

Miscellaneous Inorganic Soil

ARL Lab No	**Date Analysed**	**Units**	**Method Detection Limit**	**11-3427-1**	**11-3427-2**	**11-3427-3**	**11-3427-4**
		Sample Marks		KM1-1	KM1-2	KM2-1	KM2-2
Phosphorus Retention	1/06/2011	#	-	1.7	1.5	0.2	0.5

Miscellaneous Inorganic Soil

ARL Lab No	Date Analysed	Units	Method Detection Limit	11-3427-5	11-3427-6	11-3427-7	11-3427-8	11-3427-9	11-3427-10
		Sample Marks		KM3-1	KM3-2	KM4-1	KM4-2	KM4-3	KM5-1
Phosphorus Retention	1/06/2011	#	-	0.8	0.8	0.2	0.1	0.5	0.8

Miscellaneous Inorganic Soil

ARL Lab No	Date Analysed	Units	Method Detection Limit	11-3427-11	11-3427-12	11-3427-13	11-3427-14	11-3427-15
		Sample Marks		KM5-2	KM6-1	KM6-2	KM7-1	KM7-2
Phosphorus Retention	1/06/2011	#	-	1.1	1.1	1.5	1.4	37.2

APPENDIX 3

On-site Groundwater
Monitoring Data

DoW Groundwater Monitoring Data 1980's to 1990's

Name	Collected Date	Water level	Datum
F4	17/04/80	3.060	AHD
F4	21/07/82	3.749	AHD
F4	28/09/82	4.144	AHD
F4	22/03/83	3.834	AHD
F4	31/08/83	4.535	AHD
F4	22/09/83	4.725	AHD
F4	09/11/83	4.605	AHD
F4	06/01/84	4.446	AHD
F4	14/03/84	3.908	AHD
F4	11/04/84	3.767	AHD
F4	18/07/84	3.912	AHD
F4	12/09/84	4.086	AHD
F4	17/10/84	4.213	AHD
F4	14/11/84	4.162	AHD
F4	15/01/85	3.941	AHD
F4	07/08/85	3.796	AHD
F4	25/09/85	4.046	AHD
F4	28/10/85	3.846	AHD
F4	26/11/85	3.886	AHD
F4	23/01/86	3.666	AHD
F4	17/02/86	3.546	AHD
F4	01/04/86	3.426	AHD
F4	12/05/86	3.466	AHD
F4	14/07/86	3.486	AHD
F4	11/08/86	3.646	AHD
F4	13/10/86	3.746	AHD
F4	19/11/86	3.636	AHD
F4	12/01/87	3.646	AHD
F4	10/02/87	3.536	AHD
F4	14/04/87	3.366	AHD
F4	11/05/87	3.716	AHD
F4	14/07/87	3.636	AHD
F4	17/08/87	8.526	AHD
F4	21/10/87	3.641	AHD
F4	17/11/87	3.631	AHD
F4	06/01/88	3.716	AHD
F4	09/02/88	3.626	AHD
F4	26/04/88	3.746	AHD
F4	17/08/88	3.796	AHD
F4	13/10/88	3.946	AHD
F4	14/11/88	4.146	AHD
F4	04/01/89	4.126	AHD
F4	06/02/89	3.646	AHD
F4	05/05/89	3.646	AHD
F4	28/06/89	3.646	AHD
F4	10/08/89	3.796	AHD
F4	26/10/89	3.646	AHD

F4	23/11/89	3.646	AHD
F4	22/01/90	3.646	AHD
F4	13/02/90	3.646	AHD
F4	30/03/90	3.596	AHD
F4	10/07/90	3.646	AHD
F4	21/08/90	3.746	AHD
F4	30/10/90	3.646	AHD
F4	03/12/90	3.646	AHD
F4	24/01/91	3.646	AHD
F4	06/03/91	3.646	AHD
F4	14/05/91	3.646	AHD
F4	01/07/91	3.646	AHD
F4	13/08/91	3.896	AHD
F4	04/11/91	3.646	AHD
F4	19/12/91	5.346	AHD
F4	05/03/92	3.946	AHD
F4	06/10/92	4.366	AHD
F4	19/03/93	3.736	AHD
F4	10/09/93	3.826	AHD
F4	15/03/94	3.426	AHD
F4	02/11/94	4.696	AHD
F4	03/04/95	3.126	AHD
F4	14/11/95	3.986	AHD
F4	28/05/96	3.236	AHD
F4	08/10/96	4.286	AHD
F4	26/05/97	3.406	AHD
F4	29/05/98	3.186	AHD
F4	23/11/98	3.586	AHD
F4	20/05/99	3.066	AHD
F5	17/04/80	3.380	AHD
F5	21/07/82	4.889	AHD
F5	28/09/82	4.839	AHD
F5	17/01/83	3.629	AHD
F5	22/02/83	3.805	AHD
F5	22/03/83	3.682	AHD
F5	16/06/83	4.966	AHD
F5	31/08/83	5.231	AHD
F5	22/09/83	4.999	AHD
F5	09/11/83	4.556	AHD
F5	06/01/84	4.212	AHD
F5	14/03/84	3.807	AHD
F5	11/04/84	3.731	AHD
F5	06/06/84	4.488	AHD
F5	18/07/84	4.784	AHD
F5	12/09/84	4.869	AHD
F5	17/10/84	4.546	AHD
F5	14/11/84	4.479	AHD
F5	15/01/85	4.119	AHD
F5	20/03/85	3.744	AHD
F5	07/08/85	4.739	AHD

F5	25/09/85	4.639	AHD
F5	28/10/85	4.359	AHD
F5	26/11/85	4.229	AHD
F5	23/01/86	3.839	AHD
F5	17/02/86	3.739	AHD
F5	01/04/86	3.614	AHD
F5	12/05/86	3.584	AHD
F5	14/07/86	4.269	AHD
F5	11/08/86	4.729	AHD
F5	13/10/86	4.339	AHD
F5	19/11/86	3.889	AHD
F5	12/01/87	3.839	AHD
F5	10/02/87	3.579	AHD
F5	14/04/87	3.209	AHD
F5	11/05/87	3.569	AHD
F5	14/07/87	4.209	AHD
F5	17/08/87	4.459	AHD
F5	21/10/87	4.199	AHD
F5	17/11/87	4.019	AHD
F5	06/01/88	3.819	AHD
F5	09/02/88	3.539	AHD
F5	26/04/88	3.389	AHD
F5	17/08/88	5.019	AHD
F5	13/10/88	4.539	AHD
F5	14/11/88	4.439	AHD
F5	04/01/89	4.189	AHD
F5	06/02/89	3.539	AHD
F5	05/05/89	3.689	AHD
F5	28/06/89	4.239	AHD
F5	10/08/89	4.739	AHD
F5	26/10/89	4.639	AHD
F5	23/11/89	4.439	AHD
F5	22/01/90	3.989	AHD
F5	13/02/90	3.739	AHD
F5	30/03/90	3.739	AHD
F5	10/07/90	4.339	AHD
F5	21/08/90	4.739	AHD
F5	30/10/90	4.489	AHD
F5	03/12/90	4.389	AHD
F5	24/01/91	3.739	AHD
F5	06/03/91	3.489	AHD
F5	14/05/91	3.439	AHD
F5	01/07/91	4.239	AHD
F5	13/08/91	5.089	AHD
F5	04/11/91	4.639	AHD
F5	19/12/91	4.239	AHD
F5	05/03/92	3.839	AHD
F5	06/10/92	4.639	AHD
F5	19/03/93	3.659	AHD
F5	10/09/93	4.689	AHD

F5	15/03/94	3.539	AHD
F5	02/11/94	4.289	AHD
F5	03/04/95	3.289	AHD
F5	14/11/95	4.269	AHD
F5	28/05/96	3.429	AHD
F5	08/10/96	4.749	AHD
F5	26/05/97	3.579	AHD
F5	29/05/98	3.479	AHD
F5	23/11/98	4.079	AHD
F5	20/05/99	3.509	AHD
F8	17/04/80	13.500	AHD
F8	29/07/82	15.016	AHD
F8	17/01/83	13.925	AHD
F8	23/02/83	13.515	AHD
F8	22/03/83	13.809	AHD
F8	16/06/83	14.103	AHD
F8	31/08/83	15.141	AHD
F8	22/09/83	15.176	AHD
F8	09/11/83	14.626	AHD
F8	14/03/84	14.101	AHD
F8	07/08/85	14.836	AHD
F8	25/09/85	14.766	AHD
F8	28/10/85	14.686	AHD
F8	26/11/85	14.486	AHD
F8	23/01/86	14.086	AHD
F8	17/02/86	13.936	AHD
F8	01/04/86	13.846	AHD
F8	12/05/86	13.746	AHD
F8	11/08/86	14.546	AHD
F8	13/10/86	14.386	AHD
F8	19/11/86	13.956	AHD
F8	12/01/87	13.936	AHD
F8	12/02/87	13.636	AHD
F8	14/07/87	14.106	AHD
F8	17/08/87	14.226	AHD
F8	21/10/87	14.091	AHD
F8	17/11/87	13.966	AHD
F8	06/01/88	13.786	AHD
F8	09/02/88	13.546	AHD
F8	26/04/88	13.416	AHD
F8	17/08/88	14.806	AHD
F8	13/10/88	14.786	AHD
F8	14/11/88	14.786	AHD
F8	04/01/89	14.346	AHD
F8	06/02/89	13.886	AHD
F8	05/05/89	13.786	AHD
F8	28/06/89	14.106	AHD
F8	10/08/89	14.486	AHD
F8	26/10/89	14.686	AHD
F8	23/11/89	14.486	AHD

F8	22/01/90	14.186	AHD
F8	13/02/90	13.986	AHD
F8	30/03/90	14.786	AHD
F8	10/07/90	14.186	AHD
F8	21/08/90	14.536	AHD
F8	30/10/90	14.386	AHD
F8	03/12/90	14.036	AHD
F8	24/01/91	13.936	AHD
F8	06/03/91	13.686	AHD
F8	14/05/91	13.586	AHD
F8	01/07/91	14.166	AHD
F8	13/08/91	14.936	AHD
F8	04/11/91	14.536	AHD
G4	17/04/80	3.160	AHD
G4	21/07/82	3.820	AHD
G4	28/09/82	4.249	AHD
G4	17/01/83	4.068	AHD
G4	22/03/83	3.643	AHD
G4	16/06/83	3.523	AHD
G4	31/08/83	4.255	AHD
G4	22/09/83	4.552	AHD
G4	09/11/83	4.514	AHD
G4	06/01/84	4.249	AHD
G4	14/03/84	3.793	AHD
G4	11/04/84	3.673	AHD
G4	06/06/84	3.632	AHD
G4	18/07/84	3.809	AHD
G4	12/09/84	3.977	AHD
G4	17/10/84	4.070	AHD
G4	14/11/84	4.034	AHD
G4	15/01/85	3.833	AHD
G4	20/03/85	3.548	AHD
G4	07/08/85	3.738	AHD
G4	25/09/85	3.778	AHD
G4	28/10/85	3.898	AHD
G4	26/11/85	3.848	AHD
G4	23/01/86	3.588	AHD
G4	17/02/86	3.488	AHD
G4	01/04/86	3.393	AHD
G4	12/05/86	3.318	AHD
G4	14/07/86	3.398	AHD
G4	11/08/86	3.558	AHD
G4	13/10/86	3.638	AHD
G4	19/11/86	3.498	AHD
G4	12/01/87	3.588	AHD
G4	10/02/87	3.368	AHD
G4	14/04/87	2.988	AHD
G4	11/05/87	3.238	AHD
G4	14/07/87	3.348	AHD
G4	17/08/87	3.468	AHD

G4	21/10/87	3.528	AHD
G4	17/11/87	3.508	AHD
G4	06/01/88	3.478	AHD
G4	09/02/88	3.258	AHD
G4	26/04/88	3.188	AHD
G4	17/08/88	4.018	AHD
G4	13/10/88	3.988	AHD
G4	14/11/88	3.088	AHD
G4	04/01/89	4.248	AHD
G4	06/02/89	3.588	AHD
G4	05/05/89	3.488	AHD
G4	28/06/89	3.588	AHD
G4	10/08/89	3.788	AHD
G4	26/10/89	3.988	AHD
G4	23/11/89	3.788	AHD
G4	22/01/90	3.488	AHD
G4	13/02/90	3.388	AHD
G4	30/03/90	3.288	AHD
G4	10/07/90	3.538	AHD
G4	21/08/90	3.788	AHD
G4	30/10/90	3.738	AHD
G4	03/12/90	3.388	AHD
G4	24/01/91	3.338	AHD
G4	06/03/91	3.188	AHD
G4	14/05/91	3.088	AHD
G4	01/07/91	3.488	AHD
G4	13/08/91	3.988	AHD
G4	04/11/91	3.738	AHD
G4	19/12/91	4.088	AHD
G4	05/03/92	3.688	AHD
G4	06/10/92	4.103	AHD
G4	19/03/93	3.458	AHD
G4	10/09/93	3.648	AHD
G4	15/03/94	3.258	AHD
G4	02/11/94	3.888	AHD
G4	03/04/95	2.958	AHD
G4	15/11/95	3.708	AHD
G4	28/05/96	3.023	AHD
G4	08/10/96	3.908	AHD
G4	26/05/97	3.168	AHD
G4	29/05/98	2.978	AHD
G4	23/11/98	3.358	AHD
G4	20/05/99	2.888	AHD
G7	17/04/80	12.170	AHD
G7	21/07/82	13.810	AHD
G7	28/09/82	13.880	AHD
G7	17/01/83	13.179	AHD
G7	23/02/83	12.878	AHD
G7	22/03/83	12.732	AHD
G7	16/06/83	12.876	AHD

G7	31/08/83	14.132	AHD
G7	22/09/83	13.971	AHD
G7	09/11/83	13.582	AHD
G7	06/01/84	13.222	AHD
G7	14/03/84	12.810	AHD
G7	11/04/84	12.696	AHD
G7	06/06/84	13.211	AHD
G7	18/07/84	13.492	AHD
G7	12/09/84	13.666	AHD
G7	17/10/84	13.452	AHD
G7	14/11/84	13.473	AHD
G7	15/01/85	13.105	AHD
G7	20/03/85	12.715	AHD
G7	07/08/85	13.500	AHD
G7	25/09/85	13.350	AHD
G7	28/10/85	13.280	AHD
G7	26/11/85	13.280	AHD
G7	23/01/86	12.780	AHD
G7	17/02/86	12.580	AHD
G7	01/04/86	12.455	AHD
G7	12/05/86	12.280	AHD
G7	14/07/86	12.860	AHD
G7	11/08/86	13.260	AHD
G7	13/10/86	12.980	AHD
G7	19/11/86	12.740	AHD
G7	12/01/87	12.680	AHD
G7	10/02/87	12.430	AHD
G7	14/04/87	11.950	AHD
G7	11/05/87	12.230	AHD
G7	14/07/87	12.960	AHD
G7	17/08/87	13.130	AHD
G7	21/10/87	12.950	AHD
G7	17/11/87	12.840	AHD
G7	06/01/88	12.700	AHD
G7	09/02/88	12.460	AHD
G7	26/04/88	12.200	AHD
G7	17/08/88	13.910	AHD
G7	13/10/88	13.580	AHD
G7	14/11/88	13.530	AHD
G7	04/01/89	13.310	AHD
G7	06/02/89	12.780	AHD
G7	05/05/89	12.880	AHD
G7	28/06/89	13.280	AHD
G7	10/08/89	13.680	AHD
G7	26/10/89	13.730	AHD
G7	23/11/89	13.580	AHD
G7	22/01/90	13.180	AHD
G7	13/02/90	12.980	AHD
G7	30/03/90	12.780	AHD
G7	10/07/90	13.280	AHD

G7	21/08/90	13.580	AHD
G7	30/10/90	13.530	AHD
G7	03/12/90	13.280	AHD
G7	24/01/91	12.930	AHD
G7	06/03/91	12.680	AHD
G7	14/05/91	12.530	AHD
G7	01/07/91	13.230	AHD
G7	13/08/91	14.030	AHD
G7	04/11/91	13.630	AHD
G7	19/12/91	13.380	AHD
G7	05/03/92	12.980	AHD
G7	06/10/92	13.620	AHD
G7	19/03/93	12.660	AHD
G7	10/09/93	13.430	AHD
G7	15/03/94	12.380	AHD
G7	02/11/94	13.010	AHD
G7	03/04/95	11.880	AHD
G7	15/11/95	13.090	AHD
G7	28/05/96	11.900	AHD
G7	08/10/96	13.575	AHD
G7	26/05/97	12.150	AHD
G7	29/05/98	11.900	AHD
G7	23/11/98	12.730	AHD
G7	20/05/99	12.080	AHD
G8	17/04/80	10.820	AHD
G8	21/07/82	12.773	AHD
G8	28/09/82	12.818	AHD
G8	17/01/83	12.073	AHD
G8	23/02/83	11.859	AHD
G8	22/03/83	11.641	AHD
G8	16/06/83	11.757	AHD
G8	31/08/83	12.951	AHD
G8	22/09/83	12.845	AHD
G8	09/11/83	12.545	AHD
G8	06/01/84	12.206	AHD
G8	14/03/84	11.801	AHD
G8	06/06/84	12.261	AHD
G8	18/07/84	12.493	AHD
G8	12/09/84	12.641	AHD
G8	17/10/84	12.479	AHD
G8	14/11/84	12.537	AHD
G8	15/01/85	12.173	AHD
G8	20/03/85	11.243	AHD
G8	07/08/85	12.578	AHD
G8	25/09/85	12.383	AHD
G8	28/10/85	12.243	AHD
G8	26/11/85	12.243	AHD
G8	23/01/86	11.893	AHD
G8	17/02/86	11.693	AHD
G8	01/04/86	11.507	AHD

G8	12/05/86	11.343	AHD
G8	14/07/86	12.043	AHD
G8	11/08/86	12.383	AHD
G8	13/10/86	12.193	AHD
G8	19/11/86	11.863	AHD
G8	12/01/87	11.793	AHD
G8	10/02/87	11.593	AHD
G8	14/04/87	11.063	AHD
G8	11/05/87	11.503	AHD
G8	14/07/87	12.093	AHD
G8	17/08/87	12.253	AHD
G8	21/10/87	12.113	AHD
G8	17/11/87	11.968	AHD
G8	06/01/88	11.783	AHD
G8	09/02/88	11.483	AHD
G8	26/04/88	11.623	AHD
G8	17/08/88	12.943	AHD
G8	13/10/88	12.693	AHD
G8	14/11/88	12.793	AHD
G8	04/01/89	12.443	AHD
G8	06/02/89	11.993	AHD
G8	05/05/89	11.893	AHD
G8	28/06/89	12.193	AHD
G8	10/08/89	12.693	AHD
G8	26/10/89	12.793	AHD
G8	23/11/89	12.593	AHD
G8	22/01/90	12.193	AHD
G8	13/02/90	12.043	AHD
G8	30/03/90	11.843	AHD
G8	10/07/90	12.193	AHD
G8	21/08/90	12.693	AHD
G8	30/10/90	12.593	AHD
G8	03/12/90	12.443	AHD
G8	24/01/91	11.843	AHD
G8	06/03/91	11.693	AHD
G8	14/05/91	11.503	AHD
G8	01/07/91	12.193	AHD
G8	13/08/91	12.893	AHD
G8	04/11/91	12.593	AHD
G8	19/12/91	12.393	AHD
G8	05/03/92	11.993	AHD
G8	06/10/92	12.723	AHD
G8	19/03/93	12.143	AHD
G8	10/09/93	12.443	AHD
G8	02/11/94	12.233	AHD
G8	03/04/95	10.973	AHD
G8	28/05/96	11.303	AHD
G8	08/10/96	12.893	AHD
G8	26/05/97	11.693	AHD
G8	29/05/98	11.233	AHD

G8	23/11/98	12.043	AHD
G8	20/05/99	11.603	AHD
HS1B	10/03/89	8.920	AHD
HS1B	05/07/89	8.720	AHD
HS1B	11/10/89	9.170	AHD
HS1B	19/01/90	9.020	AHD
HS1B	11/04/90	8.820	AHD
HS1B	18/07/90	8.770	AHD
HS1B	26/10/90	8.920	AHD
HS1B	16/01/91	8.920	AHD
HS1B	03/04/91	8.770	AHD
HS1B	19/07/91	8.920	AHD
HS1B	23/09/91	8.820	AHD
HS2C	20/07/88	4.614	AHD
HS2C	19/09/88	4.594	AHD
HS2C	09/12/88	3.994	AHD
HS2C	10/03/89	3.794	AHD
HS2C	05/07/89	4.194	AHD
HS2C	11/10/89	4.294	AHD
HS2C	19/01/90	3.944	AHD
HS2C	11/04/90	3.644	AHD
HS2C	18/07/90	4.744	AHD
HS2C	26/10/90	3.994	AHD
HS2C	16/01/91	3.694	AHD
HS2C	03/04/91	3.594	AHD
HS2C	19/07/91	4.994	AHD
HS2C	23/09/91	4.394	AHD
HS2C	21/04/92	3.724	AHD
HS2C	23/09/92	4.324	AHD
HS2C	23/03/93	4.094	AHD
HS2C	27/09/93	4.394	AHD
HS2C	05/04/94	3.724	AHD
HS2C	22/11/94	4.204	AHD
HS2C	07/04/95	3.584	AHD
HS2C	21/05/96	3.514	AHD
HS2C	15/10/96	4.224	AHD
HS2C	05/06/97	4.294	AHD
HS2C	24/05/98	3.554	AHD
HS2C	08/12/98	3.814	AHD
HS2C	04/05/99	3.544	AHD
DoW 1	21/07/82	1.692	AHD
DoW 1	18/09/02	1.38	AHD
DoW 1	02/09/03	1.27	AHD
DoW 1	18/10/05	0.87	AHD
DoW 1	05/09/06	0.62	AHD
DoW 1	09/10/07	0.7	AHD
DoW 1	09/09/08	0.73	AHD
DoW 1	04/09/09	0.86	AHD
DoW 1	20/09/10	0.34	AHD
DoW 2	24/08/89	1.929	AHD

DoW 2	05/09/90	2.369	AHD
DoW 2	12/10/92	2.229	AHD
DoW 2	13/10/93	2.119	AHD
DoW 2	20/11/95	1.959	AHD
DoW 2	18/09/96	1.979	AHD
DoW 2	27/09/00	1.469	AHD
DoW 2	26/09/01	1.189	AHD
DoW 2	18/09/02	1.169	AHD
DoW 2	02/09/03	1.089	AHD
DoW 2	07/09/04	1.019	AHD
DoW 2	19/10/05	0.879	AHD
DoW 2	06/09/06	0.629	AHD
DoW 2	09/10/07	0.819	AHD
DoW 2	06/11/08	0.939	AHD
DoW 2	06/10/09	0.859	AHD
DoW 2	12/11/10	0.769	AHD
DoW 3	08/10/07	10.025	AHD
DoW 3	06/08/08	10.305	AHD
DoW 3	08/09/09	10.415	AHD
DoW 4	19/09/88	4.614	AHD
DoW 4	11/10/89	4.914	AHD
DoW 4	18/07/90	4.764	AHD
DoW 4	19/07/91	5.014	AHD
DoW 4	23/09/92	4.344	AHD
DoW 4	27/09/93	4.404	AHD
DoW 4	22/11/94	3.924	AHD
DoW 4	15/10/96	4.239	AHD
DoW 4	03/10/00	3.684	AHD
DoW 4	26/09/01	3.904	AHD
DoW 4	18/09/02	4.294	AHD
DoW 4	02/09/03	4.114	AHD
DoW 4	07/09/04	4.234	AHD
DoW 4	19/10/05	4.274	AHD
DoW 4	06/09/06	3.974	AHD
DoW 4	04/09/07	4.604	AHD
DoW 4	03/09/08	3.924	AHD
DoW 4	01/09/09	4.394	AHD
DoW 4	12/10/10	3.114	AHD
DoW 5	05/08/84	7.612	AHD
DoW 5	21/11/88	9.006	AHD
DoW 5	11/10/89	8.856	AHD
DoW 5	25/10/90	8.556	AHD
DoW 5	27/09/91	8.356	AHD
DoW 5	08/10/92	8.296	AHD
DoW 5	27/09/93	7.976	AHD
DoW 5	20/11/95	7.996	AHD
DoW 5	08/10/96	8.126	AHD
DoW 5	08/12/98	7.836	AHD
DoW 5	26/09/01	7.676	AHD
DoW 5	17/09/02	7.656	AHD

DoW 5	02/09/03	7.656	AHD
DoW 5	07/09/04	7.696	AHD
DoW 5	19/10/05	6.726	AHD
DoW 5	05/09/06	7.626	AHD
DoW 5	06/11/07	7.686	AHD
DoW 5	14/10/08	7.686	AHD
DoW 5	16/10/09	7.676	AHD
DoW 5	17/09/10	7.586	AHD

Industry Groundwater Monitoring Data 1990's

Name	Collected Date	Water level	Datum
KMB1	27/03/95	13.807	AHD
KMB1	28/04/95	13.717	AHD
KMB1	02/06/95	13.947	AHD
KMB1	30/06/95	14.287	AHD
KMB1	02/08/95	15.227	AHD
KMB1	31/08/95	15.267	AHD
KMB1	29/09/95	15.317	AHD
KMB1	26/10/95	15.252	AHD
KMB1	22/11/95	15.117	AHD
KMB1	06/12/95	15.027	AHD
KMB1	04/01/96	14.787	AHD
KMB1	01/02/96	14.537	AHD
KMB1	01/03/96	14.222	AHD
KMB1	28/03/96	14.047	AHD
KMB1	30/04/96	13.857	AHD
KMB1	30/05/96	13.967	AHD
KMB1	03/07/96	14.347	AHD
KMB1	31/07/96	14.897	AHD
KMB1	28/08/96	15.397	AHD
KMB1	26/09/96	15.697	AHD
KMB1	28/10/96	15.497	AHD
KMB1	25/11/96	15.497	AHD
KMB1	30/12/96	15.147	AHD
KMB1	29/01/97	14.897	AHD
KMB1	24/02/97	14.667	AHD
KMB1	01/04/97	14.447	AHD
KMB1	28/04/97	14.397	AHD
KMB1	26/05/97	14.597	AHD
KMB1	10/06/97	14.797	AHD
KMB1	28/07/97	15.147	AHD
KMB1	26/08/97	15.217	AHD
KMB1	26/09/97	15.397	AHD
KMB1	27/10/97	15.047	AHD
KMB1	24/11/97	14.917	AHD
KMB1	29/12/97	14.647	AHD
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KMB1	23/11/98	14.617	AHD
KMB1	04/01/99	14.347	AHD

KMB1	27/01/99	14.047	AHD
KMB1	22/02/99	13.827	AHD
KMB1	26/03/99	13.747	AHD
KMB1	23/04/99	13.517	AHD
KMB1	31/05/99	13.977	AHD
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KMB2	30/04/96	13.814	AHD
KMB2	30/05/96	13.894	AHD
KMB2	03/07/96	14.584	AHD
KMB2	31/07/96	15.114	AHD
KMB2	28/08/96	15.364	AHD
KMB2	26/09/96	15.414	AHD
KMB2	28/10/96	15.174	AHD
KMB2	25/11/96	15.114	AHD
KMB2	30/12/96	14.814	AHD
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KMB2	01/04/97	14.214	AHD
KMB2	28/04/97	14.114	AHD
KMB2	26/05/97	14.364	AHD
KMB2	10/06/97	15.014	AHD
KMB2	28/07/97	15.164	AHD
KMB2	26/08/97	15.154	AHD
KMB2	26/09/97	15.214	AHD

KMB2	27/10/97	15.014	AHD
KMB2	24/11/97	14.714	AHD
KMB2	29/12/97	14.514	AHD
KMB2	26/01/98	14.364	AHD
KMB2	23/02/98	14.014	AHD
KMB2	30/03/98	13.914	AHD
KMB2	28/04/98	13.964	AHD
KMB2	25/05/98	13.984	AHD
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KMB2	04/01/00	14.614	AHD
KMB2	31/01/00	14.514	AHD
KMB2	28/02/00	14.364	AHD
KMB2	06/04/00	14.494	AHD
KMB2	01/05/00	14.264	AHD
KMB2	31/05/00	14.114	AHD
KMB2	03/07/00	14.514	AHD
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KMB3	30/04/96	12.358	AHD
KMB3	30/05/96	12.108	AHD
KMB3	03/07/96	12.938	AHD

KMB3	31/07/96	13.408	AHD
KMB3	28/08/96	13.658	AHD
KMB3	26/09/96	13.758	AHD
KMB3	28/10/96	13.528	AHD
KMB3	25/11/96	13.348	AHD
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KMB3	23/02/98	11.958	AHD
KMB3	30/03/98	11.508	AHD
KMB3	28/04/98	11.258	AHD
KMB3	25/05/98	11.308	AHD
KMB3	26/06/98	12.008	AHD
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KMB3	02/08/99	13.438	AHD
KMB3	30/08/99	13.566	AHD
KMB3	04/10/99	13.608	AHD
KMB3	01/11/99	13.578	AHD
KMB3	29/11/99	13.488	AHD
KMB3	04/01/00	12.858	AHD
KMB3	31/01/00	12.508	AHD
KMB3	28/02/00	12.058	AHD
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KMB3	03/07/00	12.258	AHD
KMB4	27/03/95	13.263	AHD
KMB4	28/04/95	13.123	AHD

KMB4	02/06/95	13.513	AHD
KMB4	30/06/95	13.918	AHD
KMB4	02/08/95	14.768	AHD
KMB4	31/08/95	14.748	AHD
KMB4	29/09/95	14.728	AHD
KMB4	26/10/95	14.723	AHD
KMB4	22/11/95	14.548	AHD
KMB4	06/12/95	14.448	AHD
KMB4	04/01/96	14.183	AHD
KMB4	01/02/96	13.918	AHD
KMB4	01/03/96	13.533	AHD
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KMB4	31/07/96	14.608	AHD
KMB4	28/08/96	14.828	AHD
KMB4	26/09/96	14.878	AHD
KMB4	28/10/96	14.708	AHD
KMB4	25/11/96	14.578	AHD
KMB4	30/12/96	14.278	AHD
KMB4	29/01/97	13.978	AHD
KMB4	24/02/97	13.678	AHD
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KMB4	28/07/97	14.478	AHD
KMB4	26/08/97	14.528	AHD
KMB4	26/09/97	14.578	AHD
KMB4	27/10/97	14.528	AHD
KMB4	24/11/97	14.178	AHD
KMB4	29/12/97	13.928	AHD
KMB4	26/01/98	13.728	AHD
KMB4	23/02/98	13.528	AHD
KMB4	30/03/98	13.378	AHD
KMB4	28/04/98	13.228	AHD
KMB4	25/05/98	13.178	AHD
KMB4	26/06/98	13.828	AHD
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KMB4	22/02/99	13.558	AHD
KMB4	26/03/99	13.358	AHD
KMB4	23/04/99	13.248	AHD
KMB4	31/05/99	13.908	AHD

KMB4	04/07/99	14.728	AHD
KMB4	02/08/99	14.728	AHD
KMB4	30/08/99	14.678	AHD
KMB4	04/10/99	14.798	AHD
KMB4	01/11/99	14.808	AHD
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KMB4	31/01/00	13.978	AHD
KMB4	28/02/00	13.728	AHD
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KMB5	26/01/98	13.434	AHD
KMB5	23/02/98	13.184	AHD

KMB5	30/03/98	12.984	AHD
KMB5	28/04/98	12.884	AHD
KMB5	25/05/98	12.884	AHD
KMB5	26/06/98	13.384	AHD
KMB5	27/07/98	13.584	AHD
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KMB5	30/08/99	14.514	AHD
KMB5	04/10/99	14.534	AHD
KMB5	01/11/99	14.534	AHD
KMB5	29/11/99	14.344	AHD
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KMB5	31/01/00	13.654	AHD
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KMB6	31/08/95	14.586	AHD
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KMB6	30/04/96	13.246	AHD
KMB6	30/05/96	13.196	AHD
KMB6	03/07/96	13.906	AHD
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KMB6	28/08/96	14.746	AHD
KMB6	26/09/96	14.796	AHD
KMB6	28/10/96	14.646	AHD
KMB6	25/11/96	14.526	AHD
KMB6	30/12/96	14.196	AHD

KMB6	29/01/97	13.846	AHD
KMB6	24/02/97	13.596	AHD
KMB6	01/04/97	13.316	AHD
KMB6	28/04/97	13.196	AHD
KMB6	26/05/97	13.096	AHD
KMB6	10/06/97	13.996	AHD
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KMB6	26/08/97	14.496	AHD
KMB6	26/09/97	14.596	AHD
KMB6	27/10/97	14.316	AHD
KMB6	24/11/97	14.116	AHD
KMB6	29/12/97	13.796	AHD
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KMB6	23/02/98	13.296	AHD
KMB6	30/03/98	13.096	AHD
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KMB6	25/05/98	12.896	AHD
KMB6	26/06/98	13.546	AHD
KMB6	27/07/98	13.776	AHD
KMB6	24/08/98	14.046	AHD
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KMB6	23/11/98	14.096	AHD
KMB6	04/01/99	13.746	AHD
KMB6	27/01/99	13.446	AHD
KMB6	22/02/99	13.246	AHD
KMB6	26/03/99	13.176	AHD
KMB6	23/04/99	12.976	AHD
KMB6	31/05/99	13.646	AHD
KMB6	04/07/99	14.576	AHD
KMB6	02/08/99	14.596	AHD
KMB6	30/08/99	14.566	AHD
KMB6	04/10/99	14.666	AHD
KMB6	01/11/99	14.646	AHD
KMB6	29/11/99	14.336	AHD
KMB6	04/01/00	13.946	AHD
KMB6	31/01/00	13.746	AHD
KMB6	28/02/00	13.466	AHD
KMB6	06/04/00	13.196	AHD
KMB6	01/05/00	13.076	AHD
KMB6	31/05/00	13.016	AHD
KMB6	03/07/00	13.616	AHD
KMB8	01/02/96	14.307	AHD
KMB8	01/03/96	13.667	AHD
KMB8	28/03/96	13.782	AHD
KMB8	30/04/96	13.707	AHD
KMB8	30/05/96	13.567	AHD
KMB8	03/07/96	14.467	AHD
KMB8	31/07/96	15.067	AHD
KMB8	28/08/96	15.167	AHD

KMB8	26/09/96	15.187	AHD
KMB8	28/10/96	15.067	AHD
KMB8	25/11/96	14.767	AHD
KMB8	30/12/96	14.367	AHD
KMB8	29/01/97	14.017	AHD
KMB8	24/02/97	13.917	AHD
KMB8	01/04/97	13.597	AHD
KMB8	28/04/97	13.517	AHD
KMB8	26/05/97	13.567	AHD
KMB8	10/06/97	14.617	AHD
KMB8	28/07/97	14.697	AHD
KMB8	26/08/97	14.897	AHD
KMB8	26/09/97	14.867	AHD
KMB8	27/10/97	14.727	AHD
KMB8	24/11/97	14.567	AHD
KMB8	29/12/97	14.267	AHD
KMB8	26/01/98	14.167	AHD
KMB8	23/02/98	14.067	AHD
KMB8	30/03/98	13.667	AHD
KMB8	28/04/98	13.817	AHD
KMB8	25/05/98	13.967	AHD
KMB8	26/06/98	14.067	AHD
KMB8	27/07/98	14.227	AHD
KMB8	24/08/98	14.367	AHD
KMB8	25/09/98	14.657	AHD
KMB8	26/10/98	14.867	AHD
KMB8	23/11/98	14.267	AHD
KMB8	04/01/99	14.217	AHD
KMB8	27/01/99	13.467	AHD
KMB8	22/02/99	13.267	AHD
KMB8	26/03/99	13.087	AHD
KMB8	23/04/99	12.867	AHD
KMB8	31/05/99	13.967	AHD
KMB8	04/07/99	14.867	AHD
KMB8	02/08/99	14.907	AHD
KMB8	30/08/99	14.777	AHD
KMB8	04/10/99	14.797	AHD
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KMB8	29/11/99	14.567	AHD
KMB8	04/01/00	14.217	AHD
KMB8	31/01/00	13.987	AHD
KMB8	28/02/00	13.787	AHD
KMB8	06/04/00	13.767	AHD
KMB8	01/05/00	13.817	AHD
KMB8	31/05/00	13.517	AHD
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KMB9	01/02/96	12.441	AHD
KMB9	01/03/96	12.186	AHD
KMB9	28/03/96	12.016	AHD
KMB9	30/04/96	11.916	AHD

KMB9	30/05/96	11.906	AHD
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KMB9	31/07/96	13.156	AHD
KMB9	28/08/96	13.456	AHD
KMB9	26/09/96	13.456	AHD
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KMB9	23/04/99	11.656	AHD
KMB9	31/05/99	12.316	AHD
KMB9	04/07/99	13.206	AHD
KMB9	02/08/99	13.296	AHD
KMB9	30/08/99	13.206	AHD
KMB9	04/10/99	13.306	AHD
KMB9	01/11/99	13.306	AHD
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KMB9	03/07/00	12.516	AHD

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KMB10	01/03/96	13.14	AHD
KMB10	28/03/96	12.97	AHD
KMB10	30/04/96	12.85	AHD
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KMB10	03/07/96	13.66	AHD
KMB10	31/07/96	14.1	AHD
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KMB10	26/09/96	14.28	AHD
KMB10	28/10/96	14.13	AHD
KMB10	25/11/96	13.98	AHD
KMB10	30/12/96	13.48	AHD
KMB10	29/01/97	13.36	AHD
KMB10	24/02/97	12.96	AHD
KMB10	01/04/97	12.63	AHD
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KMB10	28/07/97	13.74	AHD
KMB10	26/08/97	13.9	AHD
KMB10	26/09/97	13.98	AHD
KMB10	27/10/97	13.83	AHD
KMB10	24/11/97	13.62	AHD
KMB10	29/12/97	13.18	AHD
KMB10	26/01/98	12.68	AHD
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KMB10	26/10/98	13.63	AHD
KMB10	23/11/98	13.38	AHD
KMB10	04/01/99	12.98	AHD
KMB10	27/01/99	12.83	AHD
KMB10	22/02/99	12.63	AHD
KMB10	26/03/99	12.48	AHD
KMB10	23/04/99	12.33	AHD
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KMB10	02/08/99	13.88	AHD
KMB10	30/08/99	13.88	AHD
KMB10	04/10/99	13.95	AHD
KMB10	01/11/99	14	AHD
KMB10	29/11/99	13.82	AHD
KMB10	04/01/00	13.48	AHD
KMB10	31/01/00	13.25	AHD
KMB10	28/02/00	12.8	AHD

KMB10	06/04/00	12.23	AHD
KMB10	01/05/00	12.03	AHD
KMB10	31/05/00	12.05	AHD
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KMB11	27/07/98	13.506	AHD
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KMB11	26/10/98	13.856	AHD
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KMB11	29/11/99	14.196	AHD
KMB11	04/01/00	13.866	AHD

KMB11	31/01/00	13.656	AHD
KMB11	28/02/00	13.356	AHD
KMB11	06/04/00	12.976	AHD
KMB11	01/05/00	12.806	AHD
KMB11	31/05/00	12.856	AHD
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KMB12	24/02/97	10.829	AHD
KMB12	01/04/97	10.729	AHD
KMB12	28/04/97	10.329	AHD
KMB12	26/05/97	10.229	AHD
KMB12	10/06/97	11.829	AHD
KMB12	28/07/97	12.329	AHD
KMB12	26/08/97	11.729	AHD
KMB12	26/09/97	12.829	AHD
KMB12	27/10/97	12.829	AHD
KMB12	24/11/97	12.379	AHD
KMB12	29/12/97	11.529	AHD
KMB12	26/01/98	11.249	AHD
KMB12	23/02/98	11.029	AHD
KMB12	30/03/98	10.079	AHD
KMB12	28/04/98	10.049	AHD
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KMB12	27/07/98	11.439	AHD
KMB12	24/08/98	11.959	AHD
KMB12	25/09/98	12.529	AHD
KMB12	26/10/98	12.529	AHD
KMB12	23/11/98	12.259	AHD
KMB12	04/01/99	11.979	AHD
KMB12	27/01/99	11.749	AHD
KMB12	22/02/99	11.579	AHD
KMB12	26/03/99	11.529	AHD
KMB12	23/04/99	11.369	AHD
KMB12	31/05/99	12.079	AHD
KMB12	04/07/99	12.729	AHD
KMB12	02/08/99	12.829	AHD
KMB12	30/08/99	12.879	AHD

KMB12	04/10/99	13.229	AHD
KMB12	01/11/99	13.099	AHD
KMB12	29/11/99	12.829	AHD
KMB12	04/01/00	12.379	AHD
KMB12	31/01/00	11.929	AHD
KMB12	28/02/00	11.249	AHD
KMB12	06/04/00	10.479	AHD
KMB12	01/05/00	10.529	AHD
KMB12	31/05/00	10.729	AHD
KMB12	03/07/00	11.529	AHD
KMB13	28/03/96	13.68	AHD
KMB13	30/04/96	13.27	AHD
KMB13	30/05/96	12.66	AHD
KMB13	03/07/96	13.46	AHD
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KMB13	24/02/97	13.46	AHD
KMB13	01/04/97	12.93	AHD
KMB13	28/04/97	12.91	AHD
KMB13	26/05/97	12.76	AHD
KMB13	10/06/97	14.16	AHD
KMB13	28/07/97	14.06	AHD
KMB13	26/08/97	14.26	AHD
KMB13	26/09/97	14.16	AHD
KMB13	27/10/97	14.06	AHD
KMB13	24/11/97	13.71	AHD
KMB13	29/12/97	13.38	AHD
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KMB13	02/08/99	14.61	AHD
KMB13	30/08/99	14.56	AHD

KMB13	04/10/99	15.11	AHD
KMB13	01/11/99	14.96	AHD
KMB13	29/11/99	14.56	AHD
KMB13	04/01/00	13.86	AHD
KMB13	31/01/00	13.43	AHD
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KMB13	06/04/00	12.96	AHD
KMB13	01/05/00	13.26	AHD
KMB13	31/05/00	12.91	AHD
KMB13	03/07/00	13.36	AHD
C1-S	19/04/94	10.52	AHD
C1-S	12/05/94	10.49	AHD
C1-S	28/06/94	11.18	AHD
C1-S	28/07/94	11.72	AHD
C1-S	30/08/94	11.73	AHD
C1-S	28/09/94	11.54	AHD
C1-S	01/11/94	11.32	AHD
C1-S	06/12/94	11.03	AHD
C1-S	29/12/94	10.84	AHD
C1-S	30/01/95	10.63	AHD
C1-S	08/03/95	10.48	AHD
C1-S	31/03/95	10.41	AHD
C1-S	31/05/95	10.85	AHD
C1-S	26/07/95	11.78	AHD
C1-S	29/09/95	11.78	AHD
C1-S	07/11/95	11.25	AHD
C1-S	01/03/96	10.62	AHD
C1-S	25/04/96	10.47	AHD
C1-S	19/04/94	10.52	AHD
C1-S	12/05/94	10.49	AHD
C1-S	28/06/94	11.18	AHD
C1-S	01/10/09	11.43	AHD
C1-S	01/10/10		AHD
C2-S	30/08/94	11.83	AHD
C2-S	28/09/94	11.66	AHD
C2-S	01/11/94	11.37	AHD
C2-S	06/12/94	11.17	AHD
C2-S	29/12/94	11.04	AHD
C2-S	30/01/95	10.87	AHD
C2-S	08/03/95	10.75	AHD
C2-S	31/03/95	10.65	AHD
C2-S	31/05/95	11.13	AHD
C2-S	26/07/95	11.94	AHD
C2-S	29/09/95	11.78	AHD
C2-S	07/11/95	11.42	AHD
C2-S	01/03/96	10.89	AHD
C2-S	25/04/96	10.80	AHD
C2-S	19/04/94	10.83	AHD
C2-S	12/05/94	10.84	AHD
C2-S	28/06/94	11.51	AHD

C2-S	01/10/09	11.45	AHD
C2-S	01/10/10		AHD
C3-S	19/04/94	11.37	AHD
C3-S	12/05/94	11.30	AHD
C3-S	28/06/94	11.85	AHD
C3-S	28/07/94	12.18	AHD
C3-S	30/08/94	12.13	AHD
C3-S	28/09/94	11.99	AHD
C3-S	01/11/94	11.85	AHD
C3-S	06/12/94	11.69	AHD
C3-S	29/12/94	11.59	AHD
C3-S	30/01/95	11.39	AHD
C3-S	08/03/95	11.28	AHD
C3-S	31/03/95	11.21	AHD
C3-S	31/05/95	11.56	AHD
C3-S	26/07/95	12.25	AHD
C3-S	29/09/95	12.14	AHD
C3-S	07/11/95	11.84	AHD
C3-S	01/03/96	11.43	AHD
C3-S	25/04/96	11.23	AHD
C4-S	19/04/94		AHD
C4-S	12/05/94	10.83	AHD
C4-S	28/06/94	11.53	AHD
C4-S	28/07/94	11.91	AHD
C4-S	30/08/94	11.92	AHD
C4-S	28/09/94	11.74	AHD
C4-S	01/11/94	11.54	AHD
C4-S	06/12/94	11.33	AHD
C4-S	29/12/94	11.15	AHD
C4-S	30/01/95	10.93	AHD
C4-S	08/03/95	10.76	AHD
C4-S	31/03/95	10.69	AHD
C4-S	31/05/95	11.13	AHD
C4-S	26/07/95	12.02	AHD
C4-S	29/09/95	11.88	AHD
C4-S	07/11/95	11.51	AHD
C4-S	01/03/96	10.94	AHD
C4-S	25/04/96	10.75	AHD
C5-S	19/04/94	10.43	AHD
C5-S	12/05/94	10.40	AHD
C5-S	28/06/94	11.18	AHD
C5-S	28/07/94	11.50	AHD
C5-S	30/08/94	11.47	AHD
C5-S	28/09/94	11.31	AHD
C5-S	01/11/94	11.13	AHD
C5-S	06/12/94	10.90	AHD
C5-S	29/12/94	10.74	AHD
C5-S	30/01/95	10.53	AHD
C5-S	08/03/95	10.36	AHD
C5-S	31/03/95	10.29	AHD

C5-S	31/05/95	10.76	AHD
C5-S	26/07/95	11.70	AHD
C5-S	29/09/95	11.53	AHD
C5-S	07/11/95	11.05	AHD
C5-S	01/03/96	10.52	AHD
C5-S	25/04/96	10.33	AHD
C6	19/04/94	10.32	AHD
C6	12/05/94	10.28	AHD
C6	28/06/94	10.93	AHD
C6	28/07/94	11.44	AHD
C6	30/08/94	11.33	AHD
C6	28/09/94	11.19	AHD
C6	01/11/94	11.05	AHD
C6	06/12/94	10.86	AHD
C6	29/12/94	10.68	AHD
C6	30/01/95	10.40	AHD
C6	08/03/95	10.21	AHD
C6	31/03/95	10.13	AHD
C6	31/05/95	10.51	AHD
C6	26/07/95	11.52	AHD
C6	29/09/95	11.34	AHD
C6	07/11/95	11.03	AHD
C6	01/03/96	10.35	AHD
C6	25/04/96	10.11	AHD
C7	19/04/94	10.97	AHD
C7	12/05/94	10.90	AHD
C7	28/06/94	11.42	AHD
C7	28/07/94	11.88	AHD
C7	30/08/94	11.89	AHD
C7	28/09/94	11.73	AHD
C7	01/11/94	11.59	AHD
C7	06/12/94	11.40	AHD
C7	29/12/94	11.23	AHD
C7	30/01/95	11.02	AHD
C7	08/03/95	10.80	AHD
C7	31/03/95	10.68	AHD
C7	31/05/95	10.97	AHD
C7	26/07/95	11.81	AHD
C7	29/09/95	12.01	AHD
C7	07/11/95	11.59	AHD
C7	01/03/96	11.00	AHD
C7	25/04/96	10.74	AHD
C8	19/04/94	10.22	AHD
C8	12/05/94	10.19	AHD
C8	28/06/94	10.46	AHD
C8	28/07/94	10.86	AHD
C8	30/08/94	10.78	AHD
C8	28/09/94	10.69	AHD
C8	01/11/94	10.56	AHD
C8	06/12/94	10.43	AHD

C8	29/12/94	10.33	AHD
C8	30/01/95	10.18	AHD
C8	08/03/95	10.00	AHD
C8	31/03/95	9.93	AHD
C8	31/05/95	9.99	AHD
C8	26/07/95	10.78	AHD
C8	29/09/95	10.88	AHD
C8	07/11/95	10.62	AHD
C8	01/03/96	10.17	AHD
C8	25/04/96	9.98	AHD
C9	19/04/94	10.68	AHD
C9	12/05/94	10.59	AHD
C9	28/06/94	10.85	AHD
C9	28/07/94	11.27	AHD
C9	30/08/94	11.21	AHD
C9	28/09/94	11.11	AHD
C9	01/11/94	10.99	AHD
C9	06/12/94	10.83	AHD
C9	29/12/94	10.70	AHD
C9	30/01/95	10.54	AHD
C9	08/03/95	10.41	AHD
C9	31/03/95	10.35	AHD
C9	31/05/95	10.50	AHD
C9	26/07/95	11.13	AHD
C9	29/09/95	11.30	AHD
C9	07/11/95	10.97	AHD
C9	01/03/96	10.51	AHD
C9	25/04/96	10.37	AHD
C10	19/04/94	11.26	AHD
C10	12/05/94	11.14	AHD
C10	28/06/94	11.51	AHD
C10	28/07/94	11.98	AHD
C10	30/08/94	12.01	AHD
C10	28/09/94	11.92	AHD
C10	01/11/94	11.80	AHD
C10	06/12/94	11.64	AHD
C10	29/12/94	11.50	AHD
C10	30/01/95	11.31	AHD
C10	08/03/95	11.09	AHD
C10	31/03/95	10.97	AHD
C10	31/05/95	11.10	AHD
C10	26/07/95	11.90	AHD
C10	29/09/95	12.19	AHD
C10	07/11/95	11.86	AHD
C10	01/03/96	11.31	AHD
C10	25/04/96	11.02	AHD
C11	19/04/94	11.37	AHD
C11	12/05/94	11.27	AHD
C11	28/06/94	11.71	AHD
C11	28/07/94	12.15	AHD

C11	30/08/94	12.13	AHD
C11	28/09/94	12.03	AHD
C11	01/11/94	11.90	AHD
C11	06/12/94	11.75	AHD
C11	29/12/94	11.61	AHD
C11	30/01/95	11.38	AHD
C11	08/03/95	11.17	AHD
C11	31/03/95	11.06	AHD
C11	31/05/95	11.29	AHD
C11	26/07/95	12.10	AHD
C11	29/09/95	12.33	AHD
C11	07/11/95	12.02	AHD
C11	01/03/96	11.41	AHD
C11	25/04/96	11.16	AHD
C12	19/04/94	11.14	AHD
C12	12/05/94	11.04	AHD
C12	28/06/94	11.75	AHD
C12	28/07/94	12.24	AHD
C12	30/08/94	12.23	AHD
C12	28/09/94	12.08	AHD
C12	01/11/94	11.93	AHD
C12	06/12/94	11.64	AHD
C12	29/12/94	11.41	AHD
C12	30/01/95	11.14	AHD
C12	08/03/95	10.97	AHD
C12	31/03/95	10.88	AHD
C12	31/05/95	11.29	AHD
C12	26/07/95	12.33	AHD
C12	29/09/95	12.41	AHD
C12	07/11/95	11.94	AHD
C12	01/03/96	11.15	AHD
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C13	28/09/94	11.99	AHD
C13	01/11/94	11.87	AHD
C13	06/12/94	11.78	AHD
C13	29/12/94	11.65	AHD
C13	30/01/95	11.47	AHD
C13	08/03/95	11.32	AHD
C13	31/03/95	11.27	AHD
C13	31/05/95	11.29	AHD
C13	26/07/95	11.90	AHD
C13	29/09/95	12.16	AHD
C13	07/11/95	11.92	AHD
C13	01/03/96	11.52	AHD
C13	25/04/96	11.31	AHD

C14	19/04/94	11.33	AHD
C14	12/05/94	11.27	AHD
C14	28/06/94	11.92	AHD
C14	28/07/94	12.47	AHD
C14	30/08/94	12.46	AHD
C14	28/09/94	12.32	AHD
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C14	06/12/94	11.88	AHD
C14	29/12/94	11.64	AHD
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C14	31/05/95	11.45	AHD
C14	26/07/95	12.53	AHD
C14	29/09/95	12.75	AHD
C14	07/11/95	12.27	AHD
C14	01/03/96	11.45	AHD
C14	25/04/96	11.19	AHD
C15	19/04/94	11.85	AHD
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C15	28/06/94	12.40	AHD
C15	28/07/94	12.87	AHD
C15	30/08/94	12.89	AHD
C15	28/09/94	12.72	AHD
C15	01/11/94	12.51	AHD
C15	06/12/94	12.23	AHD
C15	29/12/94	12.04	AHD
C15	30/01/95	11.88	AHD
C15	08/03/95	11.72	AHD
C15	31/03/95	11.66	AHD
C15	31/05/95	11.90	AHD
C15	26/07/95	12.90	AHD
C15	29/09/95	13.10	AHD
C15	07/11/95	12.69	AHD
C15	01/03/96	11.96	AHD
C15	25/04/96	11.73	AHD
S1	19/04/94	10.04	AHD
S1	12/05/94	10.90	AHD
S1	28/06/94	12.16	AHD
S1	28/07/94	12.49	AHD
S1	30/08/94	12.44	AHD
S1	28/09/94	12.32	AHD
S1	01/11/94	12.15	AHD
S1	06/12/94	11.84	AHD
S1	29/12/94	11.56	AHD
S1	30/01/95	11.08	AHD
S1	08/03/95	10.87	AHD
S1	31/03/95	10.81	AHD
S1	31/05/95	11.91	AHD
S1	26/07/95	12.66	AHD

S1	29/09/95	12.77	AHD
S1	07/11/95	12.41	AHD
S1	01/03/96	11.48	AHD
S1	25/04/96	10.89	AHD
S2	19/04/94	10.82	AHD
S2	12/05/94	10.95	AHD
S2	28/06/94	11.29	AHD
S2	28/07/94	11.76	AHD
S2	30/08/94	11.84	AHD
S2	28/09/94	11.72	AHD
S2	01/11/94	11.54	AHD
S2	06/12/94	11.29	AHD
S2	29/12/94	11.09	AHD
S2	30/01/95	10.83	AHD
S2	08/03/95	10.61	AHD
S2	31/03/95	10.50	AHD
S2	31/05/95	11.17	AHD
S2	26/07/95	11.79	AHD
S2	29/09/95	12.12	AHD
S2	07/11/95	11.69	AHD
S2	01/03/96	10.91	AHD
S2	25/04/96	10.64	AHD
S3	19/04/94		AHD
S3	12/05/94		AHD
S3	28/06/94		AHD
S3	28/07/94	11.92	AHD
S3	30/08/94	12.15	AHD
S3	28/09/94	12.17	AHD
S3	01/11/94	12.08	AHD
S3	06/12/94	11.79	AHD
S3	29/12/94		AHD
S3	30/01/95		AHD
S3	08/03/95		AHD
S3	31/03/95		AHD
S3	31/05/95		AHD
S3	26/07/95	11.90	AHD
S3	29/09/95	12.87	AHD
S3	07/11/95	12.46	AHD
S3	01/03/96		AHD
S3	25/04/96		AHD
S4	19/04/94	11.75	AHD
S4	12/05/94	11.66	AHD
S4	28/06/94	12.25	AHD
S4	28/07/94	12.68	AHD
S4	30/08/94	12.68	AHD
S4	28/09/94	12.60	AHD
S4	01/11/94	12.49	AHD
S4	06/12/94	12.32	AHD
S4	29/12/94	12.17	AHD
S4	30/01/95	11.96	AHD

S4	08/03/95	11.68	AHD
S4	31/03/95	11.54	AHD
S4	31/05/95	11.95	AHD
S4	26/07/95	12.72	AHD
S4	29/09/95	12.87	AHD
S4	07/11/95	12.55	AHD
S4	01/03/96	11.97	AHD
S4	25/04/96	11.65	AHD
S5	19/04/94	11.46	AHD
S5	12/05/94	11.41	AHD
S5	28/06/94	11.92	AHD
S5	28/07/94	12.38	AHD
S5	30/08/94	12.37	AHD
S5	28/09/94	12.26	AHD
S5	01/11/94	12.12	AHD
S5	06/12/94	11.92	AHD
S5	29/12/94	11.78	AHD
S5	30/01/95	11.57	AHD
S5	08/03/95	11.38	AHD
S5	31/03/95	11.28	AHD
S5	31/05/95	11.61	AHD
S5	26/07/95	12.42	AHD
S5	29/09/95	12.58	AHD
S5	07/11/95	12.05	AHD
S5	01/03/96	11.57	AHD
S5	25/04/96	11.36	AHD
S6	19/04/94	10.86	AHD
S6	12/05/94	10.80	AHD
S6	28/06/94	11.35	AHD
S6	28/07/94	11.91	AHD
S6	30/08/94	11.85	AHD
S6	28/09/94	11.71	AHD
S6	01/11/94	11.56	AHD
S6	06/12/94	11.39	AHD
S6	29/12/94	11.34	AHD
S6	30/01/95	11.09	AHD
S6	08/03/95	10.91	AHD
S6	31/03/95	10.81	AHD
S6	31/05/95	11.11	AHD
S6	26/07/95	12.10	AHD
S6	29/09/95	12.11	AHD
S6	07/11/95	11.62	AHD
S6	01/03/96	11.12	AHD
S6	25/04/96	10.88	AHD
S7	19/04/94	10.93	AHD
S7	12/05/94	10.89	AHD
S7	28/06/94		AHD
S7	28/07/94		AHD
S7	30/08/94		AHD
S7	28/09/94		AHD

S7	01/11/94		AHD
S7	06/12/94	11.92	AHD
S7	29/12/94	11.35	AHD
S7	30/01/95	11.18	AHD
S7	08/03/95	10.99	AHD
S7	31/03/95	10.79	AHD
S7	31/05/95	11.68	AHD
S7	26/07/95		AHD
S7	29/09/95		AHD
S7	07/11/95	12.25	AHD
S7	01/03/96	11.12	AHD
S7	25/04/96	10.89	AHD
S8-S	19/04/94	11.70	AHD
S8-S	12/05/94	11.72	AHD
S8-S	28/06/94	12.41	AHD
S8-S	28/07/94	12.71	AHD
S8-S	30/08/94	12.82	AHD
S8-S	28/09/94	12.76	AHD
S8-S	01/11/94	12.62	AHD
S8-S	06/12/94	12.36	AHD
S8-S	29/12/94	12.09	AHD
S8-S	30/01/95	11.83	AHD
S8-S	08/03/95	11.65	AHD
S8-S	31/03/95	11.52	AHD
S8-S	31/05/95	12.05	AHD
S8-S	26/07/95		AHD
S8-S	29/09/95		AHD
S8-S	07/11/95	12.59	AHD
S8-S	01/03/96	11.85	AHD
S8-S	25/04/96	11.66	AHD
S8-I	19/04/94	11.73	AHD
S8-I	12/05/94	11.71	AHD
S8-I	28/06/94	12.38	AHD
S8-I	28/07/94	12.72	AHD
S8-I	30/08/94	12.81	AHD
S8-I	28/09/94	12.75	AHD
S8-I	01/11/94	12.59	AHD
S8-I	06/12/94	12.36	AHD
S8-I	29/12/94	12.09	AHD
S8-I	30/01/95	11.84	AHD
S8-I	08/03/95	11.64	AHD
S8-I	31/03/95	11.52	AHD
S8-I	31/05/95	12.02	AHD
S8-I	26/07/95		AHD
S8-I	29/09/95		AHD
S8-I	07/11/95	12.59	AHD
S8-I	01/03/96	11.85	AHD
S8-I	25/04/96	11.66	AHD
S9-S	19/04/94	12.36	AHD
S9-S	12/05/94	12.32	AHD

S9-S	28/06/94	13.27	AHD
S9-S	28/07/94	13.20	AHD
S9-S	30/08/94	13.14	AHD
S9-S	28/09/94	12.87	AHD
S9-S	01/11/94	12.67	AHD
S9-S	06/12/94	12.60	AHD
S9-S	29/12/94	12.55	AHD
S9-S	30/01/95	12.45	AHD
S9-S	08/03/95	12.28	AHD
S9-S	31/03/95	12.28	AHD
S9-S	31/05/95	12.75	AHD
S9-S	26/07/95	13.28	AHD
S9-S	29/09/95	12.91	AHD
S9-S	07/11/95	12.67	AHD
S9-S	01/03/96	12.45	AHD
S9-S	25/04/96	12.32	AHD
S10	19/04/94	10.23	AHD
S10	12/05/94	10.19	AHD
S10	28/06/94	10.45	AHD
S10	28/07/94	10.76	AHD
S10	30/08/94	10.92	AHD
S10	28/09/94	10.83	AHD
S10	01/11/94	10.76	AHD
S10	06/12/94	10.69	AHD
S10	29/12/94	10.65	AHD
S10	30/01/95	10.60	AHD
S10	08/03/95	10.40	AHD
S10	31/03/95	10.26	AHD
S10	31/05/95	10.15	AHD
S10	26/07/95	10.76	AHD
S10	29/09/95	10.98	AHD
S10	07/11/95	10.82	AHD
S10	01/03/96	10.65	AHD
S10	25/04/96	10.19	AHD
S11	19/04/94	12.13	AHD
S11	12/05/94	12.07	AHD
S11	28/06/94	12.77	AHD
S11	28/07/94	13.15	AHD
S11	30/08/94	13.09	AHD
S11	28/09/94	12.85	AHD
S11	01/11/94	12.70	AHD
S11	06/12/94	12.53	AHD
S11	29/12/94	12.42	AHD
S11	30/01/95	12.29	AHD
S11	08/03/95	12.12	AHD
S11	31/03/95	12.03	AHD
S11	31/05/95	12.40	AHD
S11	26/07/95	13.25	AHD
S11	29/09/95	13.01	AHD
S11	07/11/95	12.64	AHD

S11	01/03/96	12.25	AHD
S11	25/04/96	12.01	AHD
E1	19/04/94	11.77	AHD
E1	12/05/94	11.75	AHD
E1	28/06/94	12.63	AHD
E1	28/07/94	12.76	AHD
E1	30/08/94	12.67	AHD
E1	28/09/94	12.32	AHD
E1	01/11/94	12.13	AHD
E1	06/12/94	12.03	AHD
E1	29/12/94	11.99	AHD
E1	30/01/95	11.91	AHD
E1	08/03/95	11.79	AHD
E1	31/03/95	11.82	AHD
E1	31/05/95	12.38	AHD
E1	26/07/95	12.80	AHD
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E1	07/11/95	12.03	AHD
E1	01/03/96	11.89	AHD
E1	25/04/96	11.74	AHD
E2	19/04/94	11.04	AHD
E2	12/05/94	10.96	AHD
E2	28/06/94	10.89	AHD
E2	28/07/94	11.14	AHD
E2	30/08/94	11.34	AHD
E2	28/09/94	11.28	AHD
E2	01/11/94	11.25	AHD
E2	06/12/94	11.26	AHD
E2	29/12/94	11.15	AHD
E2	30/01/95	11.29	AHD
E2	08/03/95	11.14	AHD
E2	31/03/95	11.09	AHD
E2	31/05/95	10.74	AHD
E2	26/07/95	11.07	AHD
E2	29/09/95	11.52	AHD
E2	07/11/95	11.44	AHD
E2	01/03/96	11.39	AHD
E2	25/04/96	10.97	AHD
E3	19/04/94	9.92	AHD
E3	12/05/94	9.79	AHD
E3	28/06/94	10.34	AHD
E3	28/07/94	10.81	AHD
E3	30/08/94	10.89	AHD
E3	28/09/94	10.78	AHD
E3	01/11/94	10.63	AHD
E3	06/12/94	10.22	AHD
E3	29/12/94	10.17	AHD
E3	30/01/95	9.94	AHD
E3	08/03/95	9.62	AHD
E3	31/03/95	9.40	AHD

E3	31/05/95	9.50	AHD
E3	26/07/95	10.74	AHD
E3	29/09/95	10.91	AHD
E3	07/11/95	10.29	AHD
E3	01/03/96	9.81	AHD
E3	25/04/96	9.37	AHD
Sim1	01/06/91	10.74	AHD
Sim1	01/07/91	10.74	AHD
Sim1	01/08/91	10.94	AHD
Sim1	01/09/91	10.74	AHD
Sim1	01/10/91	10.84	AHD
Sim1	01/11/91	10.74	AHD
Sim1	01/12/91	10.54	AHD
Sim1	01/01/92	10.74	AHD
Sim1	01/02/92	10.74	AHD
Sim1	01/03/92	10.84	AHD
Sim1	01/04/92	10.64	AHD
Sim1	01/05/92	10.74	AHD
Sim1	01/06/92	10.74	AHD
Sim1	01/07/92	10.64	AHD
Sim1	01/08/92	10.84	AHD
Sim1	01/09/92	10.84	AHD
Sim1	01/10/92	10.74	AHD
Sim1	01/11/92	10.74	AHD
Sim1	01/12/92	10.64	AHD
Sim1	01/01/93	10.54	AHD
Sim1	01/02/93	10.54	AHD
Sim1	01/03/93	10.34	AHD
Sim1	01/04/93	10.64	AHD
Sim1	01/05/93	10.74	AHD
Sim1	01/06/93	10.84	AHD
Sim1	01/07/93	10.74	AHD
Sim1	01/08/93	10.54	AHD
Sim1	01/09/93	10.24	AHD
Sim1	01/10/93	10.24	AHD
Sim1	01/11/93	10.54	AHD
Sim1	01/12/93	10.54	AHD
Sim1	01/01/94	10.24	AHD
Sim1	01/02/94	10.74	AHD
Sim1	01/03/94	10.54	AHD
Sim1	01/04/94	10.74	AHD
Sim1	01/05/94	10.74	AHD
Sim1	01/06/94	10.54	AHD
Sim1	01/07/94	10.24	AHD
Sim1	01/08/94	10.24	AHD
Sim1	01/09/94	10.54	AHD
Sim1	01/10/94	10.54	AHD
Sim1	01/11/94	10.24	AHD
Sim1	01/12/94	10.24	AHD
Sim1	01/01/95	10.04	AHD

Sim1	01/02/95	10.24	AHD
Sim1	01/03/95	10.04	AHD
Sim1	01/04/95	10.04	AHD
Sim1	01/05/95	9.74	AHD
Sim1	01/06/95	10.24	AHD
Sim1	31/07/95	10.74	AHD
Sim1	31/08/95	10.24	AHD
Sim1	30/09/95	10.74	AHD
Sim1	31/10/95	10.74	AHD
Sim1	30/11/95	10.74	AHD
Sim1	31/12/95	10.24	AHD
Sim1	29/02/96	9.74	AHD
Sim1	31/03/96	9.74	AHD
Sim1	30/04/96	9.74	AHD
Sim1	31/08/96	10.74	AHD
Sim1	30/09/96	11.24	AHD
Sim1	31/10/96	10.74	AHD
Sim1	30/11/96	10.74	AHD
Sim1	31/12/96	10.74	AHD
Sim1	31/01/97	10.74	AHD
Sim1	28/02/97	10.54	AHD
Sim1	31/03/97	10.14	AHD
Sim1	30/04/97	10.14	AHD
Sim1	31/05/97	10.24	AHD
Sim1	30/06/97	11.04	AHD
Sim1	31/07/97	10.84	AHD
Sim1	31/08/97	10.64	AHD
Sim1	30/09/97	11.04	AHD
Sim1	31/10/97	10.94	AHD
Sim1	30/11/97	10.54	AHD
Sim1	31/12/97	10.24	AHD
Sim1	31/01/98	9.74	AHD
Sim1	28/02/98	10.04	AHD
Sim1	31/03/98	10.04	AHD
Sim1	30/04/98	9.64	AHD
Sim1	31/05/98	9.74	AHD
Sim1	30/06/98	9.84	AHD
Sim1	31/07/98	10.04	AHD
Sim1	31/08/98	10.54	AHD
Sim1	30/09/98	10.14	AHD
Sim1	30/11/98	9.94	AHD
Sim1	31/12/98	9.84	AHD
Sim1	31/01/99	9.94	AHD
Sim1	31/03/99	10.34	AHD
Sim1	30/04/99	10.34	AHD
Sim1	31/05/99	10.44	AHD
Sim1	31/07/99	10.74	AHD
Sim1	31/08/99	10.64	AHD
Sim1	31/10/99	10.74	AHD
Sim1	30/11/99	10.64	AHD

Sim2	01/06/91	10.03	AHD
Sim2	01/07/91	10.03	AHD
Sim2	01/08/91	10.03	AHD
Sim2	01/09/91	10.23	AHD
Sim2	01/10/91	10.53	AHD
Sim2	01/11/91	10.23	AHD
Sim2	01/12/91	10.13	AHD
Sim2	01/01/92	10.33	AHD
Sim2	01/02/92	10.23	AHD
Sim2	01/03/92	10.23	AHD
Sim2	01/04/92	10.43	AHD
Sim2	01/05/92	10.13	AHD
Sim2	01/06/92	10.33	AHD
Sim2	01/07/92	10.23	AHD
Sim2	01/08/92	10.23	AHD
Sim2	01/09/92	10.33	AHD
Sim2	01/10/92	10.33	AHD
Sim2	01/11/92	10.43	AHD
Sim2	01/12/92	10.33	AHD
Sim2	01/01/93	10.13	AHD
Sim2	01/02/93	10.23	AHD
Sim2	01/03/93	10.13	AHD
Sim2	01/04/93	10.33	AHD
Sim2	01/05/93	10.43	AHD
Sim2	01/06/93	10.43	AHD
Sim2	01/07/93	10.53	AHD
Sim2	01/08/93	10.53	AHD
Sim2	01/09/93	10.33	AHD
Sim2	01/10/93	10.33	AHD
Sim2	01/11/93	10.33	AHD
Sim2	01/12/93	10.03	AHD
Sim2	01/01/94	10.23	AHD
Sim2	01/02/94	10.03	AHD
Sim2	01/03/94	10.03	AHD
Sim2	01/04/94	10.03	AHD
Sim2	01/05/94	10.03	AHD
Sim2	01/06/94	10.33	AHD
Sim2	01/07/94	10.03	AHD
Sim2	01/08/94	10.33	AHD
Sim2	01/09/94	10.13	AHD
Sim2	01/10/94	10.33	AHD
Sim2	01/11/94	10.03	AHD
Sim2	01/12/94	10.33	AHD
Sim2	01/01/95	10.03	AHD
Sim2	01/02/95	10.03	AHD
Sim2	01/03/95	9.83	AHD
Sim2	01/04/95	9.83	AHD
Sim2	01/05/95	10.03	AHD
Sim2	01/06/95	10.03	AHD
Sim2	31/07/95	9.53	AHD

Sim2	31/08/95	10.03	AHD
Sim2	30/09/95	9.53	AHD
Sim2	31/10/95	9.53	AHD
Sim2	30/11/95	9.53	AHD
Sim2	31/12/95	9.53	AHD
Sim2	29/02/96	9.53	AHD
Sim2	31/03/96	9.53	AHD
Sim2	30/04/96	9.53	AHD
Sim2	31/08/96	9.53	AHD
Sim2	30/09/96	11.03	AHD
Sim2	31/10/96	10.53	AHD
Sim2	30/11/96	10.53	AHD
Sim2	31/12/96	10.23	AHD
Sim2	31/01/97	10.23	AHD
Sim2	28/02/97	9.73	AHD
Sim2	31/03/97	9.63	AHD
Sim2	30/04/97	9.73	AHD
Sim2	31/05/97	9.73	AHD
Sim2	30/06/97	10.13	AHD
Sim2	31/07/97	9.93	AHD
Sim2	31/08/97	9.73	AHD
Sim2	30/09/97	9.83	AHD
Sim2	31/10/97	9.93	AHD
Sim2	30/11/97	9.93	AHD
Sim2	31/12/97	9.63	AHD
Sim2	31/01/98	9.33	AHD
Sim2	28/02/98	9.63	AHD
Sim2	31/03/98	9.93	AHD
Sim2	30/04/98	9.63	AHD
Sim2	31/05/98	9.73	AHD
Sim2	30/06/98	9.43	AHD
Sim2	31/07/98	9.63	AHD
Sim2	31/08/98	10.13	AHD
Sim2	30/09/98	9.73	AHD
Sim2	30/11/98	9.73	AHD
Sim2	31/12/98	9.43	AHD
Sim2	31/01/99	9.83	AHD
Sim2	31/03/99	10.13	AHD
Sim2	30/04/99	10.03	AHD
Sim2	31/05/99	10.23	AHD
Sim2	31/07/99	10.53	AHD
Sim2	31/08/99	10.43	AHD
Sim2	31/10/99	10.43	AHD
Sim2	30/11/99	10.43	AHD
Sim3	01/06/91	9.53	AHD
Sim3	01/07/91	9.63	AHD
Sim3	01/08/91	9.63	AHD
Sim3	01/09/91	9.53	AHD
Sim3	01/10/91	9.53	AHD
Sim3	01/11/91	9.33	AHD

Sim3	01/12/91	9.63	AHD
Sim3	01/01/92	9.63	AHD
Sim3	01/02/92	9.63	AHD
Sim3	01/03/92	9.83	AHD
Sim3	01/04/92	9.73	AHD
Sim3	01/05/92	9.63	AHD
Sim3	01/06/92	9.63	AHD
Sim3	01/07/92	9.53	AHD
Sim3	01/08/92	9.63	AHD
Sim3	01/09/92	9.53	AHD
Sim3	01/10/92	9.53	AHD
Sim3	01/11/92	9.63	AHD
Sim3	01/12/92	9.43	AHD
Sim3	01/01/93	9.23	AHD
Sim3	01/02/93	9.43	AHD
Sim3	01/03/93	9.53	AHD
Sim3	01/04/93	9.33	AHD
Sim3	01/05/93	9.63	AHD
Sim3	01/06/93	9.53	AHD
Sim3	01/07/93	9.53	AHD
Sim3	01/08/93	9.53	AHD
Sim3	01/09/93	9.73	AHD
Sim3	01/10/93	9.53	AHD
Sim3	01/11/93	9.53	AHD
Sim3	01/12/93	9.43	AHD
Sim3	01/01/94	9.63	AHD
Sim3	01/02/94	9.53	AHD
Sim3	01/03/94	9.33	AHD
Sim3	01/04/94	9.53	AHD
Sim3	01/05/94	9.43	AHD
Sim3	01/06/94	9.53	AHD
Sim3	01/07/94	9.53	AHD
Sim3	01/08/94	9.43	AHD
Sim3	01/09/94	9.53	AHD
Sim3	01/10/94	9.43	AHD
Sim3	01/11/94	9.53	AHD
Sim3	01/12/94	9.53	AHD
Sim3	01/01/95	9.33	AHD
Sim3	01/02/95	9.33	AHD
Sim3	01/03/95	9.03	AHD
Sim3	01/04/95	9.03	AHD
Sim3	01/05/95	9.53	AHD
Sim3	01/06/95	9.03	AHD
Sim3	31/07/95	9.53	AHD
Sim3	31/08/95	9.53	AHD
Sim3	30/09/95	9.03	AHD
Sim3	31/10/95	9.03	AHD
Sim3	30/11/95	9.53	AHD
Sim3	31/12/95	9.53	AHD
Sim3	29/02/96	9.53	AHD

Sim3	31/03/96	9.53	AHD
Sim3	30/04/96	8.53	AHD
Sim3	31/08/96	9.53	AHD
Sim3	30/09/96	10.53	AHD
Sim3	31/10/96	10.53	AHD
Sim3	30/11/96	10.53	AHD
Sim3	31/12/96	9.53	AHD
Sim3	31/01/97	9.53	AHD
Sim3	28/02/97	9.33	AHD
Sim3	31/03/97	9.23	AHD
Sim3	30/04/97	9.43	AHD
Sim3	31/05/97	9.53	AHD
Sim3	30/06/97	9.83	AHD
Sim3	31/07/97	9.63	AHD
Sim3	31/08/97	9.33	AHD
Sim3	30/09/97	9.23	AHD
Sim3	31/10/97	9.13	AHD
Sim3	30/11/97	9.43	AHD
Sim3	31/12/97	9.03	AHD
Sim3	31/01/98	8.63	AHD
Sim3	28/02/98	8.83	AHD
Sim3	31/03/98	9.03	AHD
Sim3	30/04/98	9.23	AHD
Sim3	31/05/98	8.93	AHD
Sim3	30/06/98	9.13	AHD
Sim3	31/07/98	9.43	AHD
Sim3	31/08/98	9.63	AHD
Sim3	30/09/98	9.13	AHD
Sim3	30/11/98	8.93	AHD
Sim3	31/12/98	8.83	AHD
Sim3	31/01/99	9.33	AHD
Sim3	31/03/99	9.53	AHD
Sim3	30/04/99	9.53	AHD
Sim3	31/05/99	9.53	AHD
Sim3	31/07/99	9.93	AHD
Sim3	31/08/99	9.73	AHD
Sim3	31/10/99	9.83	AHD
Sim3	30/11/99	9.83	AHD
KM4	01/09/89	12.8	AHD
KM4	01/12/89	11.9	AHD
KM4	01/04/90	11.5	AHD
KM4	01/06/90	11.8	AHD
KM4	01/10/90	12.2	AHD
KM4	01/04/91	11.3	AHD
KM4	01/06/91	11.6	AHD
KM4	01/10/91	12.2	AHD
KM4	01/12/91	11.9	AHD
KM4	01/03/92	11.4	AHD
KM4	01/07/92	12.1	AHD
KM4	01/09/92	12.2	AHD

KM4	01/03/93	11.5	AHD
KM4	01/06/93	11.1	AHD
KM4	01/09/93	11.8	AHD
KM4	01/02/94	11.25	AHD
KM4	01/05/94	11.34	AHD
KM4	09/08/94	11.54	AHD
KM4	09/11/94	11.34	AHD
KM4	05/02/95	11.01	AHD
KM4	06/04/95	10.59	AHD
KM4	20/07/95	11.05	AHD
KM4	05/10/95	11.66	AHD
KM4	18/01/96	11.29	AHD
KM4	11/04/96	10.69	AHD
KM4	16/07/96	10.95	AHD
KM4	08/10/96	11.93	AHD
KM4	22/01/97	11.526	AHD
KM4	06/06/97	10.975	AHD
KM4	03/09/97	14.89	AHD
KM4	27/01/98	14.89	AHD
KM4	01/06/98	10.8	AHD
KM4	01/08/98	10.1	AHD
KM4	01/03/99	10.8	AHD
KM4	01/06/99	14.89	AHD
KM4	01/10/99	14.89	AHD
KM4	01/01/00	14.89	AHD
KM14	01/09/89	12.6	AHD
KM14	01/12/89	11.5	AHD
KM14	01/04/90	10.9	AHD
KM14	01/06/90	11.2	AHD
KM14	01/10/90	11.7	AHD
KM14	01/12/90	11.4	AHD
KM14	01/04/91	10.8	AHD
KM14	01/06/91	11.3	AHD
KM14	01/10/91	12	AHD
KM14	01/12/91	11.7	AHD
KM14	01/03/92	11.4	AHD
KM14	01/07/92	11.9	AHD
KM14	01/09/92	12	AHD
KM14	01/03/93	11.2	AHD
KM14	01/06/93	10.9	AHD
KM14	01/09/93	11.6	AHD
KM14	01/02/94	10.91	AHD
KM14	01/05/94	10.44	AHD
KM14	09/08/94	11.15	AHD
KM14	09/11/94	10.95	AHD
KM14	05/02/95	10.58	AHD
KM14	06/04/95	10.11	AHD
KM14	20/07/95	10.91	AHD
KM14	05/10/95	11.42	AHD
KM14	18/01/96	10.97	AHD

KM14	11/04/96	10.29	AHD
KM14	16/07/96	10.73	AHD
KM14	08/10/96	11.53	AHD
KM14	22/01/97	11.09	AHD
KM14	06/06/97	10.73	AHD
KM14	03/09/97	14.82	AHD
KM14	27/01/98	14.82	AHD
KM14	01/06/98	10.537	AHD
KM14	01/08/98	9.7	AHD
KM14	01/10/98	10	AHD
KM14	01/12/98	9.8	AHD
KM14	01/03/99	10.561	AHD
KM14	01/06/99	10.149	AHD
KM14	01/10/99	11.267	AHD
KM14	01/01/00	11.107	AHD
KM17	01/09/89	13	AHD
KM17	01/12/89	12.1	AHD
KM17	01/04/90	11.6	AHD
KM17	01/06/90	11.9	AHD
KM17	01/10/90	12.3	AHD
KM17	01/12/90	12	AHD
KM17	01/04/91	11.4	AHD
KM17	01/06/91	11.9	AHD
KM17	01/10/91	12.3	AHD
KM17	01/12/91	12.2	AHD
KM17	01/03/92	11.4	AHD
KM17	01/07/92	12.4	AHD
KM17	01/09/92	12.5	AHD
KM17	01/03/93	11.4	AHD
KM17	01/06/93	11.4	AHD
KM17	01/09/93	12.1	AHD
KM17	01/02/94	11.44	AHD
KM17	01/05/94	10.96	AHD
KM17	09/08/94	11.71	AHD
KM17	09/11/94	11.48	AHD
KM17	05/02/95	11.04	AHD
KM17	06/04/95	10.59	AHD
KM17	20/07/95	11.25	AHD
KM17	05/10/95	11.81	AHD
KM17	18/01/96	11.41	AHD
KM17	11/04/96	10.72	AHD
KM17	16/07/96	11.13	AHD
KM17	08/10/96	12.15	AHD
KM17	22/01/97	11.66	AHD
KM17	06/06/97	11.175	AHD
KM17	03/09/97	15	AHD
KM17	27/01/98	15	AHD
KM17	01/06/98	10.876	AHD
KM17	01/08/98	10.1	AHD
KM17	01/10/98	10.4	AHD

KM17	01/12/98	10.2	AHD
KM17	01/03/99	10.935	AHD
KM17	01/06/99	10.253	AHD
KM17	01/10/99	11.572	AHD
KM17	01/01/00	11.448	AHD

Appendix B - Groundwater level monitoring

Water Monitoring carried out by Cardno and PB (2009 - 2011)

ID	Oct-09	Nov-09	Jan-10	Oct-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11
	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	mAHD	mAHD	mAHD
**KEML1	-0.301	-1.091	-4.631	-0.211	1.254	-0.291	-3.13	-3.77		1.253	12.669
**KEML1C	1.939	1.779	1.409	1.679	-2.258	1.549	0.72	-0.15		1.035	12.669
**KEML2	8.811	8.631	7.501	8.171	7.85	7.881	7.09	6.43		8.376	15.351
**KEML2C	2.071	2.171	-0.129	1.881	1.951	1.831	1.64	1.26		1.837	15.351
C10	11.67	11.62	11.12	10.7	10.368	10.4	10.36	10.19		10.702	15.22
C11	11.7	11.6	11.33	10.79	10.452	10.52	10.66	10.39		10.878	14.67
C12	11.95	11.79	11.25	10.85	10.486	10.48	10.54	8.49		11.127	13.65
C13	11.56	11.47	10.2	10.98	--	11.1	12.89	12.24		--	15.9
C14	12.4	12.35	--	11.27	--	10.97	5.40	5.28		11.668	13.77
C15	13.04	12.94	12.42	11.85	11.517	11.66	10.89	10.36		12.041	14.98
C1-D	11.34	11.23	10.68	10.13	10.065	9.84	--	13.43		10.774	13.43
C1-I	11.45	11.29	10.78	10.42	10.167	10.19	--	13.13		10.871	13.13
C1-S	11.43	11.34	10.77	--	#VALUE!	--	--	13.13		--	13.13
C2-D	11.37	11.32	10.87	10.64	10.24	10.3	--	12.56		10.682	12.56
C2-I	11.29	11.26	10.73	10.48	10.09	10.16	--	12.46		10.566	12.46
C2-S	11.45	11.41	10.84	--	--	--	--	12.76		10.774	12.76
C3-D	11.63	11.61	11.1	10.67	10.317	10.35	10.12	10.02		10.856	13.08
C3-I	11.59	11.55	11.12	10.64	10.28	10.33	10.05	9.91		10.927	13.08
C3-S	11.64	11.59	11.23	--	--	--	--	13.08		11.538	13.08
C4-I	11.71	11.57	11.06	10.82	10.395	10.47	10.25	10.17		11.358	13.06
C4-S	11.64	11.5	--	10.76	10.311	10.41	10.20	9.84		11.152	12.76
C6	10.93	10.83	10.16	9.81	9.493	9.5	9.39	9.21		9.682	12.61
C7	11.18	11.11	10.61	10.15	9.806	9.82	9.74	9.58		10.159	13.37
C8	10.51	10.48	10.03	9.96	9.633	9.54	9.59	9.31		9.738	13.86
C9	10.62	10.51	10.18	10	9.809	9.81	9.64	9.29		10.054	13.62
F4E	--	--	--	3.8	4.025	3.64	--	11.85			11.85
F5	4.22	4.05	3.66	3.66	3.595	3.35	3.10	2.57			7.19
F6	7.11	7.11	--	--	--	--	--	15.64			15.64
F6D	7.29	7.22	6.94	6.74	6.676	6.61	6.45	6.24			15.64
G4	3.34	3.31	3.02	2.85	2.601	2.69	2.57	2.30		2.642	13.09
G5	5.25	5.15	4.89	4.72	5.266	4.51	4.33	4.03			8.34
G6	11.3	11.33	10.4	11.01	15.59	10.94	10.84	10.60		10.722	39.1
G7	13.18	13.05	12.55	12.02	11.979	11.73	11.53	11.08		12.324	15.54
G8	12.31	12.28	11.8	11.07	--	10.78	10.67	10.41		11.647	14.06
HS1A	9.06	--	--	8.66	8.464	8.52	8.36	8.20		8.452	36.72
HS1B	9.07	9.07	8.75	8.67	8.492	8.55	8.38	8.23		8.474	36.72
KEMS10D	13.15	13.03	12.51	12.32	11.671	11.69	11.43	10.55		12.14	14.69
KEMS10S	13.31	13.2	12.65	12.43	--	--	--	14.69		12.547	14.69
KEMS12D	12.41	12.28	11.84	11.24	10.709	10.88	10.65	10.51		11.409	14.36
KEMS12S	12.42	12.28	11.83	11.27	11.159	--	--	14.36		11.559	14.36
KEMS1D	8.31	8.28	7.95	7.09	6.994	6.75	6.69	6.40		6.691	12.66
KEMS1S	9.75	9.66	9.08	8.66	--	8.29	--	12.66		--	12.66
KEMS2D	7.49	7.45	7.24	6.99	6.879	6.84	6.69	6.55			12.46
KEMS3D	4.85	4.74	4.36	4.32	3.976	4.09	3.97	3.74		4.3	8.72
KEMS3S	5.13	4.98	4.77	4.88	--	--	--	8.72		--	8.72
KEMS4D	6.25	6.26	6.01	5.86	5.606	5.7	5.52	5.28			12.94
KEMS6D	13.04	12.94	12.63	12.19	12.037	10.06	11.92	11.59			15.56
KEMS9D	12.52	12.38	11.85	11.47	--	11.14	10.89	10.45		12.677	14.95
KWS3/98	9.5	9.61	7.78	4.98	8.342	4.68	4.40	4.06		5.008	14
S1	12.35	12.2	11.66	11.2	10.561	10.97	10.38	9.69		12.206	14.55
S10	11.46	11.35	11.35	11.04	11.006	11.02	10.71	10.48		11.031	14.05
S11	13.31	13.25	12.73	12.6	12.294	12.37	12.12	11.74		12.829	14.65
S3	13.04	13.04	--	--	--	--	--	17.64		--	17.64
S4	12.55	12.48	11.77	11.23	11.31	10.88	11.09	10.77		11.956	14.71
S5	11.77	11.69	11.31	11.14	11.029	9.08	10.65	10.37		11.497	14.12
S6	11.79	11.62	11.14	11.1	10.796	10.83	10.55	10.11		11.41	14

-- Unable to be located

Our Ref: V9085--JLN100006.10—DPC

Contact: Dave Coremans

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40 The Esplanade
Perth
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Attention - Mr Johnathon Roach

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Dear Jonathan

HYDROLOGICAL MONITORING AT KEMERTON INDUSTRIAL PARK

As you are aware, Cardno was engaged to conduct three months of groundwater monitoring at Kemerton Industrial Park to support future preparation of a Water Management Strategy. This letter report documents the results of the groundwater monitoring program. This letter report is a stand alone document that may be utilised for future detailed design stages and other management documents that may be required in the Structure Planning process.

1. Introduction

1.1 Project Background

The Kemerton Industrial Park (hereafter referred to as the study area) is situated approximately 17kms north east of Bunbury between the South West Highway and Old Coast Road. The study area comprises of 2106ha of industrial land with a buffer of 5437ha. The location of the study area is shown in **Figure 1**. In order to deliver the study area to a project ready status for the Heavy Use Industrial Land Strategy, a District/ Local Water Management Strategy is required.

Cardno was engaged by Landcorp to undertake groundwater level and quality monitoring throughout the study area for a period of three months. The results from the groundwater monitoring will inform the future Water Management Strategy for the study area and will supplement the information already collected in previous studies.

1.2 Project Objective

The objective of the groundwater monitoring program was to capture a second winter of groundwater level and groundwater quality data to meet DOW requirements. This will ensure that any future development is able to fulfil the stormwater management requirements of the DOW.

1.3 Purpose of this Report Letter

The purpose of this report letter is to document the results of the three months of groundwater levels and quality monitoring, undertaken in October 2009, November 2009 and January 2010.

Belgium Brussels **Indonesia** Jakarta **Kenya** Nairobi **New Zealand** Auckland Christchurch Wellington
Papua New Guinea Port Moresby **Sri Lanka** Colombo **United Arab Emirates** Abu Dhabi **United Kingdom** London
United States of America Portland Washington Phoenix Sacramento Boise Las Vegas Charlotte

2. Methodology

2.1 Groundwater Levels

Groundwater levels were measured in October 2009, November 2009 and January 2010 at 55 monitoring bores located within the study area. The locations of these bores are shown in **Figure 2**. The bores were measured using an audible dip meter to record standing water levels relative to the ground surface.

2.2 Groundwater Quality

The groundwater quality investigation was undertaken in January 2010. Of the 55 bores originally located and measured for groundwater levels, 41 were serviceable and able to be sampled. The bores were purged using an electric pump prior to sampling. A Hydrolab Quanta water quality meter was used to collect field chemical data. Purging of the well was continued for approximately five minutes before water was collected for field chemical analysis and sample collection. Groundwater parameters that were measured *in situ* include:

- pH;
- Temperature;
- Salinity;
- Dissolved Oxygen (DO);
- Electrical Conductivity (EC); and
- Oxidation-Reduction Potential (Eh).

Upon collection, groundwater samples were placed directly into laboratory prepared and supplied containers. The samples were then placed on ice immediately following collection and transported to the laboratory under standard Chain of Custody procedures. The parameters selected for groundwater analysis include:

- Total Nitrogen (TN);
- Total Phosphorous (TP);
- Ortho-Phosphorous (Ortho P);
- Oxides of Nitrogen (NO_x);
- Total Kjeldahl Nitrogen (TKN); and
- Ammonium (NH_4).

2.2.1 Chain of Custody

Standard chain of custody forms were completed for all samples transferred to the laboratory detailing the sample identification, collection date and the requested analysis. Upon receipt of the samples the laboratory completed the chain of custody forms and provided a copy to Cardno for confirmation.

2.2.2 Laboratory Analysis

The laboratory used for this investigation was the ALS Laboratory Group. ALS is a National Association of Testing Authorities (NATA) accredited laboratory (NATA Accreditation No. 825) and is accredited for compliance with ISO/IEC 17025. All primary and QA/QC samples were submitted to ALS for analysis.

3. Assessment Criteria

In order to provide an indication of the relative concentration of nutrients within groundwater, comparison of nutrient concentrations and field chemistry parameters with the ‘default trigger values’ for surface waters in South Western Australia, provided within the *National Water Quality Management Strategy* (ANZECC 2000). These trigger values are not specifically intended for application to groundwater nutrient concentrations but (as there are no nationally published trigger values available for groundwater quality) do provide a comparative analysis. The guideline values are summarised in **Table 3.1**.

Table 3.1 Trigger Values for Nutrient Concentrations and Physiochemical Parameters in South Western Australia (ANZECC 2000)

TN (mg/L)	**TP** (mg/L)	**Ortho P** (mg/L)	**NH_4** (mg/L)	**NO_x** (µg/L)	**DO** (% Sat)	**pH**	**Salinity** (µS/cm)
1.2	0.065	0.04	0.08	0.15	80-120	6.5-8.0	120-300

Discussion of the nutrient concentrations in the following sections refers to their relative concentration compared to the default trigger values. The terms 'low', 'moderate', 'high' and 'very high' are used in the following manner:

- 'Low' – nutrient concentration below, equal to or marginally above the default trigger value;
- 'Moderate' – nutrient concentration up to five times the default trigger value;
- 'High' – nutrient concentration between five and 10 times the default trigger value; and
- 'Very High' – nutrient concentrations more than 10 times the default trigger value.

Principally, comparison is made for the TN and TP concentrations. However, some comment is also provided for nutrient species (Ortho P, NH_4, NO_x) where these form a substantial portion of the overall nutrient concentrations

4. Monitoring Results

4.1 Groundwater Levels

A table summary of all groundwater level data collected is presented in **Appendix A**. Groundwater levels ranged from 0.61mBGS (at site C2-S in October 2009) to 28.1mBGS (at site G6 in January 2010). The shallowest depths to groundwater were recorded in October for all sites. Groundwater levels were at their deepest in January for all sites. Groundwater depths were generally less than 5mBGS in October and varied across the site. Groundwater contours were generated from the October 2009 data. The contours are shown in **Figure 2**. Groundwater flow was generally in a westerly direction with a north western component in the north eastern corner of the study area.

4.2 Groundwater Quality

The Certificate of Analysis containing the results of the laboratory analysis is attached in **Appendix A**. Comparison of the nutrient concentrations of the 41 bores sampled with the default trigger values for slightly disturbed ecosystems provided in the *National Water Quality Management Strategy* (ANZECC 2000) indicates:

- TN concentrations ranging from 'Low' to 'High';
- TP concentrations ranging from 'Low' to 'Very High';
- NH_4 concentrations ranging from 'Low' to 'Very High';
- NO_x concentrations ranging from 'Low' to 'Very High'; and
- Ortho P concentrations ranging from 'Low' to 'High'.

TN concentrations were generally 'moderate' across the study area. 'High' TN concentrations were recorded at bores S11 (11.3mg/l), S4 (8.0mg/l), HS1B (11.4mg/l) and KEMS10S (7.7mg/l). The 'high' TN readings at bores S11, S4 and KEMS10S were made up of over 90% TKN (TKN comprises the sum of the organic N and ammonium components). The 'high' TN reading at Bore HS1B differs from other 'high' TN readings as 87% of the TN make up was comprised of NO_x. NO_x comprises the oxides of nitrogen, nitrite (NO^2) and nitrate (NO^3). Elevated NO_x concentrations are potentially a concern as NO_x is known to have a correlation with accelerated algal growth, and because NO_2 is toxic to some aquatic species. Bores found to have 'low' TN concentrations (KEMS2D, KEMS3D, KEMS4D, KEMS6D, KEMS10D, F6D, KEML2C, KEML1C, KEML1, C11, C1I and KWS398) were spread out over the study site and either had a depth to groundwater of >5mBGS or a vegetated buffer upstream of the groundwater flow direction. NH_4 concentrations were generally above the default trigger value throughout the site. Bores HS1B, KEMS10S, KEM3D and KEML2C were the only bores sampled that did not exceed the NH_4 trigger value.

TP concentrations were generally 'low' throughout the study area. TP concentrations were 'very high' at sites KEMS12S (0.94mg/l) and KEMS12D (1.14mg/l), located in the centre of the study site. Ortho P concentrations were recorded as 'high' at these sites. Ortho P is phosphorous that is in a form not bound to any carbon molecules and not bound to other phosphates in the form of a condensed phosphate, and therefore it is immediately available for biological uptake (McKelvie, 2000). Bore KEMS12S was found to have Ortho P concentrations of 0.3mg/l and Bore Kems12D 0.26mg/l, identifying a significant portion of biologically available phosphorous at these sites.

Results of the field chemical analysis are presented in **Appendix A**. The Ph levels were generally below default trigger ranges. DO concentrations were consistently below the default trigger ranges while EC values varied across the site and were generally above the default trigger range.

5. Discussion

This round of sampling was able to capture groundwater levels for October and November 2009, and groundwater levels and quality data for January 2010. 55 of the 87 bores listed in the consultancy brief provided by Landcorp were able to be accessed/ located. Groundwater level data was obtained for 55 groundwater bores. Of the 55 groundwater bores accessed and measured for groundwater levels, 41 were serviceable and able to be sampled for groundwater quality in January. Groundwater levels were generally less than 5mBGS in October 2009, with the shallowest depths to groundwater recorded to the north of Marriot Road near the eastern boundary of the study area.

Areas with a larger separation distance from the surface to groundwater generally displayed lower nutrient concentrations. The exception to this was the highest TN concentration recorded, at site HS1B (which had a depth to groundwater of 26.65mBGS in October 2009), where 87% of the TN concentration was made up of NO_x. TN and TP concentrations were found to be at their highest concentrations in areas of the study site that had been cleared for agricultural use.

It can be inferred from the data gathered on this single water quality monitoring occasion that the unconfined superficial aquifer is susceptible to contamination from surface and near surface processes particularly in those areas cleared for agricultural use.

Ph and DO values were generally below default trigger ranges. The DO values are expected to be lower than the trigger value as they are from groundwater and the trigger value applies to surface water. EC values were generally above the default trigger range which is consistent with the close proximity of the study area to the coast.

6. Conclusions and Recommendations

The findings detailed in this letter report are consistent with those presented in *Kemerton Water Study Phase 2* (Aquaterra, 2002) in terms of groundwater levels, groundwater flow direction and groundwater nutrient concentrations. Additionally, it was identified in the *Kemerton Water Study Phase 2* (Aquaterra, 2002) that runoff from cleared farmland areas was the likely cause of the elevated nutrient concentrations within the study area, which is consistent with the findings of this study. Further, the *Kemerton Water Study Phase 2* (Aquaterra, 2002), describes the geological variability of the study site which is apparent in both the superficial sands and the underlying bedrock. Therefore it is deemed unnecessary to conduct additional sampling occasions to characterise the regional scale groundwater characteristics.

This letter report is a stand alone document that may be utilised for future detailed design stages and other management documents that may be required in the Structure Planning process. The groundwater monitoring results provide a snapshot of baseline conditions which can be used as a guide to establish trigger values in the Water Management Strategy. However, given the variability observed and the size of the site, site specific monitoring at a higher resolution would provide a clearer basis to establish post-development trigger values.

In order to more accurately inform future development (e.g. subdivision), it is recommended that future water management approaches are informed by additional finer scale site specific groundwater level and groundwater quality monitoring due to the relatively large size of the study area, the inherent hydrogeological variability (both vertically and laterally) and the potential for fine scale hydrological characteristics to be missed at this broad scale. This will provide a higher resolution of data which will inform the various proponents of the specific attributes of the proposed site rather than the Kemerton Industrial Park in its entirety.

Should you have any queries or concerns, please do not hesitate to contact me directly on 9273 3888.

Yours sincerely

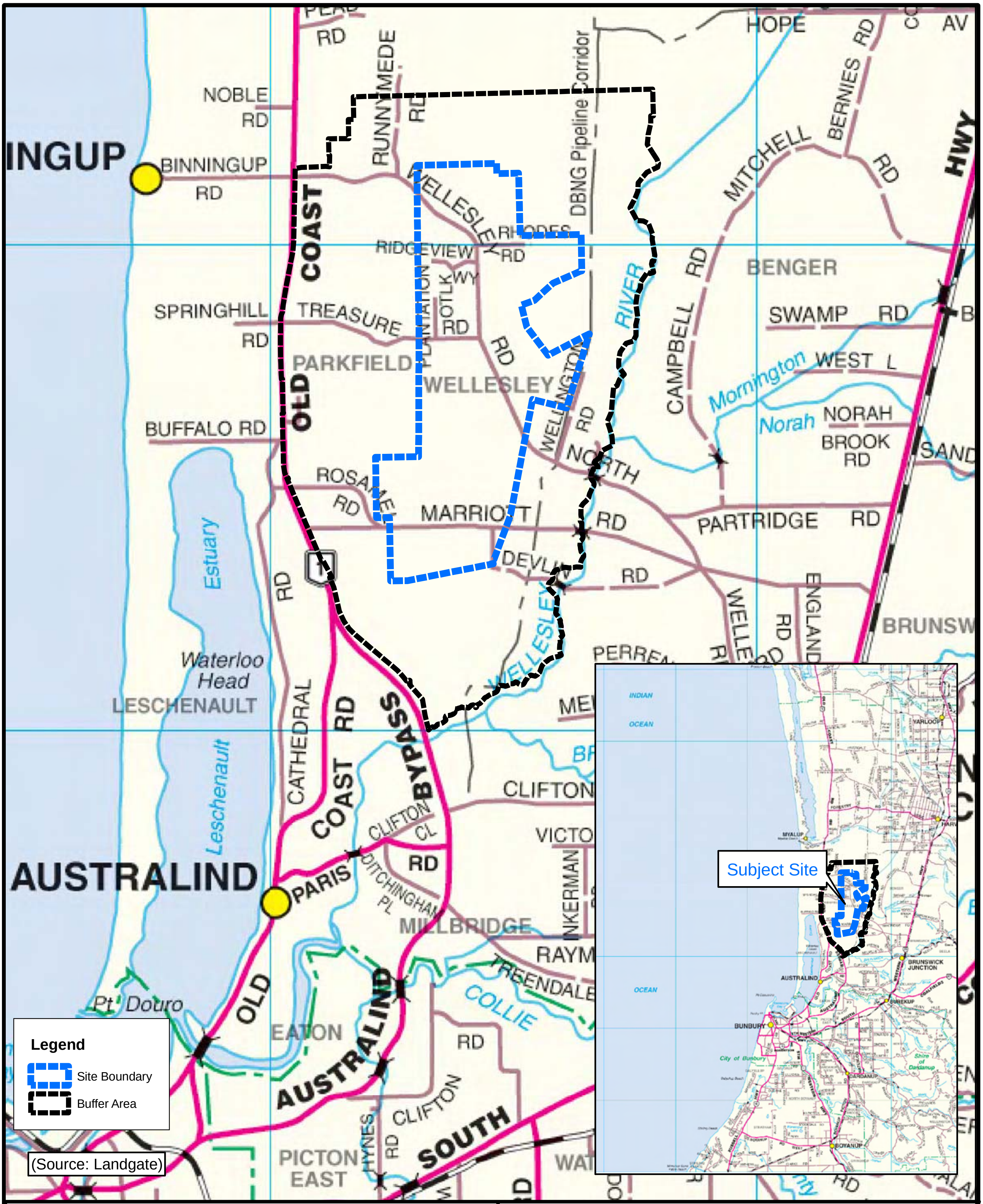
David Coremans
Section Leader Hydrology and Hydraulics
for **Cardno**

References

Australian and New Zealand Environment and Conservation Council (ANZECC), 2000, *National Water Quality Management Strategy,* Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

Aquaterra, 2002, *Kemerton Water Study Phase 2,* Prepared for Landcorp, Western Australia.

McKelvie, I., 2000, *Phosphates*, (in Nollet, L. 2000. *Handbook of Water Analysis*), Marcel Dekker, New York.



Legend

▨ Site Boundary

▨ Buffer Area

(Source: Landgate)

DATE	No.	ACTIVITY - REVISION DESCRIPTION	DES	DRN	CHK'D	APPD

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Scale: **1:100,000**

0 1,000 2,000 4,000 6,000 8,000 10,000 Metres

PROJECT **Kemerton Industrial Park - Groundwater Monitoring**

DRAWING TITLE **FIGURE 1 : Locality Plan**

PRINCIPAL **LandCorp**

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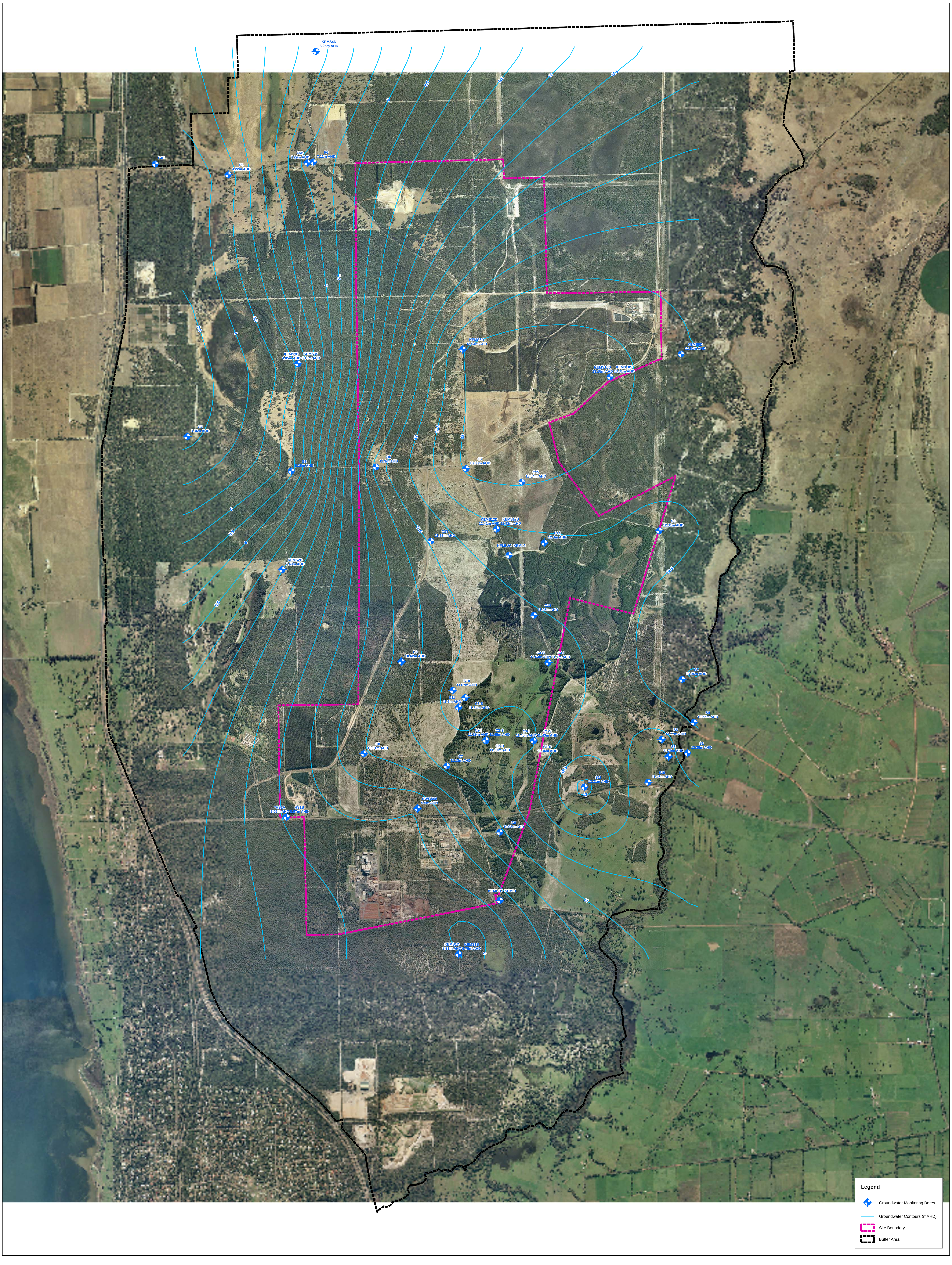
Project Number **V9085**
Original **A4**
Drawing Number **SK01**
Revision
Designed JN
Checked
Drawn MGW
Approved
Local Authority Shire of Harvey
Sheet 1 of 1
Date 22/02/10



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DATE	No.	ACTIVITY - REVISION DESCRIPTION	DES	DRN	CHK'D	APPD

DATE	No.	ACTIVITY - REVISION DESCRIPTION	DES	DRN	CHK'D	APPD

PROJECT **Kemerton Industrial Park - Groundwater Monitoring**

DRAWING TITLE **FIGURE 2 : Groundwater Contours**

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Scale: **1:18,500** 0 200 400 800 1,200 1,600 2,000 2,400 2,800 Metres

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Project Number	Drawing Number	Revision	Original
V9085	**SK02**	**00**	**A1**

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Date 22/02/10
Drawn MGW
Approved
Local Authority Shire of Busselton
Sheet of

Appendix A

Table 1 Field Chemistry Results

	F5	F6D	KEMS4D	KEMS6D	G7	KEMS10S	KEMS10D
Temp (celcius)	22.65	21.85	6.43	20.39	21.03	21.37	20.73
Cond (ms/cm)	0.631	0.956	21.63	0.544	0.38	0.979	0.614
DO (mg/L)	2.98	2.16	0.41	2.03	2.02	3.06	2.28
pH	6.59	7.25	2.58	5.88	6.12	5.18	6.25
Salinity (ppt)	0.31	0.47	6.99	0.26	0.18	0.48	0.3
DO(%)	34.7	26.9	0.2	22.7	25.6	34.6	25.9
Redox (mV)	-24	-46	-26	-63	-32	-51	-47

Table 2 Field Chemistry Results

	KEMS2D	C13	HS1B	KWS398	C8	C3S	C3I
Temp (celcius)	21.53	20.02	20.81	19.93	20.57	20.45	20.48
Cond (ms/cm)	0.575	0.468	1.59	1.165	0.24	0.265	0.129
DO (mg/L)	1.99	1.84	7.53	2.15	1.9	2.17	1.63
pH	5.74	6.02	7.44	5.31	5.84	5.32	5.27
Salinity (ppt)	0.28	0.34	0.8	0.58	0.11	0.13	0.06
DO(%)	22.5	24.02	82.8	23.8	21	22.2	18.2
Redox (mV)	25	17	190	-124	-131	-70	-105

Table 3 Field Chemistry Results

	C3D	C10	C2S	C2I	C2D	C7	C1D
Temp (celcius)	20.65	21.94	18.81	18.52	18.76	21.42	19.08
Cond (ms/cm)	0.129	0.241	1.5	0.842	1.222	0.489	0.182
DO (mg/L)	1.95	2.16	1.92	1.72	1.61	1.46	0.44
pH	5.08	5.23	6.25	6.15	6.2	5.46	5.45
Salinity (ppt)	0.06	0.12	0.75	0.42	0.6	0.24	0.09
DO(%)	21.9	25	20.3	19.5	17.7	16.8	10.3
Redox (mV)	-93	-41	-125	-14	-161	-142	-81

Table 4 Field Chemistry Results

	C1I	C9	C11	C4I	C12	KEM2C	KEM2
Temp (celcius)	19.61	18.81	19.2	19.46	20.07	19.66	20.51
Cond (ms/cm)	0.201	0.616	0.61	0.676	0.301	4.16	0.906
DO (mg/L)	1.21	1.96	4.72	1.68	2.84	1.88	1.14
pH	6.16	5.2	5.3	5.42	5.41	8.09	8.12
Salinity (ppt)	0.1	0.3	0.29	0.33	0.14	2.19	0.44
DO(%)	13.1	21.3	20.2	19.1	20.8	20.3	13.1
Redox (mV)	-110	-106	-85	-62	-84	-148	-116

Table 5 Field Chemistry Results

	KEML1C	KEML1	C6	S10	S11	S4	S5
Temp (celcius)	19.3	19.04	17.89	20.98	22.35	21.47	20.08
Cond (ms/cm)	1.357	0.52	2.53	0.866	0.474	0.432	0.151
DO (mg/L)	2.21	1.82	2.15	2.98	1.71	2.89	1.66
pH	7.8	7.88	6.85	5.37	6.58	5.97	5.73
Salinity (ppt)	0.67	0.25	1.29	0.42	0.23	0.21	0.07
DO(%)	23.9	20	23	33.3	14.1	32.4	18.7
Redox (mV)	-122	-97	-102	131	144	-57	60

Table 6 Field Chemistry Results

	KEMS12S	KEMS12D	C15	KEMS1D	KEMS3D	KEMS9D
Temp (celcius)	20.02	18.81	20.45	19.63	20.02	20.7
Cond (ms/cm)	0.581	0.566	0.156	0.6	0.986	0.475
DO (mg/L)	2.18	1.67	1.84	1.85	2.14	1.74
pH	6.95	6.98	5.53	6.52	6.58	5.41
Salinity (ppt)	0.28	0.27	0.08	0.29	0.48	0.23
DO(%)	22.6	16.9	20.5	20.4	23.8	19.3
Redox (mV)	-47	-62	-43	45	25	-80

Table 7 Groundwater Levels

		Oct-09		Nov-09		Jan-10	
ID	**Collar Height**	**mBTOC**	**mBGL**	**mBTOC**	**mBGL**	**mBTOC**	**mBGL**
C1-D	0.70	2.09	1.39	2.20	1.50	2.75	2.05
C1-I	0.40	1.68	1.28	1.84	1.44	2.35	1.95
C1-S	0.40	1.70	1.30	1.79	1.39	2.36	1.96
C2-D	0.50	1.19	0.69	1.24	0.74	1.69	1.19
C2-I	0.40	1.17	0.77	1.20	0.80	1.73	1.33
C2-S	0.70	1.31	0.61	1.35	0.65	1.92	1.22
C3-D	0.30	1.45	1.15	1.47	1.17	1.98	1.68
C3-I	0.30	1.49	1.19	1.53	1.23	1.96	1.66
C3-S	0.30	1.44	1.14	1.49	1.19	1.85	1.55
C4-I	0.70	1.35	0.65	1.49	0.79	2.00	1.30
C4-S	0.40	1.12	0.72	1.26	0.86	*Dry*	*Dry*
C6	0.50	1.68	1.18	1.78	1.28	2.45	1.95
C7	0.50	2.19	1.69	2.26	1.76	2.76	2.26
C8	0.60	3.35	2.75	3.38	2.78	3.83	3.23
C9	0.50	3.00	2.50	3.11	2.61	3.44	2.94
C10	0.80	3.55	2.75	3.60	2.80	4.10	3.30
C11	0.70	2.97	2.27	3.07	2.37	3.34	2.64
C12	0.40	1.70	1.30	1.86	1.46	2.40	2.00
C13	0.50	4.34	3.84	4.43	3.93	5.70	5.20
C14	0.30	1.37	1.07	1.42	1.12	*Dry*	*Dry*
C15	0.70	1.94	1.24	2.04	1.34	2.56	1.86
F4E	0.50	*Dry*	*Dry*	*Dry*	*Dry*	*Dry*	*Dry*
F5	0.60	2.97	2.37	3.14	2.54	3.53	2.93
F6	0.50	8.53	8.03	8.53	8.03	*Locked*	*Locked*
F6D	0.50	8.35	7.85	8.42	7.92	8.70	8.2
G4	0.80	9.75	8.95	9.78	8.98	10.07	9.27
G5	0.60	3.09	2.49	3.19	2.59	3.45	2.85
G6	0.60	27.80	27.20	27.77	27.17	28.70	28.1
G7	0.90	2.36	1.46	2.49	1.59	2.99	2.09
G8	0.70	1.75	1.05	1.78	1.08	2.26	1.56
HS1A	1.00	27.66	26.66	*Locked*	*Locked*	*Locked*	*Locked*
HS1B	1.00	27.65	26.65	27.65	26.65	27.97	26.97
KWS3/98	0.80	4.50	3.70	4.39	3.59	6.22	5.42
S1	0.40	2.20	1.80	2.35	1.95	2.89	2.49
S3	0.60	4.60	4.00	4.60	4.00	*Dry*	*Dry*
S4	0.60	2.16	1.56	2.23	1.63	2.94	2.34
S5	0.70	2.35	1.65	2.43	1.73	2.81	2.11
S6	0.30	2.21	1.91	2.38	2.08	2.86	2.56
S10	0.50	2.59	2.09	2.70	2.20	2.70	2.20
S11	0.50	1.34	0.84	1.40	0.90	1.92	1.42
KEMS1D	0.50	4.35	3.85	4.38	3.88	4.71	4.21
KEMS1S	0.50	2.91	2.41	3.00	2.50	3.58	3.08
KEMS2D	0.60	4.97	4.37	5.01	4.41	5.22	4.62
KEMS3D	0.50	3.87	3.37	3.98	3.48	4.36	3.86
KEMS3S	0.50	3.59	3.09	3.74	3.24	3.95	3.45
KEMS4D	0.50	6.69	6.19	6.68	6.18	6.93	6.43
KEMS6D	0.40	2.52	2.12	2.62	2.22	2.93	2.53
KEMS9D	0.50	2.43	1.93	2.57	2.07	3.10	2.60
KEMS10D	0.50	1.54	1.04	1.66	1.16	2.18	1.68
KEMS10S	0.50	1.38	0.88	1.49	0.99	2.04	1.54
KEMS12D	0.40	1.95	1.55	2.08	1.68	2.52	2.12
KEMS12S	0.40	1.94	1.54	2.08	1.68	2.53	2.13
**KEML1	0.40	12.97	12.57	13.76	13.36	17.30	16.90
**KEML1C	0.40	10.73	10.33	10.89	10.49	11.26	10.86
**KEML2	0.60	6.54	5.94	6.72	6.12	7.85	7.25
**KEML2C	0.60	13.28	12.68	13.18	12.58	15.48	14.88

CERTIFICATE OF ANALYSIS

Work Order	: **EP1000380**	Page	: 1 of 11
Client	: **CARDNO (WA) PTY LTD**	Laboratory	: Environmental Division Perth
Contact	: MR JORMA NOLAN	Contact	: Michael Sharp
Address	: PO BOX 155 SUBIACO WA, AUSTRALIA 6904	Address	: 10 Hod Way Malaga WA Australia 6090
E-mail	: jorma.nolan@cardno.com.au	E-mail	: michael.sharp@alsenviro.com
Telephone	: +61 08 9273 3888	Telephone	: +61-8-9209 7655
Facsimile	: +61 08 9388 3831	Facsimile	: +61-8-9209 7600
Project	: V9078	QC Level	: NEPM 1999 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 22-JAN-2010
Sampler	: JLN	Issue Date	: 02-FEB-2010
Site	: Kemerton		
		No. of samples received	: 44
Quote number	: EP-379-09	No. of samples analysed	: 44

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA Accredited Laboratory 825

This document is issued in accordance with NATA accreditation requirements.

Accredited for compliance with ISO/IEC 17025.

WORLD RECOGNISED ACCREDITATION

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Perth Inorganics
Kim McCabe	Senior Inorganic Chemist	Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insuffient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When date(s) and/or time(s) are shown bracketed, these have been assumed by the laboratory for processing purposes. If the sampling time is displayed as 0:00 the information was not provided by client.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **LOR raised for TP for sample 'KWS398' due to matrix effects.**

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	HS1B	KWS398	QA2	C8	C3S
			Client sampling date / time	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-001**	**EP1000380-002**	**EP1000380-003**	**EP1000380-004**	**EP1000380-005**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.02**	**0.62**	**0.64**	**0.35**	**0.25**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**10.0**	**0.03**	**0.04**	**0.73**	**0.03**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**1.4**	**0.9**	**1.2**	**0.7**	**2.1**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**11.4**	**1.0**	**1.2**	**1.4**	**2.1**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.05**	<0.05	<0.01	**0.01**	**0.23**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.03**	<0.01	<0.01	<0.01	**0.01**

Analytical Results

Sub-Matrix: **WATER**			*Client sample ID*	**C3I**	**C3D**	**C10**	**C2S**	**C21**
			Client sampling date / time	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-006**	**EP1000380-007**	**EP1000380-008**	**EP1000380-009**	**EP1000380-010**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.25**	**0.26**	**0.27**	**0.30**	**0.28**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.02**	**0.02**	**1.36**	**0.03**	**0.03**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**2.5**	**2.7**	**0.7**	**1.5**	**1.7**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**2.6**	**2.8**	**2.0**	**1.5**	**1.7**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.15**	**0.18**	**0.02**	**0.14**	**0.06**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	<0.01	<0.01	<0.01	**0.02**	**0.02**

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	**C2D**	**C7**	**F5**	**F6D**	**QA1**
			Client sampling date / time	20-JAN-2010 15:00	20-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-011**	**EP1000380-012**	**EP1000380-013**	**EP1000380-014**	**EP1000380-015**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.32**	**0.73**	**0.14**	**0.40**	**0.39**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.05**	**0.04**	**0.29**	**0.03**	**0.03**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**1.7**	**2.5**	**1.8**	**0.7**	**0.6**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**1.8**	**2.6**	**2.1**	**0.7**	**0.7**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.05**	**0.01**	**0.21**	**0.09**	**0.14**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.01**	<0.01	**0.10**	**0.07**	**0.07**

Analytical Results

Sub-Matrix: **WATER**			*Client sample ID*	**KEMS4D**	**KEMS6D**	**G7**	**KEMS10D**	**KEMS10S**
			Client sampling date / time	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-016**	**EP1000380-017**	**EP1000380-018**	**EP1000380-019**	**EP1000380-020**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.04**	**0.38**	**0.54**	**0.38**	**0.02**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.09**	**0.04**	**3.42**	**0.11**	**0.13**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**0.2**	**0.5**	**1.8**	**1.0**	**7.6**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**0.2**	**0.5**	**5.2**	**1.1**	**7.7**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.02**	**0.02**	**0.10**	**0.02**	**0.10**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.01**	**0.01**	<0.01	**0.01**	**0.04**

Analytical Results

Sub-Matrix: **WATER**			*Client sample ID*	**KEMS9D**	**KEMS3D**	**KEMS2D**	**C13**	**S10**
			Client sampling date / time	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00	19-JAN-2010 15:00	21-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-021**	**EP1000380-022**	**EP1000380-023**	**EP1000380-024**	**EP1000380-025**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.26**	**0.06**	**0.36**	**0.10**	**0.16**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.18**	**0.15**	**0.08**	**0.47**	**0.06**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**2.8**	**0.1**	**0.6**	**0.9**	**2.0**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**3.0**	**0.3**	**0.7**	**1.4**	**2.1**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.10**	**0.02**	**0.02**	<0.01	**0.28**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.03**	**0.01**	<0.01	<0.01	**0.16**

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	**S11**	**S4**	**S5**	**KEMS12S**	**KEMS12D**
			Client sampling date / time	21-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-026**	**EP1000380-027**	**EP1000380-028**	**EP1000380-029**	**EP1000380-030**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.16**	**0.21**	**0.24**	**0.41**	**0.40**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.03**	**0.05**	**0.02**	**0.04**	**0.06**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**11.3**	**8.0**	**1.9**	**4.2**	**4.5**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**11.3**	**8.0**	**1.9**	**4.2**	**4.6**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.27**	**0.20**	**0.07**	**0.94**	**1.14**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.06**	**0.05**	**0.05**	**0.30**	**0.26**

Analytical Results

Sub-Matrix: **WATER**			*Client sample ID*	**C15**	**KEMS1D**	**QA3**	**C1D**	**C1I**
			Client sampling date / time	21-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-031**	**EP1000380-032**	**EP1000380-033**	**EP1000380-034**	**EP1000380-035**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.78**	**0.57**	**0.51**	**0.24**	**0.25**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.07**	**0.17**	**0.04**	**0.04**	**0.04**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**3.3**	**2.9**	**3.2**	**1.6**	**0.8**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**3.4**	**3.1**	**3.3**	**1.6**	**0.8**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.03**	**0.14**	**0.05**	**0.24**	**0.11**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	<0.01	**0.02**	**0.02**	**0.01**	<0.01

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	C9	C11	C4I	C12	KEM2C
			Client sampling date / time	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00	20-JAN-2010 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EP1000380-036**	**EP1000380-037**	**EP1000380-038**	**EP1000380-039**	**EP1000380-040**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.84**	**0.11**	**0.58**	**1.16**	**0.73**
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.05**	**0.16**	**0.09**	**0.05**	**0.02**
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**1.6**	**1.0**	**1.6**	**1.8**	**0.9**
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**1.6**	**1.2**	**1.7**	**1.9**	**0.9**
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.02**	**0.04**	**0.03**	**0.02**	**0.02**
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	<0.01	<0.01	**0.03**	<0.01	<0.01

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	**KEM2C**	**KEML1C**	**KEML1**	**C6**	----
			Client sampling date / time	20-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00	21-JAN-2010 15:00	----
Compound	CAS Number	LOR	Unit	**EP1000380-041**	**EP1000380-042**	**EP1000380-043**	**EP1000380-044**	**----**
EK055G: Ammonia as N by Discrete Analyser								
Ammonia as N	7664-41-7	0.01	mg/L	**0.02**	**0.24**	**0.09**	**0.50**	----
EK059G: NOX as N by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.06**	**0.03**	**0.06**	**0.03**	----
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser								
Total Kjeldahl Nitrogen as N	----	0.1	mg/L	**0.1**	**0.2**	**0.1**	**2.2**	----
EK062: Total Nitrogen as N (TKN + NOx)								
^ Total Nitrogen as N	----	0.1	mg/L	**0.2**	**0.2**	**0.2**	**2.2**	----
EK067G: Total Phosphorus as P by Discrete Analyser								
Total Phosphorus as P	----	0.01	mg/L	**0.03**	**0.08**	**0.31**	**0.07**	----
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	----	0.01	mg/L	**0.02**	**0.07**	**0.06**	**0.03**	----

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco
PROJECT MANAGER (PM): Dave Coremans
PROJECT ID: V9078
SITE: Kemerton P.O. NO.:
RESULTS REQUIRED (**Date**): ASAP QUOTE NO.: EP/379/09

SAMPLER: JLN
MOBILE:
PHONE:
EMAIL REPORT TO: jorma.nolan@cardno.com.au
EMAIL INVOICE TO: (if different to report)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

Notes:

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION															
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1													Notes
1	HS1B		20/01/2010		W	2	X													unfiltered
2	KWS398		20/01/2010		W	2	X													unfiltered
3	QA2		20/01/2010		W	2	X													unfiltered
4	C8		20/01/2010		W	2	X													unfiltered
5	C3S		20/01/2010		W	2	X													unfiltered
6	C3I		20/01/2010		W	2	X													unfiltered
7	C3D		20/01/2010		W	2	X													unfiltered
8	C10		20/01/2010		W	2	X													unfiltered
9	C2S		20/01/2010		W	2	X													unfiltered
10	C2I		20/01/2010		W	2	X													unfiltered
11	C2D		20/01/2010		W	2	X													unfiltered
12	C7		20/01/2010		W	2	X													unfiltered

Environmental Division
Perth
Work Order
EP1000380
Telephone : + 61-8-9209 7655

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Jorma Nolan	Date:22/01/10	Name: Josh	Date: 22/1/10	Con' Note No:
Of: Cardno	Time: 1300	Of: ALS	Time: 13:51	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

ALS LABORATORY GROUP

COC Page ___ of ___

ENFM (204/5)

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno	SAMPLER: JLN
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco	MOBILE:
PROJECT MANAGER (PM): Dave Coremans	PHONE:
PROJECT ID: V9078	EMAIL REPORT TO: jorma.nolan@cardno.com.au
SITE: Kemerton P.O. NO.:	EMAIL INVOICE TO: (if different to report)
RESULTS REQUIRED (Date): ASAP QUOTE NO.: EP/379/09	

FOR LABORATORY USE ONLY

COOLER SEAL (circle appropriate)

Intact: Yes No N/A

SAMPLE TEMPERATURE

CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION															Notes:
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1													
13	F5		19/01/2010		W	2	X													unfiltered
14	F6D		19/01/2010		W	2	X													unfiltered
15	QA1		19/01/2010		W	2	X													unfiltered
16	KEMS4D		19/01/2010		W	2	X													unfiltered
17	KEMS6D		19/01/2010		W	2	X													unfiltered
18	G7		19/01/2010		W	2	X													unfiltered
19	KEMS10D		19/01/2010		W	2	X													unfiltered
20	KEMS10S		19/01/2010		W	2	X													unfiltered
21	KEMS9D		19/01/2010		W	2	X													unfiltered
22	KEMS3D		19/01/2010		W	2	X													unfiltered
23	KEMS2D		19/01/2010		W	2	X													unfiltered
24	C13		19/01/2010		W	2	X													unfiltered

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Jorma Nolan	Date:22/01/10	Name: Josh	Date: 22/1/10	Con' Note No:
Of: Cardno	Time: 1300	Of: AU	Time: 13.50	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco
PROJECT MANAGER (PM): Dave Coremans
PROJECT ID: V9078
SITE: Kemerton
P.O. NO.:
RESULTS REQUIRED (**Date**): ASAP
QUOTE NO.: EP/379/09

SAMPLER: JLN
MOBILE:
PHONE:
EMAIL REPORT TO: jorma.nolan@cardno.com.au
EMAIL INVOICE TO: (if different to report)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

Notes:

Environmental Division
Perth
Work Order
EP1000380
Telephone : +61-8-9209 7655

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION			
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1	Notes
1	HS1B		20/01/2010		W	2	X	unfiltered
2	KWS398		20/01/2010		W	2	X	unfiltered
3	QA2		20/01/2010		W	2	X	unfiltered
4	C8		20/01/2010		W	2	X	unfiltered
5	C3S		20/01/2010		W	2	X	unfiltered
6	C3I		20/01/2010		W	2	X	unfiltered
7	C3D		20/01/2010		W	2	X	unfiltered
8	C10		20/01/2010		W	2	X	unfiltered
9	C2S		20/01/2010		W	2	X	unfiltered
10	C2I		20/01/2010		W	2	X	unfiltered
11	C2D		20/01/2010		W	2	X	unfiltered
12	C7		20/01/2010		W	2	X	unfiltered

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Jorma Nolan	Date:22/01/10	Name: Josh	Date: 22/1/10	Con' Note No:
Of: Cardno	Time: 1300	Of: ALS	Time: 13:51	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco
PROJECT MANAGER (PM): Dave Coremans
PROJECT ID: V9078
SITE: Kemerton
P.O. NO.:
RESULTS REQUIRED (Date): ASAP
QUOTE NO.: EP/379/09

SAMPLER: JLN
MOBILE:
PHONE:
EMAIL REPORT TO: jorma.nolan@cardno.com.au
EMAIL INVOICE TO: (if different to report)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

Notes:

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION															Notes
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1													
13	F5		19/01/2010		W	2	X													unfiltered
14	F6D		19/01/2010		W	2	X													unfiltered
15	QA1		19/01/2010		W	2	X													unfiltered
16	KEMS4D		19/01/2010		W	2	X													unfiltered
17	KEMS6D		19/01/2010		W	2	X													unfiltered
18	G7		19/01/2010		W	2	X													unfiltered
19	KEMS10D		19/01/2010		W	2	X													unfiltered
20	KEMS10S		19/01/2010		W	2	X													unfiltered
21	KEMS9D		19/01/2010		W	2	X													unfiltered
22	KEMS3D		19/01/2010		W	2	X													unfiltered
23	KEMS2D		19/01/2010		W	2	X													unfiltered
24	C13		19/01/2010		W	2	X													unfiltered

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Jorma Nolan	Date:22/01/10	Name: Josh	Date: 22/1/10	Con' Note No:
Of: Cardno	Time: 1300	Of: AU	Time: 13.50	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

ALS LABORATORY GROUP

ENFM (204/5)

COC Page ___ of ___

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco
PROJECT MANAGER (PM): Dave Coremans
PROJECT ID: V9078
SITE: Kemerton
P.O. NO.:
RESULTS REQUIRED (**Date**): ASAP
QUOTE NO.: EP/379/09

SAMPLER: JLN
MOBILE:
PHONE:
EMAIL REPORT TO: jorma.nolan@cardno.com.au
EMAIL INVOICE TO: (if different to report)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

Notes:

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION															
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1													
25	S10	W	21/01/2010		P, H	2	X													unfiltered
26	S11	W	21/01/2010		P, H	2	X													unfiltered
27	S4	W	21/01/2010		P, H	2	X													unfiltered
28	S5	W	21/01/2010		P, H	2	X													unfiltered
29	KEMS12S	W	21/01/2010		P, H	2	X													unfiltered
30	KEMS12D	W	21/01/2010		P, H	2	X													unfiltered
31	C15	W	21/01/2010		P, H	2	X													unfiltered
32	KEMS1D	W	21/01/2010		P, H	2	X													unfiltered
33	QA3	W	21/01/2010		P, H	2	X													unfiltered

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Jorma Nolan	Date:22/01/10	Name: Josh	Date: 22/1/10	Con' Note No:
Of: Cardno	Time: 1300	Of: ALS	Time: 13.51	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

ALS LABORATORY GROUP

COC Page ___ of ___

ENFM (204/5)

CHAIN OF CUSTODY DOCUMENTATION

ALS Laboratory Group

CLIENT: Cardno
ADDRESS / OFFICE: 2 Bagot Rd, Subiaco
PROJECT MANAGER (PM): Dave Coremans
PROJECT ID: V9078
SITE: Kemerton
P.O. NO.:
RESULTS REQUIRED (Date): ASAP
QUOTE NO.: EP/379/09

SAMPLER: JLN
MOBILE:
PHONE:
EMAIL REPORT TO: jorma.nolan@cardno.com.au
EMAIL INVOICE TO: (if different to report)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION																Notes:
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles	Suite 1														
34	C1D	W	20/01/2010		P, H	2	X														unfiltered
35	C1I	W	20/01/2010		P, H	2	X														unfiltered
– SNR	C1S	W	20/01/2010		P, H	2	X														unfiltered
36	C9	W	20/01/2010		P, H	2	X														unfiltered
37	C11	W	20/01/2010		P, H	2	X														unfiltered
38	C4I	W	20/01/2010		P, H	2	X														unfiltered
39	C12	W	20/01/2010		P, H	2	X														unfiltered
40	KEM2C	W	20/01/2010		P, H	2	X														unfiltered
41	KEM2	W	20/01/2010		P, H	2	X														unfiltered
42	KEML1C	W	21/01/2010		P, H	2	X														unfiltered
43	KEML1	W	21/01/2010		P, H	2	X														unfiltered
44	C6	W	21/01/2010		P, H	2	X														unfiltered

RELINQUISHED BY:
Name: Jorma Nolan | Date:22/01/10
Of: Cardno | Time: 1300
Name: | Date:
Of: | Time:

RECEIVED BY
Name: Josh | Date: 22/1/10
Of: ALS | Time: 13-51
Name: | Date:
Of: | Time:

METHOD OF SHIPMENT
Con' Note No:
Transport Co:

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag.

Australian Laboratory Services INTERNAL SUBCONTRACTING WORK SHEET

PLEASE REFER TO WEBVIEW/LIMS FOR FURTHER DETAILS

RECEIPT TEMP: .... °C

WORK ORDER ALS SAMPLE ID(s)	SAMPLE DATE(S)	WATER	SOIL	Oil and Grease	MBAS/Surfactants	~~COD~~ NOx	TOC / DOC / TIC	Methane / Gases	Specific Gravity	TBT	UT - PAH / Phenols / OC / OP	UT - Metals - Filt / Unfilt	Fluoride / Asbestos / PSD	Sulphite / Thiocyanate	COMMENTS (URGENT - SHORT HOLDING / TAT) (NON-STANDARD CONTAINERS)
EP0100380 - 001	19/01	x													
↓	↓	↓													
044	21/01	↓													

Temperature

Esky:

Samples:

TYPE OF CONTAINERS

1L / 500 mL Purple Glass: ______
1L / 500 mL Brown Glass: ______
1L / 500 mL Orange Glass: ______
[✓ 125mL] / 250mL Purple: 44
40 mL Maroon: ______
250mL Orange Plastic: ______
40mL White Vial : ______
40mL Purple Vial : ______
250 mL Green: ______
60 mL Red/Green T / F : ______
Soil Jar: ______
Soil Bag: ______
Other Container: ______

PERTH TO:
(samples.perth@alsenviro.com) fax (08) 9209 7600

☒	BRISBANE	(samples.brisbane@alsenviro.com) fax (07) 3243 7218
☐	MELBOURNE	(samples.melbourne@alsenviro.com) fax (03) 9538 4400
☐	NEWCASTLE	(incoming.newcastle@alsenviro.com) fax (02) 4968 0349
☐	SYDNEY	(samples.sydney@alsenviro.com) fax (02) 8784 8566
☐	ORANGE	(incoming.orange@alsenviro.com) fax (02) 6393 1111

DISPATCH DETAILS:
COC ATTACHED: Y / [✓ N]
CARRIER: [✓ AAE] / TNT
OTHER: ....
CON. NOTE: ....
No. ESKIES: L .... M .... S ....

RELINQUISHED BY:
CHECK: ....
NAME: Andrea
DATE: 22/01/10 TIME: 3:00
SIGNED: ....

RECEIVED BY:
NAME: ....
DATE: / / TIME: ....
SIGNED: ....

ENFM(62/3).P

Return this form by email to samples.sydney@alsenviro.com to confirm receipt of samples

Page _____ of _____

Average Annual Maximum and Maximum Groundwater Levels for the Kemerton KIP Area

BoreID	Easting(mE)	Northing(mN)	AAMGL	MGL
C10	384298	6325712	11.4425	12.19
C11	384362	6326525	11.5675	12.33
C12	385199	6326545	11.7625	12.41
C13	384067	6327369	11.58	12.16
C14	385314	6327349	12.1475	12.75
C15	385065	6328026	12.55	13.1
C1-S	385194	6325153	11.64667	11.78
C2-S	384663	6325161	11.74	11.94
C3-S	384435	6325631	12.023333	12.25
C4-S	385357	6326022	11.485	12.02
C5-S	384472	6324396	11.60	11.70
C6	384819	6324138	10.8	11.52
C7	384231	6324873	11.1825	12.01
C8	383311	6325010	10.4025	10.88
C9	383728	6326031	10.67	11.3
DoW1	379089	6331548	0.94	0.94
DoW2	380086	6324695	1.377	1.377
DoW3	384926	6323326	10.248	10.248
DoW4	386579	6323078	4.249	4.249
DoW5	388799	6330435	7.914	7.914
E1	386166	6324301	12.78	12.8
E2	386204	6323895	11.43	11.52
E3	385904	6323674	10.9	10.91
F4	380946	6331546	4.062	4.696
F5	381807	6331433	4.580	5.231
F6D	382684	6331566	6.765	7.29
F8	384600	6331500	14.744	15.176
G4	381351	6328529	3.922	4.552
G7	384445	6328172	13.573	14.030
G8	386598	6327483	12.686	12.951
HS1B	382451	6324307	8.645	9.070
HS2C	386713	6323227	4.544	4.994
KEMS10S	386044.5	6329191	12.62	13.31
KEMS12S	384785.3	6327503	11.645	12.42
KEMS1S	384362.8	6322787	8.955	9.75
KEMS2D	382405	6327052	6.94	7.49
KEMS3S	382580	6329338	4.755	5.13
KEMS4D	382780	6332801	5.81	6.26
KEMS6D	384408	6329496	12.415	13.04
KEMS9D	386832	6329443	11.745	12.52
KM14	383946	6323742	11.7224	14.82
KM17	384164	6324139	12.30164	12.5
KM4	384058	6323987	12.446364	14.89
KMB1	385836	6334154	15.351	15.697
KMB10	387562	6334003	13.985	14.28
KMB11	387712	6334251	14.2585	14.536
KMB12	387946	6333852	12.929	13.229
KMB13	386182	6333647	14.5725	15.11

KMB2	386414	6334390	15.234	15.414
KMB3	387372	6333201	13.578	13.758
KMB4	386851	6333695	14.716	14.878
KMB5	386825	6333102	14.56	14.734
KMB6	386819	6333134	14.632	14.796
KMB8	386362	6334046	15.022	15.187
KMB9	387352	6332677	13.306	13.456
S1	386902	6326017	12.1025	12.77
S10	386465	6324692	10.975	11.46
S11	385759	6324640	13.17	13.25
S2	386328	6326029	11.98	12.12
S3	386843	6325834	12.693333	13.04
S4	385973	6325357	12.1825	12.87
S5	386617	6325168	11.7925	12.58
S6	386692	6324980	11.6525	12.11
S7	386367	6325198	12.25	**12.25**
S8-S	385695	6324855	12.705	12.82
S9-S	386192	6324750	12.89	12.91
Sim1	383735	6323343	10.784444	11.04
Sim2	383583	6323118	10.396667	11.03
Sim3	383330	6323072	9.7855556	10.53
River1	387330	6326488	7.2	7.2
River10	381600	6315822	0.4	0.4
River11	379384	6313445	0.1	0.1
River12	380662	6313624	0.2	0.2
River13	380892	6314979	0.3	0.3
River14	381915	6317756	0.9	0.9
River15	382085	6318744	1.15	1.15
River16	381983	6316717	0.65	0.65
River17	383158	6319971	1.73	1.73
River18	384181	6320414	2.06	2.06
River19	385859	6321291	2.9	2.9
River2	386173	6323132	4	4
River20	386183	6322348	3.4	3.4
River21	386668	6323643	4.33	4.33
River22	386668	6324162	4.66	4.66
River23	386915	6325329	5.7	5.7
River24	387265	6325892	6.46	6.46
River25	387400	6326951	7.6	7.6
River26	387512	6327671	8	8
River27	387804	6328233	8.4	8.4
River28	387922	6329024	9.3	9.3
River29	388162	6329451	9.86	9.86
River3	386814	6324636	5	5
River30	388068	6330300	10.8	10.8
River31	387670	6330780	11.2	11.2
River32	387559	6331899	12.1	12.1
River33	387799	6332390	12.6	12.6
River4	388140	6329824	10.4	10.4
River5	388140	6332589	13.1	13.1
River6	387736	6331224	11.6	11.6
River7	387760	6328591	8.8	8.8
River8	384970	6320807	2.4	2.4
River9	382173	6319469	1.4	1.4

Water Quality Data

Format Guideline Exceedances

		Ammonia as N	**Nitrate (as N)**	**Nitrite (as N)**	**Nitrate + Nitrite as N**	**Kjeldahl Nitrogen Total**	**Nitrogen (Total)**	**Phosphorus (Total)**	**Reactive Phosphorus as P**
		mg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	µg/L
WETLANDS (ANZECC 2000)		**0.04**	**N/A**	**N/A**	**0.1**	**N/A**	**1.5**	**0.06**	**30**
C10	20/01/2011	**0.6**	0.81	0.013	**0.82**	620	**1.4**	0.02	<2
C11	20/01/2011	**0.45**	<0.005	<0.005	<0.005	850	**0.85**	0.02	<2
C12	21/01/2011	**1.8**	0.034	<0.005	**0.034**	2800	**2.8**	0.03	**3**
C15	19/01/2011	**1.2**	0.081	<0.005	**0.081**	2900	**3**	0.01	**9**
C1-D	20/01/2011	**0.035**	1.0	0.018	**1**	800	**1.8**	0.05	**5**
C1-I	20/01/2011	**0.06**	<0.005	<0.005	<0.005	870	**0.87**	0.03	**2**
C2-D	20/01/2011	**0.2**	<0.005	<0.005	<0.005	1100	**1.1**	0.04	<2
C2-I	20/01/2011	**21**	0.023	0.11	**0.14**	32000	**32**	**4.7**	**2400**
C3-D	20/01/2011	**0.3**	0.022	<0.005	**0.022**	1300	**1.3**	0.02	**4**
C3-I	20/01/2011	**1.4**	0.028	<0.005	**0.028**	2800	**2.8**	0.04	<2
C4-I	19/01/2011	**1.2**	<0.005	0.022	**0.02**	2100	**2.1**	0.05	**20**
C4-S	19/01/2011	**0.97**	<0.005	0.03	**0.03**	1900	**1.9**	0.05	**27**
C6	19/01/2011	**0.56**	0.005	0.019	**0.024**	2400	**2.4**	0.03	**17**
C7	20/01/2011	**1.1**	<0.005	<0.005	<0.005	2600	**2.6**	0.03	<2
C8	19/01/2011	**0.53**	<0.005	<0.005	<0.005	980	**0.98**	<0.01	<2
C9	20/01/2011	**0.84**	<0.005	0.083	**0.083**	1700	**1.8**	**0.08**	**29**
F5	18/01/2011	**0.071**	0.016	<0.005	**0.016**	690	**0.7**	0.05	**48**
F6D	21/01/2011	**0.51**	<0.005	<0.005	<0.005	730	**0.73**	**0.09**	**64**
F4E	21/01/2011	**1**	0.03	0.011	**0.041**	1700	**1.7**	**0.09**	**82**
G4	21/01/2011	**0.5**	0.019	<0.005	**0.019**	1300	**1.3**	**0.08**	**47**
G5	19/01/2011	**0.049**	0.061	<0.005	**0.061**	510	**0.58**	<0.01	<2
G7	19/01/2011	**0.91**	<0.005	<0.005	<0.005	1600	**1.6**	0.02	<2
KEML1C	19/01/2011	**0.015**	0.012	<0.005	**0.012**	270	**0.28**	**0.1**	**56**
KEML2	21/01/2011	**0.35**	<0.005	<0.005	<0.005	1300	**1.3**	**0.13**	**22**
KEML2C_D	21/01/2011	**1**	<0.005	<0.005	<0.005	1100	**1.1**	<0.01	<2
KEMS10D	21/01/2011	**0.64**	0.022	<0.005	**0.022**	970	**0.99**	0.02	**16**
KEMS12D	19/01/2011	**0.29**	<0.005	0.02	**0.023**	1200	**1.2**	**0.08**	<2
KEMS1D	19/01/2011	**0.9**	0.058	0.027	**0.085**	4100	**4.2**	**0.29**	<2
KEMS3_D	21/01/2011	**0.084**	<0.005	<0.005	<0.005	90	**0.09**	0.01	<2
KEMS4D	21/01/2011	0.029	<0.005	<0.005	<0.005	180	**0.18**	0.02	**6**
KEMS6D	20/01/2011	**0.37**	<0.005	<0.005	<0.005	590	**0.59**	0.03	**4**
S1	18/01/2011	**0.088**	0.013	0.011	**0.024**	600	**0.62**	0.02	**3**
S10	18/01/2011	**0.13**	0.021	<0.005	**0.021**	290	**0.31**	0.02	**3**
S11	18/01/2011	**0.35**	0.29	<0.005	**0.29**	4000	**4.3**	0.06	**61**
S4	18/01/2011	**0.49**	0.26	<0.005	**0.26**	3600	**3.9**	0.05	**42**
S5	18/01/2011	**0.14**	0.066	<0.005	**0.066**	1400	**1.5**	0.05	**49**
S6	18/01/2011	**0.035**	<0.005	0.031	**0.031**	1300	**1.4**	**0.1**	**58**

APPENDIX 4

DoW Groundwater Management Areas and Groundwater Allocation Report

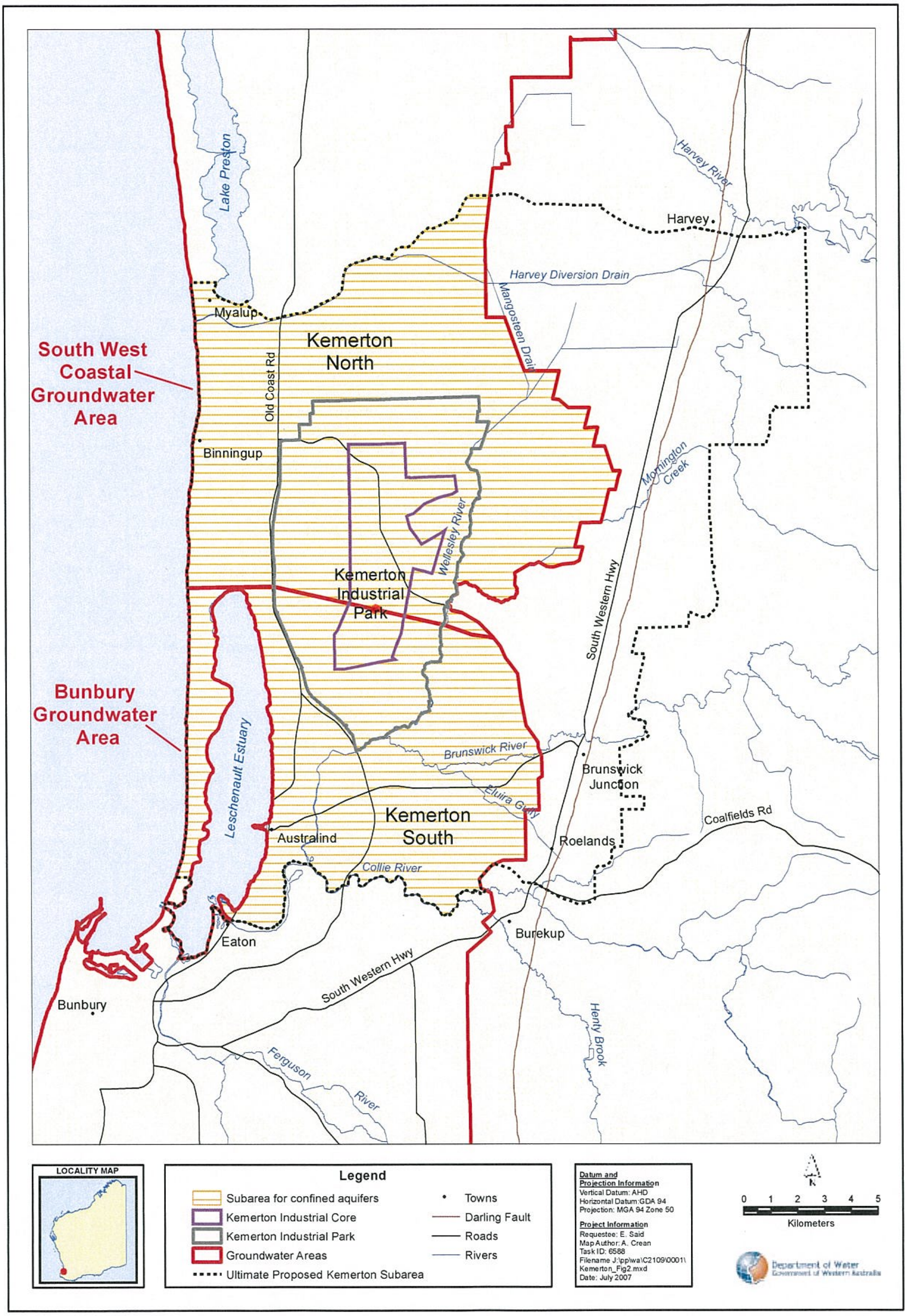

Figure 1.3 New subareas for the regionally confined aquifers within the South West Coastal and Bunbury Groundwater Areas

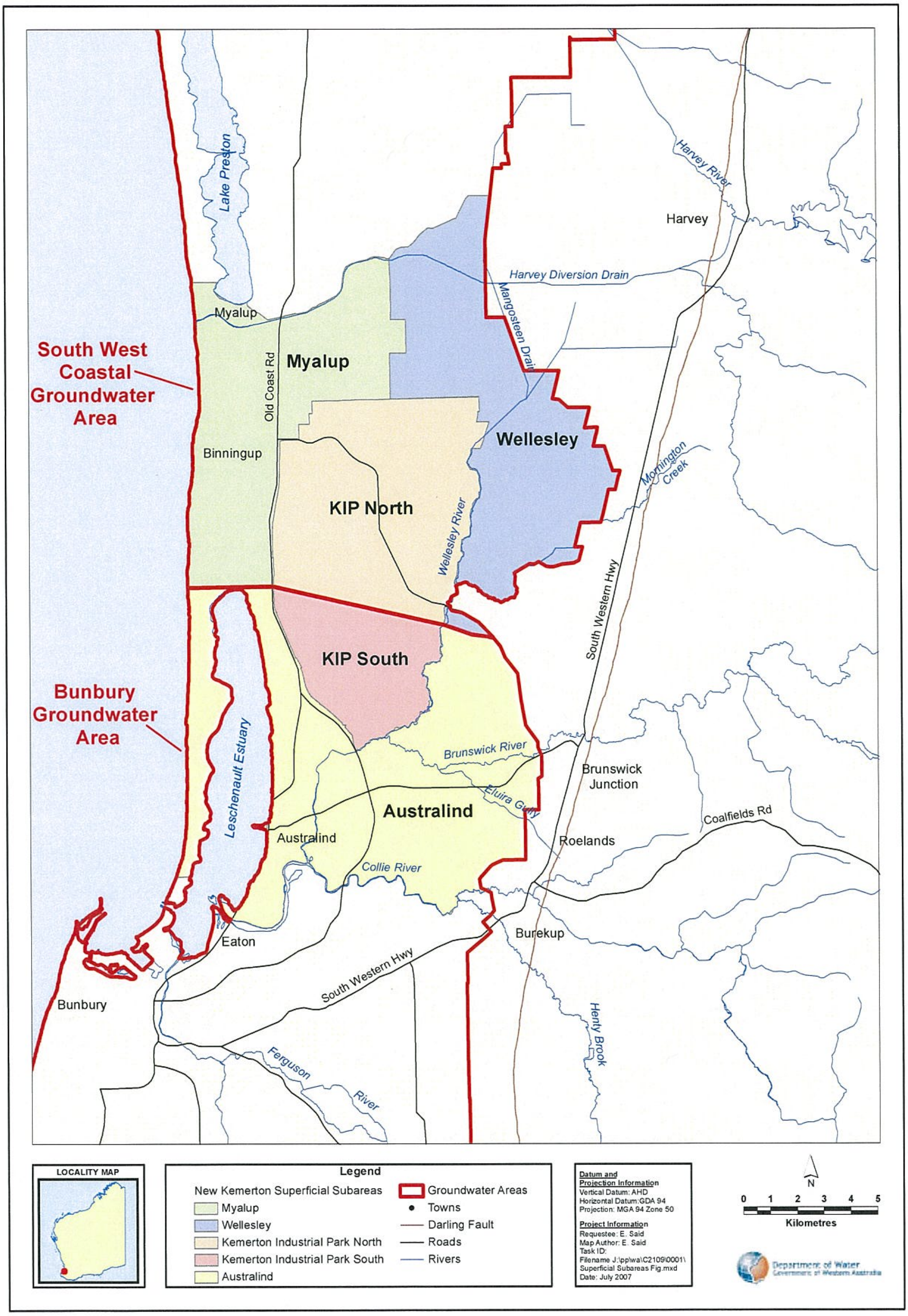

Figure 1.2 New subareas for the superficial aquifers within the South West Coastal and Bunbury Groundwater Areas

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

Resource Allocation Report

(All Volumes in kL)

Water Online

Data Last Refreshed : **29 Jul 2016**
Rows Returned :**38**

As Of Date : 29 Jul 2016
Resource Type : All
Allocation Planning Area : All
Management Area : Bunbury,South West Coastal
Management Sub Area : All
Allocation Category : All
Component : General

Management Area	Management Sub Area	Resource	Component	Component Status	Allocation Limit	Allocated Volume	Committed Volume	Remaining Volume	% Allocated and Committed	Additional Requested
Bunbury	Kemerton Industrial Core South	Perth - Cattamarra Coal Measures.	General	G1	4,000,000	992,000	0	**3,008,000**	**24.80%**	0
Bunbury	Kemerton Industrial Park South	Perth - Superficial Swan	General	G4	199,950	248,700	0	**-48,750**	**124.38%**	0
Bunbury	Kemerton South	Perth - Leederville.	General	G4	1,690,000	1,752,200	0	**-62,200**	**103.68%**	1,500
South West Coastal	Kemerton Industrial Core North	Perth - Cattamarra Coal Measures.	General	G1	6,000,000	0	0	**6,000,000**	**0.00%**	0
South West Coastal	Kemerton Industrial Park North	Perth - Superficial Swan	General	G2	753,500	415,900	0	**337,600**	**55.20%**	0
South West Coastal	Kemerton North	Perth - Leederville.	General	G4	500,000	500,000	0	**0**	**100.00%**	0
					75,823,396	**48,760,335**	**12,500**	**27,050,561**	**64.32%**	**372,531**

LICENSING DATABASE RESOURCE ALLOCATION INFORMATION

The Department of Water is committed to quality service to its customers and makes every attempt to ensure accuracy, currency and reliability of the data contained in this document. Note, resource allocations generally change on a daily basis therefore circumstances after time of publication may impact the quality of this information.

APPENDIX 5

Wetland Risk Analysis Report

WETLANDS RISK ANALYSIS

Kemerton Strategic Industrial Area

rpsgroup.com.au

WETLANDS RISK ANALYSIS

Kemerton Strategic Industrial Area

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Report No: D1054201:2
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Document Status

Version	***Purpose of Document***	***Orig***	***Review***	***Review Date***	***Format Review***	***RPS Release Approval***	***Issue Date***
Draft A	*Draft for Client Review*	*ShaMcS*	*CarDav*	*18.02.16*			
Rev 0	*Final for Issue*		*CarDav*	*24.02.16*	*SN 24.02.16*	*C. Davies*	*25.02.16*
Rev 1	*Final for Issue*	*DanWil*	*CarDav*	*25.07.16*	*SN 22.08.16*	*C. Davies*	*23.08.16*

Disclaimer

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(compiled at rear of report)

PLATES

(contained within report text) **Page**

APPENDICES

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1.0 INTRODUCTION

1.1 Purpose of this Report

This report has been prepared as part of the broader environmental and water related investigations undertaken to support the Structure Planning approval for the Kemerton Strategic Industrial Area (KSIA) by LandCorp, on behalf of the Department of State Development (DSD).

More specifically, this Wetland Risk Analysis report has been prepared as a component of the Overarching Water Management Strategy (OWMS) for the KSIA. Following an initial review of the OWMS by the relevant regulatory agencies, a requirement was made for further assessment (provided herein) of the risk to wetlands from the proposed development. Further background details on the regulator consultation which led to the scoping and preparation of this report are provided in Section 2.0.

1.2 Planning Context

The long-term, lot-scale proponent driven nature in which the site will be developed, presents a unique planning context which calls for a tailored approach to the supporting environmental approvals process. To this end, an OWMS has been prepared for the site rather than the Local Water Management Strategy (LWMS) that would normally accompany Structure Planning.

The intention of the OWMS is to address the regional water related issues so that future lot-scale proponents are aware of detailed investigation that may be required at subdivision stage. The benefit of this approach is that the OWMS identifies broad water management issues and measures, while deferring certain investigation and design costs until such time as a specific proponent is present, and there is a better understanding of actual land requirements in terms of size, configuration, location and servicing requirements.

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2.0 STAKEHOLDER CONSULTATION

This risk analysis has been undertaken in response to outcomes of a meeting held between Krish Seewraj (Department of Water – DoW), Peter Hanly (Department of Parks and Wildlife – DPaW), Jonathan Roach (LandCorp) and Glenn Yeatman (RPS) at the DPaW Bunbury office on 30 October 2015. The meeting focused on the proposed approach to delineate wetland buffers in the context of the planning and water management framework for the KSIA. The site location, proposed structure plan and existing land uses are provided in Figures 1 to 3.

The meeting was the culmination of ongoing comments and responses as part of the existing water management review process. Specifically, Comment 13 of the comments/responses table progressed as follows:

DoW Comment 1:

> At the LWMS stage it is expected that wetlands and their buffers are mapped to ensure that adequate land has been set aside. Of note several conservation category wetlands abut the proposed lots and roads indicating no account has been taken of required buffers. It is also noted that the PRI is very low and groundwater is shallow, so consideration of buffers is critical.

RPS Response 1:

> Please see cover letter to this table. It is proposed that detailed buffer assessment is provided at subdivision stage.

(Note: The cover letter that is referred to in this response is provided in Appendix 1 of this report. The purpose of the letter was to provide clarification to the DoW regarding the unique planning framework for the KSIA, which is described in Section 1.2 of this report).

DoW Comment 2:

> Based on the response it is considered this report should have the level of detail normally provided in a DWMS. As such review Guidelines for district water management strategies (DoW 2013) noting that the department will be guided by the level of detail required by DPaW and also refers to the detail required in Operational policy 4.3: Identifying and establishing waterways foreshore areas.
>
> (DoW 2012)

RPS Response 2:

> The wetland buffers will be broadly in accordance with DPaW's management objectives with a 50 m buffer around mapped wetlands, recognising that the required buffer may vary, depending upon threats posed.

DoW Comment 3:

> This detail needs to be discussed and confirmed with DPaW, two options exist one to meet and discuss requirements or two to map out using the criteria indicated the proposal and provide that to DPaW for comment.

The principal outcomes of the 30 October 2015 meeting included:

- Wetland buffers should be based on vertical separation (e.g. two metres), not purely horizontal separation.
- Further detail is required on surface/groundwater separation distances to help assess the risks to the high conservation value wetlands.
- An accurate groundwater contour map should be prepared, detailing where water is close to the surface, to identify the constrained areas of the site.
- RPS to review existing AAMGL mapping to help identify high risk, high conservation value wetland areas based on vertical separation distances.
- RPS/LandCorp to provide this mapping with separation distances identified to DoW and DPaW for review and comment.
- RPS to detail a process to address risks at the appropriate stage (once the final land use and user is known).
- Once agreement has been reached, the water management report can be finalised.

Meeting minutes are provided in Appendix 2.

This wetland risk analysis has been completed to address these meeting outcomes and to better quantify the risk of KSIA development activities to nearby wetlands. The analysis is intended to better guide the KSIA water management framework and to provide individual lot proponents and regulators with more relevant detail to inform water management decisions at subdivision stage. Other additional risks to the wetlands will need to be assessed on a case-by-case basis as more specific and relevant issues pertaining to particular construction methods and other footprint and operational details are known, and required wetland studies can be undertaken.

3.0 QUALITATIVE RISK ANALYSIS

3.1 Overview

KSIA activities have the potential to result in hydrological impacts at nearby wetlands. The potential impacts are:

- impact of water level changes to wetlands
- impact of poor groundwater quality to wetlands
- impact to wetlands by vegetation clearing or development encroachment.

There are two categories related to wetland vegetation health that have been incorporated into the qualitative risk analysis. These are

1. Depth from ground surface to Average Annual Maximum Groundwater Level (AAMGL).

2. Wetland conservation status.

Details of these categories are provided in the following sections.

3.2 Qualitative Risk Categories

3.2.1 Depth to Water

The pre-development depth to water beneath each wetland is important because greater depths to water provide more unsaturated zone moisture for vegetation use (Froend et al. 2004). Hence, larger unsaturated zones are likely to minimise the impact of changes to water levels and quality, while smaller depths to water have a greater likelihood of impact.

Mapping of AAMGL contours and depth to AAMGL are provided in Figures 4 and 5. The mapping indicates the lower lying areas are located at the south-eastern part of the site.

3.2.2 Wetland Conservation Status

The Environmental Protection Authority (EPA) has established three wetland management categories depending on the quality of the wetland. The details of these wetland categories, as defined in EPA (1993) are:

- A Conservation Category Wetland (CCW) has a high degree of naturalness and the management objective is to maintain and enhance natural attributes and function.

- A Resource Enhancement Wetland (REW) has been modified and has a moderate degree of naturalness and human interest. The management objective is to maintain and enhance the existing ecological function. Opportunities may exist for commercial developments to enhance the conservation values of these wetlands.

- A Multiple Use Wetland (MUW) is significantly degraded, possessing few natural attributes and limited human-use interest. The management objective should be in the context of the current wetland value, interactions with adjacent wetlands of higher conservation value, and the potential value to the community if rehabilitated.

The conservation status of the wetlands within the site has been considered as part of the risk analysis because impacts to higher conservation wetlands are considered to have greater consequences than impacts to those with a lower conservation status. However, the impact of lower category wetlands must also be considered in terms of potential for consequent impacts upon nearby wetlands of higher conservation status. It should be noted that wetlands classified as "not assessed" are not necessarily of low conservation value. They should be assessed and then placed into the correct management category.

Figure 6 shows the depth to AAMGL in relation to wetland mapping and Figure 7 shows wetland mapping in relation to the KSIA structure plan.

3.3 Qualitative Risk Analysis Results

The qualitative risk analysis was undertaken on a total of 84 wetlands which are listed in Table 1. Figure 6 shows the depth to AAMGL in relation to wetland mapping and is intended to provide a qualitative indication of wetland risk areas (i.e. high conservation status and low depth to AAMGL). Note that the reference to EPP lakes in Figure 6 and Table 1 is by name only; the Environmental Protection (Swan Coastal Plain Lakes) Policy 1992 was revoked in late 2015, and some of the geomorphic classifications need to be reviewed where the EPP protection has been removed.

Table 1 lists the minimum depth to AAMGL and conservation status at each mapped wetland. Section 3.0 provides a specific description of each REW and CCW.

General management strategies for the developments are provided in Section 5.0. It is proposed that specific management strategies for individual wetlands are undertaken on a case by case basis with the individual lot proponent and regulator at subdivision stage, guided by the information provided in this risk analysis.

Table 1: Wetlands List

Wetland ID	Wetland Conservation Status	Min Depth to AAMGL (m)	Wetland ID	Wetland Conservation Status	Min Depth to AAMGL (m)
1496	CCW	0	14491	REW	-0.4
1499	CCW	1.7	1501	MUW	1.8
1531	CCW	1.1	1502	MUW	-0.5
1671	CCW	1 to 2	1503	MUW	0.9
1672	CCW	1.6	1504	MUW	0.7
1673	CCW	1 to 2	1505	MUW	1
1680	CCW	1 to 2	1508	MUW	2
1689	CCW	0.5	1509	MUW	1
1717	CCW	-2.1	1528	MUW	0.9
1731	CCW	1	1666	MUW	1.3
1827	CCW	<1	1667	MUW	1.6
1833	CCW	0	1668	MUW	1
1834	CCW	0.5	1669	MUW	1
1851	CCW	0.5	1674	MUW	1
1854	CCW	0.6	1678	MUW	0.1
14485	CCW	1 to 2	1679	MUW	1
14487	CCW	1.3	1681	MUW	1
14488	CCW	0.5	1683	MUW	1.1
14489	CCW	2.8	1684	MUW	0
14545	CCW	2.5	1685	MUW	1
14546	CCW	0	1686	MUW	1.5
14551	CCW	-0.2	1687	MUW	1
EPP3	EPP	1.1	1688	MUW	1.1
EPP4	EPP	1.2	1698	MUW	0.2
EPP5	EPP	0.3	1699	MUW	0
EPP6	EPP	0	1700	MUW	-0.5
EPP7	EPP	0.3	1701	MUW	-0.9
EPP8	EPP	-0.5	1702	MUW	0.9
EPP9	EPP	-0.8	1703	MUW	1.5
1529	REW	0.9	1715	MUW	0.2
1530	REW	1	1732	MUW	1.2
1675	REW	3.4	1825	MUW	1.4
1677	REW	0.3	1826	MUW	1.1
1682	REW	1	1840	MUW	0.2
1716	REW	0.5	1842	MUW	0.2
1837	REW	0.1	1843	MUW	0.2

Wetland ID	**Wetland Conservation Status**	**Min Depth to AAMGL (m)**	**Wetland ID**	**Wetland Conservation Status**	**Min Depth to AAMGL (m)**
1839	REW	-0.1	1860	MUW	-2.6
1858	REW	0.4	1862	MUW	< 0
2052	REW	0.5	2035	MUW	1.2
14481	REW	0.1	15224	MUW	0
14482	REW	0.2	1670	NA	1.7
14483	REW	0.2	2033	NA	2

Note:
MUW indicates Multiple Use Wetland, REW is Resource Enhancement Wetland, CCW is Conservation Category Wetland, EPP indicate former Environmental Protection Policy Wetland, NA is not assessed.

4.0 WETLAND DESCRIPTIONS AND ASSESSMENT

4.1 Summary and Future Assessments

This section provides a description of each CCW, REW and former EPP lakes and the assessment required at subdivision stage. Of note is that the actual ground position of each wetland needs to be reviewed as data sets often have a displacement error and the accuracy of boundaries varies according to the scale of aerial photography used at the time of mapping. As shown in many of the plates in this section, mapped boundaries often do not match wetland characteristics such as vegetation, soils and topography (i.e. the true wetland boundary) and so remapping may be warranted to improve the accuracy of the data.

As recommended in the EPA's advice when the EPP Lakes Policy was revoked, a comprehensive update of the geomorphic wetland dataset should be undertaken for wetlands identified in this report, at subdivision stage. It should also be noted that a number of wetland classifications warrant review with field surveys and assessments, and this may raise the conservation status of some wetlands. Assessment required at subdivision stage should cover all wetlands and include:

1. Monitoring of current groundwater regimes and quality.

2. Review of wetland classification.

3. Biophysical assessment of buffer requirements.

4. Review of proposed land use change and risks presented by:
    a. Groundwater connectivity and grade.
    b. Surface water drainage management.
    c. Process water management.
    d. Process and site pollutants and their management.
    e. Transport corridors.
    f. Other relevant site details.

4.2 Wetland Descriptions

4.2.1 CCW 1496

Wetland 1496 is a CCW that is located at the northern part of the proposed industry zone. It is mostly located outside the site's eastern boundary within industry buffer, with a small portion within proposed industry zone. The western part of the wetland has been intersected by the services corridor that includes overhead powerlines (Plate 1).

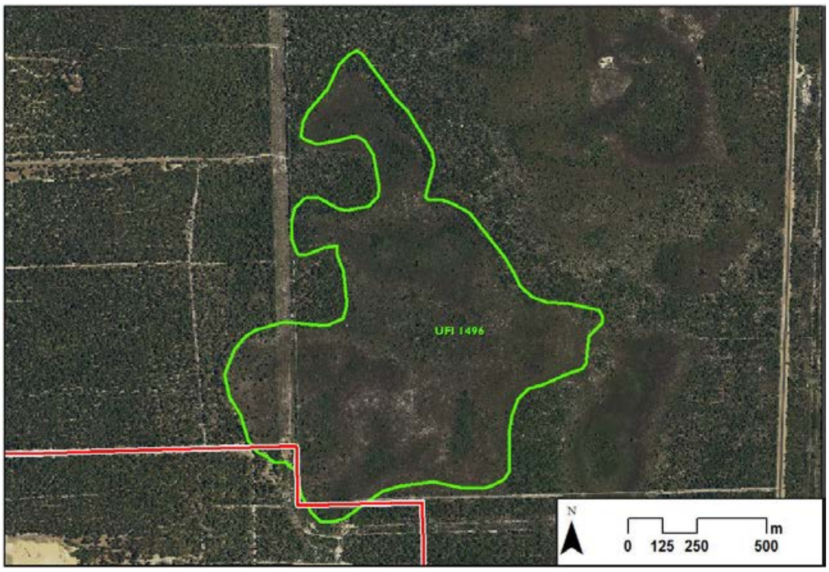

Plate 1: **Wetland 1496**

4.2.2 CCW 1499

Wetland 1499 is a CCW that is located at the northern end of the proposed industry zone. The wetland is located approximately 100 m south-west of existing industry; and a track and services corridor that includes overhead powerlines is located directly west (Plate 2).

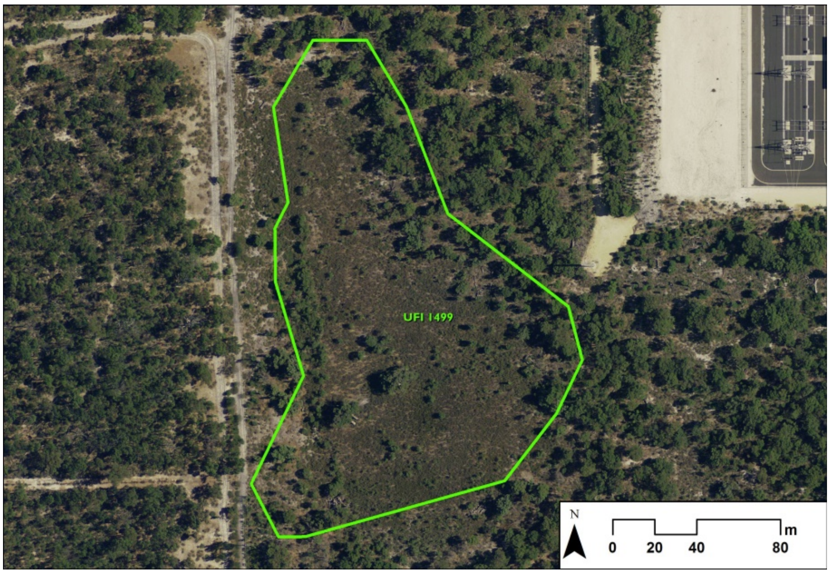

Plate 2: **Wetland 1499**

4.2.3 CCW 1531

Wetland 1531 is a CCW that is located at the southern end of the site, within proposed industry buffer. Most of the wetland is located outside the site, and its northern end abuts the site's southern boundary and an existing track. The wetland contains tracks and what appears to be a man-made soak (Plate 3).

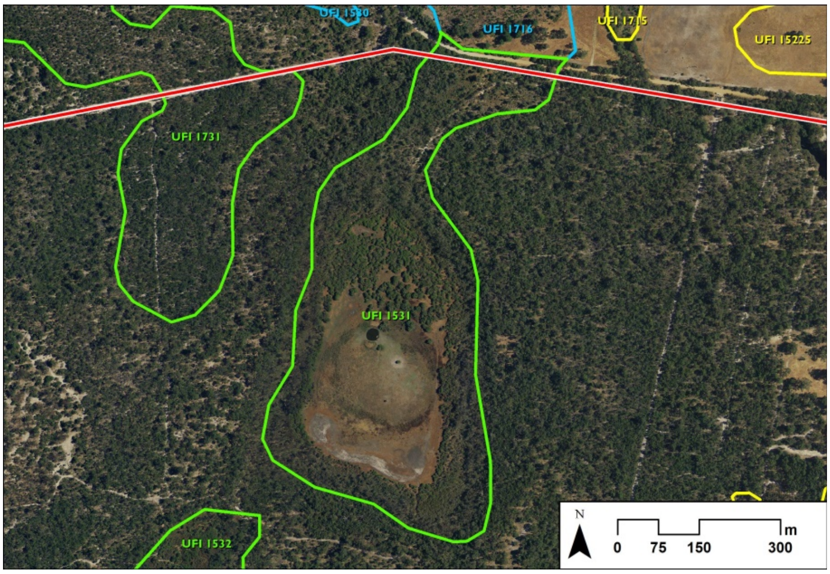

Plate 3: Wetland 1531

4.2.4 CCW 1671

Wetland 1671 is a CCW that is located at the north-eastern part of the site. It is mostly located outside the site's eastern boundary within industry buffer, with a small portion within proposed industry zone. The wetland is located approximately 100 m south-east of existing industry and is intersected by a north–south running track within its western boundary (Plate 4).

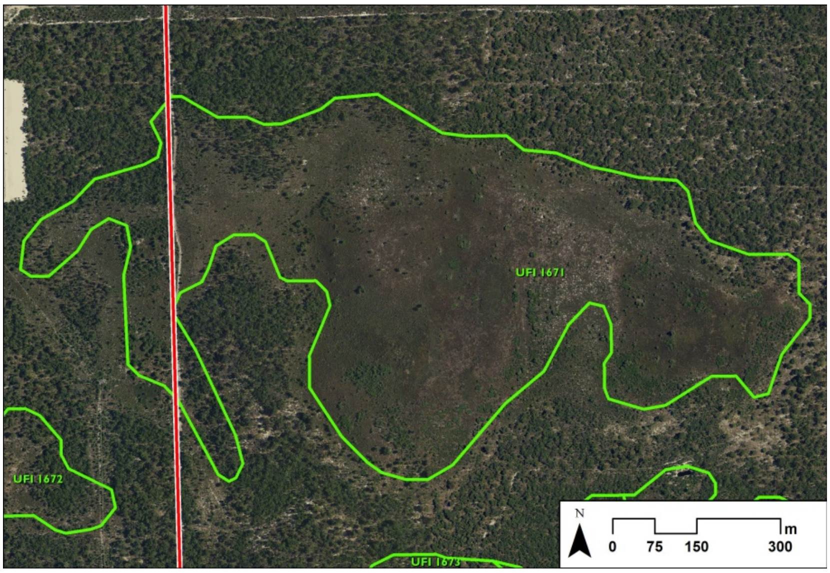

Plate 4: Wetland 1671

4.2.5 CCW 1672

Wetland 1672 is a CCW that is located at the northern end of the site, within proposed industry buffer. The wetland is intersected by numerous tracks and a services corridor that includes overhead powerlines. A separate services corridor is located adjacent to its eastern boundary (Plate 5).

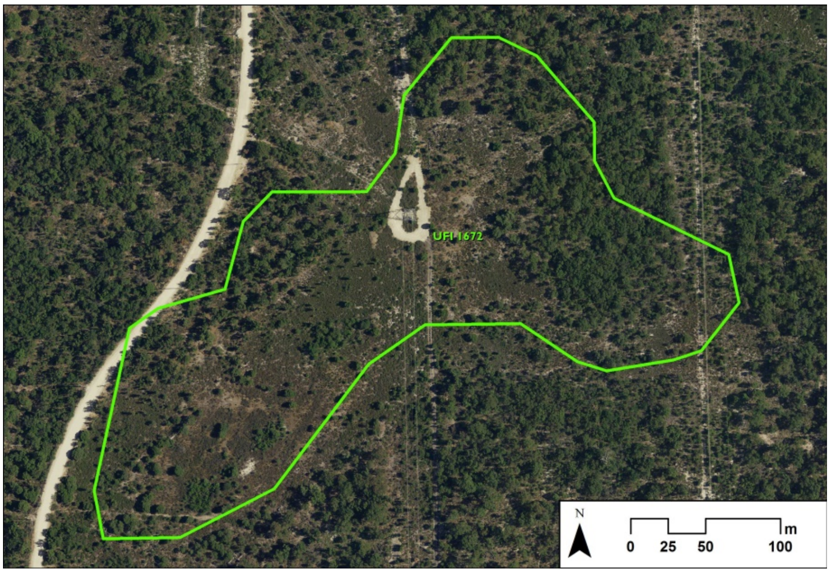

Plate 5: Wetland 1672

4.2.6 CCW 1673

Wetland 1673 is a CCW that is located outside and adjacent to the northern end of the proposed industry zone. It is located within industry buffer and is intersected by a south-west to north-east running track; and its southern boundary is coincident with a track (Plate 6).

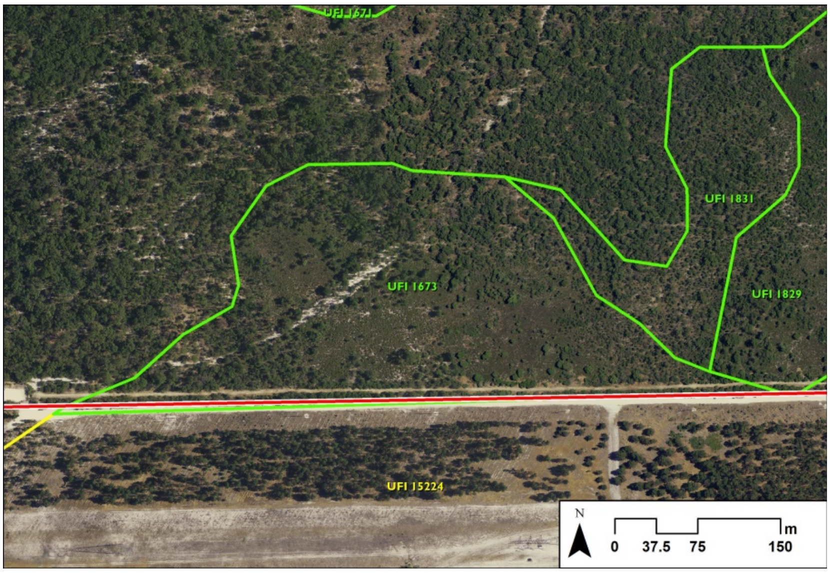

Plate 6: Wetland 1673

4.2.7 CCW 1680

Wetland 1680 is a CCW that is located at the north-eastern part of the site. It is mostly located outside the site's eastern boundary within proposed ROS, and adjacent to proposed industry zone. The site is intersected by a north–south running track within its western boundary, and its northern boundary is adjacent to Mitchell Road (Plate 7).

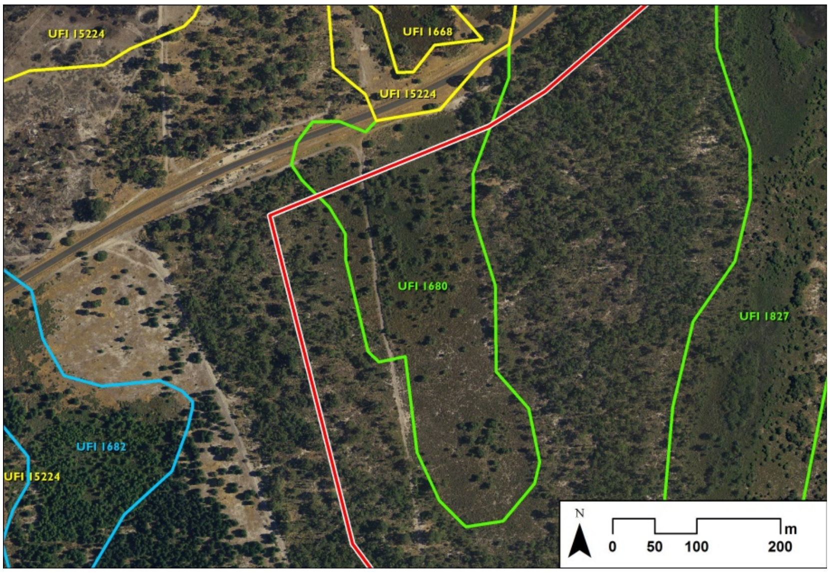

Plate 7: Wetland 1680

4.2.8 CCW 1689

Wetland 1689 is a CCW that is located within industry buffer at the central eastern part of the site. It is located adjacent to Wellesley Road to the south and is intersected by an east–west track (Plate 8).

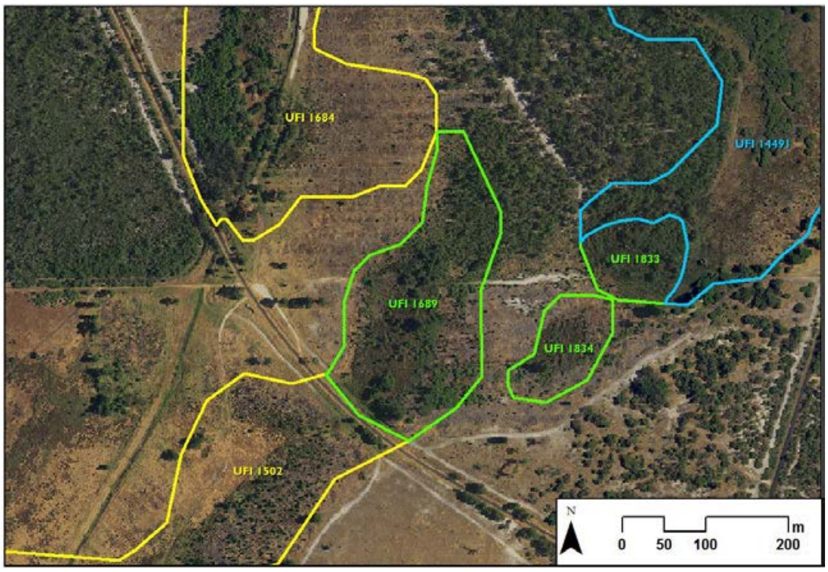

Plate 8: Wetland 1689

4.2.9 CCW 1717

Wetland 1717 is a CCW that is located within ROS adjacent to the south-eastern corner of the site and corresponds to the Wellesley River foreshore. The majority of this wetland is located further to the south of the site (Plate 9).

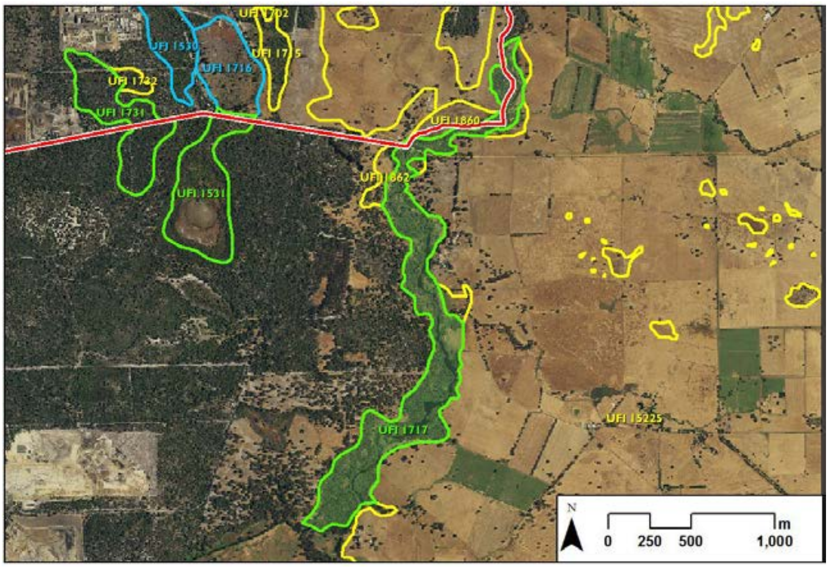

Plate 9: Wetland 1717

4.2.10 CCW 1731

Wetland 1731 is a CCW located across the southern industry zone boundary. It is mostly located within industry zone with a proportion located within the industry buffer. The mapped wetland is directly adjacent to operating industrial uses (chemical plant and smelter), and is dissected by existing tracks across its north and centre (Plate 10).

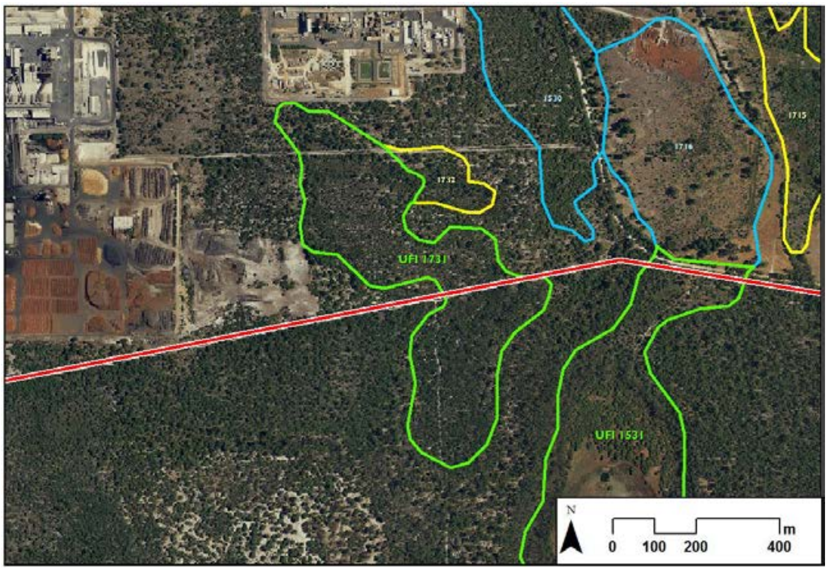

Plate 10: Wetland 1731

4.2.11 CCW 1827

Wetland 1827 is a CCW that is located across the eastern industry zone boundary and is concurrent with EPP 3. It is mostly located outside the site's eastern boundary within ROS, with a portion within proposed industry area. The northern part of the wetland has been intersected by Mitchell Road (Plate 11).

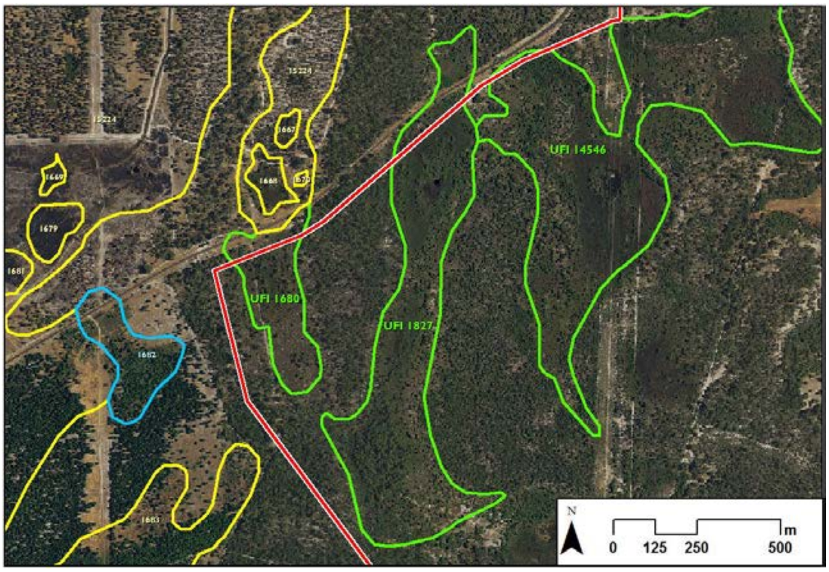

Plate 11: Wetland 1827

4.2.12 CCW 1833

Wetland 1833 is a CCW located within industry buffer at the south-eastern part of the site. The mapped wetland has a track within its southern and western boundaries (Plate 12).

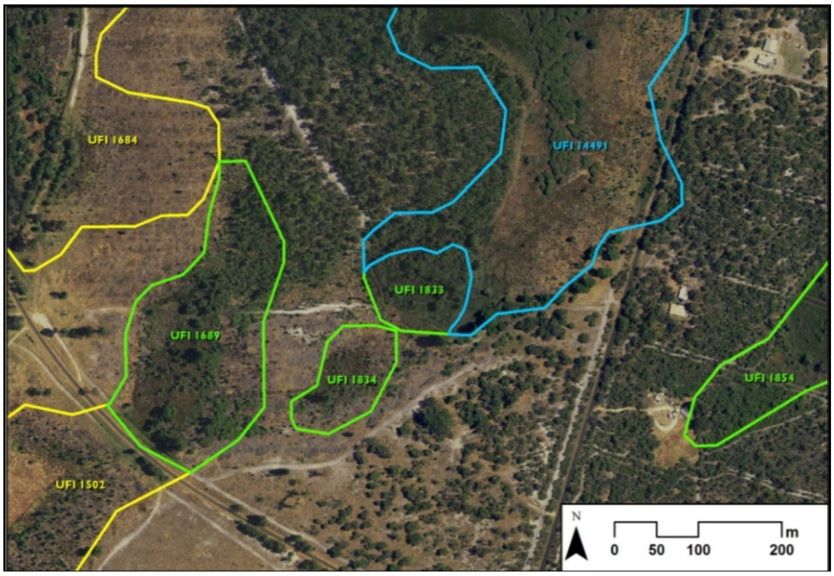

Plate 12: Wetland 1833

4.2.13 CCW 1834

Wetland 1834 is a CCW located within industry buffer at the south-eastern part of the site. The mapped wetland has been heavily cleared (Plate 13).

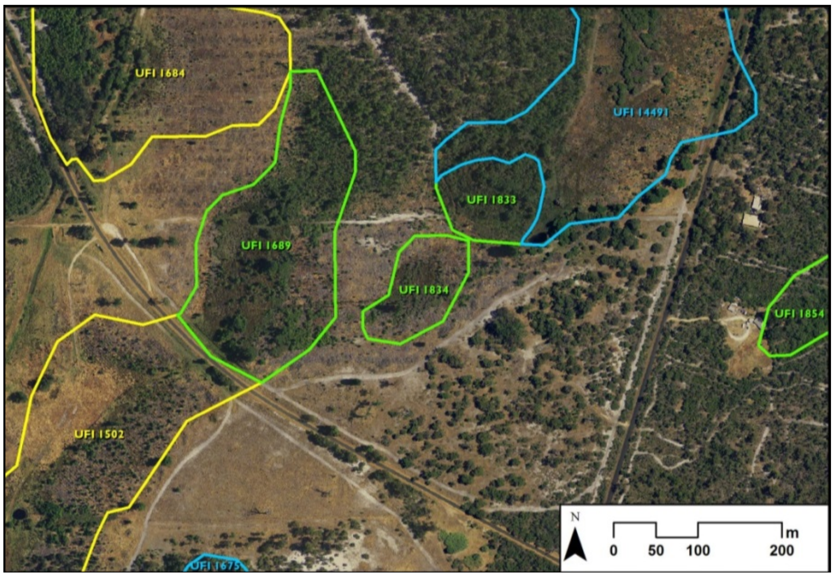

Plate 13: Wetland 1834

4.2.14 CCW 1851

Wetland 1851 is a CCW located within proposed industry buffer at the central eastern part of the site. The mapped wetland has tracks within its eastern and southern boundary and it has been modified by clearing (Plate 14).

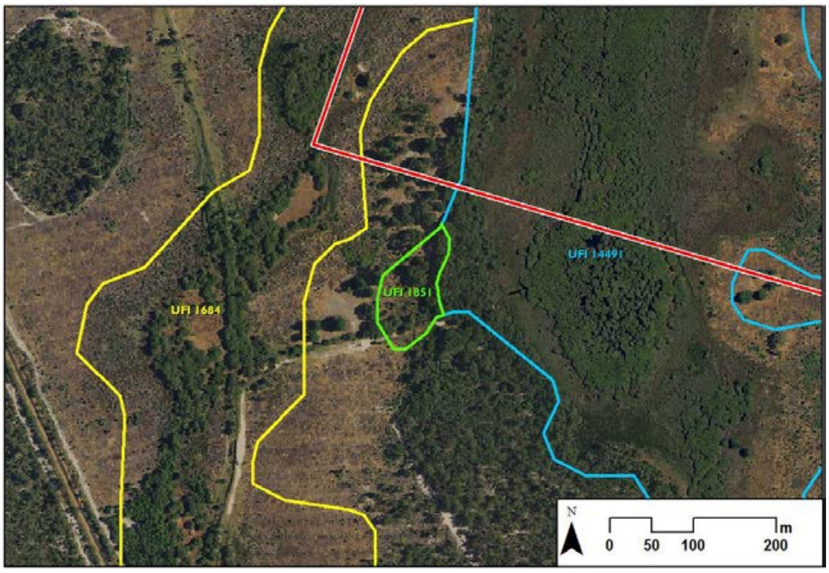

Plate 14: Wetland 1851

4.2.15 CCW 1854

Wetland 1854 is a CCW that is concurrent with Wetland EPP 5, and is located within ROS at the east central part of the site. It is intersected by a series of tracks which appear to be due to existing land subdivision. A services corridor including overhead powerlines is located directly east (Plate 15).

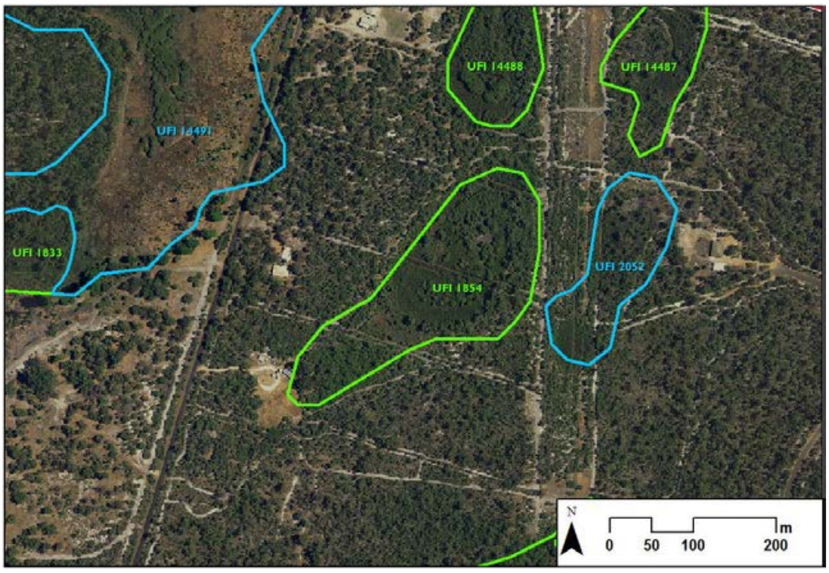

Plate 15: Wetland 1854

4.2.16 CCW 14485

Wetland 1675 is an REW that is located at the north-eastern part of the site within proposed industry buffer. Services corridors are located directly west and east, and tracks are located to the north, east and west. A man-made soak appears to be located at the centre of the wetland (Plate 26).

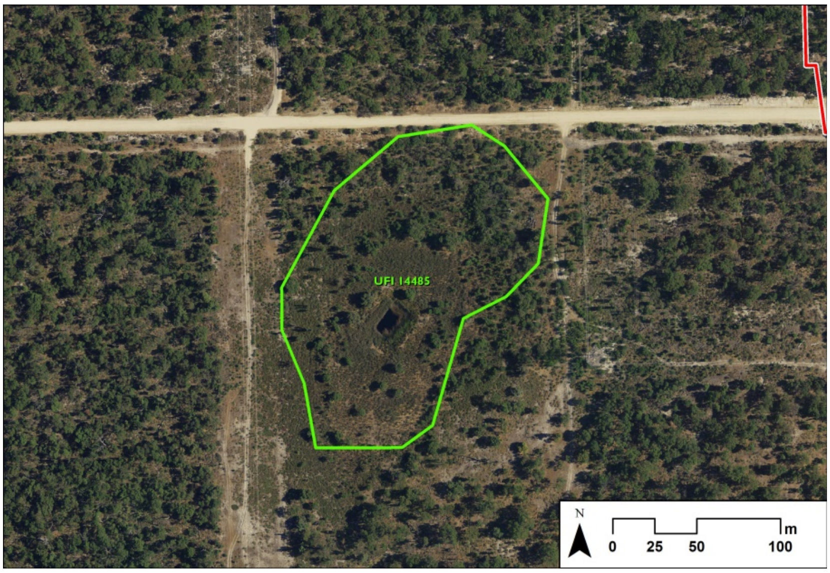

Plate 16: Wetland 14485

4.2.17 CCW 14487

Wetland 14487 is a CCW that is located within ROS and industry buffer at the east-central part of the site. It is intersected by a series of tracks, and a services corridor including overhead powerlines is located directly west (Plate 17).

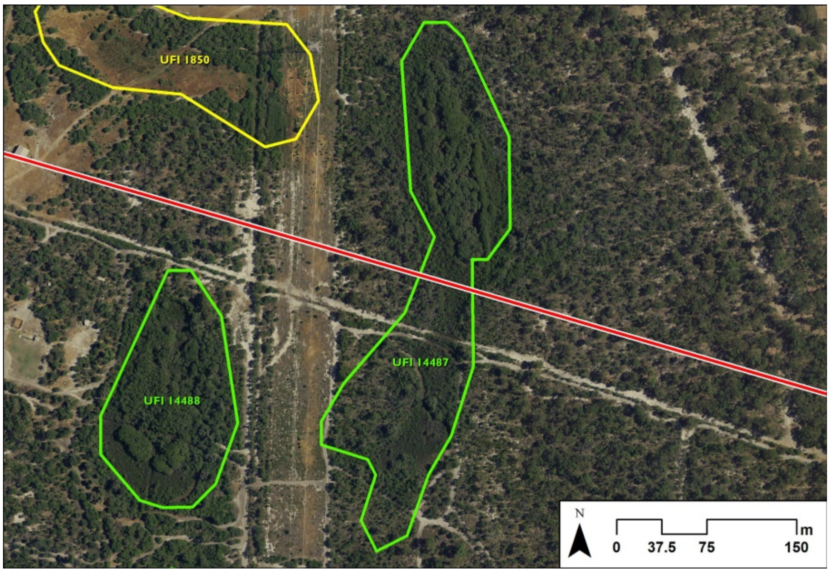

Plate 17: Wetland 14487

4.2.18 CCW 14488

Wetland 14488 is a CCW that is located within ROS at the east central part of the site. It is intersected by a series of tracks, and a services corridor including overhead powerlines is located directly east (Plate 18).

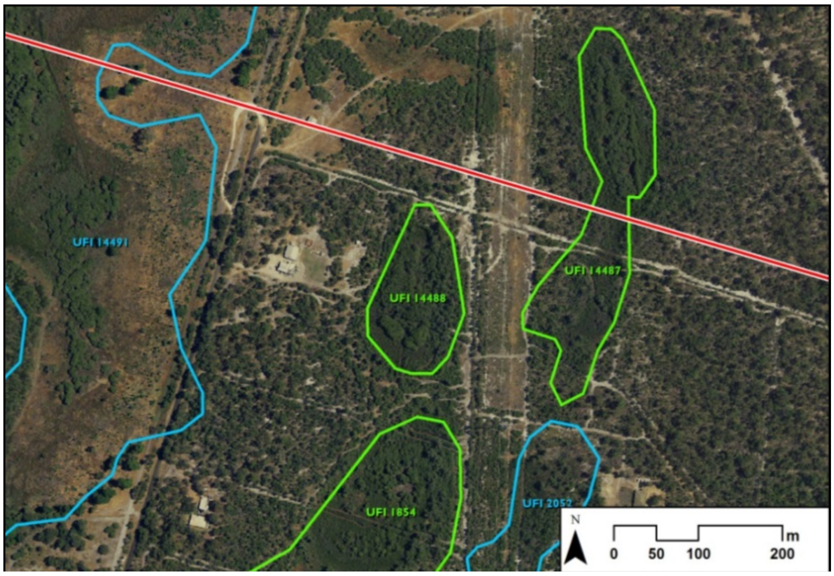

Plate 18: Wetland 14488

4.2.19 CCW 14489

Wetland 14489 is a CCW that is located within proposed industry zone at the northern part of the site, with Wellesley Road located east and several tracks around the wetland (Plate 19).

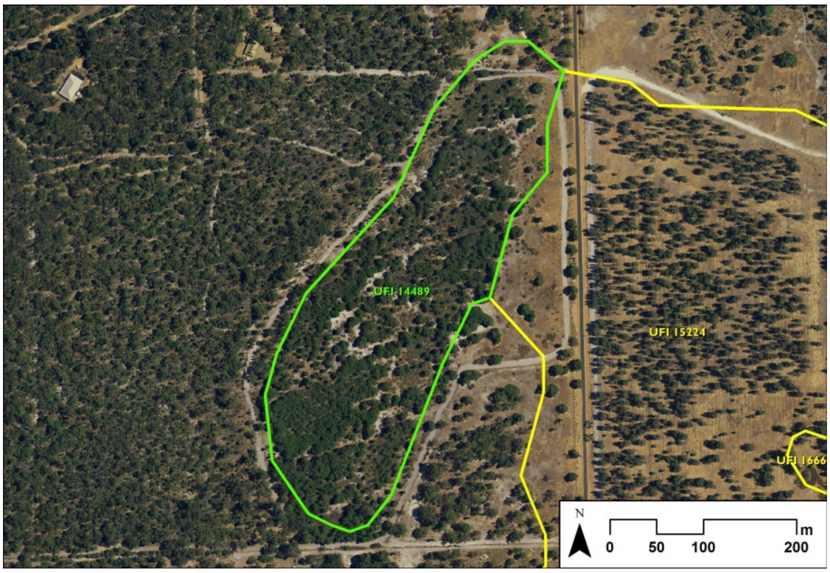

Plate 19: Wetland 14489

4.2.20 CCW 14545

Wetland 14545 is a CCW that is located within proposed industry zone at the northern part of the site. It is intersected by a series of tracks and Wellesley Road (Plate 20).

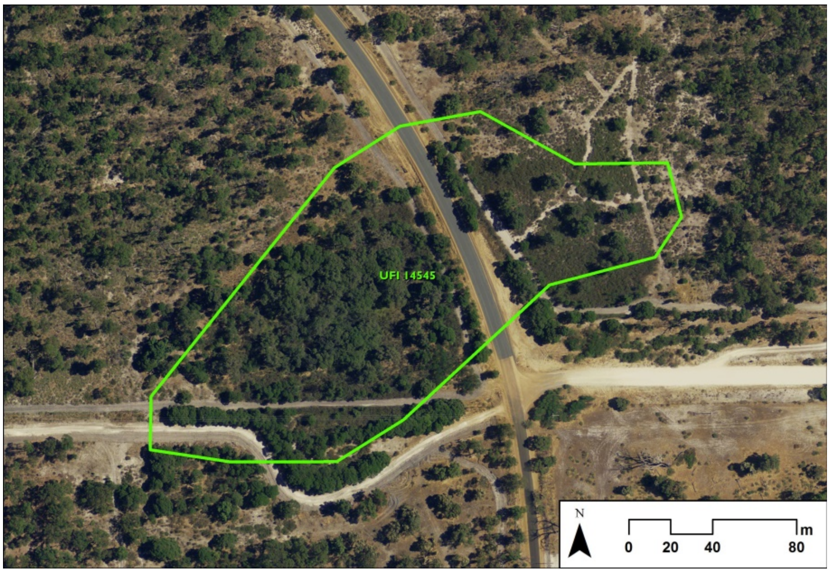

Plate 20: Wetland 14545

4.2.21 CCW 14546

Wetland 14546 is a CCW located within ROS and industry buffer at the north-eastern part of the site, and is directly east of industry zone. It is dissected by Wellington Road at its east (unsurfaced) and a services corridor (including overhead powerlines) across its centre, and its northern mapped edge is adjacent to Mitchell Road (Plate 21).

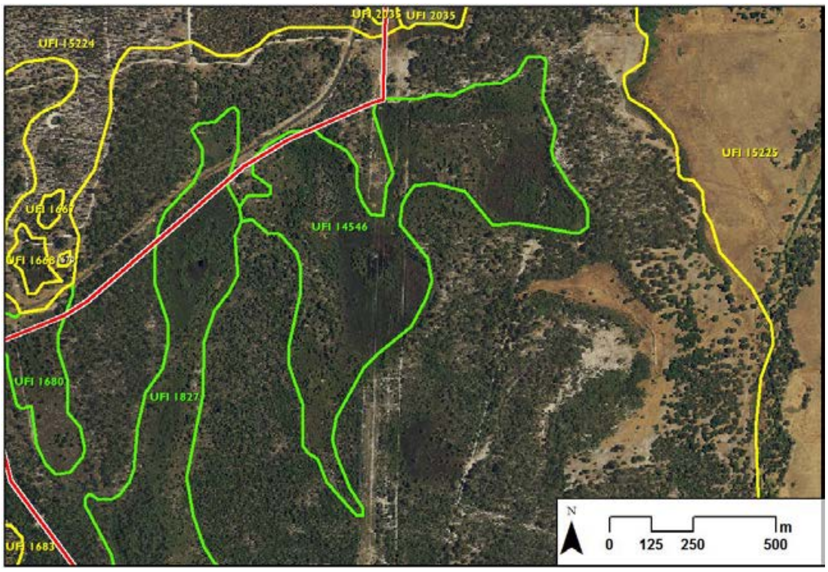

Plate 21: Wetland 14546

4.2.22 CCW 14551 and EPP6

Wetland 14551 is concurrent with EPP6 and both are located within ROS at the east central part of the site. They lie under a services corridor including overhead powerlines (Plate 22 and Plate 23).

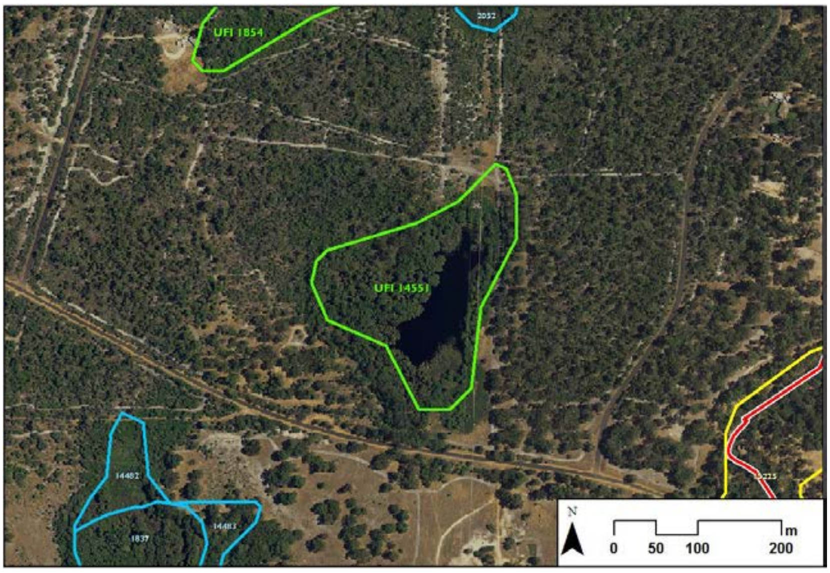

Plate 22: Wetland 14551

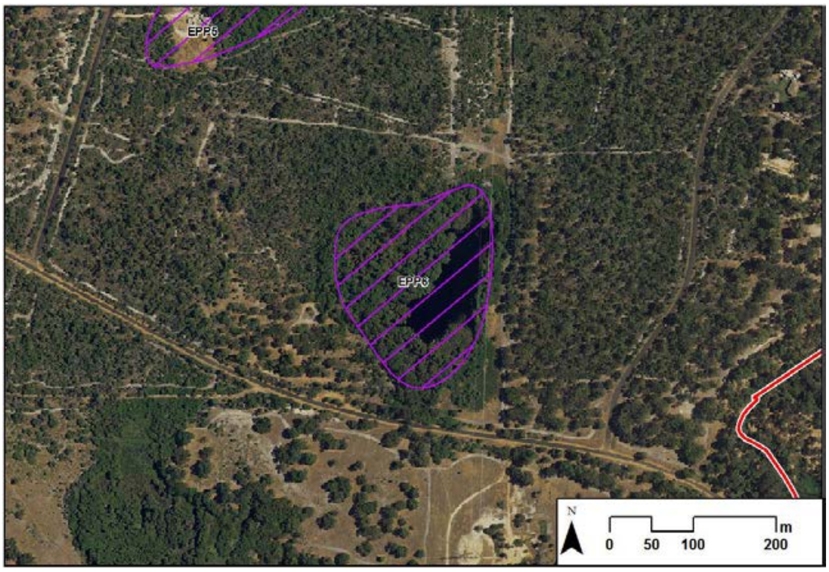

Plate 23: Wetland EPP6

4.2.23 REW 1529

Wetland 1529 is an REW that is located within industry zone at the south-western part of the site. It is located adjacent to Marriott Road to the north and has been intersected by a north–south track (Plate 24).

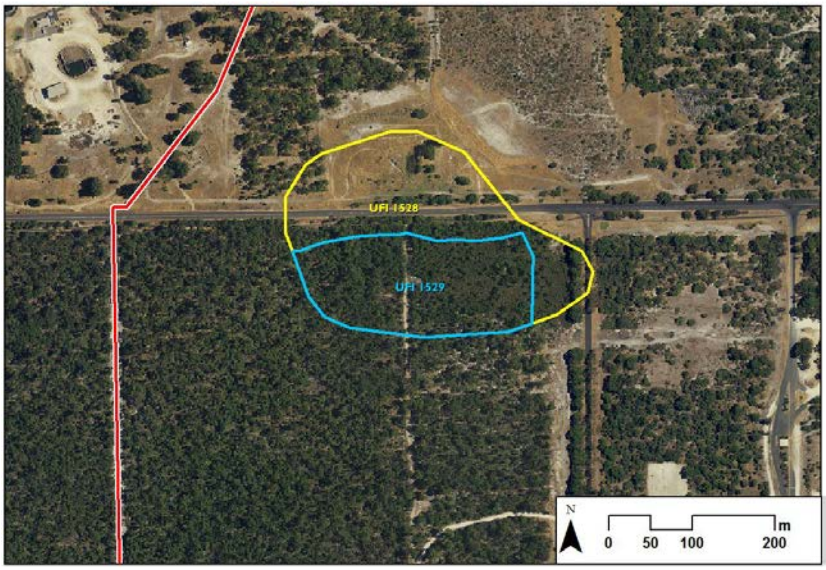

Plate 24: Wetland 1529

4.2.24 REW 1530

Wetland 1530 is an REW located at the southern part of the site, within industry zone. The mapped wetland is directly adjacent to operating industrial uses (chemical plant and substation), and is dissected by existing tracks across its south and east (Plate 25).

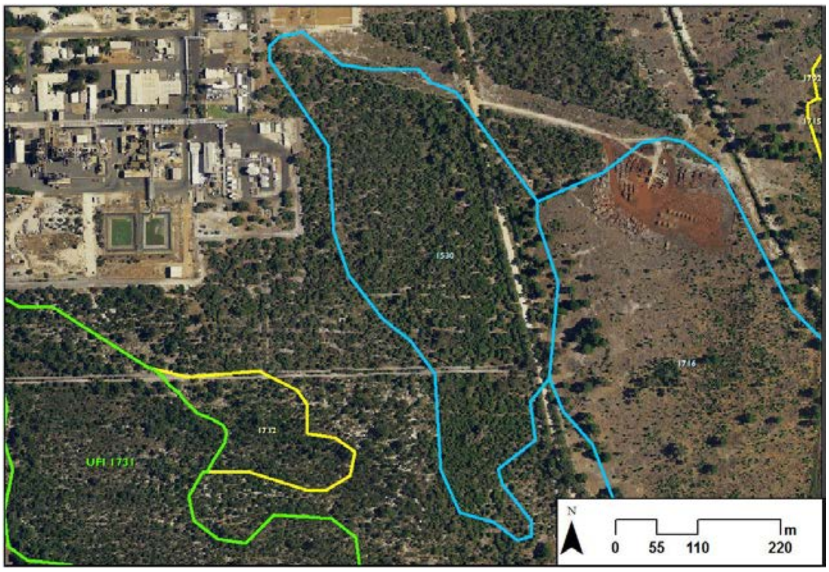

Plate 25: **Wetland 1530**

4.2.25 REW 1675

Wetland 1675 is an REW that is located at the south-eastern part of the site within proposed industry buffer (Plate 26).

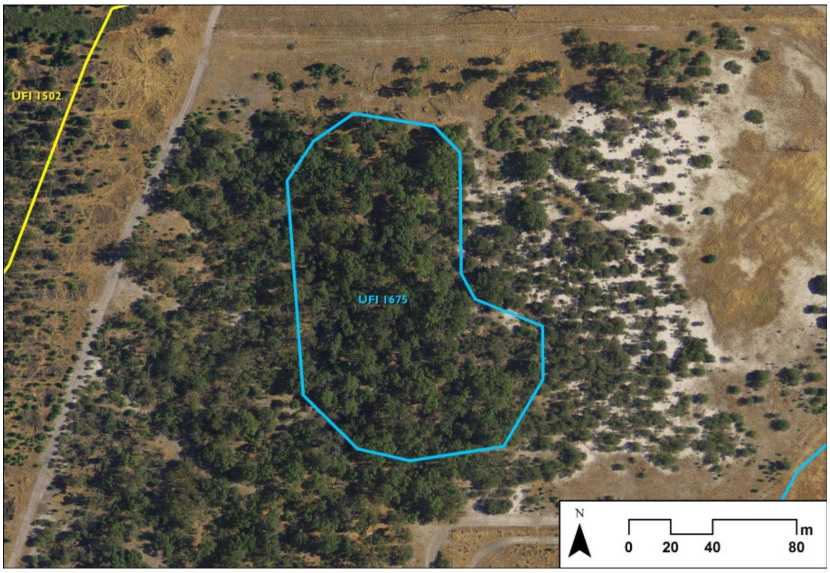

Plate 26: **Wetland 1675**

4.2.26 REW 1677

Wetland 1677 is an REW located at the southern part of the site, within industry buffer. The mapped wetland is predominantly cleared, has a man-made dam/soak at its south and has an open drain at its west (Plate 27).

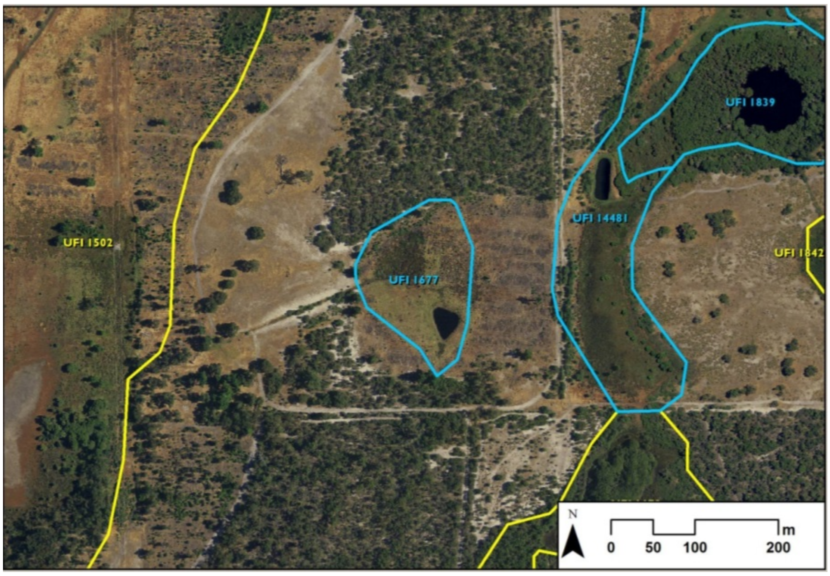

Plate 27: Wetland 1677

4.2.27 REW 1682

Wetland 1682 is an REW located at the east central part of the site within industry zone. The mapped wetland has been dissected by Mitchell Road at its north and an unsurfaced road and powerlines at its west. The northern area of the mapped wetland has been cleared (Plate 28).

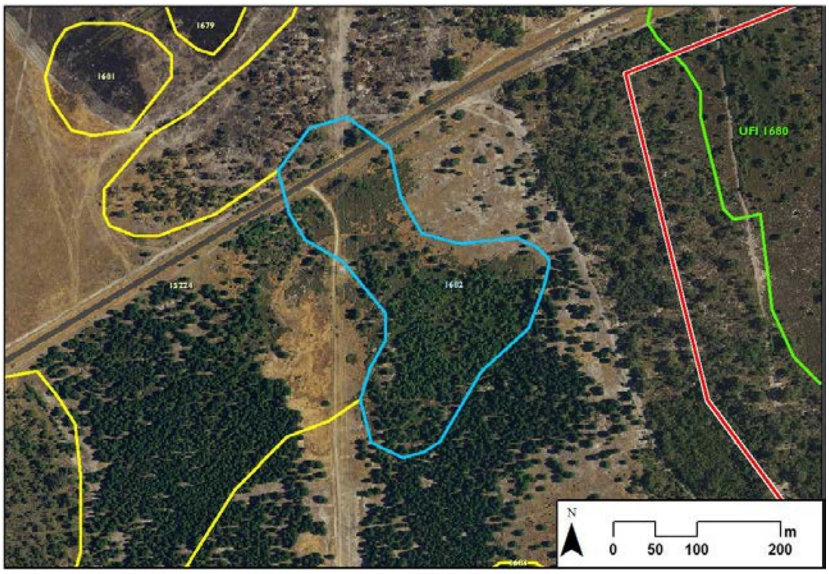

Plate 28: Wetland 1682

4.2.28 REW 1716

Wetland 1716 is an REW located across the eastern industry zone boundary. It is mostly located within the proposed industry buffer. The mapped wetland is cleared and has operating industry within its northern boundary. An open drain is located directly east and an unsurfaced road is located directly west (Plate 29).

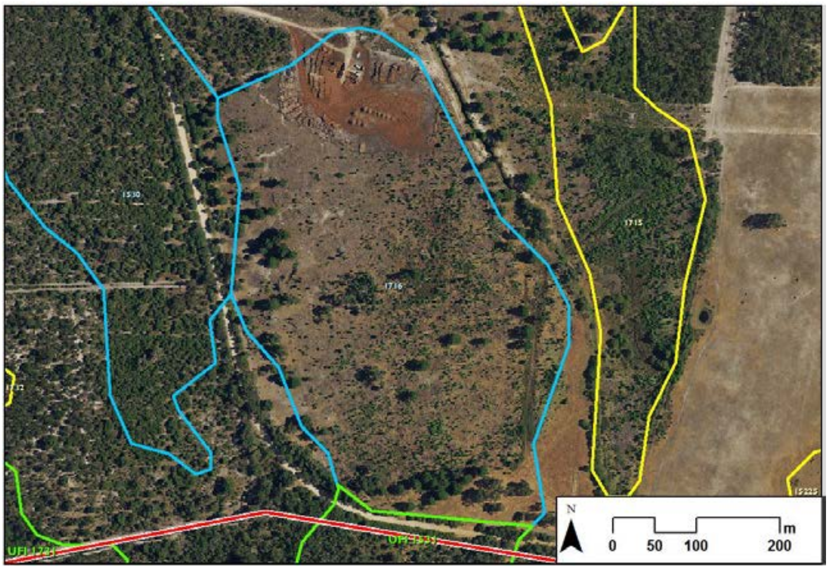

Plate 29: Wetland 1716

4.2.29 REW 1837

Wetland 1837 is an REW located at the south-eastern part of the site, within ROS. The mapped wetland appears to be well vegetated (Plate 30).

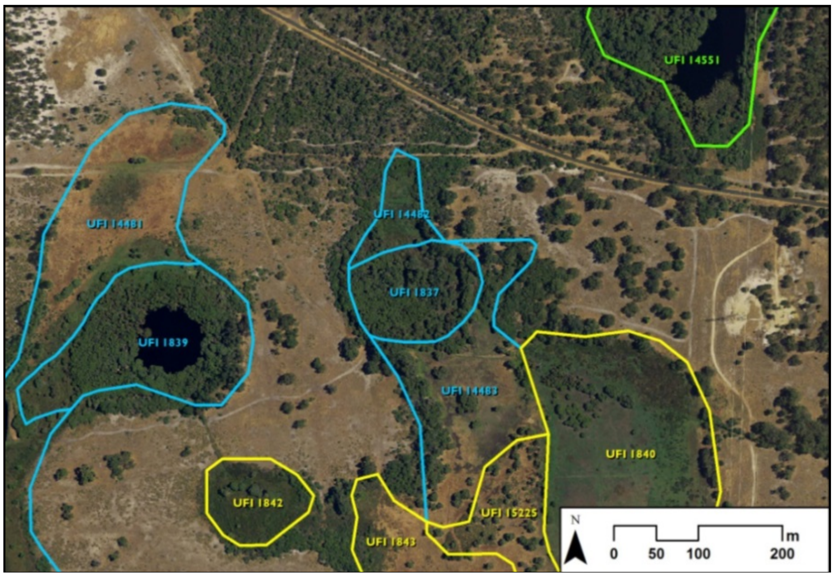

Plate 30: Wetland 1837

4.2.30 REW 1839

Wetland 1839 is an REW located within proposed industry buffer and ROS at the south-eastern part of the site, and is concurrent with EPP 8 and REW 14481. The mapped wetland appears to be well vegetated (Plate 31).

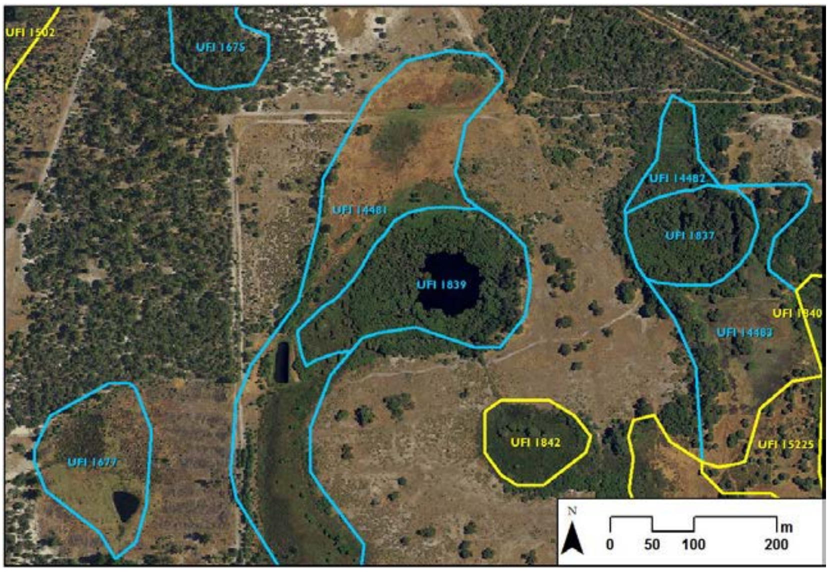

Plate 31: Wetland 1839

4.2.31 REW 1858

Wetland 1858 is an REW located within industry zone at the south-eastern part of the site. It is intersected by Marriott Road at its south and a services corridor including overhead powerlines is located directly east. It has been modified by clearing and it contains a number of tracks (Plate 32).

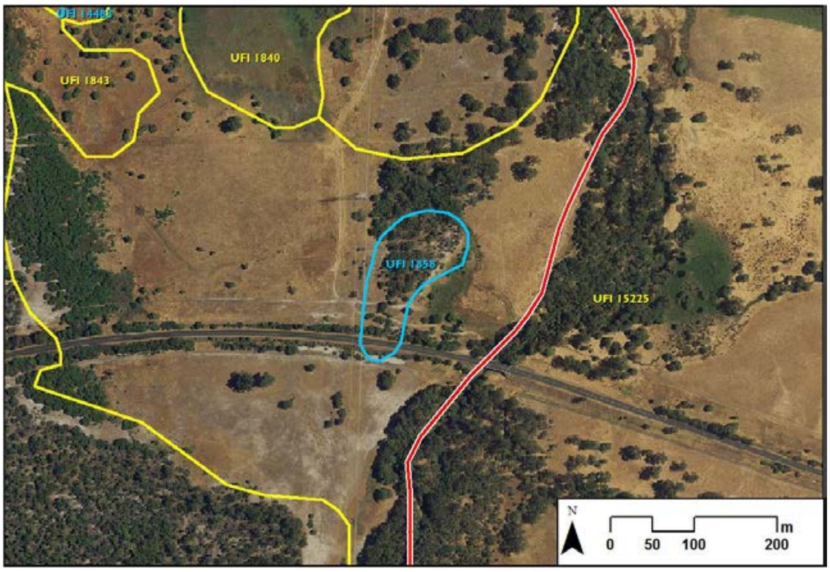

Plate 32: Wetland 1858

4.2.32 REW 2052

Wetland 2052 is an REW located within ROS at the east central part of the site. It is intersected by a series of tracks, and a services corridor including overhead powerlines is located within its boundary (Plate 33).

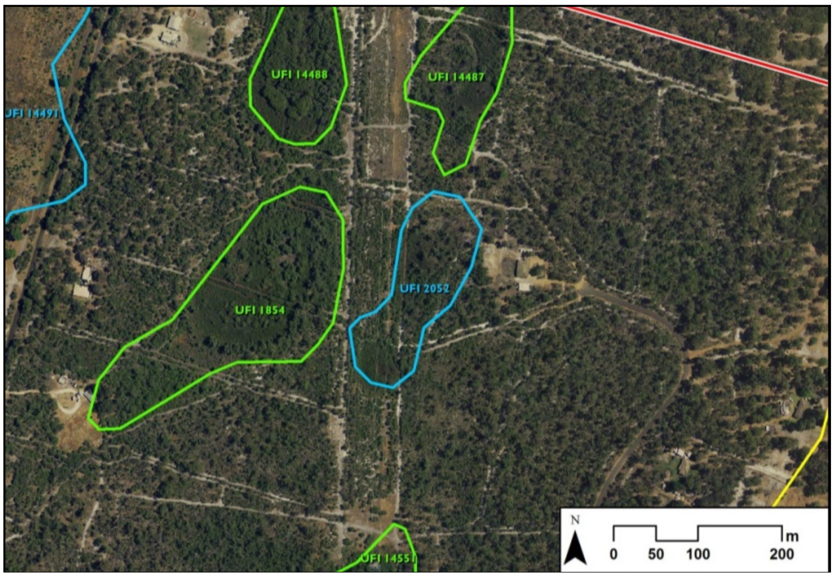

Plate 33: Wetland 2052

4.2.33 REW 14481

Wetland 14481 is an REW located within proposed industry buffer at the south-eastern part of the site, and is concurrent with EPP 8. Unsurfaced tracks are located across its north and west and it has been heavily modified by clearing. It appears a dam/seep is located within its western boundary (Plate 34).

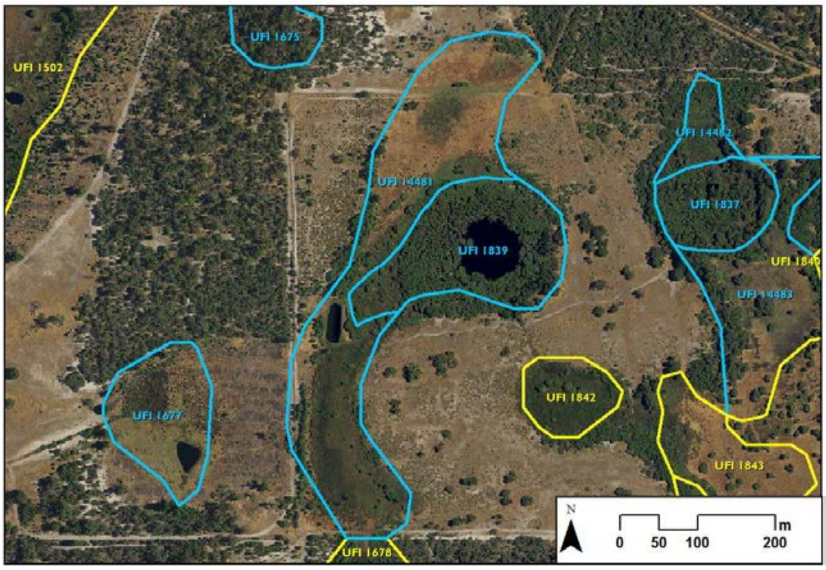

Plate 34: Wetland 14481

4.2.34 REW 14482

Wetland 14482 is an REW located at the south-eastern part of the site, within ROS. The mapped wetland is dissected by existing tracks across its north and centre and appears to have been impacted by clearing (Plate 35).

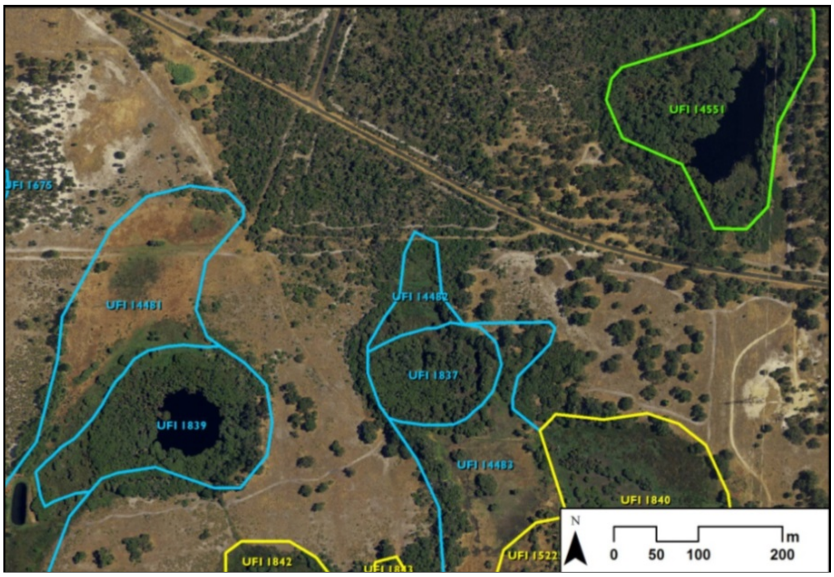

Plate 35: Wetland 14482

4.2.35 REW 14483

Wetland 14483 is an REW located within ROS at the south-eastern part of the site, within ROS. An unsurfaced track is located directly south and the wetland has been modified by clearing (Plate 36).

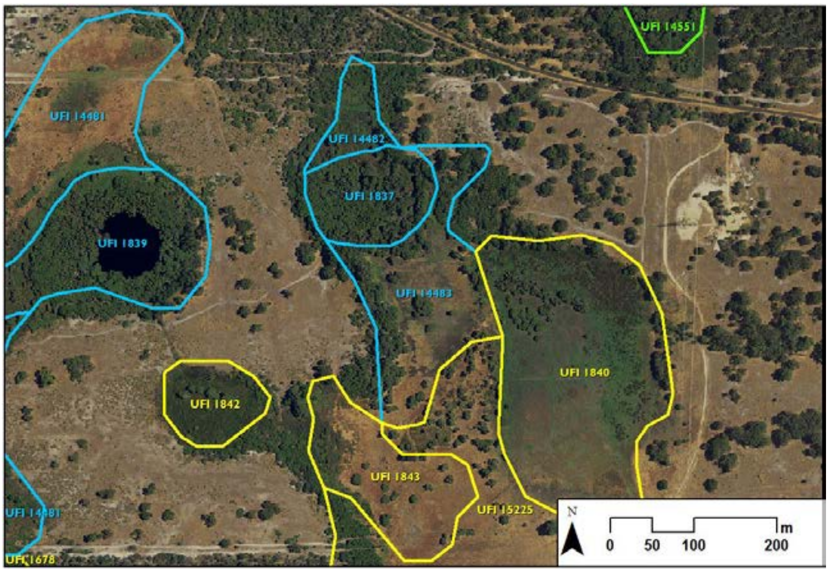

Plate 36: Wetland 14483

4.2.36 REW 14491

Wetland 14491 is an REW that is located across the site's eastern boundary within the industry buffer. A significant proportion has been cleared and the mapped wetland has various unsurfaced tracks (Plate 37).

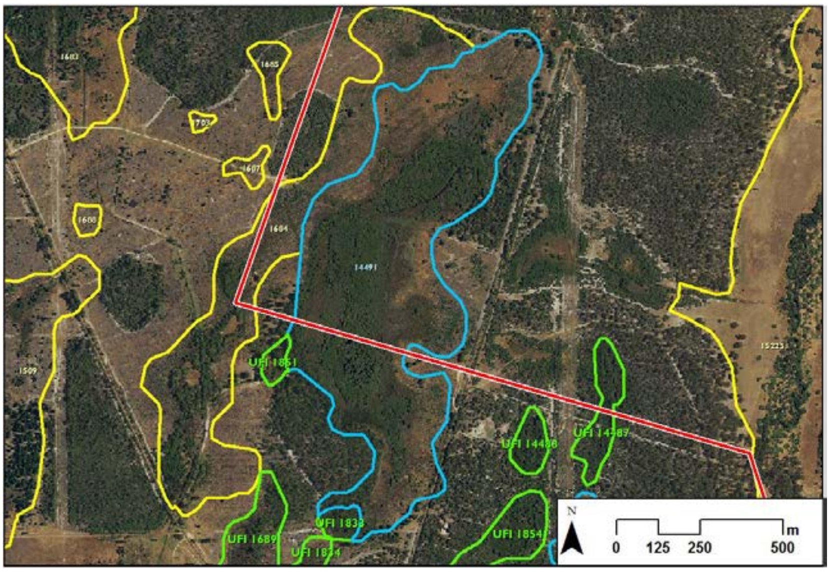

Plate 37: Wetland 14491

4.2.37 EPP3

Wetland EPP 3 is located within ROS adjacent to the eastern industry zone boundary and is concurrent with CCW 1827. The northern part of the wetland is adjacent to Mitchell Road (Plate 38).

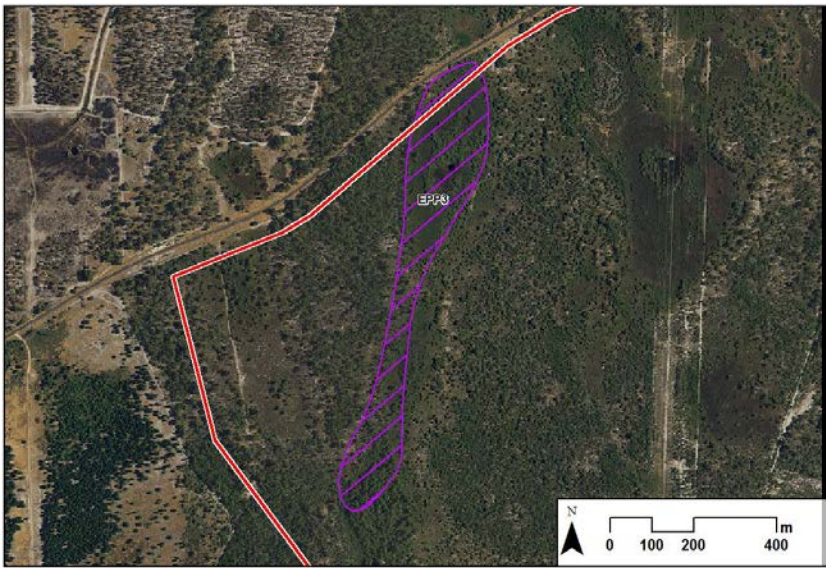

Plate 38: Wetland EPP3

4.2.38 EPP4

Wetland EPP4 is located within ROS and industry buffer at the east central part of the site. It is intersected by tracks and a services corridor including overhead powerlines within its western boundary (Plate 39).

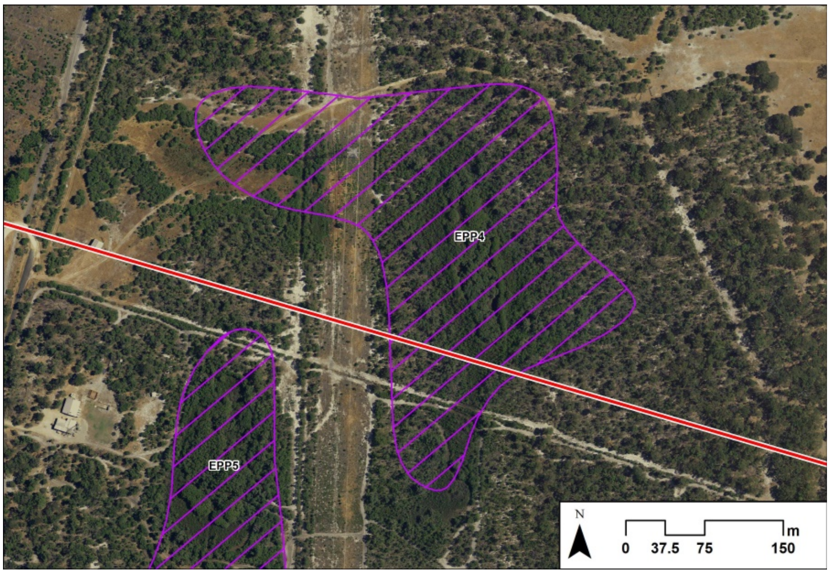

Plate 39: Wetland EPP4

4.2.39 EPP5

Wetland EPP5 is concurrent with Wetlands 14488 and 1854 and is located within ROS at the east central part of the site. It is intersected by a series of tracks which appear to be due to existing land subdivision. A services corridor including overhead powerlines is located directly east and its southern end has been impacted by clearing (Plate 40).

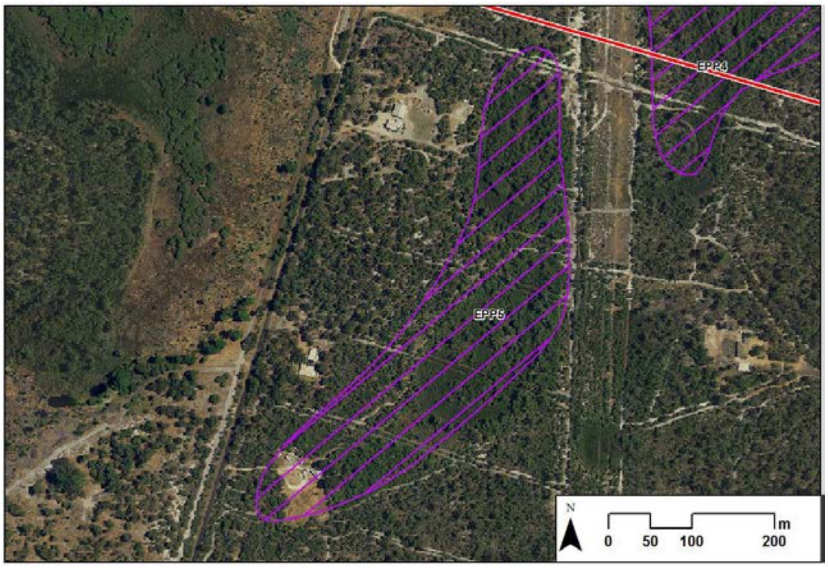

Plate 40: Wetland EPP5

4.2.40 EPP8

Wetland EPP8 is located within Wetlands 14481 and 1839 within ROS at the south-eastern area of the site. The north-western and south-eastern part of the mapped wetland has been cleared (Plate 41).

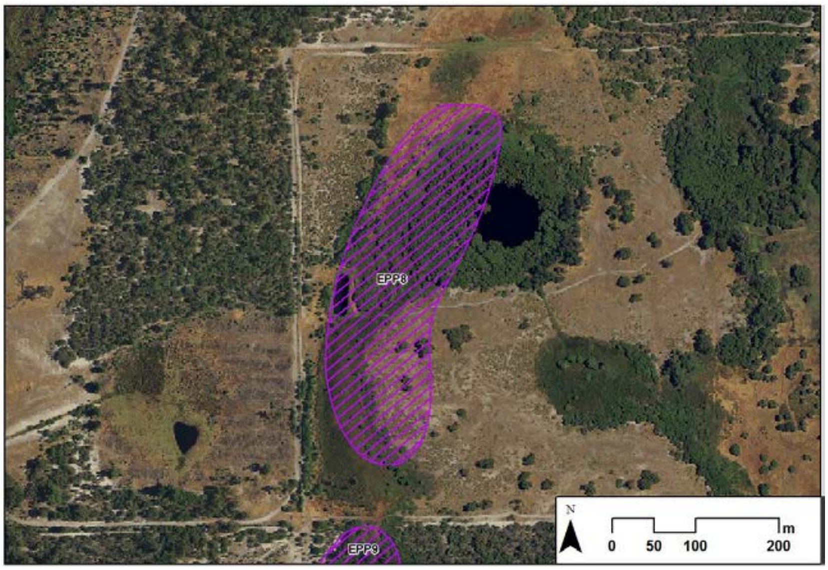

Plate 41: Wetland EPP8

4.2.41 EPP9

Wetland EPP 9 is located within industry buffer at the southern part of the site and is concurrent with MUW 1678. A track is located directly north and the north-west edge has been modified by clearing (Plate 42).

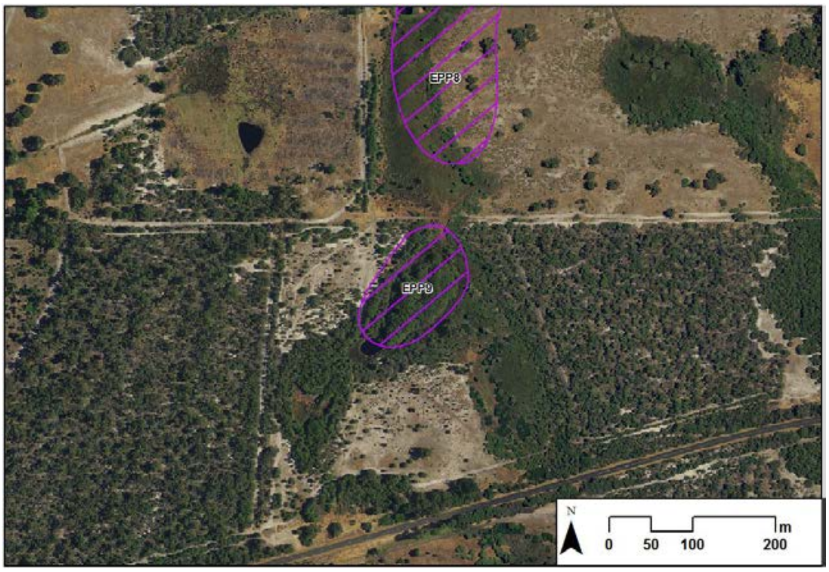

Plate 42: Wetland EPP9

5.0 MANAGEMENT AND CONTINGENCY MEASURES

KSIA management strategies will be implemented to:

- Minimise impact from KSIA development on wetland water levels.
- Minimise impact from KSIA development on wetland water quality.
- Minimise development encroachment on wetlands by providing suitable buffers.

General management strategies for wetlands are outlined in the OWMS and are summarised in Table 2 below. It is proposed that specific management strategies for individual wetlands are undertaken on a case-by-case basis with the proponent and regulator at subdivision stage, guided by the information provided in this risk analysis.

Table 2: General Water Management Principles for Wetland Protection

Key Management Element	Water Management Principles
Wastewater	The following are the preferred options to manage industrial wastewater at the KSIA Industry to treat effluent to predetermined acceptance criteria and recycled on site or to a neighbouring industry. Industrial wastewater to be collected centrally and recycling opportunities sought or disposal considered. If a critical mass of industry is reached, a combined application for a common outfall could be made whereby wastewater is treated to an acceptable standard on site or centrally within the KSIA prior to disposal (subject to required environmental approvals).
Surface Water	Rainfall up to the 1:10 year ARI event will be retained and infiltrated within lot boundaries using infiltration swales and biofilters containing native vegetation and amended soils. Lot run-off in excess of 1 in 10-year ARI event shall discharge to roadside swales. Roadside conveyance swales shall be sized to convey the critical 10-year ARI storm event from road run-off. Large rainfall events (>10 year) up to the 1:100 year ARI event will be conveyed by the roads and road side swales where possible to drainage areas (taking due consideration to minimising wetland impacts) within the site for storage and/or treatment prior to infiltration Stormwater storage areas have been sized to accommodate the 1:100 year ARI event within Catchments 1 to 7. Catchments 8 to 10 are sized to cater for the 1:10 year ARI event with overflow to Wellesley River in the 100 year being below pre-development 1:10 year rates. Best management practices and treatment measures shall be put in place to retain the quality of stormwater at Kemerton

Key Management Element	Water Management Principles
Groundwater	The use of soil amendment in the drainage basin(s) in order to increase the retention of nutrients, prior to infiltrating to groundwater. Industry operators within the site will be encouraged to implement Industrial BMPs for their industry with regard to protection of water resources. These may include oil and water separators or bunding of vehicle wash-down areas and limitations on the quantity and period of time hazardous materials can be held on site. The use of native vegetation swales in lieu of a piped drainage network where possible to remove sediment and contaminants prior to infiltration. The use of a soil amendment around soakwells or beneath building envelopes to minimise the leaching of contaminants to groundwater. A post-development groundwater monitoring program will be implemented to compare to pre-development conditions. A clearance of 1.5 m from AAMGL to finished lot levels will be achieved for infrastructure protection. Further investigation and management will be undertaken at the subdivision stage under an Acid Sulfate Soil (ASS) and Dewatering Management Plan to minimise drawdown extent and mobilising ASS.
Post-development Monitoring and Assessment	Post-development groundwater monitoring will occur over a minimum period of three years. Where the lot abuts wetlands, monitoring may extend to five years, in consultation with DoW and/or DPaW. Consideration will be required of DER monitoring requirements for prescribed premises and where viable, monitoring requirements will be combined for efficiency. Opportunistic surface water monitoring of the drainage areas will occur for water quality every year during the first winter flush and two months later for a minimum period of three years Water quality will be compared with ANZECC (2000) freshwater guidelines. Trigger values for the site will be calculated by adding 20% to the median value calculated from predevelopment monitoring to take into account seasonal variability and uncertainty associated with sampling and laboratory methods. These values will be outlined in the lot scale Water Management Plan(s) and they will determine when contingency measures will be used. Contingency measures will be implemented in the event of trigger values being exceeded in two consecutive monitoring events. The post-development results of the monitoring program will be compared against the pre-development data and reported annually to the Shire of Harvey (SoH) and DoW, and will be reviewed annually in conjunction with the SoH and DoW Enhancement/restoration work may be required for wetland buffers that abut the structure plan to afford them greater protection. Wetland enhancement/restoration works (in addition to the buffer) should be required as an offset for high at risk wetlands that have been fully or partially truncated, or have fully or partially reduced buffers.

6.0 REFERENCES

Environmental Protection Authority. 1993. A Guide to Wetland Management in the Perth and Near Perth Swan Coastal Plain Area. Bulletin 686. An update to EPA Bulletin 374.

Froend, R. and Loomes, R. 2004. Approach to determination of ecological water requirements of groundwater dependent ecosystems in Western Australia – A report to the Department of Environment, Edith Cowan University, Perth.

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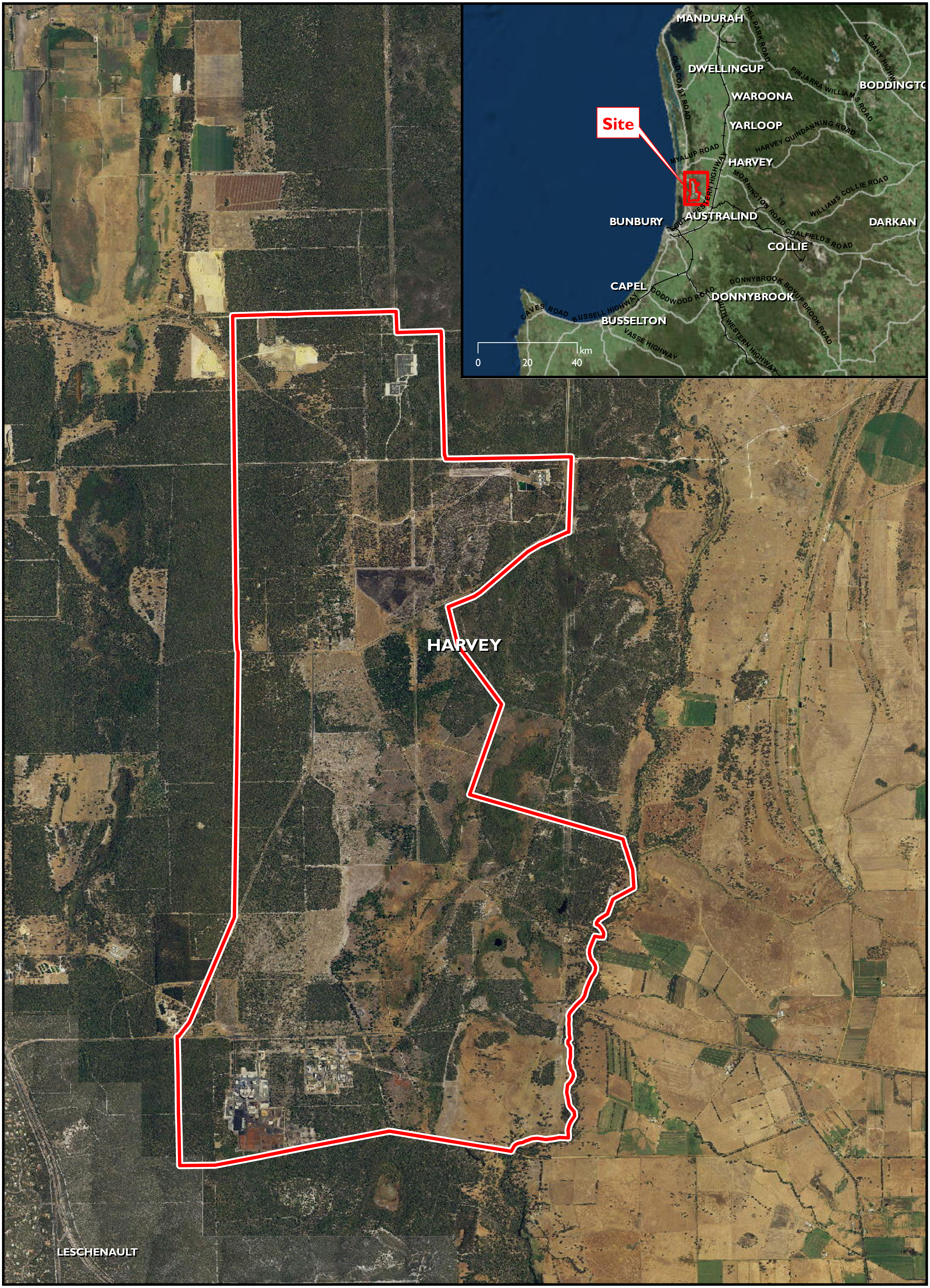
FIGURES



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RPS

Job Number: D10542-WAR
Doc Number: 001
Date: 17.02.16
Scale Main Map 1:50,000 Overview Map 1:2,000,000 @ A4
Created by: MA
Source: Imagery - Landgate

GDA 1994 MGA Zone 50

0 250 500 1,000 m

Figure 1

Site Location

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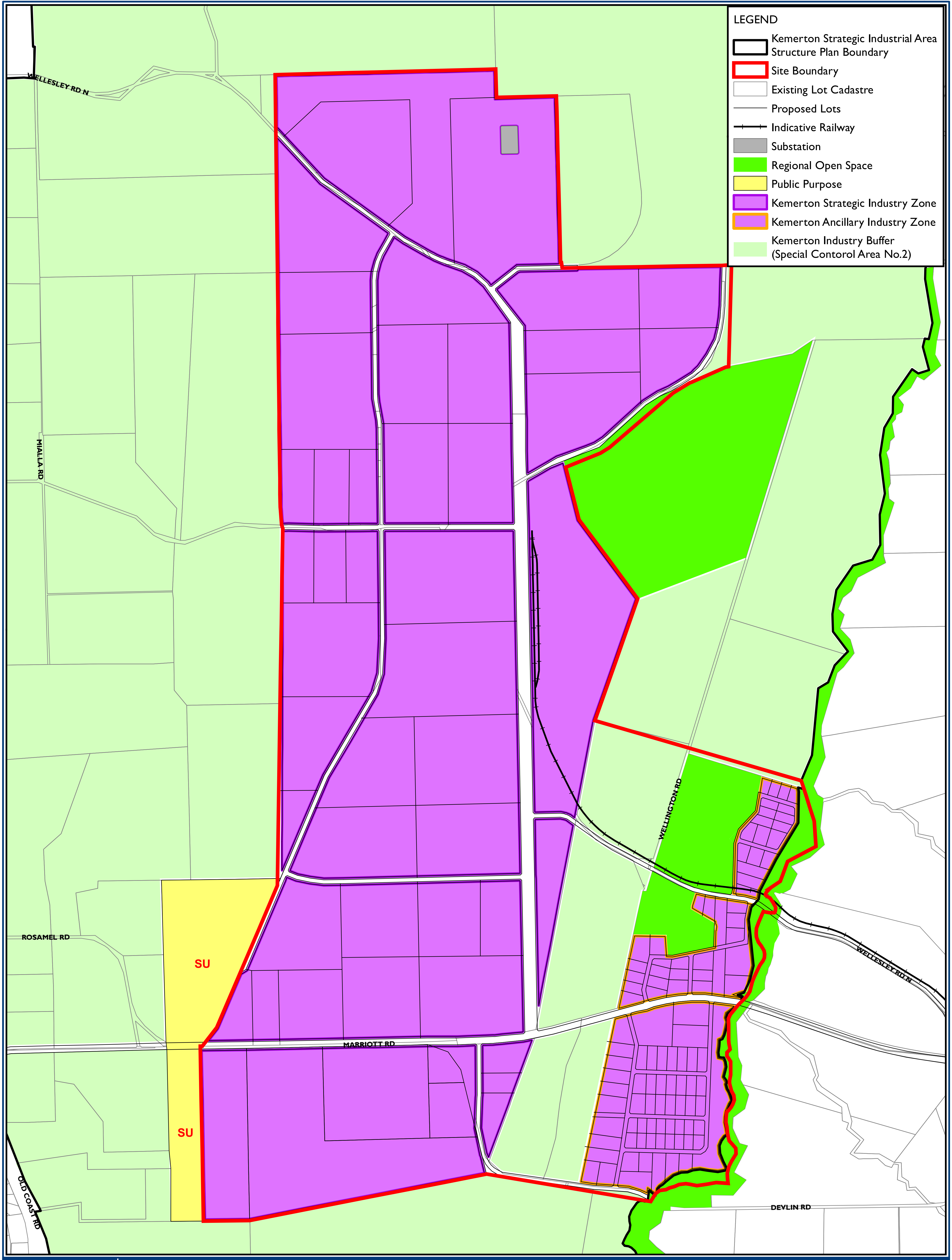

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Doc Number: 002
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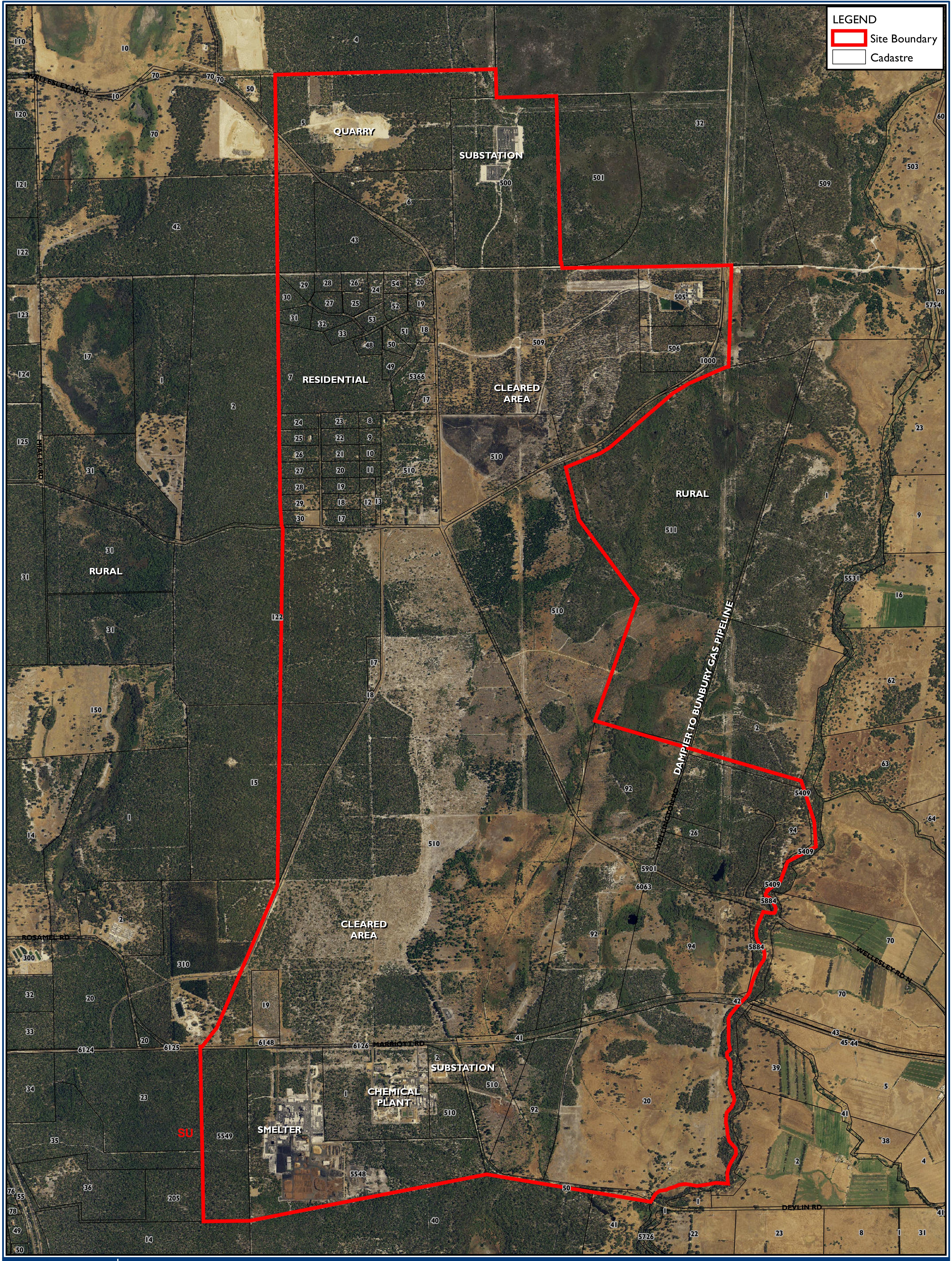
Created by: MA
Source: Local Structure Plan 710-065 ST1A 2014-10-06

Figure 2

Local Structure Plan



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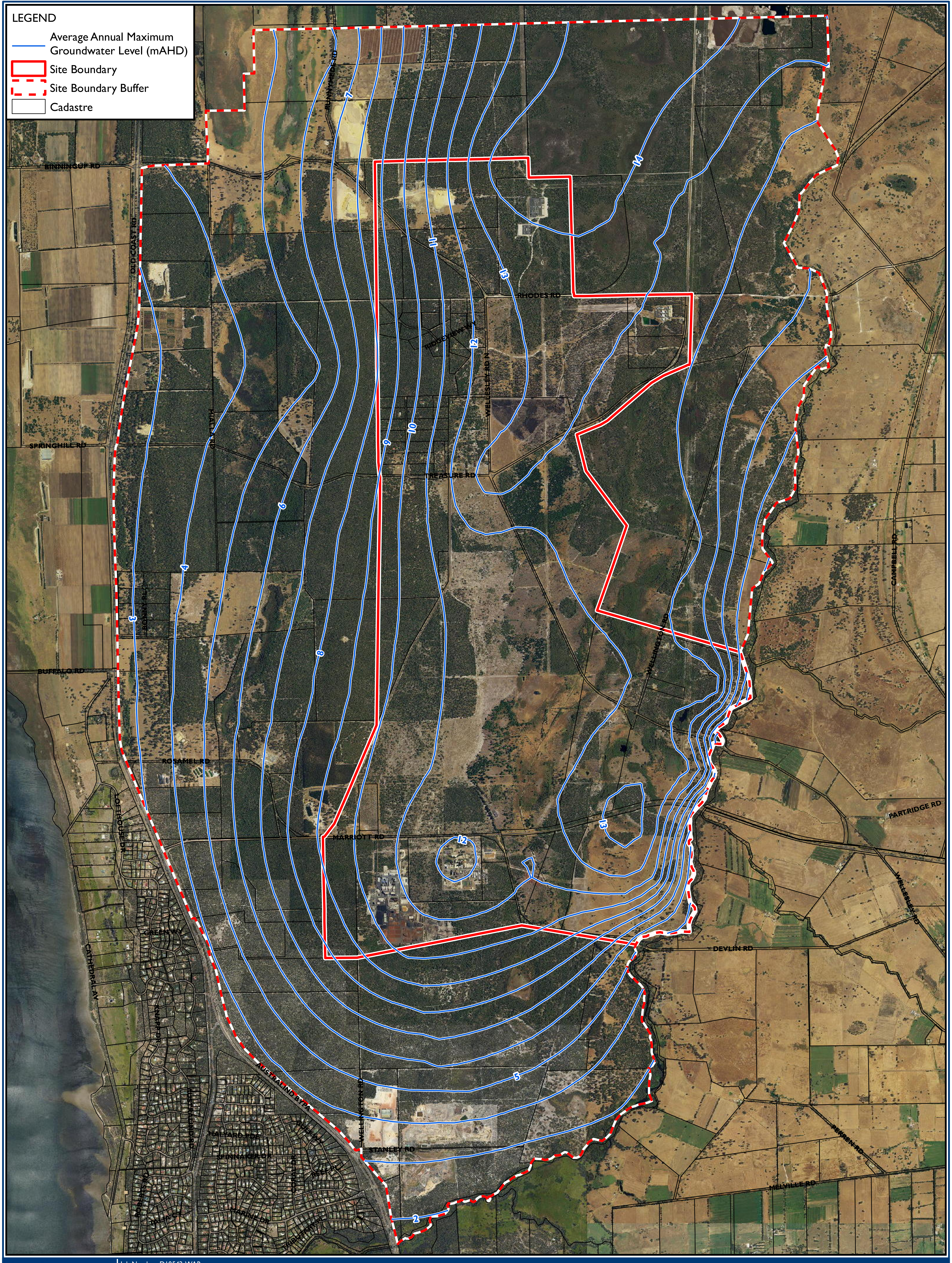
Created by: MA
Source: Cadastre - Landgate, 2013 Orthophoto - Landgate, Feb 2015

GDA 1994 MGA Zone 50

0 125 250 500 750 1,000 m

Figure 3

Existing Land Uses



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Created by: MA
Source: Cadastre - Landgate, 2013 Orthophoto - Landgate, Feb 2015

GDA 1994 MGA Zone 50

0 135 270 540 810 1,080 m

Figure 4

Average Annual Maximum Groundwater Levels (AAMGL)

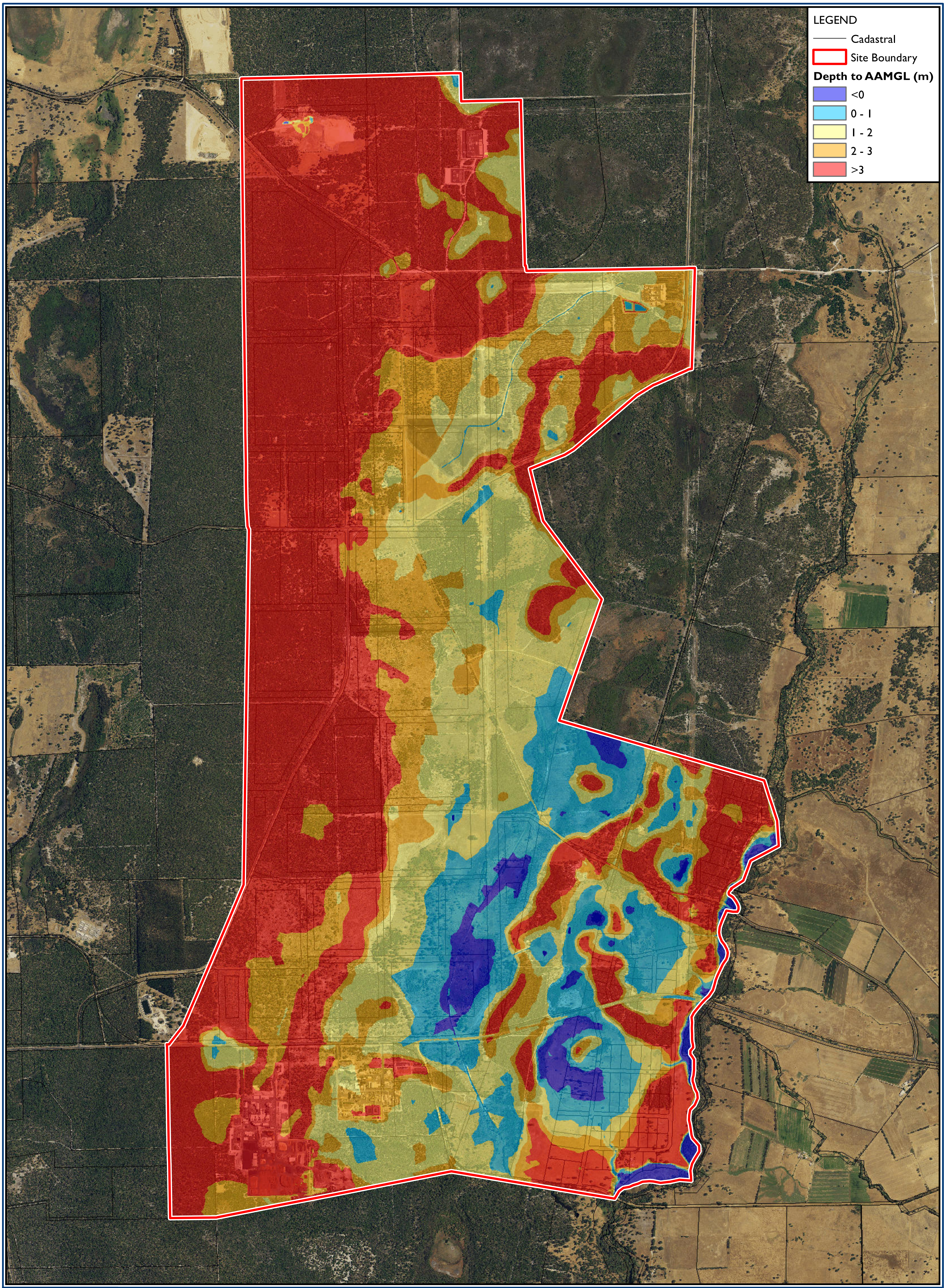

Figure 5

Pre-development depth to AAMGL

RPS

Job Number: D10542-WAR
Doc Number: 005
Date: 17.02.16
Scale: 1:25,000 @ A3
Created by: MA
Source: Orthophoto - Landgate, Feb 2015

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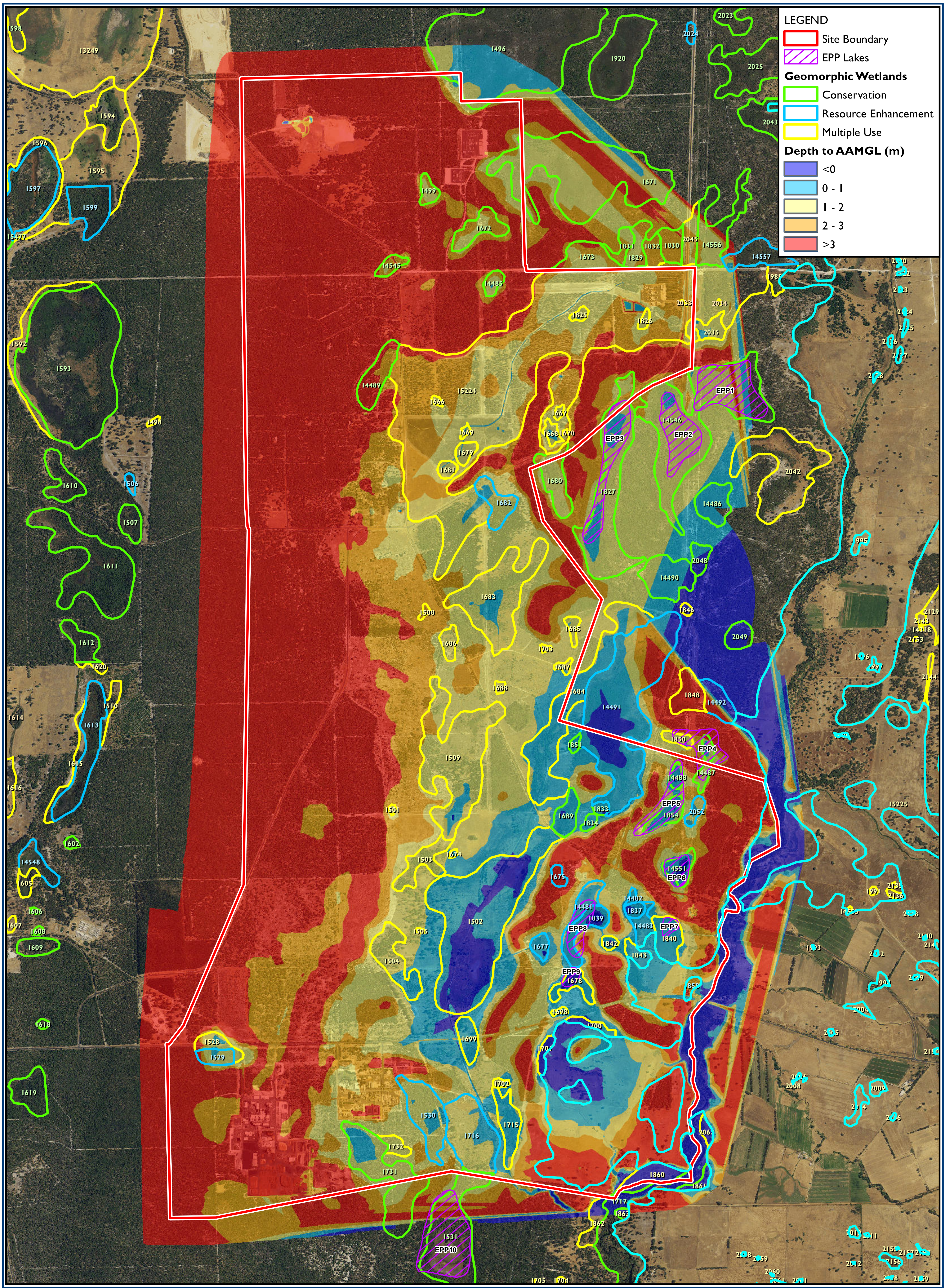

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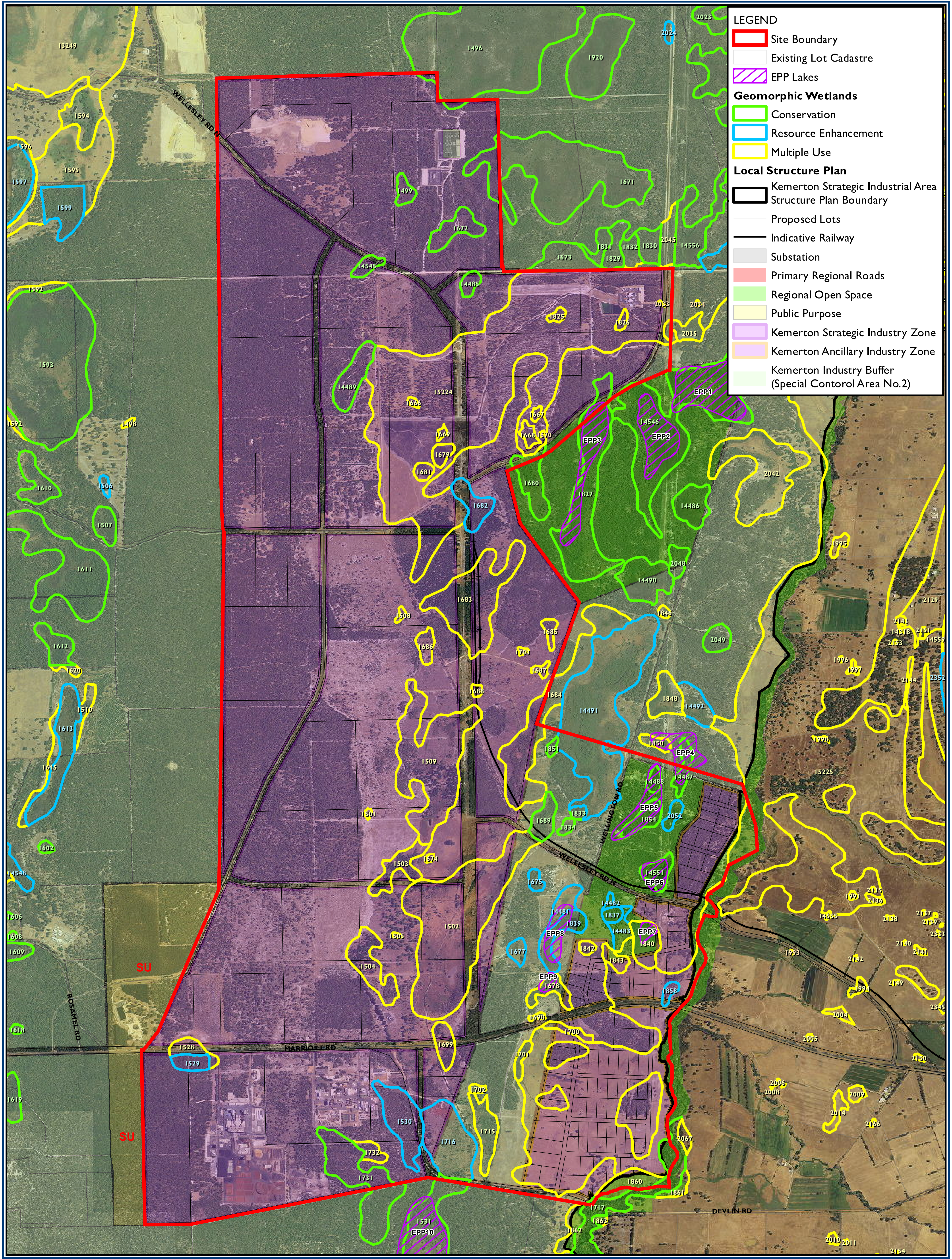
Scale: 1:25,000 @ A3
Created by: MA
Source: Orthophoto - Landgate, Feb 2015 Wetlands - DPaW, 2015 EPP - DEC, 92

GDA 1994 MGA Zone 50

0 0.25 0.5 1 km

Figure 6

Pre-development depth to AAMGL and Wetland Mapping



Job Number: D10542-WAR
Doc Number: 007
Date: 17.02.16
Scale: 1:25,000 @ A3
Created by: MA
Source: Local Structure Plan 710-065 ST1A 2014-10-06

0 125 250 500 750 1,000 metres

Figure 7

Structure Plan and Wetland Mapping

APPENDIX 1

Water Management Framework Correspondence

38 Station Street, Subiaco, WA 6008 • PO Box 465, Subiaco 6904, Western Australia
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Our Ref: D10542

Email: carl.davies@rpsgroup.com.au
Date: 31 August 2015

Krish Seewraj
Department of Water
PO Box 261
BUNBURY WA 6231

Dear Krish

KEMERTON STRATEGIC INDUSTRIAL AREA- WATER MANAGEMENT

The attached table provides responses to your comments on the Kemerton Strategic Industrial Area (KSIA) LWMS (RPS 2015). In reviewing our responses it is requested that consideration is taken of the KSIA statutory planning framework which is described below, and which we acknowledge required more detailed clarification in the original LWMS. The KSIA water management framework is intended to meet the overall objectives of BUWM; however, it is also intended to meet the unique planning and environmental assessment context of the KSIA planning process.

KSIA Planning Framework

This KSIA LWMS has been developed in the context of the KSIA statutory planning framework to not only address the objectives of BUWM and demonstrate that the area is capable of supporting future development with respect to water related constraints, but also to inform the water management detail required by each proponent at subdivision stage. The report identifies the planning and environment context of the subject site, and outlines the key water servicing, drainage and environmental management considerations to be progressed in support of subsequent design development and planning approval phases. Further consideration of relevant government policies and advice may be warranted as subdivision occurs incrementally over a long term timeframe.

Section 1.9 of the KSIA Structure Plan refers to an overarching environmental management plan (EMP). The LWMS falls under this overarching EMP, as water is a Deferred Factor under Ministerial Statement 697. Section 1.9 of the Structure Plan includes the following,

1.9.1. The overarching Environmental Management Plan (EMP) establishes the deferred environmental factors, to be addressed by a proponent through a proposal specific EMP at the Subdivision or Development Application stages.

1.9.2 A proposal specific EMP will only be required as a condition at either the Subdivision or Development Application stages if the proposal will have an impact on the deferred environmental factors.

1.9.3 Any conditions in a proposal specific EMP must be capable of being complied with during the execution of the proposal and not create ongoing obligation beyond the completion of the proposal.

As described in the EMP (Ecological 2015), proponents will be required to complete site-specific environmental management documents to develop in the future that are cognisant of the requirements of the over-arching documents. The over-arching documents are intended to broadly address the conditions of Ministerial Statement 697, however the lot scale future management documents will be required to address all of the conditions to an acceptable level of detail. All future proponents will be responsible for obtaining their own State and Commonwealth approvals associated with their lots; it is noted there are a number of State and Commonwealth environmental values throughout areas zoned for development however this does not necessarily mean that disturbance is allowed in these areas.

On the basis of the KSIA planning framework, it may be appropriate to refer to the existing LWMS as an Overarching Water Management Strategy (OWMS) to recognise that the same level of detail typically required in an LWMS under the BUWM framework is not intended for this OWMS. The intention of the OWMS is to address the regional water related issues so the proponent is aware of detailed investigation that may be required at subdivision stage. The benefit of this approach is that the OWMS identifies broad water management issues while deferring certain investigation and design costs until such time as a specific proponent is present, and a better understanding of actual land requirements in terms of size, configuration, location, co-location, flood immunity and servicing requirements is known.

Development Responsibilities

The Department of State Development (DSD) is the Lead Agency for the KSIA and LandCorp is the KSIA estate manager, landowner and lessor. When considering Business Case submissions from future heavy industry proponents seeking to establish within the KSIA, DSD and LandCorp will consider the proposal in the context of the Structure Plan, and the supporting technical reports and operational requirements of the KSIA. This is to ensure the KSIA is developed to its full potential, namely to establish resource processing industries and associated support activity in order to fulfil its designated role as a SIA in the south-west region. This process occurs well before the lodgement of a Development Application with the Shire of Harvey and / or Western Australian Planning Commission.

As proponents' development requirements can vary considerably based on the type of industry, associated operational requirements and footprint, and site-specific characteristics, the imposition of conventional information requirements (and subsequent subdivision / development conditions) is not always appropriate as it does not reflect the long term, proponent-driven development nature of the SIA. Information requirements (and subsequent subdivision / development conditions) should be considered on a case-by-case basis. In the heavy industrial areas, proponents will be required to investigate, fund and implement the specific infrastructure and services they require to support their developments on their sites (i.e. power, water, telecoms, and wastewater solutions).

Development of the KSIA is intended to occur over a long-term timeframe, depending upon the demand for individual sites within the heavy industrial areas. Due to the uncertain nature and timing of the demand for sites, the specific needs of each proponent and subsequent servicing requirements, development of sites is intended only when required by a future proponent. Proponents may have large or no servicing requirements depending on the nature of their proposal or may elect to self-service within their own sites. Where proponents require services to be extended to their sites, this is expected to be undertaken in a coordinated way with the rest of the KSIA. Of note is that responsibility may not 100% rest with the proponent in instances where there is shared infrastructure such as road or drainage basins (which may require LandCorp input).

Response Table

The attached provides responses to your review comments based on the described KSIA water management framework. It would be greatly appreciated if a meeting could be arranged between yourself and a representative of DSD and Landcorp, either by phone conference or in person, to further discuss the KSIA water management and planning framework.

Yours sincerely
RPS

CARL DAVIES
Principal Hydrogeologist

cc: Jonathan Roach, Landcorp

APPENDIX 2

Meeting Minutes 30 October 2015

RPS

38 Station Street, Subiaco, WA 6008 • PO Box 465, Subiaco 6904, Western Australia
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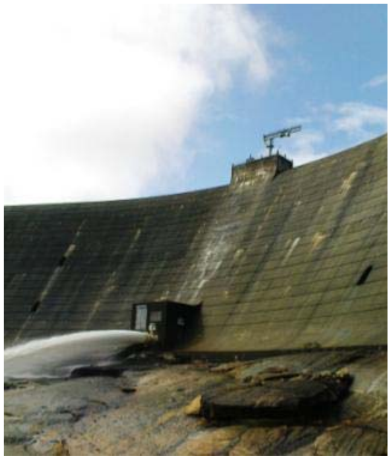
MINUTES OF MEETING – RPS and DER Bunbury for Lot 122 Old Coast Road (Hovey)			
RPS REF:	D1054201	DATE: 30 October 2015	TIME: 11:00 am–12:00 pm
VENUE	**DPAW BUNBURY**		
PURPOSE	Discussions with DPaW and DoW re: Water Management in the Kemerton Strategic Industrial Area		
PRESENT	DPaW: Peter Hanly (PH), DoW: Krish Seewraj (KS), RPS: Glenn Yeatman (GY), LandCorp: Jonathan Roach (JR)		

AGENDA		**ACTION**
1.	**PURPOSE** • Discuss the proposed Kemerton Water Management Strategy and specifically, concerns about wetland buffers.	
2.	**PROJECT BACKGROUND** • RPS has prepared a LWMS for the Kemerton Industrial Area. • DPaW and DoW have reviewed the LWMS and provided comments. • The key outstanding comment is related to the protection of on-site wetlands.	
3.	**MINUTES** • PH stated that a standard 50 m buffer allowance to on-site wetlands does not provide sufficient guidance. Buffers should be based on vertical separation (e.g. two metres) not purely horizontal separation. • PH stated that further detail is required on surface/groundwater separation distances to help assess the risks to the high conservation value wetlands. • KS stated that an accurate groundwater contour map should be prepared, detailing where water is close to the surface, to identify the constrained areas of the site. • JR stated that the OEPA assessment correspondence details approach/ process for Management Strategy assessment. • KS stated that sufficient detail is required in the LWMS to identify risks to the high conservation wetlands, and to map out a process to address risks at the appropriate stage (once the final land use and user is known).	
4.	**SUMMARY AND FUTURE WORKS**	
	• RPS to review existing AAMGL mapping to help identify high risk, high conservation value wetland areas based on vertical separation distances	RPS
	• RPS/LandCorp to provide this mapping with separation distances identified to DoW and DPaW for review and comment	RPS
	• RPS to detail a process to address risks at the appropriate stage (once the final land use and user is known)	RPS
	• Once agreement has been reached, the LWMS can be finalised.	RPS

APPENDIX 6

Marsden Jacob Associates Study



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Executive Summary

Water sources in the Collie River Basin, including Wellington Dam, present a significant water supply opportunity for agriculture and industry in south west Western Australia. The South West Development Commission (SWDC) has commissioned Marsden Jacob Associates to undertake an economic analysis of the likely demand for industrial quality water supplies that may be obtained from the Wellington Dam or sources above the dam, including the Upper Collie/Kemerton region.

While the Upper Collie/Kemerton region occupies only a small portion of the total South West Region, it produces a substantial portion of the South West Region's mining and manufacturing output. Mining, industry and agriculture in the Upper Collie/Kemerton region contribute more than $2.9 billion to the State's annual production. In addition, more than 1,200 hectares of industrial land in the Kemerton, Picton/Preston, Coolangatta and Shotts industrial parks is currently available for further industrial expansion.

Water supply is a key factor in both maintaining existing industrial output and supporting growth in the region. A review of water use within industrial estates indicates that demand can vary significantly between areas. Water use by two comparable benchmarked industrial estates was approximately 0.02-0.03 GL/ha. If this water use were replicated in the Upper Collie/Kemerton region, water requirements for the area would increase by 6-9 GL/year in the Coolangatta and Shotts Industrial Parks (Upper Collie), 18-27 GL/yr in the Kemerton Industrial Park and 20-30 GL/year in the Picton/Preston Industrial Park. These estimates are in addition to existing water use and reflect water requirements when the sites are fully developed, which may not occur for number of years, if at all.

Importantly, the above estimates are based on benchmark water use only. Of the industries that could potentially locate in the region, water requirements can vary significantly. Some industries require very little water, while in other industries, individual users could require 10 GL per year or more. Actual water demand will ultimately depend on the exact type of industry and the rate of development. Additional demand could also be generated from existing users if groundwater or surface water allocations are reduced in the future due to climate change, poor land management or other factors.

The uncertainties regarding future water use requirements suggest that a flexible, risk based approach to water supply systems will be more appropriate than developing a scheme based on absolute estimates of volume.

Localised water availability

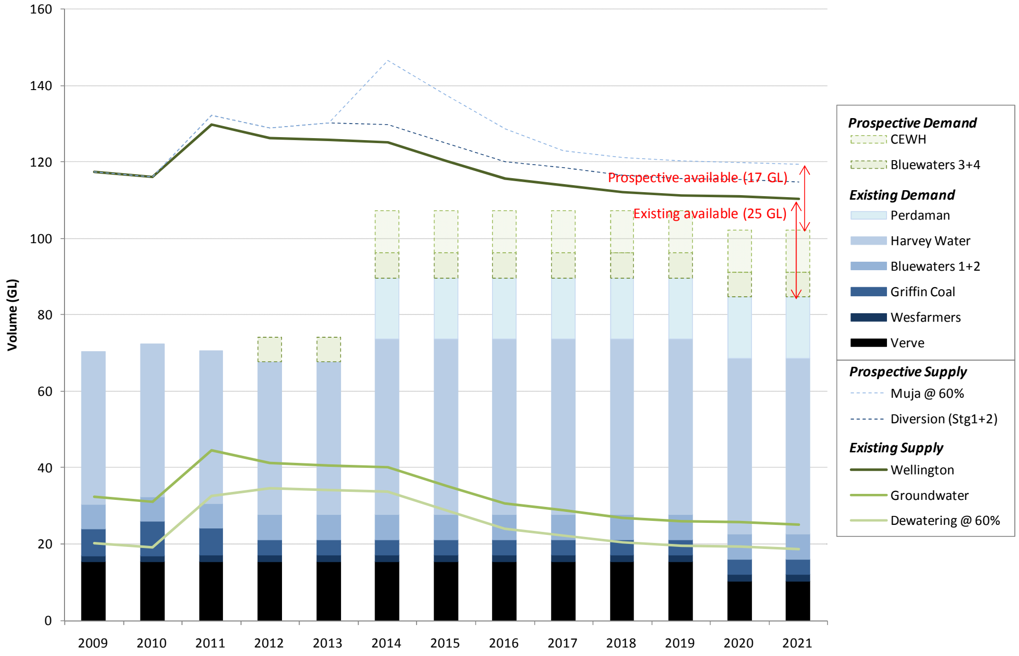
The need for large scale, multi-user infrastructure in the region will be driven in part by the availability of local water sources and the ease with which these sources can be accessed by new users.

Upper Collie

Figure 1 demonstrates that existing supplies are forecast to exceed demand by around 25 GL in 2021. Prospective supply and demand (which are interrelated due to mine dewatering requirements) could see the volume available reduce to 17 GL, with slightly lower volumes available in the immediately preceding years. The volume available would be sufficient to meet the additional demand estimate of 6-9GL per year in the Coolangatta/Shotts industrial parks. We note that the supply forecasts rely on dewatering occurring in accordance with current forecasts and dewatering water being made available to all users.

In addition, while the Department of Water currently does not have a policy on the issue, new water users could potentially apply to transfer water outside of the Upper Collie area (e.g. to the Kemerton Industrial Park), thereby reducing the volume available for local users.

Figure 1: Existing and planned supply/demand in the Upper Collie

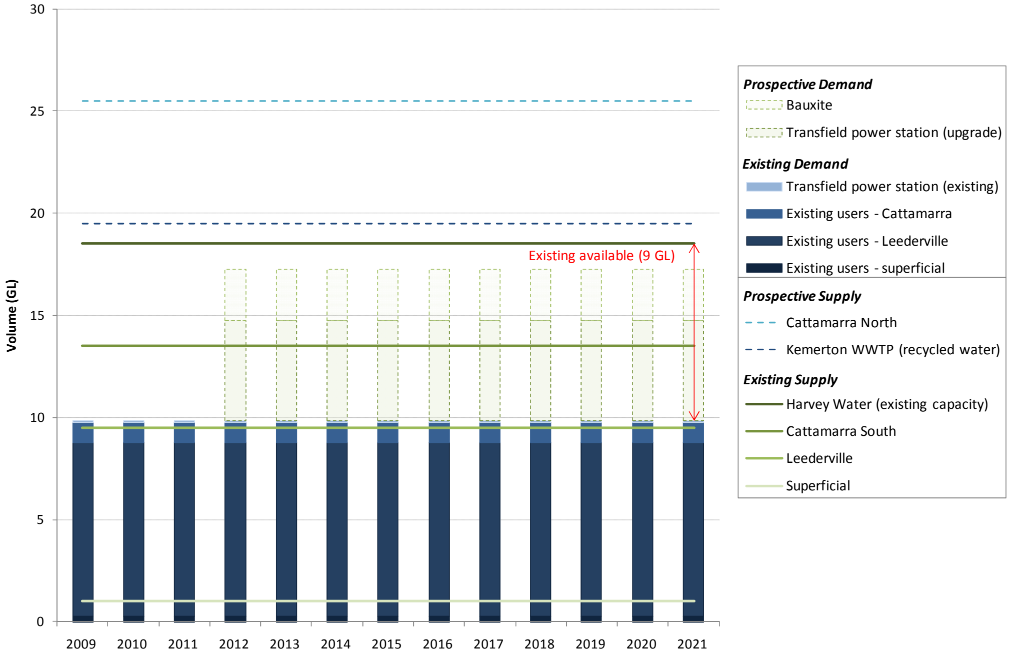


Kemerton

Figure 2 indicates that around 9 GL per year can be provided from sources considered “easily accessible” in the Kemerton industrial area, including the Superficial, Leederville and Cattamarra South aquifers (Cattamarra North is relatively deep and has high salinity levels) and Harvey Water’s existing pipeline to the area.

If the Transfield power station is upgraded (4.9 GL/year) and the proposed Bauxite Resources refinery is constructed (up to 3 GL/year), less than 1 GL/year would be available for further industrial expansion. The prospective supplies in Figure 2 (Cattamarra North and water recycling) are still relatively unproven and would require additional planning and infrastructure to access and treat the water.

Figure 2: Existing and planned supply/demand in Kemerton industrial area



At full development of the Kemerton Industrial Park, the benchmark forecast suggests that additional water use could be in the order of 18-27 GL/year. This requirement would be additional to existing water use requirements. To supply volumes of this magnitude would require significant new water infrastructure.

Picton/Preston

As local groundwater sources are almost fully allocated within the Picton/Preston Industrial Park, additional water supplies would be required for any new industrial development in the area. Water sources for the Picton/Preston Industrial Park potentially include Harvey Water (Wellington Dam) or access to groundwater reserved for town water supplies. In addition, some water needs may be met through increased recharge of the superficial aquifer due to land development.

Agriculture

It is anticipated that growth in irrigated agriculture will be met within existing water entitlements. Water is available for agriculture in the Wellesley groundwater subarea and may become available from Harvey Water if salinity in Wellington Dam improves or if additional water efficiency projects are funded by government. Other sources that are technically available include other groundwater subareas, water recycling and supplies from urban water service providers, however the cost of accessing these supplies is likely to make them unaffordable for agricultural purposes. As in other areas of Australia, agriculture will continue to be constrained to locations that have access to relatively low cost water supplies.

Cost of water

A number of water supply options are available to supply each industrial estate, including accessing water from DOW's diversion scheme or an alternative disposal scheme proposed by Harvey Water, water purchases from Harvey Water, desalination of saline groundwater, water supplies from the Water Corporation's Integrated Water Supply Scheme (IWSS) or accessing town water supplies. A summary of the cost of each option is provided in Table 1 and described in more detail in the body of this report.

Table 1: Indicative cost, reliability and quality of water supply options

Water source	Volume	Capital exp.	Operating exp.	Unit cost	Reliability	Quality
Upper Collie						
Wellington Dam	8 GL	$6m	$0.43/kL	$0.50/kL	80% - 100%	Non-potable <1200 TDS
DOW diversion	2.5 GL	n.a.	$3m pa	$1.20/kL	80% - 100%	Potable
Expanded diversion	2 GL	$18m	$2.4m pa	$1.90/kL	80% - 100%	Potable
Kemerton						
Cattamarra Sth groundwater	3 GL?			$0.20-$0.50/kL?	~100%	Non-potable <1200 TDS
Harvey Water	7 GL	$3m-$6m	$0.63/kL		By agreement	Non-potable <1200 TDS
Diversion pipeline	5 GL	$50m	$250k pa	$0.71/kL	80% - 100%	Non-potable >1200 TDS
Water recycling	1 GL+			$0.40-$1.50/kL?	~100%	Non-potable <1200 TDS
IWSS	Unlimited?			$1.87/kL+	~100%	Potable
Diversion pipeline + desal	5 GL	$50m	$6m pa	$2.90/kL	80% - 100%	Potable
Picton/Preston						
Harvey Water	7 GL	$3m	$0.63/kL		By agreement	Non-potable <1200 TDS
Town water supply	6 GL			$1.28/kL+	~ 100%	Potable

Note that the results in Table 1 do not account for other benefits that would be available from some options – in particular the benefits of reducing salinity in Wellington Dam or the benefits of providing brine disposal infrastructure, which are issues for the region.

Price of water

Demand for water in the region will ultimately be determined by both the volume required by prospective users and the willingness of those users to pay the cost of supply. In many cases, the cost of water will be a relatively small component of overall cost and industrial users may therefore exhibit a high willingness to pay for water before alternative locations become more attractive. Benchmarking indicates that industrial users at other industrial sites across Australia have demonstrated a willingness to pay between $1.28/kL and $2.48/kL for scheme water and/or treated recycled water.

Industrial users with access to groundwater will have a significantly lower cost alternative. Groundwater supplies typically cost between $0.20-$0.50/kL including the cost of bore installation, treatment and ongoing operation.

1. Introduction

1.1 Background

The Collie River Basin is a significant surface water catchment in the south west of Western Australia. It includes two substantial dams – the Harris Dam (79 gigalitres (GL) of storage capacity) and further downstream the Wellington Dam (186 GL of storage capacity).

Large scale water supplies in the Collie River Basin have a long history, as Wellington Dam was constructed in 1933, enlarged in 1945 and again in 1960. The dam previously provided a drinking water supply for the local area, but increased clearing in the catchment resulted in rising salinity levels and potable water use was therefore discontinued. In addition, the high salinity has constrained the usefulness of the water for irrigation purposes. Therefore Wellington Dam has been significantly underutilised, even during the recent period of drought, and has been the subject of significant media attention. While inflows have reduced materially over the last two decades, the low level of water usage has meant that the dam overflowed in both 2005 and 2007.

In addition to water supplies for consumptive use, the Collie River Basin also provides water for recreational activities and for the environment (including Leschenault Inlet and the Wellington National Park) and the region also has substantial groundwater resources that currently provide water for power generation and mining activities.

1.1.1 Current Situation

The State Government has committed to developing infrastructure to treat and remove the water stored by the first stage of the Collie East Branch Diversion Trial and to further improve salinity by desalination or other means in the future. The long term intention is to reduce the TDS (salinity) of Wellington Dam to levels that make the water viable for industrial, agricultural or potable use.

In addition to the surface water available from Wellington Dam, groundwater from mine dewatering currently yields between 17 and 22 GL per annum and this is expected to increase to 22-37 GL by 2010. Groundwater in this area is generally of a high quality, with Total Dissolved Solids (TDS) typically well below the limit required for potable water use. However, with mining activity moving into more saline areas of the aquifer, the groundwater quality is expected to deteriorate, which may result in difficulties regarding both the use and the disposal of the saline water. Therefore there is a range of potential water qualities and quantities that could be made available in the region and a broad range of possible customers.

In addition to potable water use, surface or groundwater sources could also potentially be supplied for irrigation, power generation (including Verve's power stations at Muja and Collie and Griffin's power stations Bluewaters I and II) and industrial use (e.g. at Kemerton Industrial Park or the proposed urea plant recently announced by Perdaman Chemicals and Fertilisers).

A wide range of possible water sources and uses is therefore potentially available, including many possible permutations of water supply schemes. The key water sources and uses are shown in the Table 2 below.

Table 2: Potential water sources and uses

Potential Water Sources	Potential Water Uses
Mine dewatering - current - growth Wellington Dam - current - scour water - desalination - reduced TDS Collie diversion - government funded plant - augmented scheme Groundwater - Kemerton - Cardiff - Shotts	Irrigation Power generation (eg cooling) Mining (eg dust suppression) New industry (eg Perdaman urea plant) Kemerton Industrial Area Picton/Preston Industrial Park

Source: MJA Analysis

The table above demonstrates the complexity of the Collie River Basin salinity and water supply management options and the need for careful assessment of the possible options to ensure they are technically feasible and maximise the value to the community, the environment and the economy.

1.1.2 Options to reduce salinity in the Upper Collie Basin

An independent review of options to reduce salinity in the Upper Collie Basin was a Liberal party election commitment and the review was undertaken in 2009 with the summary report published on 25 August 2010. The review considered 18 public submissions and four shortlisted options were assessed in detail for their technical feasibility, cost and physical outputs.

The Department of Water has noted that one of the next steps arising from the review is the need to complete a demand assessment for water supplies in the region:

The need to understand more clearly the demand for industrial water in the region and ways of managing the demand and supply balance to be feasible in the long term.[1]

1.2 Analysis undertaken

The South West Development Commission (SWDC) has commissioned Marsden Jacob Associates to undertake an economic analysis of the likely demand for industrial quality water supplies that may be obtained from the Wellington Dam or sources above the dam.

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[1] http://www.water.wa.gov.au/Managing+our+water/Managing+salinity/Options+to+reduce+salinity+in+the+Collie+Basin/default.aspx, accessed 2 December 2010

The objective of the current study is to *'undertake a business planning exercise to assess market demand by industry for water that may flow from improved water quality in the Wellington Dam and Upper Collie'*. This includes an economic analysis to compare industry demand for water and indicate demand pricing determined by the capacity of supply and cost of treatment to supply; also a benchmarking exercise for similar industry parks to assess water use, quality and cost of supply.

The study involved two stages. The first undertook a review of present industry use and future industry growth, and the second stage reviewed the future supply options and indicative costings.

This report is comprised of:

Section 2: Overview of industries in the Upper Collie region

Section 3: Available water sources

Section 4: Existing and planned water demand

Section 5: Similar industrial sites in Australia

Section 6: Analysis of potential future demand

Section 7: New supply options

Section 8: Water pricing

As demand for water in Wellington Dam will be impacted by the accessibility of water from other sources, Section 3 reviews the water available from alternative sources. In Section 4 we consider existing and planned projects in the region and in Section 5 we examine industrial areas elsewhere in Australia to assist with benchmarking of industry types, water use and water pricing.

In Section 6 we combine the water availability and water demand information to identify demand that is unlikely to be sourced from local sources and may require additional infrastructure solutions. Section 7 reviews the cost of new water supply options and Section 8 examines water pricing considerations and provides benchmark prices from other industrial areas in Australia.

2. Overview of industries in the Upper Collie region

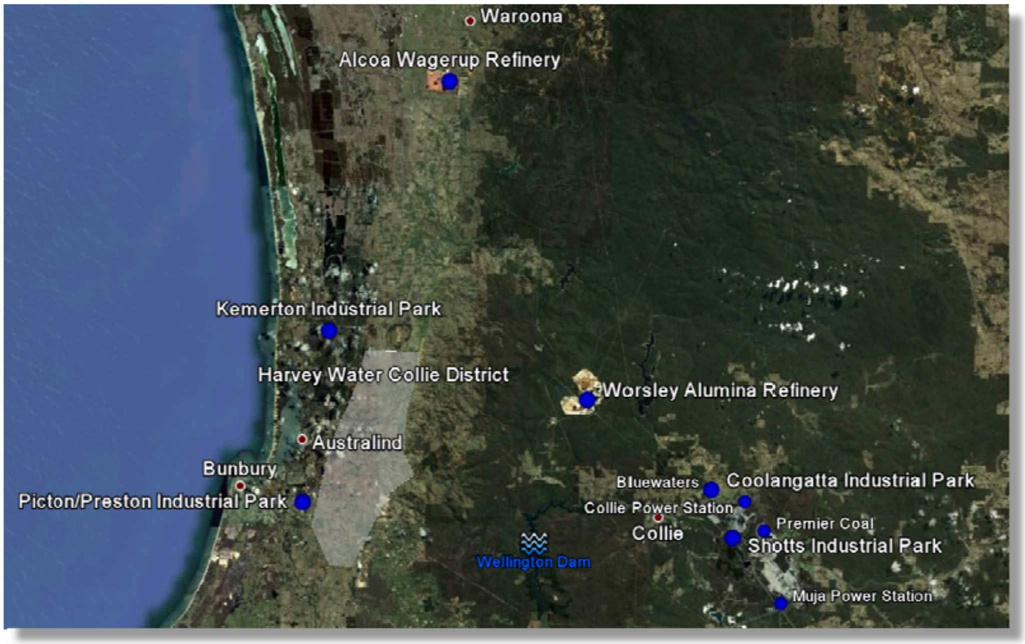
2.1 Introduction

The South West region is the State's most diversified economy and supports substantial mining, manufacturing and agriculture industries as well as retailing and tourism.[2] The specific area under consideration for this study includes those areas that could potentially be supplied water from the Wellington Dam/Upper Collie region, including:

- various coal mines and power generators in the Collie area;
- Industry at the Shotts Industrial Park and the proposed Coolangatta Industry Park;
- Industry at the Kemerton Industry Park;
- Picton/Preston Industrial Park;
- the Harvey Water Irrigation Cooperative land area.

Figure 3 shows the locations of the industrial parks and other major industries in the area.

Figure 3: Industrial site locations



2.2 Coal mines

Both Wesfarmers Premier Coal Limited and Griffin Coal operate open cut mines, each producing around three million tonnes of coal per year.

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[2] South West Development Commission, Greater Bunbury Infrastructure Investment Plan, October 2010

Griffin Coal currently operates pits at Ewington 1 and 2 as well as Muja, while Wesfarmers Premier Coal currently has operations at Pit 1 and Pit 3.

Currently Collie coal is predominantly used for power generation, both within the immediate region as well as in other power stations across Western Australia.

2.3 Power Generation

Power generation is a key industry within the Collie region. Currently over 37% of generating capacity within the South West Integrated System resides in this region.[3]

Verve energy is a Government Trading Enterprise and was formed in 2006 as part of the State Government energy market reforms. Verve is the key generating company within the South West Integrated System and has several power stations within the Collie Region, as detailed below.

Collie A Power Station	Coal fired base load power station which is capable of producing up to 340MW. The plant is owned by Verve Energy, and operated and maintained by Transfield Worley Power Services.
Muja A and B	Coal fired base load power stations which are currently closed and are being refurbished and recommissioned by joint venture company Vinalco.
Muja C and D	Coal fired base load power stations consisting of two 227MW units.

In addition to the plants owned by Verve there are three further power stations.

Kemerton Peaking Plant is dual-fuel power station capable of using either diesel or gas to provide peak of up to 300MW. Kemerton was built by Transfield Services Energy and Verve has a 25-year agreement to purchase power as required. The plant was installed in 2005 and the was upgraded to its current capacity in 2008.

Griffin Energy operates the Bluewaters 1 and 2 power stations within the Coolangatta Industrial Estate. Bluewaters 1 and 2 are coal fired base load power stations with a capacity of 416 Megawatts

As noted below Worsley Alumina includes a co-generation power station, capable of producing over 100MW of capacity.

2.3.1 Shotts industrial park

The Shotts industrial park is proposed to be located around 7km east of the town of Collie, centred on the Shotts townsite. The park itself was first proposed in 2001.

Recently a steering committee including LandCorp, the Shire of Collie, the South West Development Commission, the Department of Planning, and the Department of State Development has been guiding the investigations into the project and State Cabinet endorsed the Shotts Industrial Park business case in February 2009.

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[3] Capacity Credit allocations within the *2011/12 Statement of Opportunities*, Independent Market Operator released in July 2010

The Shotts site comprises approximately 220 hectares of available land (excluding services) adjacent to the Wesfarmers Premier Coal mine, this area includes 15 hectares of rail, roads and services, and 220 hectares are useable space made up of five lots.

Proposed industrial developments include Perdaman Chemicals and Fertiliser (PCF) urea plant (approximately 120 hectares) and Premier Coal's char plant (54 hectares). As these plants proceed, they will account for the majority of the land area at Shotts.

2.3.2 Coolangatta Industrial Estate

Coolangatta Industrial Estate is a newly established industrial area, located 4.5 kilometres north east of Collie that houses the existing Bluewaters I and II power stations, each comprising a 200 megawatt power plant, in addition to the proposed Bluewaters III and IV facilities. The site is proposed to be developed in three separate stages and will cover 491 hectares upon completion.

2.4 Worsley Alumina

Worsley Alumina is an alumina refinery processing material from a mine in the Boddington area that is transported on an overland conveyor.

The refinery is currently undergoing an expansion that is expected to lift the capacity of the refinery from 3.5 million tonnes per annum to 4.6 million tonnes per annum.

As noted above, the site includes a cogeneration power plant capable of producing over 100MW of power.

2.5 Kemerton Industrial Park

The Kemerton Industrial Park (KIP) was established in 1985 to create a substantial industrial area for heavy industry. The object in creating the park was to provide for downstream processing and value-adding to the South West region of Western Australia's extensive primary resources, especially its substantial mineral resources, for both export and domestic markets.

Pending the finalisation of the relevant structure plan, the total area of the KIP is 7,543 hectares (ha) comprising:

- 2,019 ha of Industry Core
- 293 ha Support Industry Area
- 5,231 ha of Buffer Areas – made up of Inter Industry Buffer (212 ha) and Buffer Area (5,019 ha)[4]

The Buffer Area is not intended for industrial activities, but instead ensures the impacts of activities within the industry core do not impact on neighbours outside the boundary of the KIP. The Buffer Area includes a public purpose area - waste

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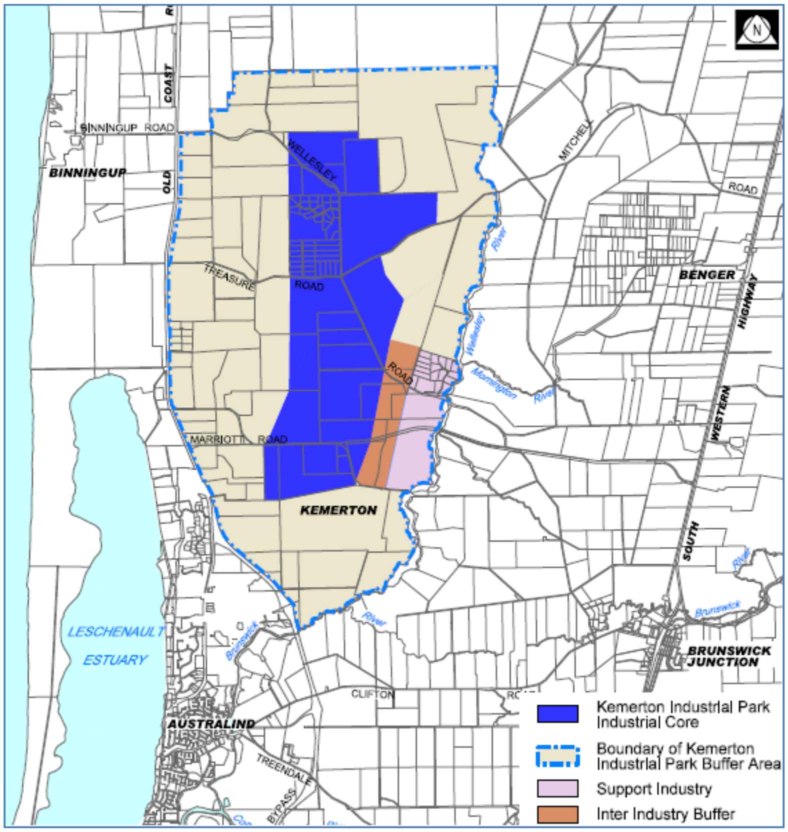
[4] Kemerton Industrial Park Strategy Plan, prepared for LandCorp and Department of State Development, November 2009

water treatment plant, regional open space, conservation, as well as rural uses (including agriculture and quarrying), plantations and landfill sites.

Figure 4: Kemerton Industrial Area



Source: Adapted from LandCorp, Kemerton Industrial Park Strategy Plan, 2009

Currently the largest industries in the area are:

- Simcoa Operations Pty Ltd, producing silicon and silica fume;
- Cristal Global (formerly Millenium Inorganic Chemicals), producing Titanium Dioxide; and
- Kemerton Power station (discussed in section 2.3, above).

2.6 Picton Industrial Park / Preston Industrial Park

The Picton Industrial Park is four kilometres east of Bunbury and covers 2,950 hectares. The area is divided into:

- North Preston or Preston (northern precinct) and
- South Preston or Preston (southern precinct).

North Preston covers around 300-400 hectares of which LandCorp owns about 120 Ha.[5]

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[5] Pers Comms, Land Corp, Jonathan Roach 10 Nov. 10

Parts of the northern precinct are already developed and there are currently 16 industries operating, including limestone products manufacturing, warehousing, earthmoving, recycling, distribution of oil products, manufacturing, and processing.[6]

There is advanced planning (a structure plan published in May 2009) for a further 245 hectares in the northern precinct. This land has been identified as having the potential to host a technology park and general industry development.

Significant tracts of land in both the Northern and Southern parts of Preston are constrained due to the presence of wetlands and native vegetation both considered to be environmentally significant. The EPA published a bulletin (Bulletin 1282) on this area in 2008, providing informal advice.[7]

It currently appears that around half of the land in the southern precinct is undevelopable due to the presence of vegetation and wetlands as well as the need for significant fill.

2.7 Agriculture

The Collie region supports a range of agriculture and horticultural activities, particularly on the coastal plain around Kemerton.

Part of the region is supplied water through Harvey Water's Collie River Irrigation District which covers an area of 16,332 hectares[8]. In addition, much of the area is able to source groundwater, although this water source is constrained in some areas.

Currently the irrigation water supplied by the Collie River Irrigation District is underutilised, due largely to the high salinity of this water.

Pasture for both dairy and beef production are key uses of water in the region[9] while outside the Harvey Water Irrigation Area, Myalup is described as producing mostly annual vegetable crops[10].

2.8 Economic output

The Gross Regional Product of the region increased steadily including through the Global Financial Crisis of 2008 - 2009.[11] Summary data on the total production for the whole of the South West Region is provided in Table 3.

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[6] Roads to Export –Greater Bunbury Infrastructure Investment Plan-SWDC October 2010

[7] Pers Comms, Land Corp, Jonathan Roach 10 Nov. 10

[8] GHD, Report for Collie River Irrigation System Planning, Environmental Report, September 2008

[9] Harvey Water, Land Use Statistics, www.harveywater.com.au/about_us.asp?aboutid=4, Accessed 9 November 2010

[10] Department of Water *State Water Strategy*, 2005

[11] South West Development Commission

Table 3: Economic Productivity Data for the South West Region

Gross Regional Product (2008-09)	South West ($ Millions)	% of State Total
Gross Regional Product)	11,299	6.6%
GRP per capita ($)	74,293	
Agriculture (2008-09)		
Total Agricultural Production	624	8.7%
Mining(2008-09)		
Total Mining Value	1,965	2.8%
Forestry(2008-09)		
Total Production	69	74.4%
Fishing (2008-09)		
Total Catch by Value	6	2.2%
Manufacturing (2006-07)		
Turnover	2,731	6.1%
Building and Construction (2009-10)		
Total Approvals Value	873	6.7%

Source: Department of Regional Development and Lands *Statistical Snapshot - Regional Economies*, October 2010

While the Collie region only occupies a small portion of the total South West Region, it produces a substantial portion of the South West Region's mining and manufacturing output. The Collie region's contribution to the State's production is estimated in Table 4.

Table 4: Estimated Economic Productivity Data for the Collie Region

Industry	Product	$ millions (2009)
Mining	Coal	333
	Alumina	1,302
	Mineral sands	166
Energy	Electricity Generation[1]	700
Manufacture	Titanium dioxide pigment (2005)	300
	Silicon (2005)	75
Agriculture / Horticulture[2]	Livestock, Produce and Crops	50-60
Total of identified industries (only) [3]		$2.9 bn

Notes:

1. Estimate based on total market capacity of South West Integrated System
2. Estimated figure based on pro rata of production for the South West Region
3. Excludes miscellaneous industries for which no detailed local information is available (e.g. chlorine production, timber supplies, abattoirs)

Source: MJA analysis of Department of Regional Development and Lands *Statistical Snapshot - Regional Economies*, October 2010; and www.swdc.wa.gov.au/information-centre/statistics/gross-regional-product.aspx

The Project Steering Committee also requested that MJA undertake an analysis of the potential economic output of industry in the region based on information gathered for benchmarking in Section 5. The Steering Committee agreed that the economic output per hectare for Kwinana and Gladstone represented reasonable extremes for estimating output at Kemerton on the basis that Gladstone had a higher proportion of lower value primary processing industries with larger land area requirements, while Kwinana had more concentrated, higher value secondary processing industries.

Figure 5 shows the land area, economic output and forecasts for the relevant areas. MJA note that the forecasts provided in Figure 5 are at a very high level and have not been developed with reference to specific industries that could locate in the region. The estimates should therefore be considered illustrative only. Actual economic output will depend on the number and type of industries that ultimately locate in each industrial area.

Figure 5: Economic output forecast by area

Area	Land area[2]	Existing economic output	Economic output per hectare	Derived economic output forecast[1]
Existing				
Kwinana	1,200 ha	$16 bn	$13.3m/ha	
Gladstone	2,800 ha	$5 bn	$1.8m/ha	
South West (economic output derived from land area)				
Kemerton	900 ha	$0.5 bn		$2.1-12.5 bn
Picton	1,000 ha	-		$1.8-13.3 bn
Upper Collie	300 ha	$1.0 bn		$1.5-5.0 bn
Alumina		$1.3 bn		
Agriculture		$0.1 bn		

Notes:

1. *Derived economic output for existing and new industries if land area is fully developed. Derived from existing economic output plus vacant land area multiplied by (a) $1.8m/ha (cf Gladstone) for lower end of range (b) $13.3m/ha (cf Kwinana) for upper end of range.*
2. *Excludes roads, native vegetation and undeveloped land. Kwinana and Gladstone estimates based on MJA analysis of aerial photographs. Kemerton area best estimate from South West Development Commission.*

3. Available water sources

An objective of this study is to quantify the likely demand for industrial water supplies from the Wellington Dam. The water demand from Wellington Dam is inherently affected by the availability and cost of accessing water from other water sources. Therefore, in this section we examine the water available from Wellington Dam and water available from alternative sources.

The key water sources available in the region include:

- Wellington Dam
- Groundwater and mine dewatering
- Saline water diversion scheme
- Recycled water from Verve Pipeline or Kemerton Wastewater Treatment Plant
- Integrated Water Supply Scheme

Each of these water sources is described in more detail below.

3.1 Wellington Dam[12]

3.1.1 Existing allocations

Wellington Dam has an estimated yield of 86.2 gigalitres (GL) and a storage capacity of 185 GL, but is currently underutilised due to high salinity levels (approximately 950 mg/L) [13]. Since 2001, inflows into Wellington Dam have been significantly below the estimated yield (average 74 GL), but storage levels have remained high due to the limited draw from the dam.[14] Allocations or reliability may be reviewed in the next allocation plan (planned for 2011 or 2012) or as necessary.

The allocation limit in Wellington Dam is currently 85.1 GL, with water currently allocated or reserved as shown in Table 2.

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[12] Information on Wellington Dam that is not otherwise referenced was sourced from personal communications with Department of Water, 21 October 2010.

[13] *Water source options in the Collie-Wellington Basin, Collie-Wellington Basin* Water Source Options Steering Committee, May 2007.

[14] *Water source options in the Collie-Wellington Basin, Collie-Wellington Basin* Water Source Options Steering Committee, May 2007.

Table 5: Current Allocation – Wellington Dam

Type	Purpose	Volume
Allocation	Irrigation (Harvey Water)	68 GL
Reserve (17GL)	Priority Allocation for power generation	5.1 GL
	Assigned to Perdaman	12 GL
Total		85.1 GL

Harvey Water irrigators currently use around 47.5 GL of the 68 GL per year entitlement (average since 1996/97)[15]. Harvey Water has been in negotiations with a number of industrial customers to supply some water from the remaining allocation. To expand the potential for industrial supply, Harvey Water has constructed a pipeline that can, at present, transfer up to 6 GL of water from the Collie River catchment including Wellington dam to Harvey Dam. This water is normally transferred during the winter months when the water is less saline. This water can only be transferred in winter months and Harvey Water has indicated that additional water could potentially be transferred if the quality of water from Wellington Dam improved. In addition, Harvey Water has constructed a pipeline capable of supply up to 5 GL per year of water to the Transfield Worley power station as and when required (currently demand from Transfield is 100 ML per year).

The *Alumina Refinery (Worsley) Agreement Act 1973* binds the state to allocate water from the Wellington Reservoir to Worsley, if there is water available. However, Worsley Alumina has not applied for an actual water entitlement from the Wellington Reservoir at this stage.

3.1.2 Collie Water Recovery Project[16]

Salinity in Wellington Dam has recently stabilised at around 945 mg/L. In 2001 the Government undertook a significant exercise to review salinity management in the area and determined that the majority of salt in the dam came from the Collie River East river. The preferred option for managing salinity is the diversion of water from the Collie River East at Buckingham into available mining voids combined with higher water use farming systems and trees in the long-term.

By diverting the highly saline ‘first flush’ winter flows, DOW estimates that the salinity in Wellington Dam could be reduced to a target level of 600 – 750 mg/L. This will benefit irrigators and may make the water more attractive to industry. Due to the high salinity, irrigators in the Collie area currently use only 47.5 GL of Harvey Water’s 68 GL entitlement.

Harvey Water has indicated that if salinity is reduced to the target levels and a Commonwealth funded initiative to pipe the Collie irrigation area is undertaken, Harvey Water would provide 11 GL of water to the Commonwealth Environmental

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[15] Pers comms, Geoff Calder, 18 November 2010.

[16] Except where otherwise referenced, information on the DOW diversion scheme has been sourced from the Request For Quote for this project and through personal communications with DOW (John Platt), 20 October.

Water Holder (CEWH), 11 GL for industrial use (including the 4 GL per year currently being negotiated with Perdaman) and the remaining 46 GL for irrigation.

To demonstrate the feasibility of the concept, a diversion trial was established in 2005 and involved a temporary pumping station and weir installation at Buckingham to divert the highly saline, low volume 'first flush' autumn/winter flows into the disused Chicken Creek 4 mining void. The results of the trial indicated that the effect of diverting the saltiest river flows from the river at Buckingham had a measurable effect in the reservoir.

The first stage of the Recovery Project would involve emptying the Chicken Creek 4 mining void by approximately the end of 2012 by desalinating the water and disposing of the brine stream through Verve's nearby ocean outfall pipeline. This stage has received funding commitments of $30 million, including $15 million from the National Action Plan for Salinity and Water Quality and a matching $15 million from the State Government.

The second stage requires identification of suitable alternative storage and could provide up to 2.5 GL per year of desalinated water. The third stage would involve upgrading the capacity of the diversion scheme, with the potential to produce up to 4.5 GL per year of desalinated water. Funding sources for the second and third stages have not yet been determined.

Harvey Water Proposal[17]

As an alternative to the proposed desalination plant, Harvey Water has proposed a 5GL high salinity / low volume autumn/winter annual diversion using high lift pumps and disposal via a new HDPE pipeline laid in the power line easement and would run close to the Kemerton Industrial Park. The proposal would require landholder approval. Water in the pipeline could be disposed of or transported to sources of demand.

Harvey Water estimates that the proposed scheme would cost around $75 million to construct, but would be significantly less expensive than the desalination plant to operate. Harvey Water has offered to provide $10 m of the capital and to fund the annual operating costs. The proposal would also see salinity levels in Wellington decrease significantly.

Harvey Water notes that a further significant benefit of their proposal is that salinity in Wellington Dam would be improved to the extent that average 8-10 GL of water that is currently released as scour water each year could be made available for increased consumptive use or improving water supply reliability.

3.1.3 Scour and other water

Water from the Wellington Reservoir is released (scoured) to maintain acceptable irrigation water quality. Scour water is currently released annually during winter (June to September) and varies in volume between 1GL -40 GL. The volume of water scoured is based on a calculation that considers salinity levels in the upper and lower water levels and the total dam storage. This water is not currently utilised for consumption, but could potentially be desalinated depending on environmental approvals and cost feasibility.

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[17] Pers Communication, Geoff Calder, 13 October 2010

This option was recently examined in an independent review commissioned by the Minister for Water Of the four options shortlisted, the review concluded that the option was the "*least likely option to deliver fresh water to Wellington Reservoir in a way that would justify the costs involved with a particular note that the capital costs associated with the project were high and uncertain.*"[18]

Water allocations are also potentially available from parts of the Collie River (e.g. 14 GL in the Collie East Branch). However, prospective users would be required to treat, transport and store the water to meet their individual requirements.

3.2 Upper Collie groundwater and mine dewatering[19]

In addition to water available from Wellington Dam, the region has significant groundwater resources. A large quantity of groundwater is currently abstracted as mine dewater to ensure that the Collie coal mines are able to operate safely and efficiently. The right to extract water for dewatering for both Premier Coal and Griffin is enshrined in the *Collie Coal (Griffin) Agreement Act 1979* and the *Collie Coal (Western Collieries) Agreement Act 1979*.

Dewatering provides a large short-term supply of water which is currently used for power generation and mining activities. Dewatering is typically characterised by large volumes in the early years of mine establishment followed by a period of lower volumes to cater for ongoing operations.

Current dewatering entitlements include:

- 17 GL for Premier Coal, who are also expected to shortly enter an application for a further 37 GL due to the expansion of Pit 3. In 3-4 years, after the initial expansion, Premier Coal is expecting to return to producing around 15-18 GL per year;
- 32 GL for Griffin Coal from Ewington and Muja. Due to the current difficulties being faced by Griffin, it is not clear if or when this full entitlement will be utilised.

While DOW has reiterated on a number of occasions that the companies producing dewater do not have the right to reallocate that water to third parties (including other arms of the same company), DOW has also noted that it does not currently have the legislative power to reallocate dewater to third parties under the *Rights in Water and Irrigation Act 1914*. This situation could potentially limit the volume of dewater that can be utilised by third parties.

In addition to dewatering, further entitlements exist for the groundwater resource. Verve has production bores at Shotts, Cardiff, Western, WD6 and Stockton North and South. Groundwater allocation is treated as backup for circumstances in which dewater is inadequate.

DOW has recognised that the groundwater resources other than dewatering are currently being extracted beyond sustainable limits and has indicated an intention to reduce groundwater entitlements to Verve when water supplies from Wellington

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[18] http://www.water.wa.gov.au/Managing+our+water/Managing+salinity/ Options+to+reduce+salinity+in+the+Collie+Basin/default.aspx, accessed 24 January 2011.

[19] Pers Comm – DOW 21 October

Dam become feasible (anticipated to be 2016/17). DOW notes that good land use practice improves the availability of groundwater, but can add to the overall cost of land management.

The local groundwater resource is split into the Cardiff and Premier sub areas. Combined, these have a total allocation of 12 GL, while the sustainable allocation has been estimated by DOW as 6.5 GL.

Groundwater entitlements have generally had access to high quality water, although the water has become increasingly saline in recent years. The dewatering water is of mixed quality, with increasing salinity as mining activity begins to move further south.

3.3 Groundwater in the Kemerton area

Groundwater in the Kemerton area is currently used for industry, agriculture and public use/public water supply (PWS). The Kemerton Water Management Plan was released in July 2007 and identifies a total of 29 GL per year as the total water allocation limit. Currently, over 18 GL per year has been allocated or reserved for public use (see Table 6 for details).

Of the 11 GL available, over 2 GL is contained in the superficial aquifer. The dispersed nature of the superficial aquifer makes extraction of the water for industrial use difficult. In addition, the water from Cattamarra Coal Measures in Kemerton North is relatively deep with high salinity. Therefore, only 3 GL of water contained in the Cattamarra Coal Measures in Kemerton South might be considered readily accessible by industry.[20]

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[20] Existing bores in the Cattamarra South area have recorded water qualities of ~500mg/L TDS (at 165m to 178m deep), ~800mg/L TDS (at 210m to 240m deep) and ~1300mg/L TDS (at 310m to 360m). Pers comms DOW (Henry Sieradzki) 10 November 2010.

Table 6: Allocation limits and water use for Kemerton groundwater area

Ground-water area	Groundwater Subarea	Aquifer	Allocation Limit (ML/year)	Licensed/reserved volume (ML/yr)			
				Industrial	Agric. / Hort.	Public use/PWS	Total
South West Coastal	KIP North	Superficial	790	75			75
	Myalup	Superficial	7,350		7,350		7,350
	Wellesley	Superficial	2,150		880		880
	Kemerton North (confined aquifers)	Leederville	3,500		481	3,000	3,481
		Cattamarra Coal Measures	6,000	0			0
Bunbury	KIP South	Superficial	210	201			201
	Australind	Superficial	337		302		302
	Kemerton South (confined aquifers)	Leederville	5,000	2,370		2,630	5,000
		Cattamarra Coal Measures	4,000	992			992
Total			**29,337**	**3,638**	**9,013**	**5,630**	**18,281**

Source: Updated from Department of Water, Kemerton Water Management Plan, July 2007 (Table 1.1). Current licensed/reserved volume interpreted from Section 5 of the Kemerton Water Management Plan and confirmed by discussions with Henry Sieradzki.

3.4 Recycled water

3.4.1 Kemerton Wastewater Treatment Plant[21]

The Water Corporation's Kemerton Wastewater Treatment Plant treats wastewater from the nearby towns of Australind and Eaton. The plant is capable of treating 3 ML per day (approximately 1 GL per year) of wastewater. The Water Corporation is currently examining alternatives to upgrade the plant to treat 7.2 ML per day (2.6 GL at full capacity). Harvey Water understands that the volume available from recycling could ultimately be increased to 8 GL pa, however this could not be confirmed by MJA at the time of writing.

Some of the treated water from the plant is recycled and waters nearby tree farms at the Kemerton Industrial Park. The Water Corporation is also in discussions with a potential industrial customer to supply the remaining capacity of the plant as recycled water.

3.4.2 Verve Ocean Outfall[22]

The Verve ocean outfall pipeline is licensed for approximately 7 ML per day of discharge. Verve has indicated that the pipeline will be at full capacity if and when current negotiations with DOW and Perdaman are finalised. The Verve pipeline

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[21] Information on the Kemerton Wastewater Treatment Plant provided through personal communications with Water Corporation (George Golowyn), 11 November 2010.

[22] Information on the Verve ocean outfall pipeline provided through personal communications with Verve (Andy Wearmouth), 20 October 2010.

passes the Kemerton Industrial Park and could potentially be used as a source of recycled water, although the concentration of the waste may make recycling an expensive alternative.

3.5 Alcoa Wagerup[23]

Alcoa’s Wagerup site is currently being supplied, in part, by Harvey Water through the transfer of water from Wellington Dam to Harvey Dam. Alcoa states that current water use at both its Pinjarra and Wagerup sites is around 25 GL per year. Of this, approximately 15 GL is sourced from high quality water supplies and the majority of the remainder comes from residue and refinery run-off, and contamination recovery. Alcoa has noted that it has a target to reduce potable water use by 20 per cent and is pursuing ways to use lower grade water, however future expansions may increase the volume of water required at both Pinjarra and Wagerup.

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[23] Information sourced from the Alcoa Submission to the State Infrastructure Strategy, February 2006

4. Existing and planned water demand

In this section we review existing and planned development in the area and consider the potential demand for water.

4.1 Harvey Water

As noted in Section 3.1, Harvey Water currently has an allocation of 68 GL from Wellington Dam. Average draw by irrigators, which includes delivery losses, since 1996/7 is 47.5 GL per year. Harvey Water has indicated that if water losses are reduced through the CRISP (decreasing water requirements) and water quality is improved (having the opposite effect and increasing water demand), irrigation use is expected to be similar at around 46 GL per year. Of the remaining 22 GL, 11 GL will be transferred to the Commonwealth Environmental Water Holder and 11GL will be available for sale to industrial water users. Harvey Water will not be seeking additional water above the current allocation from Wellington Dam to service the Collie area.

If required in the future, the least expensive means of obtaining water in the Collie area would be for Harvey Water to retain some of the 11 GL of water earmarked for industrial use. The higher operating costs of other water sources, such as water recycling and long distance pipelines, are typically not viable for agricultural purposes.

4.2 Kemerton Industrial Park

Existing industry in the Kemerton Industrial Park has currently been allocated 3.6 GL per year,[24] with major users including:

- Simcoa
- Cristal Global
- Transfield Services
- Goodchild Abattoir

In addition, Transfield Services and Bauxite Resources have specifically sought access to additional water resources in the area.

Transfield Services has an existing agreement with Harvey Water to supply a further 5 GL of water from Wellington Dam if and when the Kemerton Power Station upgrades to a gas fired, base load station. The timing of the additional supply will be dependent on the timing of the upgrade and will be made via a dedicated pipeline constructed by Harvey Water.

Bauxite Resources is currently scoping locations and is also considering the Collie/Picton/Greenbushes area. Timeframes are 4-6 years until the commencement of operations. The final location will be partially reliant on the location of bauxite resources. The company is seeking to construct an alumina

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[24] See Section 3.3 for details.

refinery producing one million tonnes per annum. Water requirements are expected to be 2-3 GL per year.[25]

The process could potentially utilise saline water (e.g. excess water from the Binningup desalination plant or Verve pipeline). The company has been in discussions with Water Corporation regarding the use of up to 1 GL of recycled water from the Kemerton Wastewater Treatment Plant.[26]

Other potential industrial users have made inquiries but do not yet have a formal proposal. Currently only one company is still making active inquiries regarding water use (JX Nippon – oil and energy). Past inquiries include industries such as ply manufacturing, Titanium Dioxide applications and photovoltaic manufacturing.

4.3 Upper Collie Basin

Current water use in the Upper Collie Basin is largely sourced from a combination of mine dewatering and groundwater allocations.

4.3.1 Collie and Muja Power stations

Verve Energy's power stations in the Upper Collie Basin include the Collie A power station, the Muja A – D power stations. Current water use is around 15.5 GL per year.

4.3.2 Shotts Industrial Park

The Shotts Industrial Park consists of five lots on a land area of approximately 240 hectares.

Perdaman Chemicals and Fertilisers (PCF) plan to develop a urea plant on one lot that accounts for approximately 50% of the total land area of the Shotts Industrial Park. PCF have been assigned 12 GL from Wellington Dam and are currently negotiating the purchase of a further 4 GL (at 100% reliability) from Harvey Water. PCF have indicated that combined, these will satisfy the water requirements for the urea plant.

Premier Coal has an option over one lot and has indicated the land could potentially be used for construction of a char plant.[27] The company has a demonstration plant at Kwinana which is currently on care and maintenance. The plant is unlikely to be constructed within the next 24 months and water demand from the char plant is not expected to be large.

4.3.3 Coolangatta Industrial Park

Griffin Energy currently operate Bluewaters Units 1 and 2, which each require a total of 3.25 GL per year.[28] Griffin Energy has also applied for a further 3.25 GL for each of the proposed Bluewaters 3 and 4 power stations.[29]

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[25] Pers comms, Kevin Woodthorpe, Bauxite Resources Infrastructure Manager, 15 October 2010

[26] Pers comms Water Corporation (George Golowyn), 11 November 2010

[27] Pers comms, Digby Short, 13 October

[28] Pers comms, DOW, 21 October 2010

Further development of Coolangatta is fundamentally limited by airshed constraints, however the Collie Local Planning Strategy (April 2009) notes that: *'The development of the [Coolangatta Industrial] Estate is subject to the completion of studies associated with the structure plan, including the Collie Air Shed study, which examines the cumulative impacts of current and future development on Collie air quality. The study will provide a framework to equitably share the cost of any future emission controls among existing and future industries.'*

4.4 Worsley Alumina[30]

Worsley Alumina Refinery presently has a water allocation of 2.6 GL/yr drawn from Augustus River (a tributary of the Brunswick River). The reliability of the water allocation is not considered by DOW as the supply is sourced from a private dam. When water is unavailable from this source, Worsley's contingency option is to obtain water from the Water Corporation's Harris Dam which is the source of potable water for the Great Southern Towns Water Supply Scheme. This contingency was required in 2001, but Worsley have indicated that it should not be required this summer.

Under their State Agreement Act, Worsley has access to water in Wellington Dam, however the company has not yet made an application for the water and would be required to construct the necessary infrastructure to transport the water to their site.

4.5 Alcoa Wagerup

As noted in Section 3.5, Alcoa's Wagerup and Pinjarra sites currently uses a total of 25 GL per year, including 'freshwater' in addition to residue and refinery run-off, and contamination recovery. Harvey Water currently supplies water to Alcoa for dust suppression. Alcoa and Harvey Water have previously held discussion regarding additional supplies for an expansion at the Wagerup site. These plans were subsequently discontinued but have recently been reactivated.

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[29] Pers comms, DOW, 21 October 2010

[30] Infomation on Worsley Alumina sourced from personal communications with DOW (Henry Sieradzki) 10 November 2010

5. Similar industrial sites in Australia

In this section, we provide a brief description of several industrial sites across Australia that have similarities with the Kemerton and Upper Collie industrial areas. In the review we highlight the key industries relevant to each area. In addition to providing an overview of the types of industries that have established in other industrial parks, the identified areas provides reference sites for benchmarking of water use (Section 6.2) and water pricing (Section 8.2).

Due to the nature of publicly available information, there are varying levels of information for each of the benchmark sites.

5.1 Kwinana Industrial Area

Kwinana is located 40 kilometres south of Perth and provides the primary heavy industry hub for the Perth Region.

The Kwinana Industry Council quotes that together the industries at the site:[31]

- have a combined annual output valued at $15.77 billion per annum;
- have direct sales of $8.51 billion; and
- directly employ approximately 4,800 people and provide indirect employment to approximately another 26,000 people.

The key industries in Kwinana are summarised in Table 7.

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[31] Kwinana Industry Council, www.kic.org.au/industry.asp Accessed 16 November 2010.

Table 7: Kwinana Industries

Company	Industry	Capacity
Alcoa	Alumina refinery	2,000 kt/yr
Kwinana Nickel Refinery	Nickel refinery	70 kt/yr
Tiwest	Titanium dioxide pigment plant	105 kt/yr
Cockburn Cement	Lime and cement kilns	850 kt/yr
BP	Oil refinery	135,000 barrels/day
HIsmelt	Pig iron plant	800kt/yr (under Care and Maintenance)
CSBP	Ammonia, ammonia nitrate, cyanide, chlor-alkali, and fertilizer plants	
Coogee Chemicals	Inorganic chemicals	
Nufarm	Herbicides and other agricultural chemicals	
Nufarm Coogee	Chlor-alkali plant	
Bayer	Agricultural chemicals	
Chemeq	Veterinary products	
Ciba and Nalco	Water treatment and process chemicals	
Verve Energy	Two power stations	900-MW and 240-MW
Kwinana Cogeneration Plant and Verve Energy	Two cogeneration plants	116 MW and 40 MW
Air Liquide and BOC Gases	Two air separation plants	
Water Corporation	Water and wastewater treatment plants	

Source: van Beers D, Corder G, Bossilkov A, and van Berkel R *Industrial Symbiosis in the Australian Minerals Industry- The Cases of Kwinana and Gladstone* in Journal of Industrial Ecology, Volume 11, Number 1 2007

Kwinana industrial users currently consume in the order of 33 GL per year of water from a combination of groundwater, recycled water from the Kwinana Water Recycling Plant (KWRP), run-off and scheme water.[32]

5.2 Wollongong – Port Kembla (New South Wales)

Port Kembla is the largest heavy industrial area in the Wollongong area, covering 655 hectares.[33] Port Kembla shares some common characteristics with the Collie / Bunbury region, namely:

- Port Kembla is located approximately 90 km (by road) south of Sydney;
- the Port of Port Kembla provides access to a deep water port; and
- the region has a large supply of coal mined from the Mount Kembla mine.[34]

Current resident industries include:

- fertiliser production (Incitec);

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[32] Kwinana Industrial Area Water Planning Study 2006 (Kwinana Industries Council)

[33] Hill PDA, *Wollongong Local Government Area Employment Lands Strategy* Prepared for Wollongong City Council September, 2006

[34] Econsearch, *Economic Impact Study, A report prepared for Port Kembla Port Corporation,* 10 Dec 2009

- copper smelting (PK copper);
- coke works;
- steel production (Bluescope Steel);
- steel coating;
- scrap metal; and
- power station.

Current industrial operations on adjacent lands to the Outer Harbour foreshore include Brick and Block Masonry products manufacture, Morgan Cement, BlueScope Steel and BHP Billiton.[35]

It is estimated that the port operations have direct output of $328.1 million with flow-on effects of a further $341.5 million creating a total impact of $669.6 million. This total impact figure incorporates the value of steel, coal and other products shipped through the Port.[36]

Water use at Port Kembla is currently in the order of 20 GL per year.

5.3 Gladstone State Development Area

Gladstone State Development Area covers 28,000 hectares in the Gladstone region denoted for a range of uses including large areas of industrial zoning. While this area is still under development there are substantial existing industries in the area, as summarised in Table 8.

Table 8: Gladstone Industrial Area Industries

Company	Operation	Production
Queensland Alumina Limited	Alumina refinery	3.7 million tonnes of alumina
NRG - Gladstone Power Station	Coal–fired power station	Six 280 MW turbogenerators
Cement Australia	Cement kiln and quick lime kiln	Produces about 1,500,000 tonnes of clinker
Boyne Smelters Limited	Aluminium smelter	540,000 tonnes of aluminium
Orica Chemicals	Ammonium nitrate, sodium cyanide and chlorine	220,000 tonnes of ammonium nitrate, (600,000 after expansion) 38,000 tonnes of sodium cyanide 9,000 tonnes of chlorine
Comalco Alumina Refinery	Alumina refinery	Stage 1: 1.4 million tonnes of alumina Stage 3: 4 million tonnes of alumina
Central Queensland Port Authority	Multi-cargo port	
Queensland Energy Resources Limited	Stuart Shale Oil Project	Currently under care and maintenance

Source: Gladstone Synergy Opportunities Report – June 2005

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[35] Maunsel AECOM, *Port Kembla Outer Harbour Development - Preliminary Environmental Assessment*, 5 December 2008

[36] EconSearch *Port of Port Kembla Economic Impact Study*, 7 March 2007

The current resident industries use a total of around 44 GL of water per annum as summarised in Table 9.[37]

Table 9: Gladstone Industrial Water Use

Cooling towers	29 GL
Process purposes	7 GL
Ash and red mud disposal	6 GL
Other industrial uses	2 GL
Total annual water use	**44 GL**

The existing Gladstone industries make a significant contribution to the regional economy generating 30% of Queensland's and 10% of Australia's total volume of exports per annum valued at over $5 billion.[38]

5.4 Avon Industrial Park and Australian Trade Coast

MJA also investigated two other industrial estates – Avon Industrial Park (WA) and the Australian Trade Coast industrial and commercial precinct (Queensland). For both of these areas, information on the availability, use and cost of water was not publically available. While no benchmark figures were available for use in this analysis, we provide a brief summary of the industries located in each area for information purposes only.

Avon Industrial Park: The Avon Industrial Park is located 18km east of Northam and following the completion of Stage 2 will feature 203 hectares of industrial land within a total park area of 473 hectares. The site provides ease of access and proximity to major transport routes, including rail and the Great Eastern Highway. Current resident industries include:[39]

- Agricultural chemicals (Grass Valley Formulators)
- Manufacture and retail (Bushy Tanks, Precision Screen, DE Engineering)
- Services (Jemena Outback Power, Interquip machinery servicing)
- Kit home manufacturers (Oztek, APA and Park Avenue Homes)
- Kaolin processing pilot plant (Swan River Kaolin)

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[37] Corder G D and Moran C J *The Importance Of Water In The Gladstone Industrial Area* Submitted to Water in Mining Conference, November 2006

[38] Corder G D and Moran C J *The Importance Of Water In The Gladstone Industrial Area* Submitted to Water in Mining Conference, November 2006

[39] http://www.landcorp.com.au/project/avonindustrialpark

The Australian Trade Coast: The Australia TradeCoast is an industrial and commercial precinct within close proximity to the centre of Brisbane. Australia TradeCoast comprises approximately 8,000 hectares of land including 5,000 hectares of industrial land at the mouth of the Brisbane River and incorporates Brisbane Airport and the Port of Brisbane.[40] Australia TradeCoast claims to be the largest and fastest growing industry and trade precinct in the country and that there are 7,500 businesses within its boundaries.[41] Resident industries include:[42]

- Advanced Manufacturing (Noja Power Switchboard, Aviation, Aviation Australia, Virgin Blue)
- Chemical & Petrochemical (BP Refinery - Bulwer Island, Caltex)
- Electronics & IT (Systimax Solutions)
- Food Processing (Kerry Ingredients , OSI International Foods)
- Logistics & Freight (FedEx, Toll North, Troncs Carrying Service)

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[40] Queensland Government Submission To The Commonwealth Fuel Taxation Inquiry,

[41] Australia TradeCoast Economic Assessment and Forecast Study March 2008

[42] Australia TradeCoast Who's here http://www.australiatradecoast.com.au/aboutus/whos_here Accessed 16 November 2010

6. Analysis of potential future demand

In the following section we examine the growth potential for industry in the region and therefore the potential future demand for water.

6.1 Irrigation

As described in Section 2.7, the Collie region produces a range of agricultural and horticultural crops, including pasture for dairy and beef and vegetable crops.

Projections provided by Department of Water indicate a potential increase of 20% in value added by the agriculture and horticulture sector in the South West Region by 2020, however it is expected that, in the longer term, this value will be tempered by the influences of climate change. An increase in value in the industry may be met through a combination of higher value crop value, more productive use of inputs such as water or increased land area. Growth in particular areas will be determined by a number of factors including (but not limited to) land availability and the availability/cost of water.

Approximately 1.3 GL of superficial aquifer remains unallocated in the Wellesley sub area and could continue to be sourced for agriculture. Relatively little accessible groundwater for agriculture exists in other subareas of the Kemerton/Collie region.

With regard to irrigated agriculture, sources of water such as water recycling and pumped long distance pipelines are typically considered unaffordable for all but the highest value uses (e.g. some viticulture and other high value crops). As water availability is a key driver of demand, growth opportunities for irrigated agriculture in the Collie region may occur:

1. through an extension of Harvey Water's existing irrigation network. Harvey Water has indicated that it has previously been approached by farms in the Myalup area to extend the irrigation system, however these plans have subsequently been discontinued;
2. through water savings in the existing network. Harvey Water has submitted a water piping project titled the Collie River Irrigation System Project (CRISP) to the Commonwealth Government for partial funding. Reducing the salinity in Wellington Dam is seen as a logical precursor to funding. If funded, it is estimated that the CRISP would generate water savings of 22 GL, of which 50% (11 GL) will be transferred to the Commonwealth Environmental Water Holder. The water within Harvey Water's remaining 57 GL entitlement may be utilised by irrigators or sold for industrial use. Harvey Water has indicated that 11 GL may be made available for industry, implying that the remaining water will be available to meet increased irrigation demand.

Based on the above, it is considered likely that irrigated agriculture requirements in the Collie region can continue to be met through the existing water allocation held by Harvey Water. Growth in agricultural output is highly dependent on both the improvement in water quality in Wellington Dam and the success of the CRISP project.

A study commissioned by Harvey Water in 2010 indicated that the reduced salinity in Wellington Dam would result in more productive use of the water for irrigation, in particular greater use by higher value crops such as horticulture. The study compared different land uses across the Harvey District and estimated the potential changes in land use and gross margin per hectare. Based on a reduction in salinity to 595 mg/l, a 10 per cent increase in irrigated land for horticulture and a yield increase of 6 per cent on both existing and new land, the report estimated potential economic benefits of around $19 million.[43]

6.2 Industry

Industrial growth may occur at Kemerton, Picton/Preston, Coolangatta or Shotts industrial parks. The precise location of new demand will depend on a number of factors including (but not limited to) the availability of raw materials and labour, the cost of infrastructure, the cost to develop and/or remediate the site and transport costs.

Welker Study

A study undertaken by Welker Environmental Consultancy in 1996[44] identified more than 46 industries that might locate at KIP based on the natural attributes and existing industrial base. It was considered that these industries may choose to locate in the area to add value to primary and secondary resources available in the region. The study found these industries are likely to belong to one or more of the following groups:

- chemical and resource processing (e.g. existing inorganic chemicals and silicon smelter);
- high technology (e.g. titanium applications);
- downstream processing (e.g. silicon applications); or
- power generation.

The study did not specifically address water use requirements.

Aquaterra Study

A study by Aquaterra in 2002 (*Kemerton Water Study Phase 2*) indicated that water demand for the Kemerton Industrial Park could range between 7 GL/year and 23 GL/year depending on the specific industries that were established (Table 10). Appendix 1 provides greater detail on water use intensity by industry type.

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[43] KPMG (2010) *Cost benefit analysis of proposal to reduce salinity in Wellington Reservoir*, prepared for Harvey Water. A similar benefit ($20m) was derived in a study by URS for the Water and Rivers Commission (now the Department of Water) in 2003.

[44] Kemerton Industrial Land Demand Study (Welker, 1996)

Table 10: Future Water Demand for the Kemerton Industrial Park

Scenario	Demand	Comments
Low Growth	7 GL/yr	Status quo with demand dictated by the expansion of Cristal and Simcoa operations. Included also is the possibility of titanium sponge production and few small unspecified industries.
Medium Growth	10 GL/yr	Volume required is higher to meet the demands of a synthetic rutile plant, wool processing, iron briquetting plant and a pulp mill.
High Growth	14 to 18 GL/yr	High growth scenario view considering the full development of Kemerton with a wide range of industries including an aluminium smelter, power station and other industries.
Maximum	23 GL/yr	High growth demand plus the introduction of a 'high water demand' industry.

Source: Kemerton Industrial Park Strategy Plan, LandCorp, Dept State Development, November 2009. Original reference Aquaterra (2002) Kemerton Water Study Phase 2

As existing industrial demand is 3.6 GL, a further 5 GL may be required for the Transfield power station upgrade and 2-3 GL may be required for Bauxite Resources, the low end estimate of 7 GL/year could be considered pessimistic.

The report also references earlier work undertaken by Burns Roe Worley on water use intensity by industry. A summary of the relevant information is shown in Appendix 1.

Benchmarking

To provide a further analysis of the potential for future water demand, the other Australian industrial sites reviewed in Section 5 have been used to understand the potential water use per hectare of various industries and, on this basis, to develop a range of possible water demand scenarios.

Table 11 summarises the area, water use and industries for a number of relevant benchmarks.

Table 11: Water use benchmarking[45]

Industrial Area	Area (Ha)	Water use (GL)	Water use (GL/ha)	Industries
Kemerton (existing)	100	3.6	0.036	Smelter, power station, gas plants, mineral sands
Kwinana	1,200[1]	33	0.028	Heavy industry, smelter, fertiliser, petroleum
Coolangatta	27	7	0.259	Power generation
Shotts	174	19	0.109	Urea + Char
Port Kembla (steel works)	720	20	0.027	Heavy industry, steel works
Gladstone Industrial Area	2,800[1]	41	0.015	Alumina refineries; power station; cement kiln; Chemical production
'Rule of thumb' industrial estimate[2]	1	0.05	0.048	Based on 8 x residential lot demand

Notes:

1. Based on analysis of aerial photographs. Excludes roads, native vegetation and undeveloped land.
2. 'Rule of thumb' estimate historically used by Water Corporation for sizing infrastructure.

Source: MJA analysis

Table 11 demonstrates that water use per hectare can vary enormously depending on the industrial user, with power generation at Coolangatta being the highest of the industries examined. While there is a large range across the water use estimates, a number of the larger, more diversified industrial areas have water use between approximately 0.02 and 0.03 GL per hectare. If all remaining industrial land were fully developed, this range would translate to additional water demands of:

- 18 GL/year to 27 GL/year in the Kemerton Industrial Park (900 hectares available for development after accounting for existing industry, infrastructure and native vegetation requirements[46]);
- 20 GL/year to 30 GL/year in Picton/Preston (approximately 1,000 hectares available[47]);
- 6 GL/year to 9 GL/year at Coolangatta and Shotts (approximately 200 hectares remaining at Coolangatta and 100 hectares at Shotts). If further power generation or heavy water users such as PCF located in the remaining area, water demand could be significantly higher.

These figures indicate that the Aquaterra estimates of 7 GL/year to 23 GL/year for the Kemerton Industrial Park could potentially be understated.

Importantly, the results of the benchmarking exercise represent <u>full</u> development of the land. *Partial take-up of the land would result in correspondingly lower water requirements.*

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[45] The table sets out the water consumption charge and does not include annual water access charges or fees.

[46] Best Estimate from South West Development Commission.

[47] Based on approximation of 50% land available for development. Pers comms, LandCorp (Jonathon Roach).

6.3 Implications for new infrastructure

6.3.1 Upper Collie

If industry was established across all currently vacant land in the Shotts and Coolangatta Industrial Parks, the water use estimates developed in the previous section indicate that water requirements could be 6-9 GL/year or more. In addition, a further 5 GL/year of water from Harvey Water's allocation at Wellington Dam has been earmarked for supply to meet the proposed Transfield Power Station upgrade at Kemerton.

Table 12 and Table 13 show the water demand and availability in the Upper Collie Basin based on the information provided in Sections 3 and 4. Commencement dates for PCF, Bluewater III and IV and the transfer of water to the CEWH represent earliest case scenarios.

Table 12: Water Demand - Upper Collie

Existing and planned demand									
Year	Verve	Wes-farmers	Griffin Coal	Blue-waters I+II	Harvey Water	CEWH	PCF[1]	Blue-waters III+IV	TOTAL
2009	15.5	1.5	7.0	6.5	40.0	-	-	-	70.5
2010	15.5	1.5	9.0	6.5	40.0	-	-	-	72.5
2011	15.5	1.8	7.0	6.5	40.0	-	-	-	70.8
2012	15.5	1.8	4.0	6.5	40.0	-	-	6.5	74.3
2013	15.5	1.8	4.0	6.5	40.0	-	-	6.5	74.3
2014	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2015	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2016	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2017	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2018	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2019	15.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	107.3
2020	10.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	102.3
2021	10.5	1.8	4.0	6.5	46.0	11.0	16.0	6.5	102.3

Note 1: Includes both 12 GL assignment by DOW and 4 GL negotiated volume from Harvey Water. If full entitlement is not used, some water may be available for other purposes.

Source: MJA analysis

Table 13: Water Availability - Upper Collie

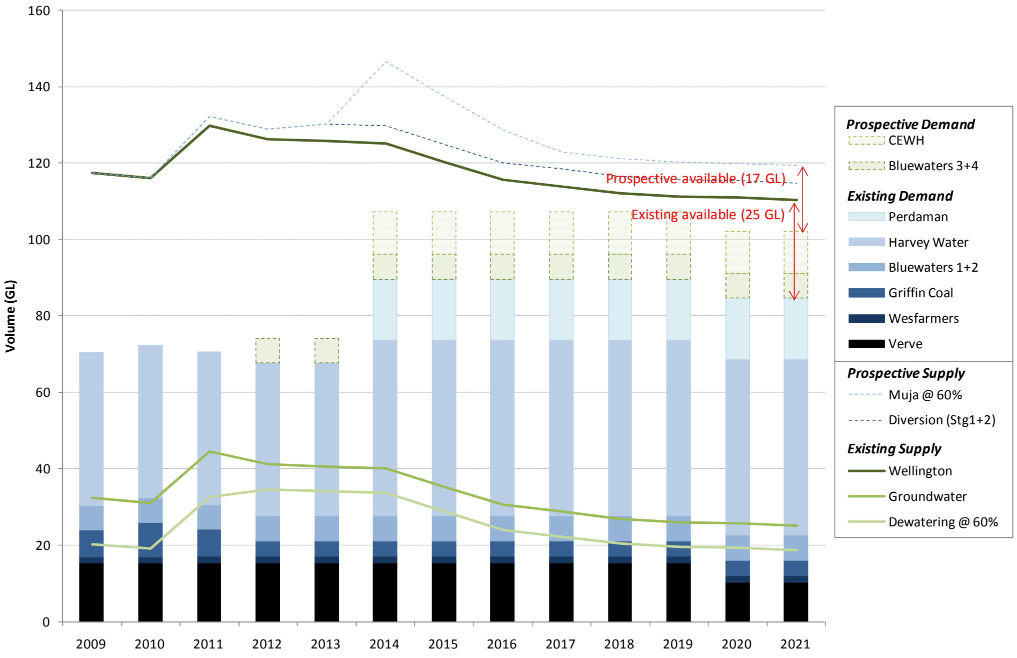
Projected water availability									"Excess" water available^1
Year	Wes-farmers	Griffin Coal	Dewatering @ 60%	Muja @ 60%	Ground-water	Diversion (Stg1+2)	Welling-ton	Total	
2009	15.0	18.9	20.3		12.0		85.1	117.4	46.9
2010	15.0	16.7	19.0		12.0		85.1	116.1	43.6
2011	27.5	26.9	32.6		12.0	2.5	85.1	132.2	61.5
2012	33.0	24.8	34.7		6.5	2.5	85.1	128.8	54.5
2013	33.0	23.8	34.1		6.5	4.5	85.1	130.2	55.9
2014	33.0	23.0	33.6	16.8	6.5	4.5	85.1	146.5	39.3
2015	25.6	22.3	28.8	12.7	6.5	4.5	85.1	137.6	30.3
2016	18.3	21.8	24.0	8.6	6.5	4.5	85.1	128.7	21.5
2017	15.9	21.3	22.3	4.5	6.5	4.5	85.1	122.9	15.6
2018	13.5	20.6	20.5	4.5	6.5	4.5	85.1	121.1	13.8
2019	12.4	20.2	19.6	4.5	6.5	4.5	85.1	120.2	12.9
2020	11.3	20.8	19.3	4.5	6.5	4.5	85.1	119.9	17.6
2021	10.2	20.9	18.7	4.5	6.5	4.5	85.1	119.3	17.0

Note 1: Projected water available less existing and planned demand (previous table).

Source: MJA analysis

The information in Table 12 and Table 13 are summarised diagrammatically in Figure 6, highlighting the distinction between existing and prospective water users and water supplies. Perdaman's (PCF's) operations have yet to commence but PCF has been classified an "existing" user due to the advanced stage of the project.

Figure 6: Existing and planned supply/demand in the Upper Collie



Source: MJA analysis

When existing and prospective water supplies from all local water sources are compared against existing and prospective water demand, the net result indicates that aggregated supply in the Coolangatta/Shotts industrial parks could potentially exceed demand by 17 GL per year in 2021 (see Table 13 for details). We note that this result does not distinguish between different water qualities from different sources.

If only existing water supplies and demand were considered, water supplies would be forecast to exceed existing demand by 25 GL in 2021.

The above forecasts assume that dewatering will occur in accordance with current forecasts and mine managers will not dispose of dewatering water in a manner that makes it difficult for other users to access. In addition, while the Department of Water currently does not have a policy on the issue, new water users could potentially apply to transfer water outside of the Upper Collie area (e.g. to the Kemerton Industrial Park), thereby reducing the volume available for local users.

6.3.2 Kemerton Industrial Park

Table 14 and Table 15 show the water demand and availability in the Kemerton Industrial Park based on the information provided in Sections 3 and 4.

Table 14: Water Demand - Kemerton

Existing demand (GL per year)					
Year	Existing users - superficial	Existing users - Leederville	Existing users - Cattamarra	Transfield power station (existing)	Total
2009	0.29	8.48	0.99	0.10	9.86
2010	0.29	8.48	0.99	0.10	9.86
2011	0.29	8.48	0.99	0.10	9.86
2012	0.29	8.48	0.99	0.10	9.86
2013	0.29	8.48	0.99	0.10	9.86
2014	0.29	8.48	0.99	0.10	9.86
2015	0.29	8.48	0.99	0.10	9.86
2016	0.29	8.48	0.99	0.10	9.86
2017	0.29	8.48	0.99	0.10	9.86
2018	0.29	8.48	0.99	0.10	9.86
2019	0.29	8.48	0.99	0.10	9.86
2020	0.29	8.48	0.99	0.10	9.86
2021	0.29	8.48	0.99	0.10	9.86

Source: MJA analysis

Table 15: Water Availability - Kemerton

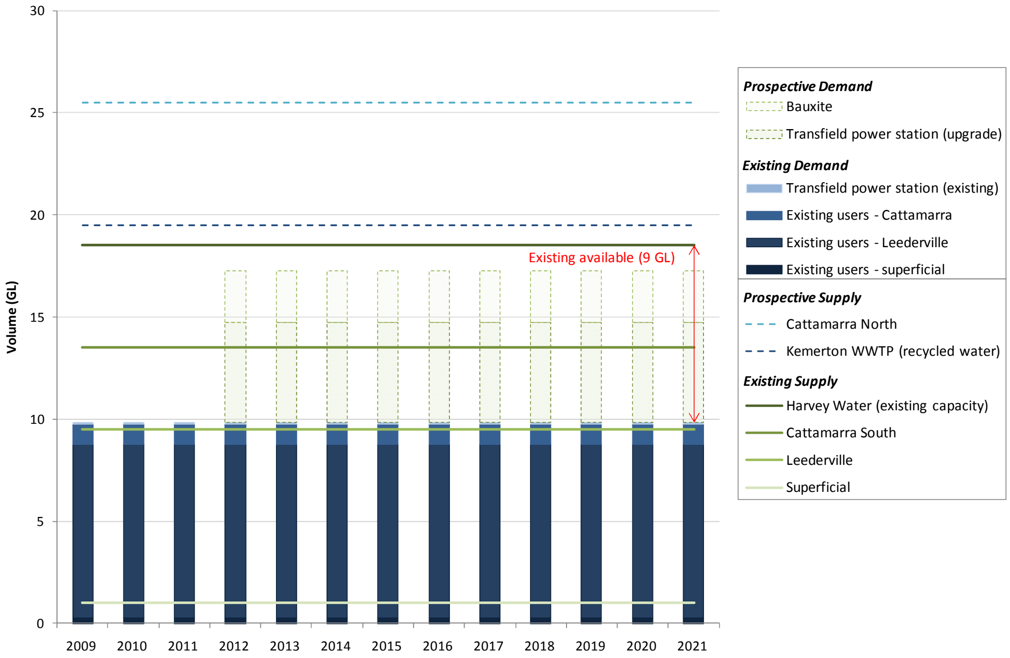
Projected water availability (GL per year)						"Excess" water available[2]
Year	Super-ficial	Leeder-ville	Cattamarra South[1]	Harvey Water (Transfield)	Total	
2009	1.0	8.5	4.0	5.0	18.5	8.6
2010	1.0	8.5	4.0	5.0	18.5	8.6
2011	1.0	8.5	4.0	5.0	18.5	8.6
2012	1.0	8.5	4.0	5.0	18.5	8.6
2013	1.0	8.5	4.0	5.0	18.5	8.6
2014	1.0	8.5	4.0	5.0	18.5	8.6
2015	1.0	8.5	4.0	5.0	18.5	8.6
2016	1.0	8.5	4.0	5.0	18.5	8.6
2017	1.0	8.5	4.0	5.0	18.5	8.6
2018	1.0	8.5	4.0	5.0	18.5	8.6
2019	1.0	8.5	4.0	5.0	18.5	8.6
2020	1.0	8.5	4.0	5.0	18.5	8.6
2021	1.0	8.5	4.0	5.0	18.5	8.6

Notes:
1. For this study, we have assumed that due to the salinity and depth, water from Cattamarra North is not considered easily accessible.
2. Projected water available less existing and planned demand (previous table).

Source: MJA analysis

The information in Table 14 and Table 15 are summarised diagrammatically in Figure 7, highlighting the distinction between existing and prospective water users and water supplies.

Figure 7: Existing and planned supply/demand in Kemerton industrial area



Based on the above analysis, existing aggregated water supplies in the Kemerton Industrial Park from all sources and of all qualities are forecast to exceed existing demand by 9 GL in 2021. The Cattamarra South aquifer has been included as an “existing” water supply while the Cattamarra North has not due to the high salinity levels and depth.

If the Transfield power station is upgraded (4.9 GL/year) and the Bauxite Resources refinery is constructed (up to 3 GL/year), less than 1 GL/year would be available for other industries.

Propsective local water sources include Cattamarra North and recycled water from Kemerton Wastewater Treatment Plant.

At full development of the Kemerton Industrial Park, benchmark forecasts suggest that additional water use could be in the order of 18-27 GL/year (see Section 6.2). To supply volumes of this magnitude would require significant new water infrastructure including, potentially, additional water supplies imported from the Upper Collie (if available), additional water recycling, water supplies from the Integrated Water Supply Scheme (IWSS), access to groundwater currently reserved for town water supplies, or desalination of saline groundwater.

The volumes available from the identified sources, in particular desalination supplies from the Water Corporation’s IWSS, could be increased to meet the requirements of industrial users in the region, although the cost of water may ultimately be prohibitive. The issue of cost will be further examined in Stage 2 of this study.

6.3.3 Other industrial areas

As local water sources are almost fully allocated within the Picton/Preston Industrial Park, additional water for new industry will be required for all new developments. Water sources for the Picton/Preston Industrial Park potentially include Harvey Water (Wellington Dam) or access to groundwater currently reserved for town water supply. In addition, some water needs may be met through increased recharge of the superficial aquifer due to land development.

Water supplies to Worsley and Alcoa (Wagerup) are currently considered adequate, although further expansions at Alcoa could potential require additional water supplies from Harvey Water or another water source in the future.

7. New supply options

The analysis in Section 6 indicated that supplies to agriculture and to industry in the Upper Collie were likely to be adequately met through local water supplies. In the Kemerton and Picton/Preston industrial estates, demand was expected to outstrip water available from easily accessible water sources if significant new development were to occur.

This section examines the cost of new water supply options to the Upper Collie, Kemerton and Picton/Preston areas.

7.1 Upper Collie

Potential water supply options for the Upper Collie region include:

- supplies sourced from Wellington Dam;
- supplies from DOW's diversion scheme;
- supplies from an augmented diversion scheme.

The cost of these sources, in addition to an indication of water supply reliability and water quality are shown in Table 16.

Table 16: New water supply cost, reliability and quality – Upper Collie

Water source	Volume	Capital exp.	Operating exp.	Unit cost	Reliability[4]	Quality[4]
Wellington Dam[1]	8 GL	$6m	$0.43/kL		80% - 100%	Non-potable <1200 TDS
DOW diversion[2]	2.5 GL	n.a.	$3m pa	$1.20/kL	80% - 100%	Potable
First stage of expanded diversion[3]	2 GL	$18m	$2.4m pa	$1.90/kL	80% - 100%	Potable

Notes:

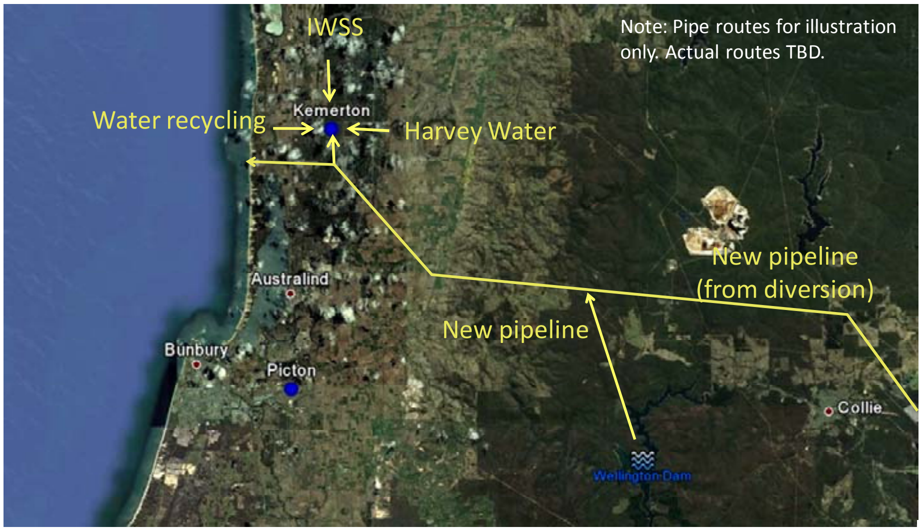
1. *Volume based on shortfall between existing demand and supply, including additional dewatering water. Information sourced from Harvey Water, provided commercial-in confidence. Operating expenditure represents combination of pumping costs and water purchases from Harvey Water's existing allocation.*
2. *Based on information provided by Department of Water. Excludes capital expenditure funded by Commonwealth and State Governments.*
3. *As 2, but includes full capital cost of scheme.*
4. *Reliability and quality estimated by Department of Water and MJA.*

7.2 Kemerton

Potential water supply options for Kemerton (Figure 8) include:

- supplies sourced from Wellington Dam and transported via Harvey Water's irrigation channels or pipes;
- a piped supply of saline water, sourced from the brine stream from DOW's diversion scheme; the high salinity of the water may necessitate desalination by some industrial users;
- a piped supply of diverted saline river water from the expanded proposal by Harvey Water
- recycled water from the Kemerton wastewater treatment plant;
- saline and/or deep water sourced from the Cattamarra aquifer;
- water sourced from the Water Corporation's IWSS.

Figure 8: Water supply options for Kemerton



The cost of these sources, in addition to an indication of water supply reliability and water quality are shown in Table 17.

Table 17: New water supply cost, reliability and quality – Kemerton

Water source	Volume	Capital exp.	Operating exp.	Unit cost	Reliability[7]	Quality[7]
Cattamarra Sth groundwater[1]	3 GL?			$0.20- $0.50/kL?	~100%	Non-potable <1200 TDS
Harvey Water[2]	7 GL	$3m-$6m	$0.63/kL		By agreement	Non-potable <1200 TDS
Brine pipeline from diversion[3]	5 GL	$50m	$250k pa	$0.71/kL	80% - 100%	Non-potable >1200 TDS
Water recycling[4]	1 GL+			$0.40- $1.50/kL?	~100%	Non-potable <1200 TDS
IWSS[5]	Unlimited?			$1.87/kL+	~100%	Potable
Brine pipeline plus desal[6]	5 GL	$50m	$6m pa	$2.90/kL	80% - 100%	Potable

Notes:

1. *Volume based on unallocated volume available. Unit cost based on estimates of Kwinana groundwater extraction and treatment.*
2. *Information sourced from Harvey Water, provided commercial-in confidence. Operating expenditure represents combination of pumping costs and charge for water resource.*
3. *Estimate from Harvey Water. Initial cost estimate approximately $80m (after inflation). Net cost of $50m shown in table assumes $30m State and Commonwealth diversion grant available to offset capital expenditure.*
4. *Current capacity 1 GL pa, potentially as much as 8 GL pa at full capacity by 2030 (pers comms Harvey Water, unconfirmed). Water recycling costs based on cost estimate for treatment and distribution provided by Water Corporation.*
5. *Source cost only $1.87/kL based on IWSS Long Run Marginal Cost. Additional costs to extend distribution system into Kemerton would also be required.*
6. *Estimate from DoW assuming $30 m State and Commonwealth government salinity reduction funding available. Desalination costs estimated from project proposal.*
7. *Reliability and quality estimated by Department of Water and MJA. .*

7.3 Picton/Preston

Potential water supply options for Picton/Preston include:

- supplies sourced from Wellington Dam and transported via Harvey Water's irrigation channels;
- water sourced from groundwater currently earmarked for town water supplies.

The cost of these sources, in addition to an indication of water supply reliability and water quality are shown in Table 18.

Table 18: New water supply cost, reliability and quality – Picton/Preston

Water source	Volume	Capital exp.	Operating exp.	Unit cost	Reliability[4]	Quality[4]
Harvey Water[1]	7 GL	$3m	$0.63/kL		By agreement	Non-potable <1200 TDS
Town water supply[2]	6 GL			$1.28/kL+	~ 100%	Potable

Notes:

1. *Information sourced from Harvey Water, provided commercial-in confidence. Operating expenditure represents combination of pumping costs and charge for water resource.*
2. *Assumes volume earmarked for town water supply available for industrial use. Cost based on current Aqwest volumetric charges. Additional fixed charges, headworks charges and/or distribution charges may also apply.*

8. Water pricing

8.1 Pricing considerations

The cost of water supply options was examined in detail in 7. The ultimate demand for water supplied at those prices will be determined by the willingness of those users to pay the cost of supply. The maximum price that will be paid by water users will typically be the minimum of:

- the price at which the proposed project becomes unviable or alternative sites become more attractive, after taking into account all other project costs and revenues. We note that water is typically a small component of industrial costs (for example, Perdaman Chemical and Fertilisers $3 billion urea plant is expected to use 12 GL of water per year – at a cost of $1/kL, this would represent only $12 million per year, or 0.4% of the initial capital cost). By comparison, water represent a larger proportion of many agricultural budgets;
- the price at which process modifications (e.g. greater internal recycling) become more affordable. The ability to modify processes is highly dependent on the industry and will typically result in a modification to the level of demand rather than avoiding that demand completely.

8.2 Price of water in similar industrial areas

An important pricing consideration will also be the benchmark price faced by similar industrial users in other jurisdictions.

A number of industrial areas of Western Australia have the opportunity to self supply water, and reduce their costs by utilising fit for purpose water. However, in many parts of Australia the only available water is from reticulated water supplies.

In areas such as Kemerton, where there is currently water available, the cost of water from the Water Corporation's reticulated supply sets the "bypass price", which effectively caps the maximum alternative water sources can cost, before industry will use the reticulated supply.

Table 19 summarises the unit price of water for a range of areas across Australia, and provides an example of the industrial areas where water would be provided at this price. The table also includes information on some recycled water schemes, which are openly available to industries in the area and provide a published price.

Table 19: Price of water at similar industrial areas[48]

Water Company	Cost ($/kl)	Example Industrial Area
Sydney water (unfiltered)	$1.69	Port Kembla
Sydney water (filtered)	$2.01	Port Kembla
City West Water (Vic)	$1.71	Altona
Barwon Water (Vic)	$1.79	Corio
Hunter Water (NSW)	$1.54	Newcastle
SA Water	$2.48	Port Adelaide
Water Corporation (metro)	$1.44	Kwinana (Scheme water)
Aqwest	$1.28	Preston Industrial Area
Water Corporation (Australind)	$1.81	Kemerton or Geraldton
Recycled water at Kwinana	$0.40-$1.50	Kwinana (Recycled water)
Sydney water Recycled water	$1.61	Rouse Hill
Sydney water Recycled water	$1.862	Homebush

Source: MJA analysis of water consumption charges for non residential customers.

The information provided in Table 19 is also presented in graphically in Figure 9.

The results indicate that benchmark prices for third party water supplies to industrial areas can range from as little as 40 c/kL (untreated recycled water) to between $1.28/kL and $2.48/kL for potable water. Industrial users in more remote areas, such as Kalgoorlie, can pay $6/kL or more for water supplied through the reticulated network.

By contrast, self supplied water from groundwater bores can cost as little as 10c/kL (where treatment is not required) to more than $2/kL if significant treatment (e.g. desalination) or transport is required.

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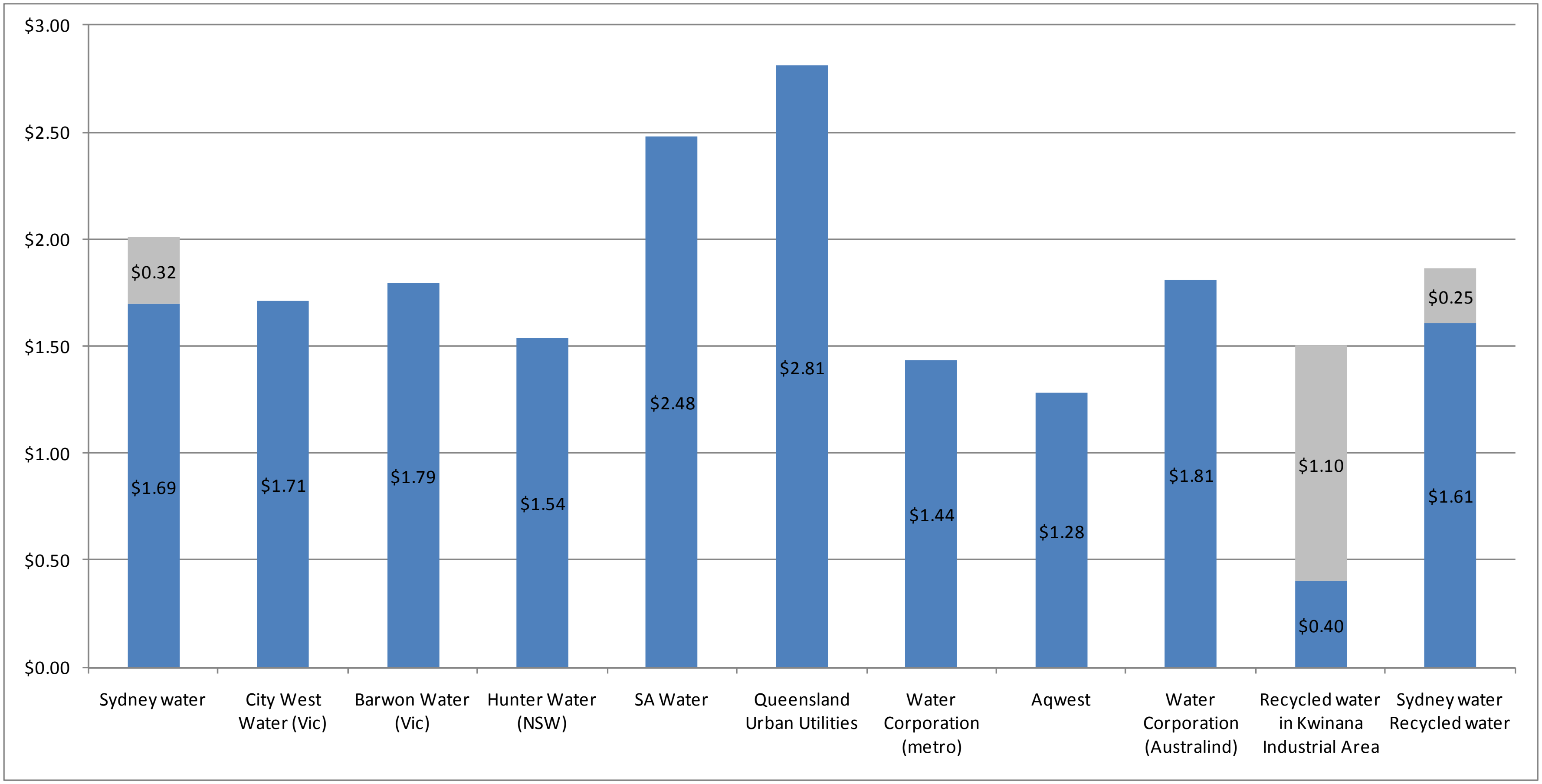
[48] The table sets out the water consumption charge and does not include annual water access charges or fees.

Figure 9: Comparison of water prices



9. Conclusions

Water supply is a key, underpinning factor in supporting industrial growth in the South West region.

Projections and benchmark forecasts developed in this report indicate that demand for industrial water is likely to increase substantially over time. To provide an indicative guide, MJA reviewed two comparable industrial estates and estimated that if similar water use were replicated in the Upper Collie/Kemerton region, then at ultimate development, water requirements for the area would increase by 6-9 GL/year in the Coolangatta and Shotts Industrial Parks (Upper Collie), 18-27 GL/yr in the Kemerton Industrial Park and 20-30 GL/year in the Picton/Preston Industrial Park.

Based on these estimates, the local water supplies in the Upper Collie area would be sufficient to meet additional demand in the area for the foreseeable future. By comparison, the Kemerton and Picton/Preston industrial estates are likely to need to import water from external water sources.

We note that benchmark estimates should be treated with caution. History has shown that individual large users could require substantial volumes of water (for example, Perdaman Chemicals and Fertilisers estimates a requirement of 12 GL per year). In addition, dewatering, groundwater and surface water availability are best estimates and could vary significantly based on changes in land management or climate. Therefore, MJA recommend a flexible, risk based approach to water supply systems rather than developing a scheme based on absolute estimates of volume.

Our review has found that a number of options are available to supply each industrial estate, including (but not limited to) accessing water from DOW's diversion scheme or an alternative disposal scheme proposed by Harvey Water, water purchases from Harvey Water, desalination of saline groundwater, water supplies from the Water Corporation's Integrated Water Supply Scheme (IWSS) or accessing town water supplies.

Unit cost estimates suggest that the various water supply solutions could cost between $0.20/kL and $2.90+/kL. Many of these solutions will require multi-user co-ordination and planning, and a number may require significant upfront investment. However, benchmarking indicates that the unit cost of most options is likely to be comparable with, or less than, charges for scheme water and/or treated recycled water in other industrial sites across Australia.

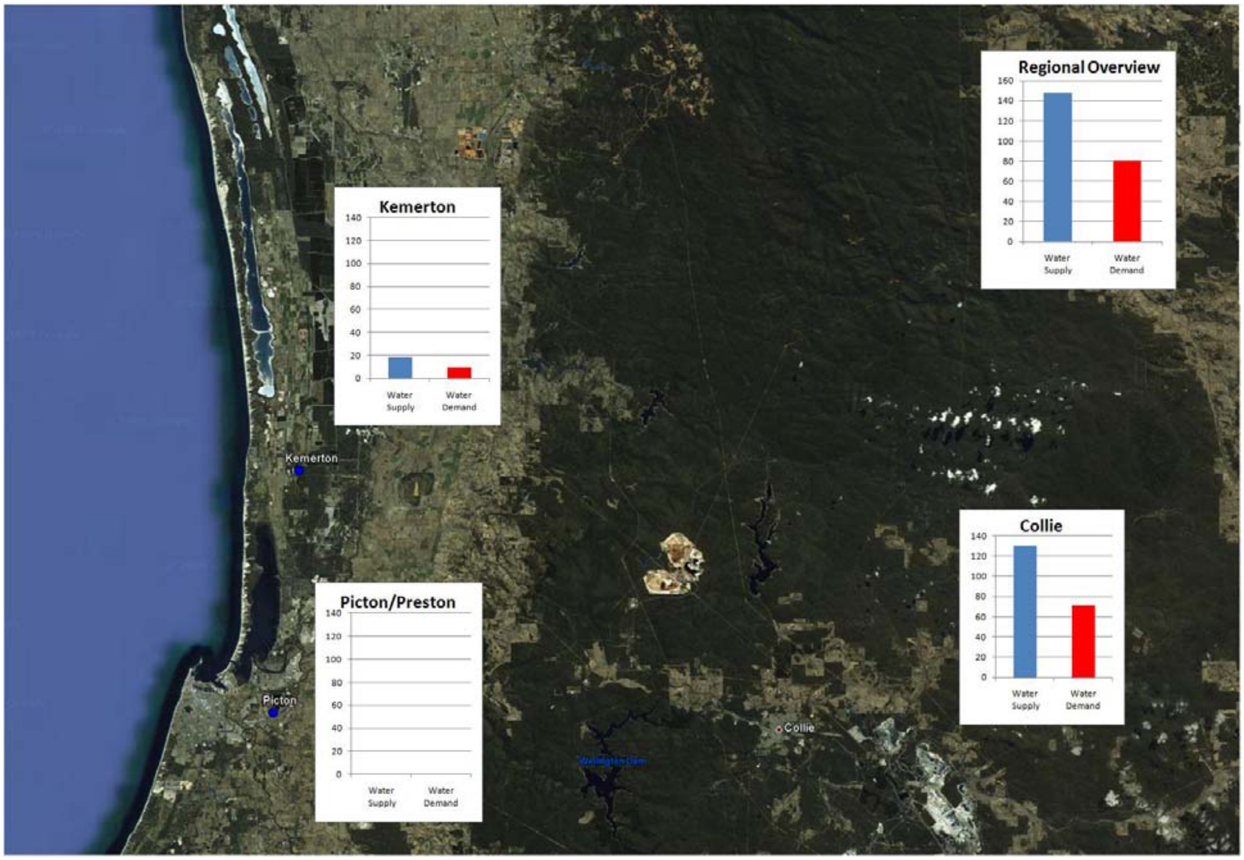
Addendum

This Addendum, requested by the Project Steering Committee, provides an overview of the regional level water supply situation and the implications of various potential water supply/demand scenarios. The Addendum also addresses specific issues raised by the Committee, including the impact of recent water supply negotiations by two industrial water users and discussion of the options presented by Harvey Water and DOW with regard to diverting saline water from the Upper Collie region.

1. Current supply/demand situation across the region

Based on the analysis presented in Section 6.3, Figure 10 summarises the current water supply and demand balance for each industrial area, in addition to providing a regional overview. The summary, which considers only water quantity and not water quality, indicates that the water supply in each of the industrial areas, and for the region as a whole, is currently significantly greater than water demand.

Figure 10: Summary of current water supply and demand for the region



In the Upper Collie area, a large volume of relatively saline water is currently available in Wellington Dam and through dewatering. This water would typically require treatment for supply to industry (such as the desalination proposals by Perdaman and Verve). In Kemerton, water is currently available in the Cattamara South aquifer and Harvey Water has capacity available for the proposed Transfield Worley power station upgrade. In the proposed Picton industrial area there are negligible volumes of water available for industrial use, but there is currently also no identified demand.

As demand grows, water availability will become rapidly constrained. However, water supplies are also expected to change over time, with potential increases from further dewatering in the Upper Collie, the development of water recycling at Kemerton, the potential for allocation of groundwater to industrial users at Picton (subject to DOW consideration and approval) and improved water quality in Wellington Dam. Conversely, the availability of some supplies may decrease, in particular due to reduced groundwater availability.

In the next section, we consider a number of potential supply/demand scenarios and the implications of each.

2. Alternative scenarios for water supply and demand

As outlined in Sections 6.2 and 6.3, both the water supply and demand levels are likely to vary over time across the region. Predicting the future water supply and demand balance requires the use of assumptions and the inclusion or exclusion of a number of possible events. For this reason, we have considered the future water balance in terms of a series of scenarios.

Using the analysis outlined in Section 6, three future scenarios were developed for this Addendum:

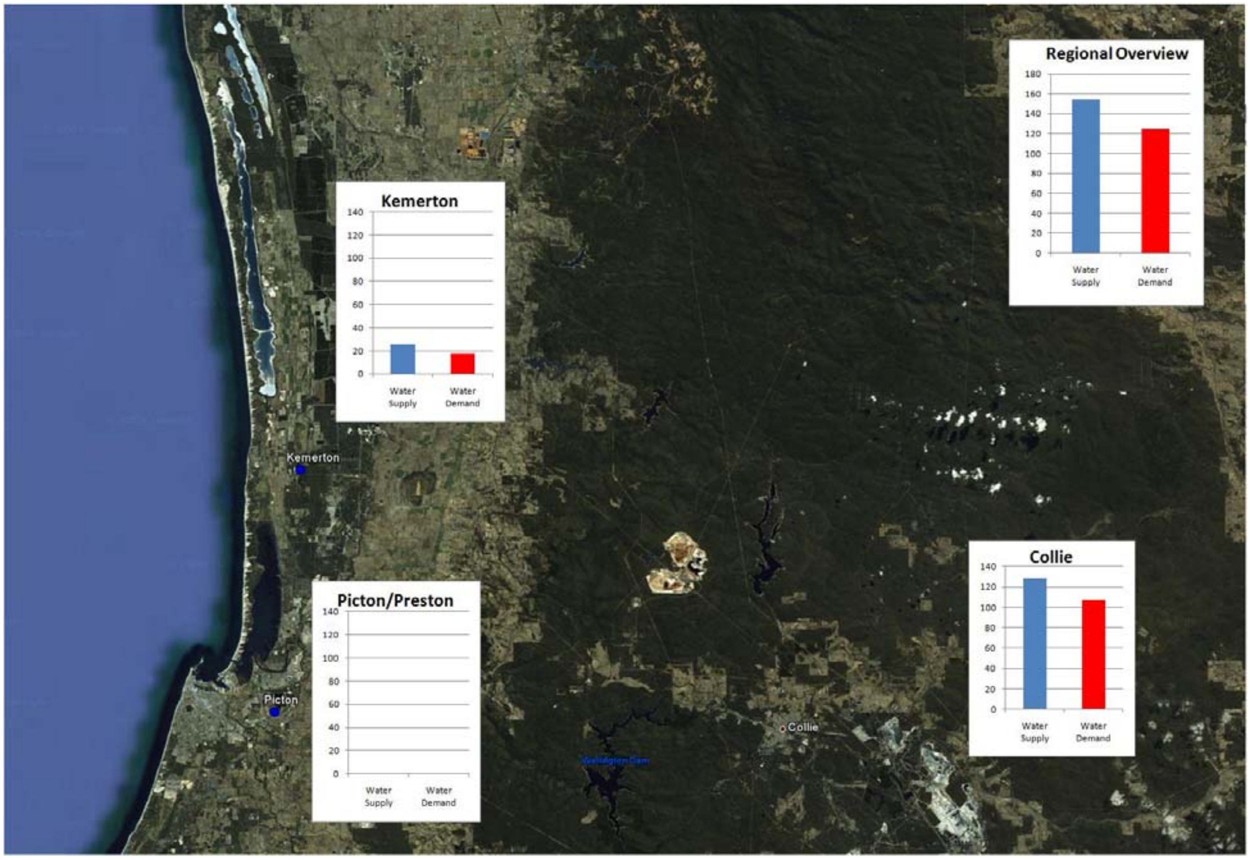
- currently identified prospective demand and supply only (based on the medium term forecast in year 2016);
- high water demand forecasts with high water supply availability (based on the longer term forecast in year 2021); and
- high water demand forecasts with low water supply availability.

Prospective demand and supply scenario

The ‘prospective demand and supply scenario’ is based on the existing situation adjusted for only those prospective changes in supply and demand that have been specifically identified. Figure 11 (see below) and Table 20 (end of this section) summarise the scenario, which utilises the information developed in Section 6.3 and is based on medium term supply and demand (year 2016).

At a regional level, the prospective demand and supply scenario results in the identified water resources being around 80% allocated, with around 30 GL of water remaining unallocated. Based on the planned and proposed changes in water supply and demand, the regional water balance is would become significantly “tighter”, but demand would not exceed supply across the region or in any sub-area.

Figure 11: Prospective demand and supply scenario



High water demand with high water supply

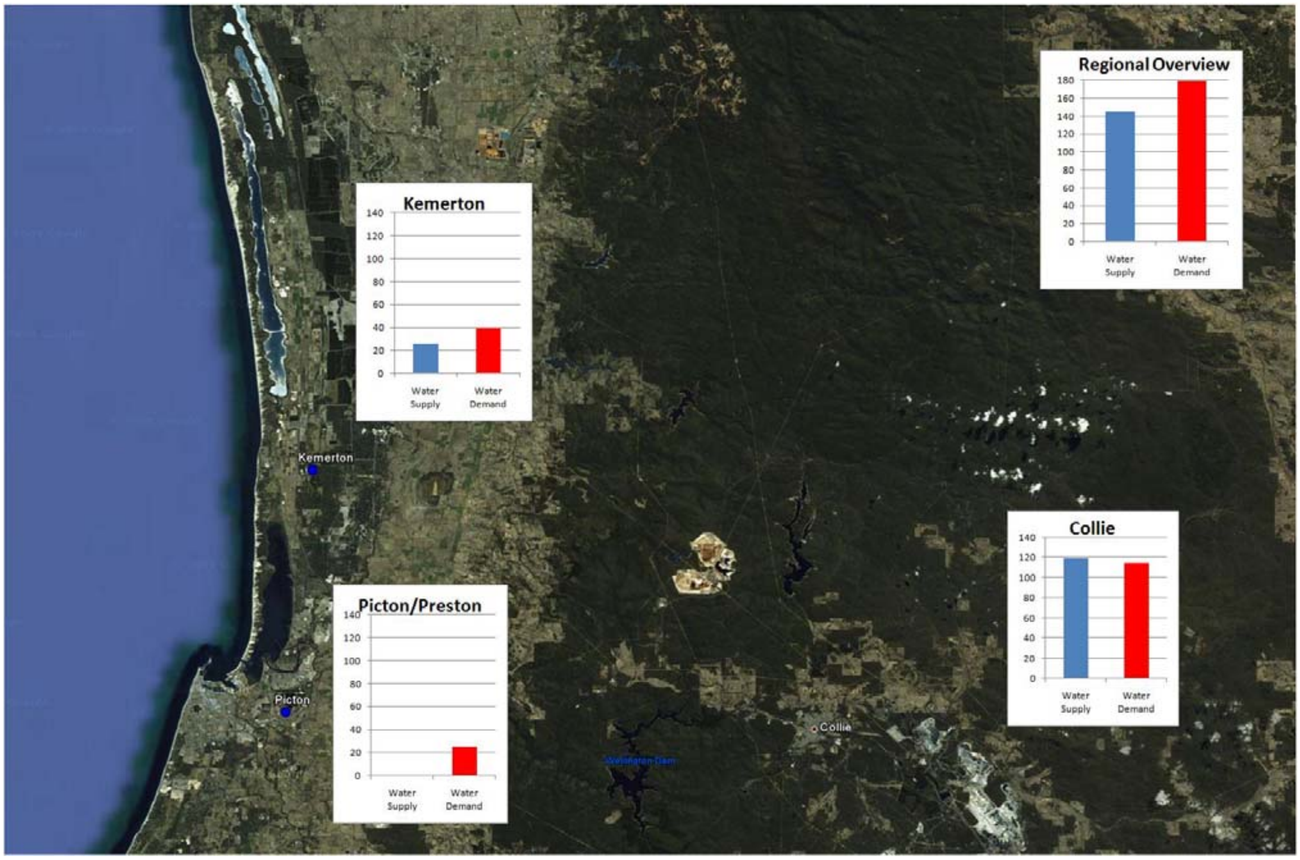
The high water demand scenario is based on estimates of total water demand if each of the industrial areas were to become fully developed. Estimates are based on benchmarked water data from other industrial areas from across Australia, as set out in Section 6.2. The average water use estimate of 0.025 GL per hectare has been utilised, although we note that water use will in reality vary substantially from one industrial area to another, depending on the industries present.

Water availability is based on long term prospective water supplies (year 2021) and includes all potential regional water sources, including sources that may require significant treatment such as dewatering, the diversion scheme in the Upper Collie, water recycling and groundwater at Cattamarra North. The analysis excludes water imported from other regions or town water supplies.

The results, shown in Figure 12 and detailed in Table 20, demonstrate that even with optimistic assumptions regarding water availability, a high demand scenario is likely to result in a regional water deficit of more than 30 GL. This scenario would necessitate the development of innovate, large scale water supply options and/or would require water to be imported from other water sources, including drawing water from town water supplies in the Bunbury region or from the IWSS.

In this scenario, the largest deficits are in Kemerton and the Picton industrial areas, with a small volume unallocated in the Upper Collie.

Figure 12: High demand-high availability scenario



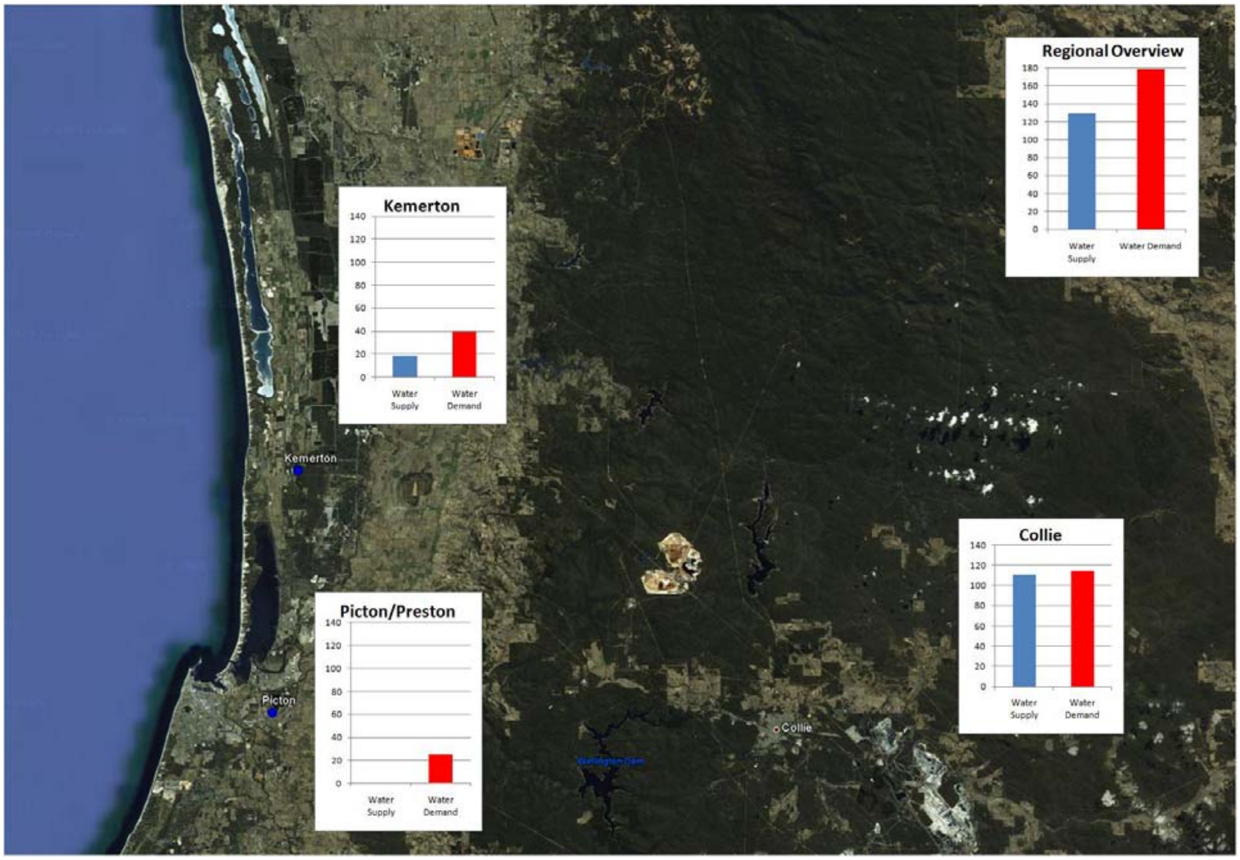
High water demand with low water supply

As with the previous scenario, this scenario utilises a high demand estimate based on benchmarking data from other industrial estates, as described in Section 6.2.

Water availability is based on current water sources, and assumes that prospective water supplies are not further developed and do not become available to local water users. This could occur, for example, if the water were allocated to other uses, if the water allocations were reduced or if the water available were not of a suitable quality. Alternative water sources, such as water imported from other regions and town water supplies, are also not included.

Under this scenario, shown in Figure 13 and Table 20, a water deficit is evident in every sub-area, in particular Kemerton and Picton. The shortfall in available water would be approximately 50 GL and would require significant additional infrastructure. Due to the size of the deficit, this scenario is likely to require the development of, or access to, large scale infrastructure on a scale similar to IWSS water sources, such as seawater desalination or large scale water recycling.

Figure 13: High Demand-Low availability scenario



Summary

The supply and demand scenarios described in the preceding sections are summarised in Table 20.

Table 20: Summary of supply and demand balance for each scenario

	Current supply / demand (GL)	Prospective demand and supply, 2016 (GL)	High demand and supply (GL)	High demand, low supply (GL)
Collie Water Supply	130	129	119	110
Kemerton Water Supply	19	26	26	19
Picton Water Supply	0	0	0	0
Total Regional Supply	**148**	**154**	**145**	**129**
Collie Water Demand	71	107	115	115
Kemerton Water Demand	10	17	40	40
Picton Water Demand	0	0	25	25
Total Regional Demand	**81**	**125**	**179**	**179**
Shortfall	na	na	34	50

3. Impact of large scale developments

Due to the large scale of industrial operations in the Collie region, the introduction or removal of individual projects can have a substantial impact on the water supply balance for the whole region. Examples of this include the planned Perdaman Chemicals and Fertiliser development, which has acquired an annual water allocation of 12 GL from Wellington Dam and 4 GL secured from Harvey Water.

More recently, Alcoa Wagerup and Worsley Alumina have each sought to secure additional water supplies to provide a higher level of water supply security. MJA understand that the volume of water sought by these two organisations equates to approximately 12 GL annually. There are a number of potential water supply options that could be pursued by these organisations, including water supplied from Wellington Dam. To the extent that water is required from Wellington Dam or other local sources investigated in this report, that volume will become unavailable for future expansion of the region.

Changes in water demand of this kind can occur rapidly as individual projects are developed or wound down, emphasising the need for a flexible, risk based approach to water management in the region.

4. Discussion of salinity diversion options

As discussed in Section 3.1.2, DOW is currently developing Stage 1 of a salinity diversion scheme, which aims to reduce salinity in Wellington Dam.

The scheme aims to remove the “first flush” of winter rains from the Collie East Branch, which would then be desalinated. Harvey Water has proposed an alternative scheme whereby the diverted water is transported for ocean disposal, or to a beneficial use elsewhere.

Both proposals would have a beneficial impact on salinity in Wellington Dam, although Harvey Water proposes a larger scheme compared with DOW’s first stage desalination plant, although further stages of the DOW scheme could be developed. A larger scheme would reduce salinity more rapidly and to a greater extent.

The DOW proposal involves treatment and diversion of the Collie East water using Reverse Osmosis, at or near the diversion site. The brine would then be disposed using the existing Verve pipeline. The DOW proposal would make high quality, low salinity water available to water users in the Upper Collie. The capital cost of Stage 1 will be government funded, but additional funding from government or water users would to required to recover ongoing operations.

Harvey Water’s proposal involves piping the untreated first flush water through a new pipeline for ocean disposal. It is proposed the pipeline would run in the existing power line easement, which would pass near Kemerton Industrial Park. Water supplied to customers via this proposal would be of a lower quality and, depending on the proposed use, may require treatment. This would allow customers to select a fit-for-purpose level of treatment, although any treatment would require additional funding from government and/or water users. Potential water users in the Kemerton Industrial Park that require low salinity water may consider sources such as the IWSS ($1.87+/kL) as an alternative to treating water from Harvey Water's pipeline (estimated to cost $2.90/kL).

A comprehensive comparison of Harvey Water and DOW's proposed options would require examination of:

1. *The capital and operating cost of each option:* The costs associated with the DOW scheme are now well developed and the costs associated with Harvey Water's proposal have currently been developed as concept level estimates. The Harvey Water proposal has a significantly higher capital cost, but lower ongoing operating cost that the DOW proposal. Harvey Water has also offered to provide $10 million toward capital costs and to fund the annual operating costs.
2. *The price that would be paid by users of each scheme:* The price paid for water will generally correlate directly with the benefits or cost savings for each user. For example, in the DOW proposal, the price that might be paid by industry should take into account potential savings in private desalination costs (e.g. Perdaman and Verve). For the Harvey Water proposal, industries in Kemerton that could potentially utilise either treated or untreated water would need to be identified separately as the costs applying to each would be significantly different.
3. *The relative speed at which each option would reduce salinity in Wellington Dam and the flow on benefits of improved water quality and quantity.*
4. *The benefits of constructing a viable alternative to the Verve ocean outfall pipeline:* This would include an examination of whether the Harvey Water pipeline can be used by other organisations seeking to dispose of waste in the region including, for example, the proposed Bluewaters power stations. If so, some proportion of the cost could potentially be recovered from beneficiaries.

Appendix 1: Water use intensity by industry

In 1998, Burns and Roe Worley estimated the likely water demand production for different types of industries. This information has been reproduced in Table 21.

Table 21: Water Use Intensity by Industry

High water use (greater than 1,000 ML/yr)

- Alumina Refinery
- Ammonia, Sulphuric Acid
- Coal Power Station
- Pulp & Paper Mill
- Rare Earths, Gallium
- Steel Mill
- Titanium Dioxide (MICL expansion)

Medium water use (300-1,000 ML/yr)

- Alumina Smelter
- Combined Cycle Gas Power Station
- Sodium Cyanide, Nitric Acid
- Synthetic Rutile

Low water use (less than 300 ML/yr)

- Activated Silicas, Fused Silica, Silicon Production, Silanes & Silicones, Silicon Carbide, High Purity Silica, Silica Sand
- Air Separation
- Chlor Alkali, Soda Chemicals, Fertiliser / Superphosphate / Chemicals, Ammonium Nitrate Emulsion, Phosphoric Acid
- Heavy Mineral Sands Separation, Titanium Slag, Titanium Metal
- Hydrogen Peroxide, Kaolin Plant, Oxalic Acid, Bentonite, Xanthates / Metham Sodium, Zeolites, Zirconium Chemicals, Zirconium Metal
- Iron Briquetting
- Lime, Cement/Lime
- Specialised Alumina Products
- Tantalum, Lithium Metal / Chemicals
- Timber Mill, Timber Products / Fibreboard, Wool Processing, Agricultural Product Processing

Source: Adapted from Burns Roe Worley Pty Ltd (1998) *Industrial Water Supply and Wastewater Management for the Kemerton Industrial Park*, prepared for Department of Resources Development (unpublished). Quoted in Aquaterra (2002) *Kemerton Water Study Phase 2 Data Volume,* pp 18-19

APPENDIX 7

Water Corporation Correspondence

GOVERNMENT OF
WESTERN AUSTRALIA

LANDCORP

Enquiries: Jonathan Roach
Telephone: 08 9482 7433

Water Corporation
PO Box 100
LEEDERVILLE WA 6902
Attention: Mr Roman Harasymow

Dear Roman

KEMERTON INDUSTRIAL PARK - WATER AND WASTEWATER STRATEGY

Thank you for meeting us on 17 May 2011 to discuss water and wastewater servicing options at Kemerton Industrial Park (KIP). Pursuant to our discussions, would you please provide the following information:

- please advise if the Corporation would favourably consider a proposal to divert some or all of the treated wastewater from the Kemerton Waste Water Treatment Plant (KWWTP) to the KIP for industrial reuse and current/anticipated future capacity;
- confirmation that the Corporation's planned disposal of treated effluent via the Verve Energy ocean outfall does not preclude the option for reuse of waste water within KIP;
- advice regarding sewer service to the core industry and support industry areas for the collection and disposal of wastewater for both domestic and treated industrial wastewater; and
- location of the closest connection point to a potable water source and capacity (likely to be funded by the developer).

We look forward to the Corporation's response to the above. In the meantime, please contact the undersigned if you have any queries or require any further information.

Yours sincerely

Jonathan Roach
Project Manager

7 June 2011

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Your Ref:
Our Ref : BY1 2011 00267 V01
Enquiries: Garry Crowd
Telephone: 9791 0423

14 June 2011

LANDCORP
Locked Bag 5
Perth Business Centre
PERTH W A 6849

ATTENTION: Mr. Jonathan Roach, Project Manager.

KEMERTON INDUSTRIAL PARK – WATER AND WASTEWATER STRATEGY

Thank you for your letter of 7 June 2011 regarding the Kemerton Industrial Park water and wastewater strategy. Roman has forwarded your letter to the South West Region office to respond.

The following responses relate to the dot points in your letter:

- The Corporation would be supportive of a proposal to draw some or all of the treated wastewater from the Kemerton WWTP subject to availability and a commercial agreement. The question of availability refers to the potential for other commercial agreements to take the water on a first in first served basis. Inflow to the WWTP for 2009/2010 averaged 3180m^3/day with growth exceeding 5% per annum over recent years. The Kemerton WWTP services the communities of Eaton and Australind.
- The Corporation's planned environmental discharge of treated wastewater via the Verve Energy outfall should not preclude commercial reuse alternatives such as KIP.
- The Corporation does not support reticulated wastewater collection from industrial areas for treatment in conventional wastewater treatment plants. Industrial estates, by nature of layout, discharge type and potential high flow rates are not readily compatible with our treatment processes. Industrial treatment, reuse and disposal are often better addressed on site or locally. Domestic flows are generally very low and again better addressed on site.
- The Corporation has previously commented to Landcorp's consultant regarding a potential water supply option. Formal planning for supply to KIP has not been undertaken in recent years and is not proposed at this time. The option was given on an informal basis and is for supply from the Harvey town scheme fed from the water tank in Fleay Road off Weir Road. Harvey is supplied by the Integrated Water Supply Scheme that services the Perth metropolitan area. The Corporation presumes the supply to KIP would be limited to domestic and low usage industry only with major industrial water use sourced through other means such as groundwater or

reuse. The KIP should promote best practice in water conservation and minimise scheme water usage. It would not be reasonable for the Corporation to comment on system capacity without an indication of what volume is being sought.

As discussed above, the Corporation does not advocate wastewater scheme collection for industrial areas and may choose not to provide wastewater services to the KIP should we be invited to be the service provider. Other service providers may be prepared to undertake the service.

The Corporation may be prepared to be the service provider for potable water supply. All infrastructure would be funded by the developer and constructed to the Corporation's standards. If supply is from the Corporation's existing supply system then it is probable that standard headwork contributions will apply. Other service providers may be sought to provide potable water supply services.

Please contact the undersigned should you seek further information.

Yours sincerely

Garry Crowd
Team Leader Property Services

APPENDIX 8

Development Drainage Design Details

Preliminary KIP Drainage Requirements (Nov 2014)

	Catch 1	**Catch 2**	**Catch 3**	**Catch 4**	**Catch 5**	**Catch 6**	**Catch 7**	**Catch 8**	**Catch 9**	**Catch 10**
Contributing Catchment Area (ha)	196	235	440	126	390	114	23	37	42	134
Basin Invert (mAHD)	16.5	13.8	12.8	12.8	12.5	11.3	11.8	10	12.5	7.5
Basin Floor Area (ha)	4.0	4.0	6.0	1.8	3.0	1.5	0.25	0.5	0.15	2
Basin Depth (m)	1	1	1	1	1	1	1	1	1	1
Basin Batters	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6	1 in 6
Basin Top Area (ha)	4.5	4.5	6.6	2.1	3.4	1.8	0.4	0.7	0.3	2.4
1 Year ARI Results										
TWL (mAHD)	16.5	13.8	12.8	12.8	12.5	11.3	11.8	10.19	12.71	7.68
Water Depth (m)	0	0	0	0	0	0	0	0.19	0.21	0.18
Top Wetted Area (ha)	4.0	4.0	6.0	1.8	3.0	1.5	0.25	0.5	0.2	2.1
Storage Volume (m3)	0	0	0	0	0	0	0	980	340	3600
10 Year ARI Results										
TWL (mAHD)	16.6	13.9	12.9	12.8	12.6	11.4	12.0	10.3	12.8	7.8
Water Depth (m)	0.06	0.06	0.05	0.00	0.05	0.08	0.22	0.28	0.28	0.26
Top Wetted Area (ha)	4.1	4.1	6	1.8	3	1.5	0.3	0.6	0.2	2.1
Storage Volume (m3)	4000	4000	3000	0	1500	1200	600	1500	460	5300
100 Year ARI Results										
TWL (mAHD)	17.3	14.5	13.7	13.7	13.3	12.1	12.6	10.8	13.2	8.3
Water Depth (m)	0.8	0.7	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.8
Top Wetted Area (ha)	4.4	4.34	6.53	2.1	3.35	1.75	0.35	0.65	0.22	2.3
Storage Volume (m3)	33500	29200	53900	17100	25400	13000	2200	4600	1300	16700
% of Catchment Area	2.2	1.8	1.5	1.6	0.9	1.5	1.5	1.8	0.5	1.7
Discharge Flow Rates (m3/s)										
Pre-Development Peak 10 yr flowrate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	1.4
Post-Development Restricted Outflow	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	1.4

Notes and Assumptions:

All basins provided minimum 0.3m clearance to MGL

Drainage swales for temporary storage and conveyance of stormwater to basins have been included along all road reserves.

- Kemerton Road: assumed 40m wide reserve with 2 x 9m wide / 0.6m deep swales with 1:6 batters
- All other roads: assumed 30m wide reserve with 2 x 3.6m wide / 0.6m deep swales with 1:3 batters

Runoff Coefficient 0.8 applied to total building envelope area. Runoff Coefficient 0.2 applied to surrounding undeveloped lot area

Runoff Coefficient 0.8 applied to total road reserve area (considers pervious and impervious surfaces)

Some modelled road elevations and lot levels require review at sub division when detailed design and sub division plans are available.

Road elevations were modelled with suitable grade for drainage