Appendix 1

Groundwater Abstraction Management Plan

South West Yarragadee Water Supply Development

Groundwater Abstraction Management Plan

September 2006

Prepared for
Water Corporation
by Strategen

South West Yarragadee Water Supply Development

Groundwater Abstraction Management Plan

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Client: Water Corporation

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SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT

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1. CONTEXT AND SCOPE

Up to ten wells will be drilled into the Yarragadee Formation in an area near Jarrahwood. These wells will be distributed across five well sites, with two wells at each site. Contingency sites to provide for modification of distribution of the pumping regime between aquifers have been selected. Wells will not be constructed at these contingency sites unless monitoring indicates they are required.

Each well site is located adjacent to an existing cleared road and will not require clearing other than that required for the construction area for each site. Collector mains will be located within the cleared areas following existing roads. The roads will be used for maintenance access without modification.

The Groundwater Abstraction Management Plan describes the management approach to groundwater abstraction to prevent any significant unexpected and adverse damage to the groundwater dependent ecosystems of the region that might result from groundwater abstraction.

Groundwater drawdown impacts will potentially affect watertable levels in several potential risk areas. The impacts of the drawdowns that are expected to occur as a result of the proposal alone are considered to be insignificant. Future growth in regional groundwater use will add to the effects.

The fundamental approach of the Water Corporation to managing the cumulative drawdown impacts in these areas is to take full responsibility for offsetting and management in those areas where the Water Corporation is the major contributor to the drawdown effect. In those areas where the Water Corporation is a minor contributor to drawdowns, involvement will be limited to monitoring, reporting, and offsetting the impacts of the Water Corporation proposal. This effectively means the Corporation will be responsible for offsetting all groundwater drawdown impacts on the eastern Blackwood Plateau. The Water Corporation does not propose to take responsibility for managing the drawdown impacts of regional users on the coastal plains, or on the Blackwood Plateau west of the Busselton Fault.

2. EPA OBJECTIVES

The overall objective of the EPA with respect to groundwater abstraction is:

> *To maintain the quantity of water so that existing and potential environmental values, including ecosystem maintenance, are protected.*

Specific objectives related to the various environmental factors potentially affected by groundwater abstraction are:

Flora and fauna

> *The Water Corporation will seek to achieve a net increase in flora and fauna in the region. At a minimum, the proposal will have no adverse impact on flora and fauna in the region.*

Rare and Priority Flora (groundwater dependent)

The Water Corporation will seek to achieve a net increase in priority and rare flora in the region. At a minimum, the proposal will have no adverse impact on priority and rare flora in the region.

Threatened Fauna

The Water Corporation will seek to achieve a net increase in the viability of threatened fauna populations in the region. At a minimum, the proposal will have no adverse impact on the distribution and viability of threatened fauna populations in the region.

Threatened Ecological Communities (TECs – groundwater dependent)

The Water Corporation will seek to achieve a net increase in the viability of threatened ecological communities in the region. At a minimum, the proposal will have no adverse impact on the distribution and viability of threatened ecological communities in the region.

Blackwood River and tributaries

The Water Corporation will seek to increase the ecological integrity of the Blackwood River and its tributaries. At a minimum, the proposal will have no significant adverse impact on the Blackwood River and its tributaries.

Wetlands

The Water Corporation will seek to increase the ecological integrity of wetlands in the region. At a minimum, the proposal will have no significant adverse impact on wetlands.

Other Groundwater Dependent Ecosystems (GDEs)

The Water Corporation will seek to increase the ecological integrity of other groundwater dependent ecosystems in the region. At a minimum, the proposal will have no significant adverse impact on other groundwater dependent ecosystems.

3. POTENTIAL IMPACTS

As the Yarragadee Formation is highly transmissive, the drawdown within the aquifer will extend throughout those parts of the Southern Perth Basin where the Formation exists. The pressure changes in the Yarragadee Formation has the potential to affect shallow watertables in some areas as described by Strategen (2006) in Volume 2 Chapter 5 Section 4.2.

The areas where abstraction may affect shallow watertables are:

- where the Yarragadee Formation outcrops west of Nannup under the Blackwood River and several tributaries
- on the coastal plains in the areas where the Yarragadee Formation directly underlies the superficial formations.

A detailed impact assessment of the abstraction impacts has been undertaken and is described by Strategen (2006). This work has been further updated by local area modelling on the Scott Coastal Plain by Aquaterra (2006). Local area modelling of the Blackwood Plateau is in progress and is being undertaken by URS Australia. No further modelling has been undertaken on the Swan Coastal Plain as the drawdowns in this area are expected to be very low and the results from the Scott Coastal Plain modelling are expected to be applicable to this area. However, URS has reviewed the detailed hydrogeology and hydrostratigraphy of the Swan Coastal Plain, Milyeannup Brook and the St John Brook area to provide more detail on the relationships between groundwater and the surface in these key areas (URS 2006).

The potential impacts of the proposed abstraction include:

- gradual but limited watertable drawdown under groundwater dependent ecosystems that may cause a change in vegetation composition
- a minor reduction in the discharge of groundwater to the Blackwood River and tributaries
- minor drawdown interference with other water users
- very gradual long-term inland migration of the deep seawater interface in the Bunbury area.

4. MANAGEMENT ACTIONS

The wellfield has been designed to minimise impacts on other water users and on the environment. The Blackwood Plateau was chosen as the general location for the wellfield as the Yarragadee aquifer is largely deep and confined in the area, there is little existing groundwater abstraction, and the area is remote from other groundwater users. The location of the wells within this broad area was refined using groundwater modelling to determine which configurations would both minimise groundwater drawdowns in environmentally sensitive areas, and minimise the impacts on other water users.

The wellfield will draw from two units of the Yarragadee Formation to spread the drawdown effects vertically. Five wells will be drilled into the shallowest, most confined Yarragadee unit (Yarragadee Unit 1) at around 400 m depth, and five wells will be drilled into a deeper unit (Yarragadee Unit 3) at around 700 m depth. Six wells operating at full capacity should provide 45 GL/yr. The additional wells will be drilled to allow for continued abstraction during maintenance, and flexibility in the proportion of water abstracted from the different layers in the Yarragadee Formation. This flexibility is important to allow for adaptive management of the abstraction regime based on the monitoring results.

Potential impacts have been avoided and minimised as far as possible through the investigations, modelling, and final wellfield configuration. When operational, management of abstraction will be undertaken within an adaptive management approach based on responding to information provided through an extensive monitoring program detailed in Section 5.1 of this Plan and the contingencies set out in Section 6.

Other management actions that have been committed to and form a major component of the overall Groundwater Abstraction Management Plan are:

1. Establishment of the South West Yarragadee Monitoring Review Group (section 7.1).
2. Implementation of the South West Yarragadee Sustainability Initiative (section 7.2).
3. Preparation of an annual Sustainability Report (section 7.3).

5. MONITORING, REVIEW AND REPORTING PROGRAM

The Water Corporation will implement an extensive biological, hydrological and physical monitoring program for the areas potentially affected by the proposed groundwater abstraction, together with control areas to allow differentiation of causes and effects. The monitoring program is based on essentially four tiers of monitoring:

1. Yarragadee pressure levels: The pumping will first change pressures in the Yarragadee aquifer as the aquifer is highly transmissive laterally. Monitoring in this layer will provide an early warning system for any changes in pressure that are different to that expected from the modelling results. Monitoring of other aquifers will also occur but the criteria bores (bores where rates of expected drawdown are defined as triggers for contingency measures) will be in the Yarragadee aquifer where pressure changes will first occur.
2. Vertical propagation: The monitoring network includes wells into the various geological units that occur between the Yarragadee Formation and the surface. Monitoring these wells will show if and how any change in pressure in the Yarragadee is being propagated vertically.
3. Groundwater level: Monitoring of water levels in both the areas of interest and in control areas (areas not hydraulically connected to the Yarragadee aquifer) to enable any water table impacts due to groundwater abstraction to be identified.
4. Surface: Vegetation, stream flow and aquatic fauna monitoring in both areas of interest and in control areas. This is to ensure that no unexplained changes occur in these systems.

The proposed South West Yarragadee Monitoring Review Group (Section 7.1) will review the monitoring results against a set of defined principles and advise whether any changes need to be made to the management of the project. The Water Corporation will prepare a public Sustainability Report that will report on the monitoring results and proposed management responses if analysis of those results indicates a response is necessary. The Sustainability Report will be prepared annually during construction and for the first five years of abstraction. The reporting frequency will then be reviewed in consultation with the Department of Environment and Conservation (DEC), Department of Water (DoW) and the Monitoring Review Group.

The monitoring programs and ongoing requirements will be reviewed every three years in consultation with the proposed Monitoring Review Group, and modifications will be proposed as necessary, for approval by the DoW.

The Water Corporation will provide opportunities for indigenous people to be employed in undertaking monitoring programs.

5.1 DETAILED MONITORING PROGRAMS

The DoW is currently undertaking a range of groundwater and surface water monitoring activities in the region that will overlap with the following detailed monitoring program which will be undertaken by the Water Corporation. The Water Corporation will take responsibility for ensuring all monitoring within its proposed program is carried out. The monitoring program is set out in Table 5.1 and details described in the following sections.

Table 5.1 Proposed monitoring program

Field	Parameter	Areas	Methods
Hydrology	Length of permanent streamflow	Poison Gully, Milyeannup Brook, St John Brook	Measured monthly from January to April by recording the coordinates of the start of the stream flow
	Stream flow	Blackwood River upstream and downstream of groundwater discharge area, Poison Gully, Milyeannup Brook, St John Brook, Adelaide Brook and control sites	Measure weekly in summer using data loggers (gauging stations not recommended, as they are a barrier to fish migration CENRM (Strategen 2006 Appendix 26))
	Surface water levels	Lake Jasper, Lake Quitjup and Vasse–Wonnerup Wetlands	Wetland water levels will be measured monthly
	Groundwater levels and groundwater quality	Wellfield, Poison Gully, Milyeannup Brook, St John Brook, Reedia Wetlands, Rosa Brook, Swan Coastal Plain and Scott Coastal Plain and control sites	Monitor watertable levels and levels in the underlying Yarragadee Formation monthly for the first three years of the project and then every two months. Selected sites will be monitored with data loggers that will be downloaded monthly. Monitor electrical conductivity and chloride levels in all wells annually (June)
Physical	Water quality	Blackwood River, Poison Gully, Milyeannup Brook, St John Brook	Salinity, conductivity, pH, nutrients (N and P) and temperature sampled monthly
	Dissolved oxygen	Blackwood River, St John Brook	Monthly in summer for 10 minute intervals over 24 hours in selected pools and results analysed weekly
	Acid sulphate soils	Swan Coastal Plain, Scott Coastal Plain	Shallow watertable sampling
Aquatic fauna	Fish numbers	Milyeannup Brook Blackwood River	Annual sampling during September or October Every five years in the Blackwood River
	Macroinvertebrates	Milyeannup Brook Blackwood River	Annual sampling during September or October Every five years in the Blackwood River
Vegetation	Tree health	Blackwood River, Poison Gully, Milyeannup Brook, St John Brook, Reedia Wetlands, Scott Coastal Plain, Swan Coastal Plain (TECs) and control sites	Permanent transects surveyed annually
	Species composition	Poison Gully, Milyeannup Brook, St John Brook, Reedia Wetlands, Scott Coastal Plain, Swan Coastal Plain (TECs) and control sites	Permanent quadrats surveyed annually
	Vegetation condition	Poison Gully, Milyeannup Brook, St John Brook, Reedia Wetlands, Scott Coastal Plain, Swan Coastal Plain (TECs) and control sites	Permanent quadrats surveyed annually
	Riparian assessment	Blackwood River	Permanent quadrats surveyed annually
	Weeds	Blackwood River	Permanent quadrats surveyed annually

5.1.1 Hydrology

The objectives of hydrologic monitoring are to:

1. Monitor Yarragadee aquifer pressures in relation to expected rates of drawdown and trigger contingencies if necessary.
2. Provide information on aquifer performance in areas of potential impact in terms of:
    - ecological system responses
    - acid sulphate soil responses
    - interference drawdowns
    - streamflow responses
    - response to climate change.
3. Validate the understanding of the conceptual hydrogeology and its interpretation in the SWAMS model.
4. Validate and improve the interpretation of the SWAMS model outputs if considered necessary by the Water Corporation.
5. Provide information for further improvement of the South West Aquifer Modelling System (SWAMS) model to minimise the need for interpretation of the results, if considered necessary by the Water Corporation.

The information obtained shall be sufficient to allow differentiation of the effects of short-term climatic variation and longer term climate change, and the impacts of groundwater abstractions other than those of the Water Corporation.

Groundwater abstraction

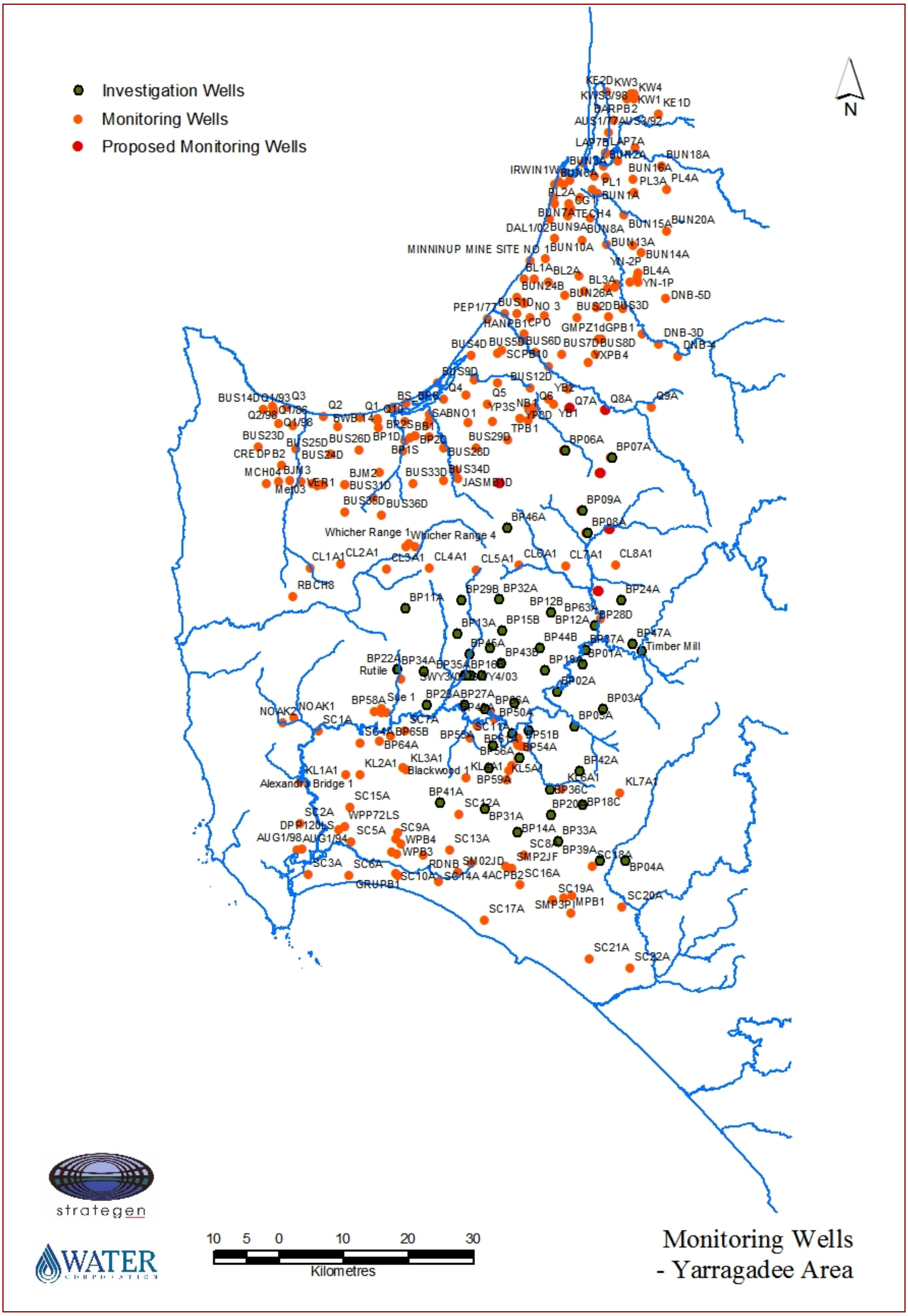
Water Corporation wells will be individually metered and monthly abstractions recorded.

Groundwater levels and water quality

The Water Corporation will establish a monitoring network and undertake baseline monitoring prior to commissioning of the wellfield. Watertable levels and levels in the underlying formation(s) will be monitored monthly for three years following commissioning of the wellfield, and then once every two months. Electrical conductivity and chloride levels in all wells will be monitored annually (June).

The groundwater level monitoring network will comprise all existing investigation wells at the locations shown in Figure 5.1, and will include monitoring of all aquifer intervals available at those sites. Continuous water level recording will be undertaken though data loggers installed in selected wells as outlined below. These sites will be used as criteria sites, with defined rates of drawdowns that, if exceeded, will trigger contingency actions (Section 6.2). The Swan Coastal Plain and Scott Coastal Plain sites cannot have defined rates of drawdowns, as they will be predominately affected by local abstraction. These sites will be monitored continuously and the pressure changes will be reviewed annually. The monitoring network includes control sites in areas not expected to be affected by the proposal.

Figure 5.1 Groundwater monitoring well locations



Most of the wells to be used for monitoring already exist. Additional wells will be drilled in the vicinity of the proposed wellfield to monitor the local impacts, and to fill gaps in the existing network. The additional monitoring wells are proposed to be drilled at BP06, BP07, BP08, BP09 (two new wells at each site, into Yarragadee Unit 1 and Yarragadee Unit 2) and at Quindalup sites Q7 and Q8 (one new well to 400 m depth at each location, as these zones are not monitored) near the proposed production wellfield. Two additional monitoring well sites are proposed to be drilled near the production wellfield, with two wells at each site to monitor Yarragadee Units 1 and 3.

Table 5.2 sets out the criteria monitoring wells and the yearly drawdown values that if exceeded, will trigger contingency action. These wells will be fitted with data loggers.

Table 5.2 Criteria monitoring wells

Bore ID	Aquifer	1 year	2 years	3 years	4 years	5 years	Ongoing
BP38	Water table	TBD*	TBD*	TBD*	TBD*	TBD*	TBD*
BP56	Water table	TBD*	TBD*	TBD*	TBD*	TBD*	TBD*
BP67	Water table	TBD*	TBD*	TBD*	TBD*	TBD*	TBD*
BP8(1)	Water table	No change					
Dd	Water table	No change					
BP6e	Yarragadee 1	-4.1	-4.7	-5	-0.17 m/yr	-0.17 m/yr	-0.17 m/yr
Cc	Yarragadee 1	-2.3	-3.0	-3.4	-3.8	-0.19 m/yr	-0.19 m/yr
Dc	Yarragadee 1	-11.0	-11.8	-12.1	-0.15 m/yr	-0.15 m/yr	-0.15 m/yr
BP10b	Yarragadee 2	-0.2	-0.5	-0.8	-1.2	-1.5	-0.19 m/yr
BP48c	Yarragadee 2	-0.6	-0.9	-1.1	-1.3	-1.5	-0.11 m/yr
Q8d	Yarragadee 2	-3.0	-4.5	-5.0	-0.20 m/yr	-0.20 m/yr	-0.20 m/yr
BP6d	Yarragadee 3	-7.2	-8.2	-8.5	-0.16 m/yr	-0.16 m/yr	-0.16 m/yr
BP10a	Yarragadee 3	-1.5	-2.1	-2.4	-0.17 m/yr	-0.17 m/yr	-0.17 m/yr
BP48a	Yarragadee 3	-1.2	-1.5	-1.7	-1.9	-2.1	-0.13 m/yr
Cd	Yarragadee 3	-3.1	-3.8	-4.1	-0.19 m/yr	-0.19 m/yr	-0.19 m/yr
Dd	Yarragadee 3	-4.8	-5.5	-6	-0.16 m/yr	-0.16 m/yr	-0.16 m/yr
KL7a3	Yarragadee 3	-1.1	-1.5	-1.8	-0.13 m/yr	-0.13 m/yr	-0.13 m/yr
Q7c	Yarragadee 3	-3.9	-5.1	-5.6	-0.21 m/yr	-0.21 m/yr	-0.21 m/yr

* To be determined from the local area modelling being undertaken by URS.

The locations of the criteria monitoring wells are presented in Figure 5.2 through Figure 5.5

The Water Corporation will work with the DoW to develop and implement a program for monitoring seawater intrusion in the Bunbury area.

Figure 5.2 Watertable criteria monitoring wells

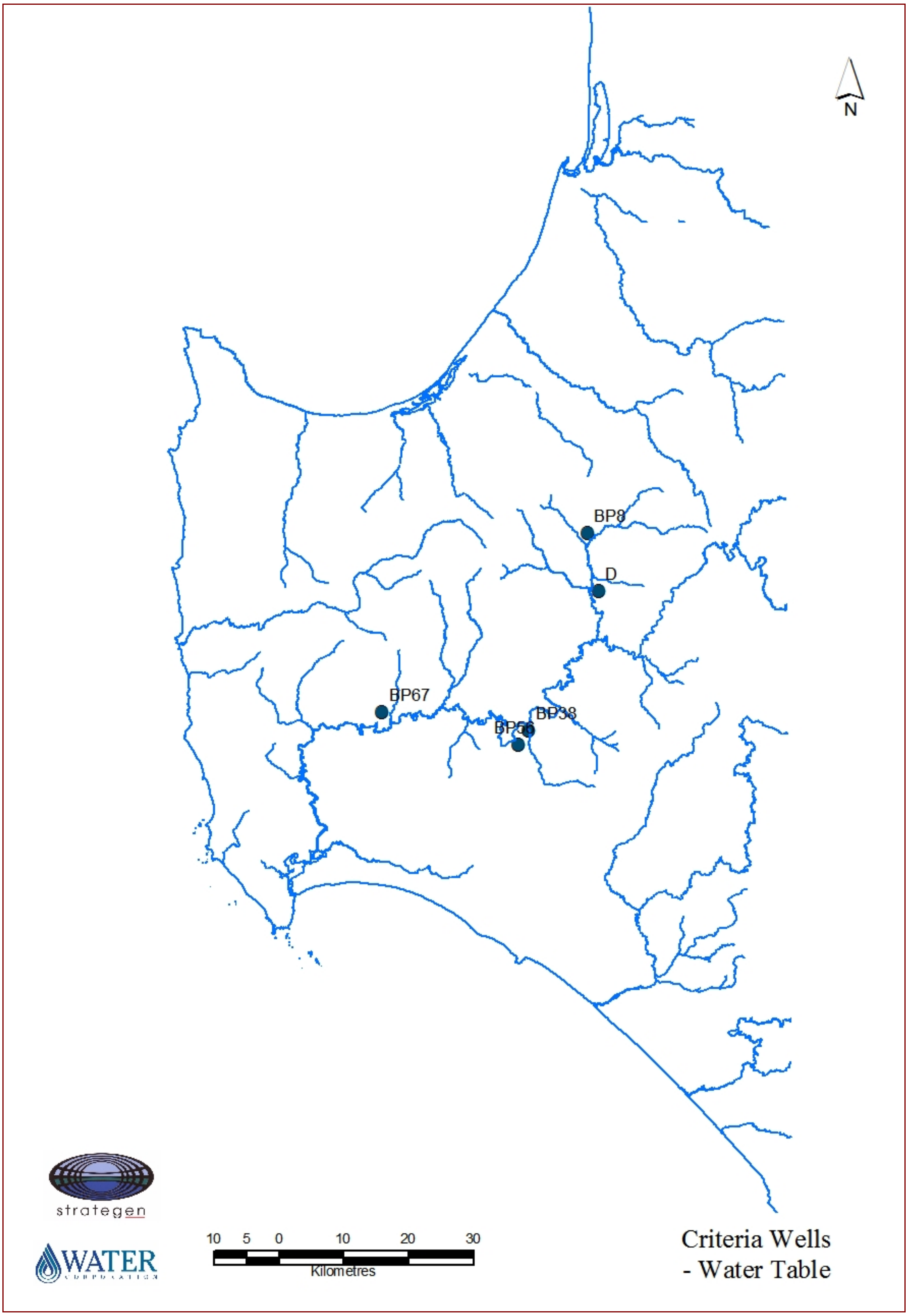


Figure 5.3 Yarragadee Formation Unit 1 criteria monitoring wells

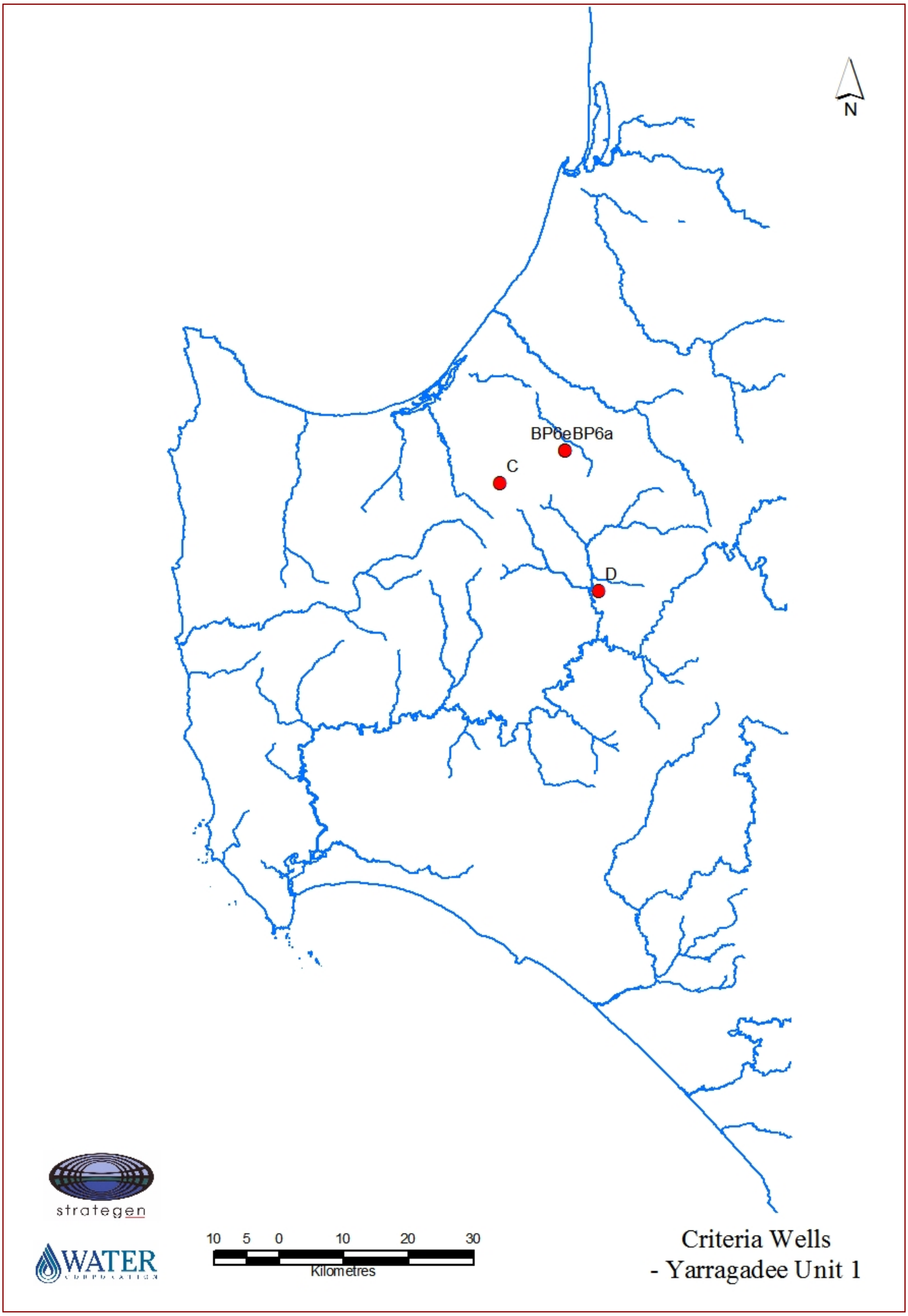


Figure 5.4 Yarragadee Formation Unit 2 criteria monitoring wells

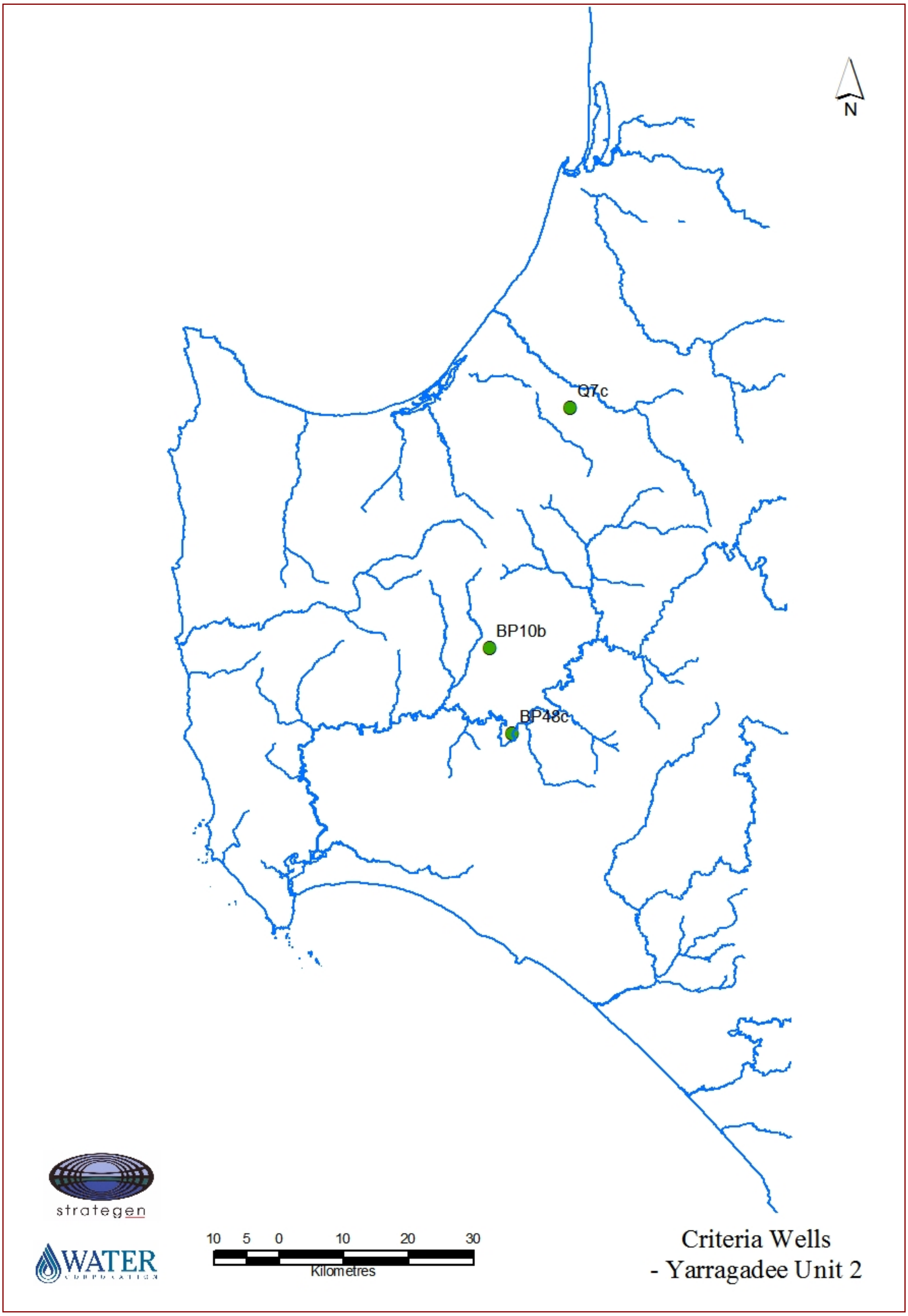
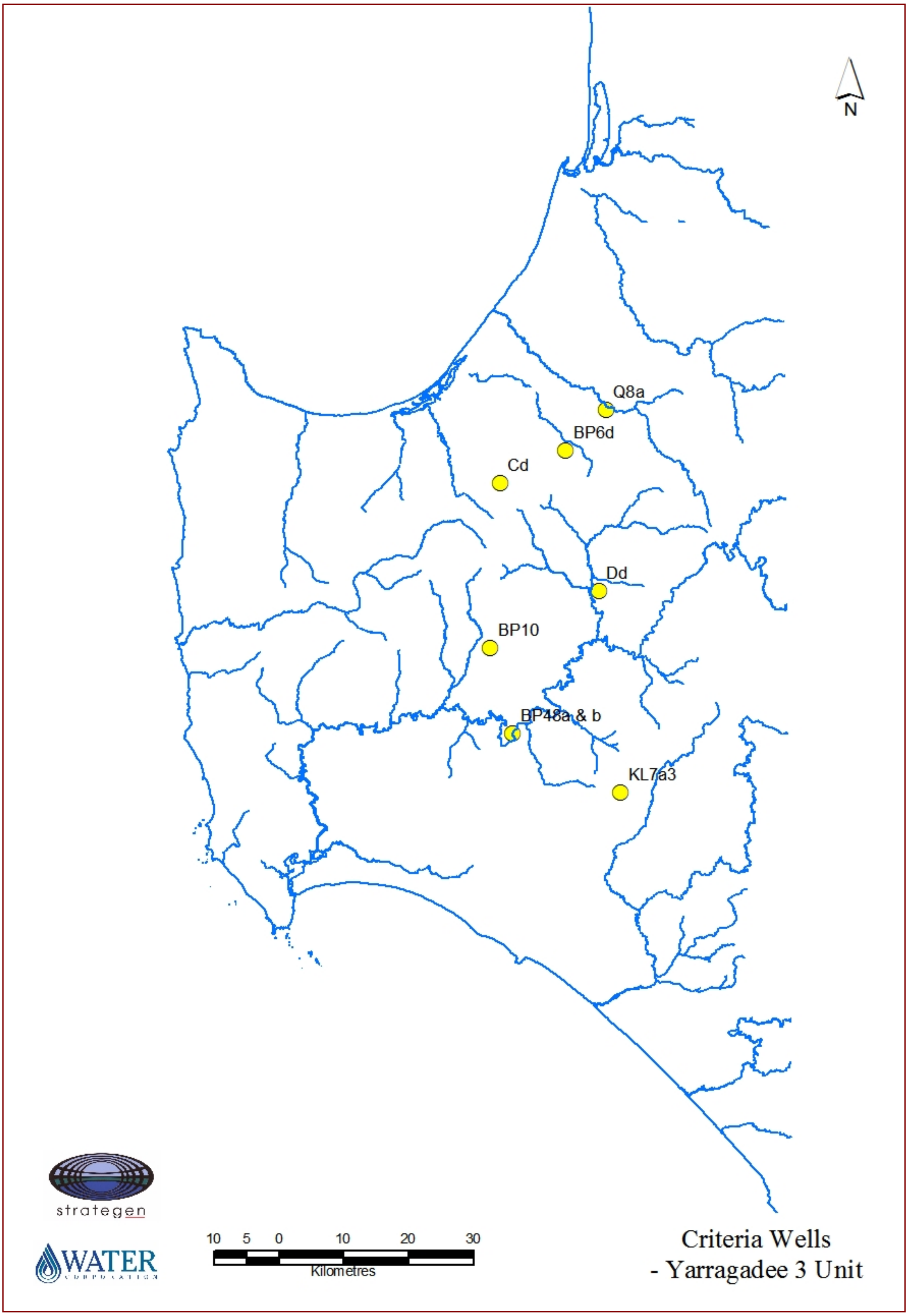


Figure 5.5 Yarragadee Formation Unit 3 criteria monitoring wells



Stream flow and stream water quality

Monthly gauging of summer streamflow will be undertaken in the Blackwood River upstream and downstream of the groundwater discharge area, St John Brook, Poison Gully and Milyeannup Brook from January to April each year at locations close to the confluence of these streams with the Blackwood River. Streamflow in St John Brook will be gauged at the point of inflow into Barrabup Pool and Workmans Pool.

Control sites will also be monitored in perennial streams that are not connected to the Yarragadee aquifer. These may include Barlee Brook.

Annual snapshot flow gauging will be undertaken in early April each year in the Blackwood River, both upstream and downstream of the Yarragadee outcrop area.

Gauging and water quality sampling of the Blackwood River at Hut Pool and Darradup, and of the Donnelly River and Barlee Brook is undertaken by the DoW as part of a regional water resource monitoring program.

Field electrical conductivity will be measured monthly during summer at all gauged sites. Dissolved oxygen will be measured monthly during summer in pools in the Blackwood River and St John Brook (at 10 minute intervals for a 24-hour period in the mid-depths of each pool).

Length of permanent streamflow in tributaries

St John Brook, Poison Gully and Milyeannup Brook will be observed monthly from January to April each year, and the location of the spring flow source will be recorded.

Surface water levels

Wetland water levels will be measured monthly in the following wetlands:

- Lake Jasper
- Lake Quitjup
- Vasse–Wonnerup Wetlands.

Acid sulphate soils

Monthly sampling and analysis will be undertaken from the superficial formations at the following wells on the eastern Scott Coastal Plain to provide information on potential acid sulphate soil impacts: SC08, SC12, SC17, SC18, SC19, SC20, SC21 and SC22 (Figure 5.1). The sample analysis may include field pH, electrical conductivity, redox potential, sulphate: chloride ratio and the levels of arsenic, iron and aluminium metals present. A similar program of sampling and analysis from the superficial formations will be undertaken for the following wells in the eastern Swan Coastal Plain: BUS6, BUS7, BUS12, BUS20, BUS21, BUS22 and BUS29 (Figure 5.1).

Monitoring of pH and salinity in the Scott River and tributaries is undertaken by DoW at the following monitoring sites (Figure 5.6):

609002	609151	6091223	6091225
609026	6091222	6091224	6091226

Figure 5.6 Scott River pH sampling locations

5.1.2 Aquatic fauna

The objective of the aquatic fauna monitoring program is to ensure the sustainability of the Balston's pygmy perch in Milyeannup Brook. Annual sampling of fish will be undertaken in Milyeannup Brook during September or October at two of sites. The sites will be located approximately 500 m and 1500 to 2500 m from the confluence with the Blackwood River.

Control sites will be used to determine streamflow responses to factors other than groundwater abstraction. Barlee Brook will be used as it is outside the area of influence of the proposal.

5.1.3 Vegetation

The objective of the terrestrial vegetation monitoring program is to observe trends in the health, species composition and condition of vegetation in potential impact areas and control areas. A series of 45 vegetation transects will be established to form the network presented in Figure 5.7, which includes seven transects located in areas of no potential impact, to provide controls.

Detailed locations of the vegetation and groundwater monitoring sites in the vicinity of Reedia wetlands, Milyeannup/Poison Gully, St John Brook and the Eastern Scott Coastal Plain are shown in Figure 5.8 through Figure 5.11.

Riparian assessment

There will be an annual winter assessment of the condition of riparian vegetation at sites along the Blackwood River from Nannup to Hut Pool.

Tree health

Annual monitoring of tagged trees will be undertaken at the established transects associated with the Blackwood River, Poison Gully, Milyeannup Brook, St John Brook, Swan and Scott Coastal Plains and control sites.

Weeds

Annual monitoring of permanent transects along the Blackwood River will be undertaken.

Species composition

There will be annual monitoring of species composition at permanent quadrats at St John Brook, Poison Gully, Milyeannup Brook, Swan and Scott Coastal Plains and control sites.

Vegetation condition

Annual monitoring of vegetation condition will be undertaken in accordance with the Keighery condition rating scale at permanent quadrats at St John Brook, Poison Gully, Milyeannup Brook, on the Swan and Scott Coastal Plains, and at control sites.

Figure 5.7 Vegetation monitoring transects, including control sites

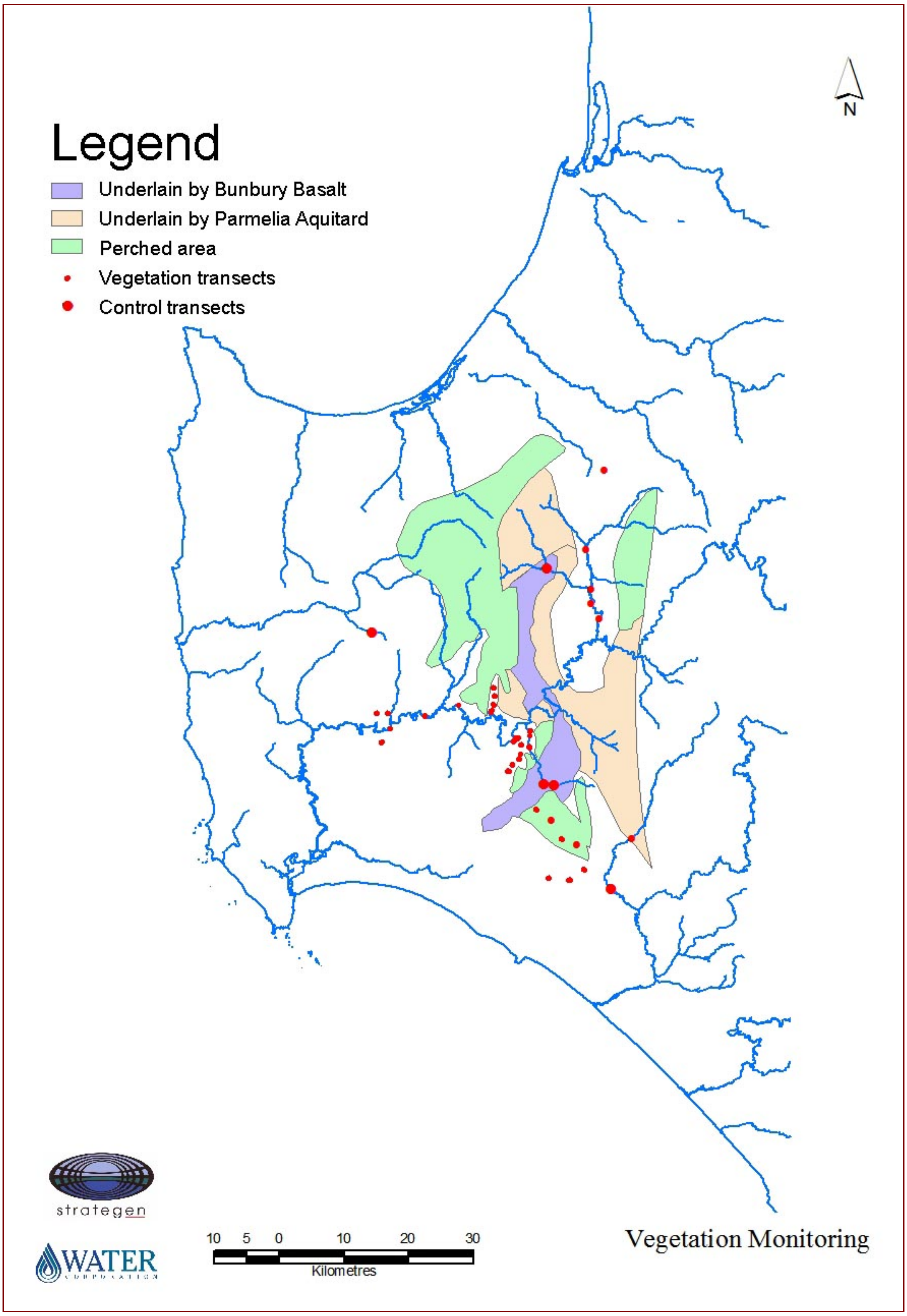


Figure 5.8 Vegetation and groundwater monitoring sites: Reedia wetlands

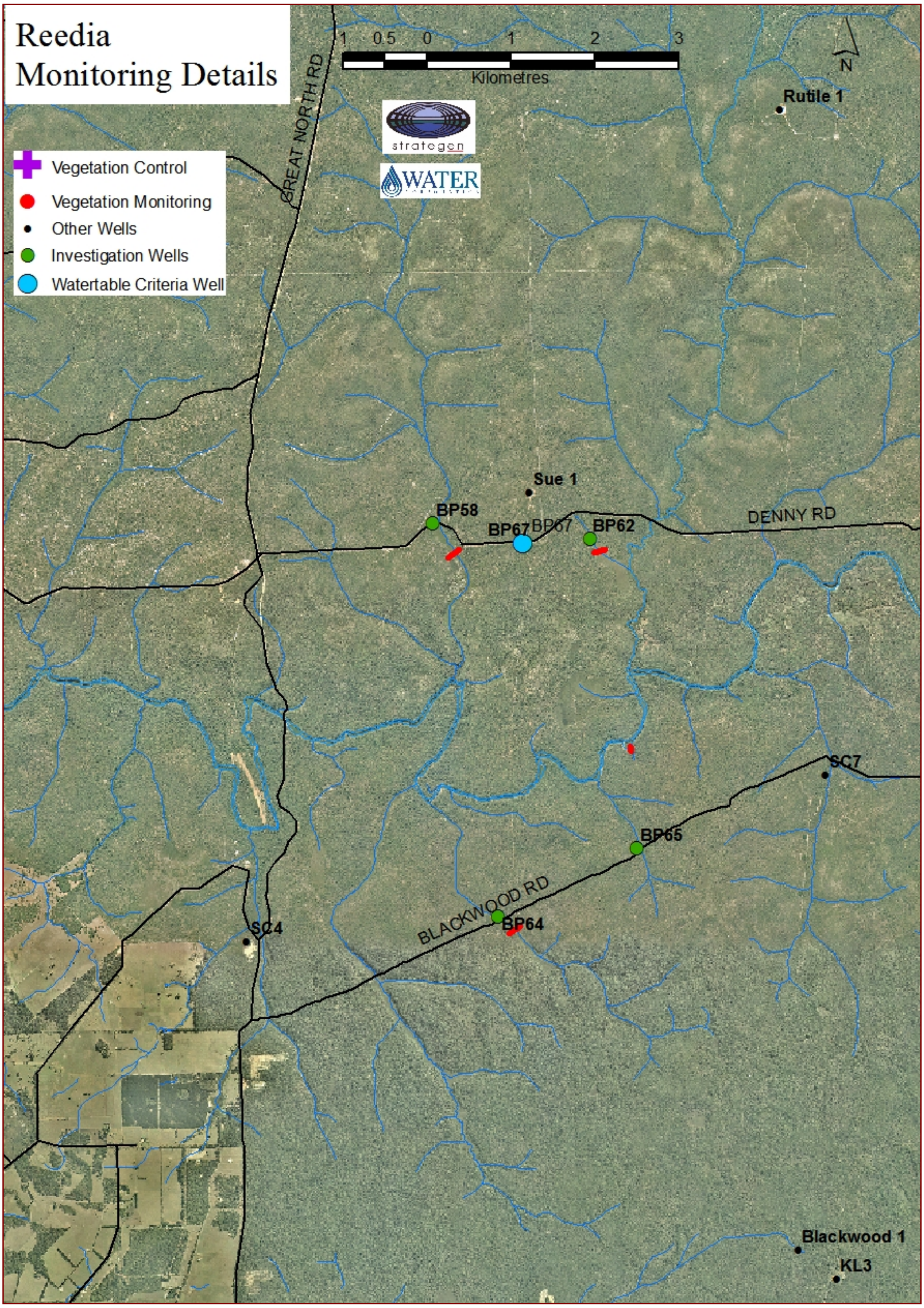


Figure 5.9 Vegetation and groundwater monitoring sites: Poison Gully/Milyeannup Brook

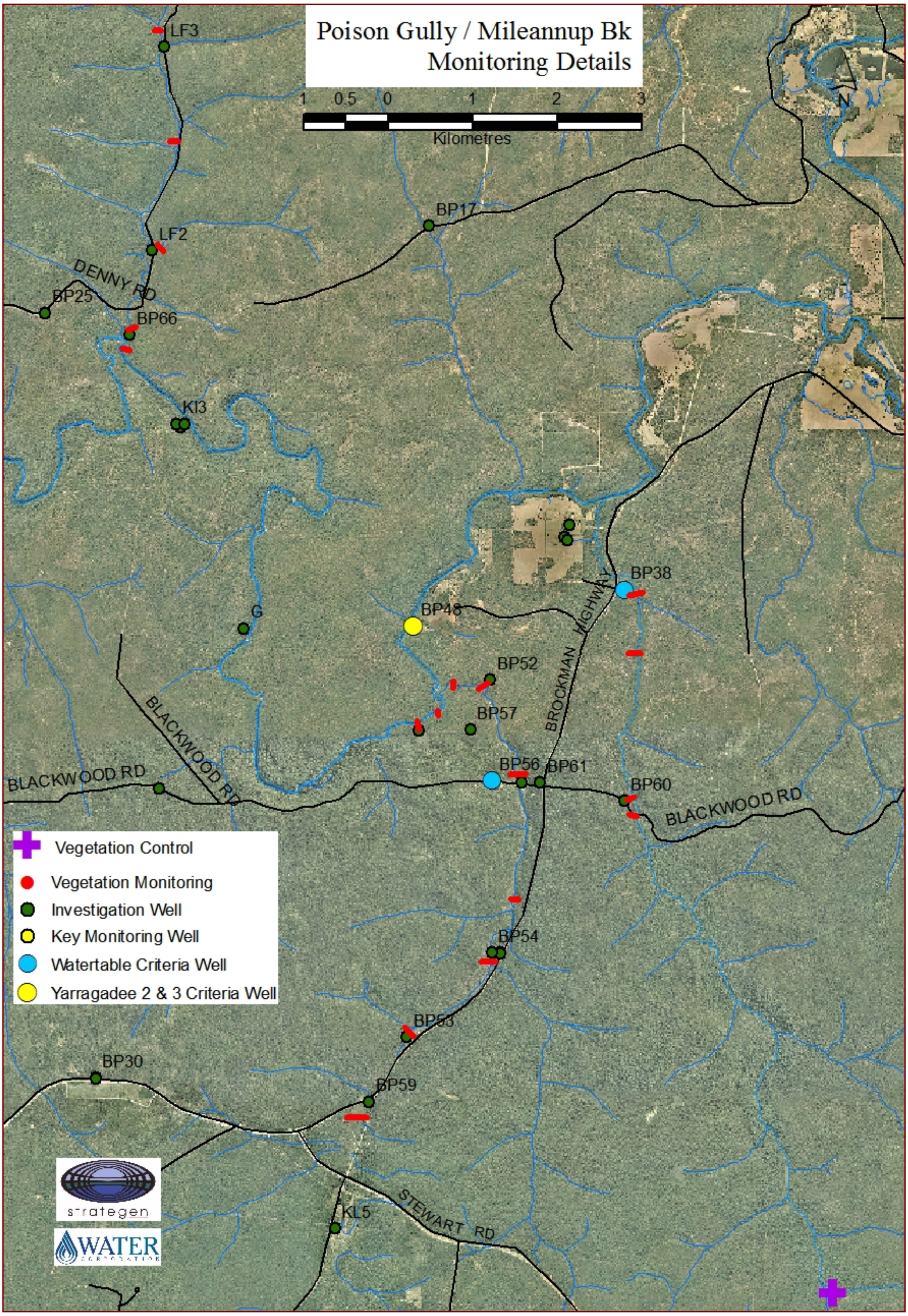


Figure 5.10 Vegetation and groundwater monitoring sites: St John Brook

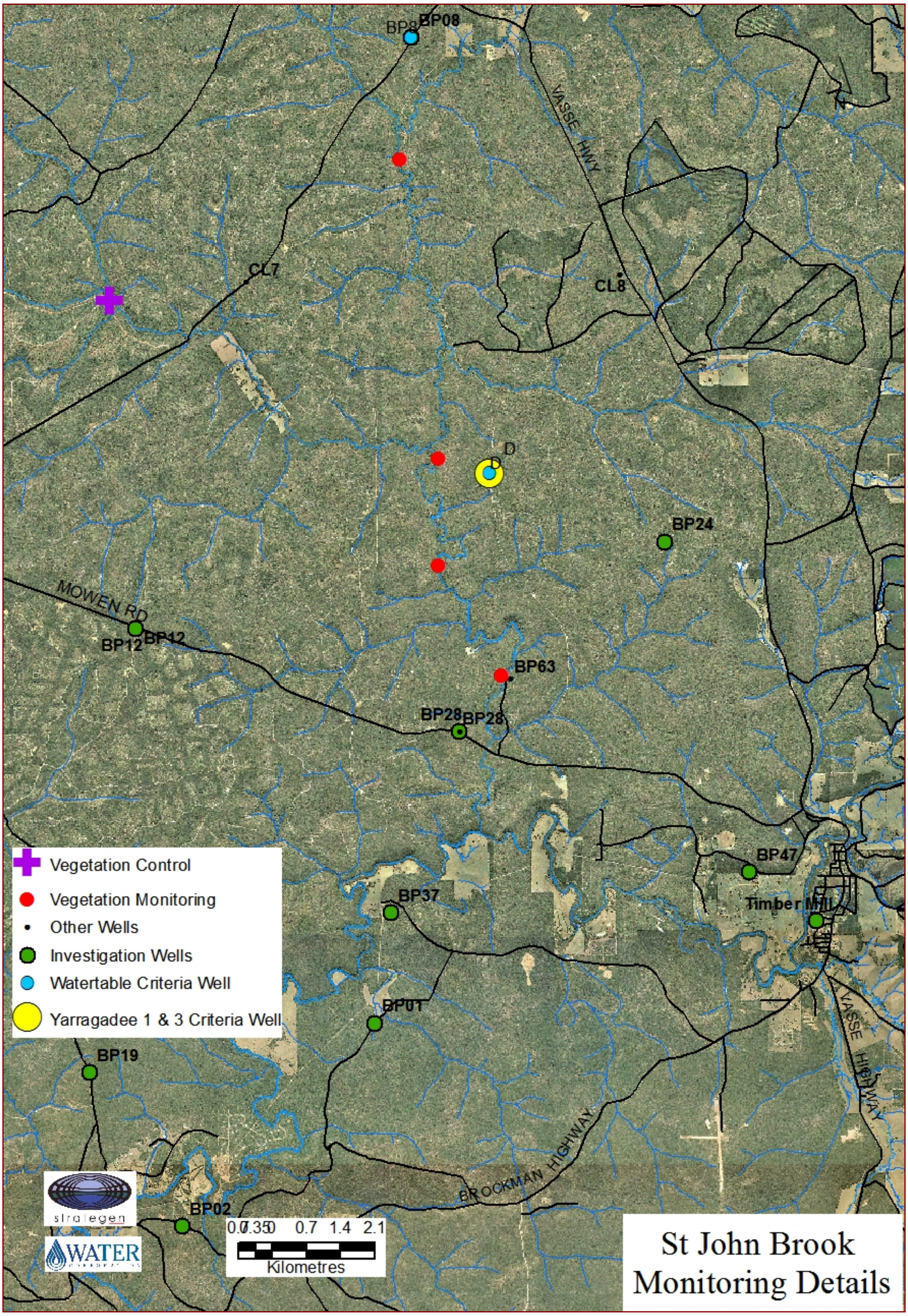
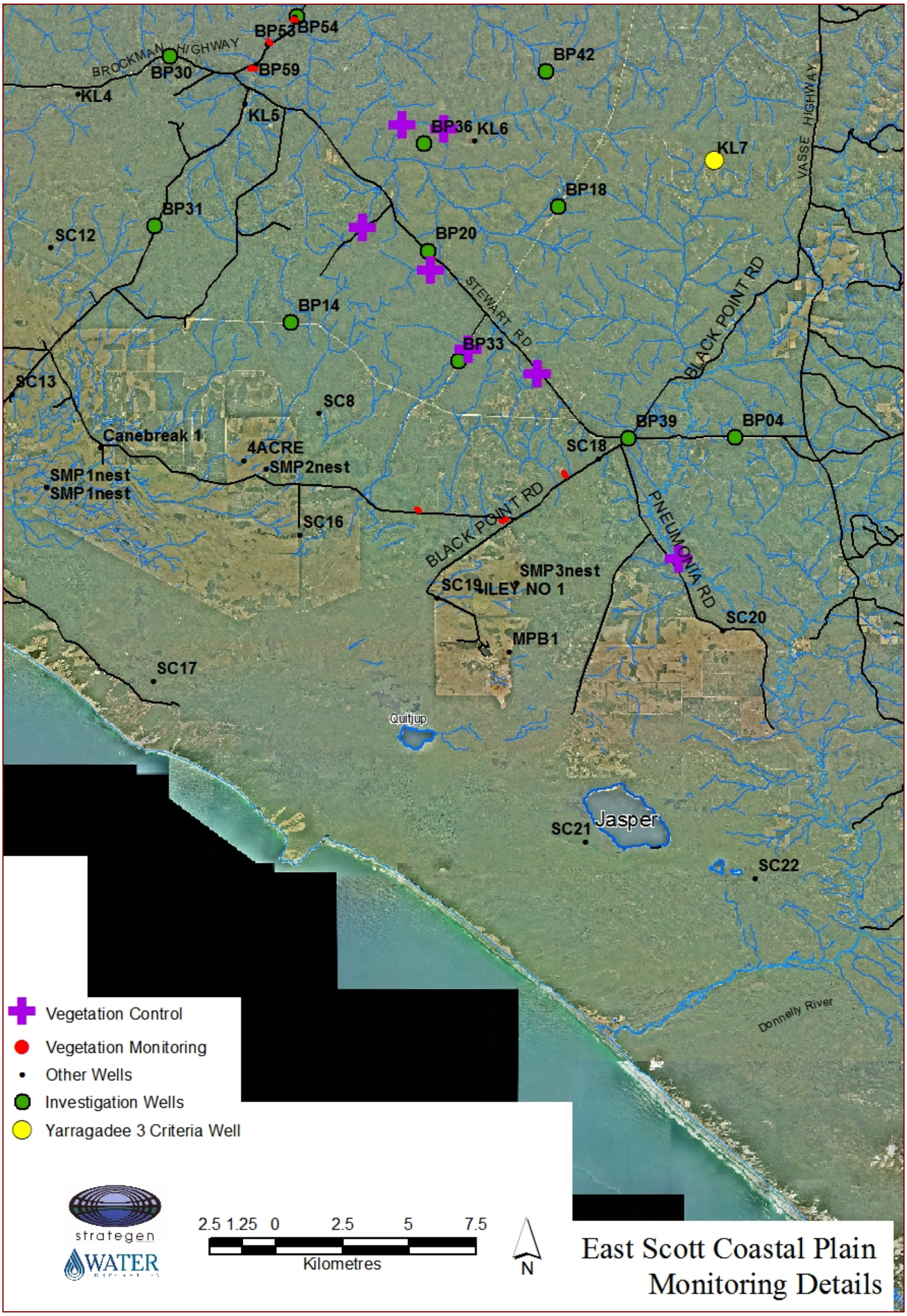


Figure 5.11 Vegetation and groundwater monitoring sites: eastern Scott Coastal Plain



6. ADAPTIVE MANAGEMENT RESPONSES INCLUDING CONTINGENCIES

If monitoring indicates that unexpected and significant impacts are likely, the Water Corporation, in consultation with the regulatory agencies and the Monitoring Review Group, will implement an appropriate contingency action within an adaptive management framework as discussed in Strategen 2006 Volume 1 Chapter 8 Section 3.2.3. Key elements of the adaptive management approach that will be applied in the operation of the South West Yarragadee Water Supply Development are:

1. Management objectives and performance measures will be regularly reviewed (annually in the first instance) and, where necessary, revised in agreement with the regulatory agencies following consultation with the South West Yarragadee Monitoring Review Group.
2. System model(s) will be used to explain responses to management actions and to help identify gaps and the limits of scientific and other knowledge.
3. The range of possible response choices will be developed and evaluated in terms of the extent to which each choice would be likely to achieve the management objectives, and the extent to which it will generate new information or foreclose future choices.
4. Monitoring will focus on significant and detectable indicators of progress toward management objectives. Monitoring will also help distinguish between natural perturbations and perturbations caused by management actions. The proposed Monitoring Review Group will be involved in the assessment of monitoring programs and their results.
5. A mechanism(s) for incorporating learning into future decisions.
6. A collaborative structure for stakeholder participation and learning. The Water Corporation intends to achieve meaningful stakeholder involvement that will enable active learning.

The proposed approach to adaptive management of the proposal will ensure that the potential benefits of the proposal will be realised, and the ecological systems dependent on the resource will be protected.

6.1 HIERARCHY OF CONTINGENCY ACTIONS

The proposed contingency measures are hierarchical, ordered by response to impacts of increasing severity as follows:

1. Site specific contingencies for supplementation of flows in the Blackwood River, St John Brook and Milyeannup Brook if unacceptable flow reductions are recorded in any of these systems.
2. Adjustment of the abstraction regime by altering the proportion of water abstracted from the different units of the Yarragadee Formation. If major adjustment of abstraction is required, additional wells will be drilled at identified contingency well sites.
3. Contingencies developed in consultation with the Monitoring Review Group and the regulatory agencies in response to environmental monitoring suggesting unacceptable impacts may occur.
4. Temporary reduction in abstraction rates while further investigations into potentially unacceptable and unexpected occurrence are undertaken.
5. Permanent reduction in abstraction rates where determined appropriate by either the Department of Water or the Water Corporation.
6. Cease abstraction and investigate alternative sources.

6.2 CONTINGENCY TRIGGERING PROCESS

An integrated approach to monitoring both hydrological and biological responses will be undertaken with a process for triggering responses if untoward changes are observed in either, with control sites to provide a basis for decision–making on the potential causes.

The process for determining the need for triggering contingency actions for each form of response is set out in Figure 6.1. As shown in the flow diagram, an unexpected change in any monitoring is sufficient to trigger contingency actions. There will be a time delay before any biological responses to hydrological changes occur so the monitoring approach is designed to enable the implementation of contingencies even before a biological response is measured.

As described in Section 5, the monitoring program is based on four tiers of monitoring:

1. Yarragadee pressure levels to monitor aquifer performance against predicted pressure changes.
2. Vertical propagation of drawdowns in aquifers between the Yarragadee and the surface.
3. Groundwater level: Monitoring of water levels in both the areas of interest and in control areas to enable any water table impacts due to groundwater abstraction to be identified
4. Surface: Vegetation, stream flow and aquatic fauna monitoring in both areas of interest and in control areas. This is to ensure that no unexplained changes occur in these systems.

The monitoring of pressures in the Yarragadee aquifer will act as an early warning system of unexpected changes as a result of the abstraction. Key monitoring wells in the Yarragadee aquifer have been identified that will have dataloggers installed. Rates of drawdown have been defined for these wells as triggers for contingency actions (Section 5.1.1, Table 5.2).

The groundwater modelling used to provide the basis for assessment of environmental impacts has predicted rates of groundwater level change in both the Yarragadee Formation and in the watertable, and consequential changes in groundwater contributions to streamflows. Comparison of the observed and modelled response will be evaluated in accordance with the process in Figure 6.1.

If required, the process step involving "*Investigate prognosis for hydrologic and environmental outcomes and implement contingency actions if considered necessary*" will be undertaken in close consultation with the regulatory agencies and with consideration by the South West Yarragadee Monitoring Review Group.

The specific contingency action and triggering process for each of these potential risk areas is set out in Table 6.1, to be read in conjunction with Figure 6.1.

Figure 6.1 Flow charts showing action process for responding to hydrological or biological monitoring triggers

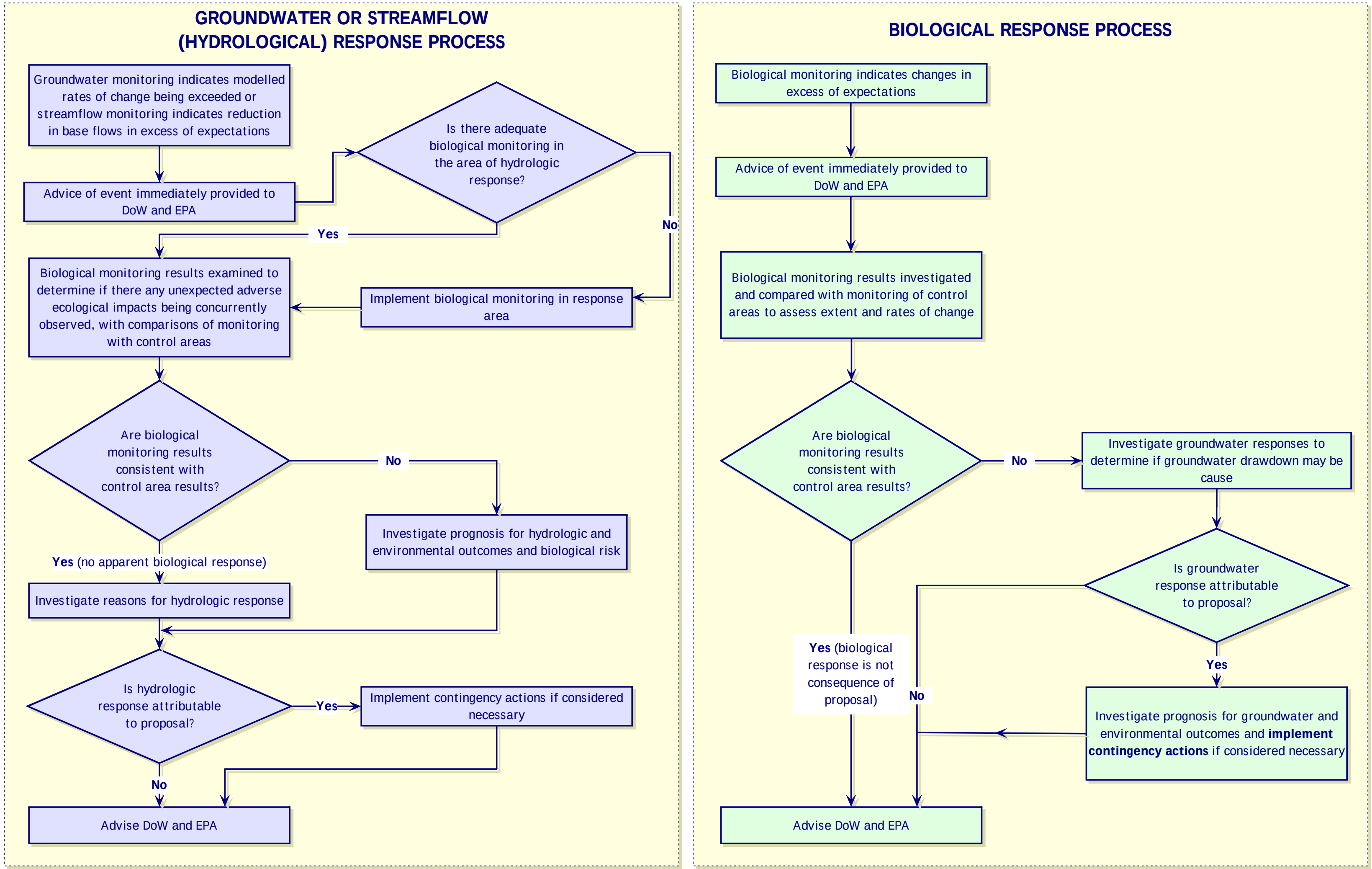


Table 6.1 Trigger levels and contingency actions

Feature	Response trigger level	Contingency action
Deep well monitoring	Pressures in the Yarragadee aquifer exceed the rates of decline defined in Table 5.2	Advise DoW and the EPA of the exceedance. Investigate reasons for hydrological response by looking at drawdowns in surrounding bores and re-calibrating the model. Assess whether changes require contingency actions. Implement the hierarchy of contingencies as required (section 6.1)
Direct groundwater discharge to Blackwood River from Yarragadee Formation	End-of-summer snapshot river gauging indicates decline in Yarragadee Formation direct discharge at rate in excess of modelled prediction.	Construct well into upper Yarragadee Formation near upstream extremity of Yarragadee outcrop and supplement summer flows as required to offset difference between predicted and observed discharge rate
Groundwater dependent vegetation on Blackwood Plateau: • Poison Gully • Milyeannup Brook • Rosa Brook • St John Brook	Groundwater level monitoring indicates rate of watertable decline in excess of modelled prediction at key monitoring sites.	Investigate monitoring results from the deeper aquifers, control sites and rainfall to determine whether the change is due to groundwater abstraction. Increase vegetation monitoring frequency to quarterly to determine if vegetation response in the specific locality(s) is within the expected range, or exceeds acceptable change*. If response is beyond expected range, decrease Water Corporation abstraction from Yarragadee Unit 3 and increase abstraction from Unit 1. Continue groundwater and vegetation monitoring to observe response. Develop further response options depending on results. If groundwater decline rate is more than twice the rate of modelled predictions, abstraction regime to be modified immediately and investigated
	Monitoring of vegetation changes indicates that change is occurring that is beyond expectations and exceeds limit of acceptable change*	Decrease Water Corporation abstraction from Yarragadee Unit 3 and increase abstraction from Unit 1. Continue groundwater and vegetation monitoring to observe response. Develop further response options depending on results
St John Brook baseflow and pools	St John Brook baseflow falls below historical minimum flow rate.	Construct well into Leederville Formation and supplement summer flows to historical minimum flow rates
Balston's pygmy perch habitat in Milyeannup Brook	If both: • regular sampling indicates the consistent presence and abundance of Balston's pygmy perch in Milyeannup Brook between 1000 m and 2500 m from the Blackwood River is being reduced • stream flow observations indicate that Milyeannup Brook does not have permanent and continuous flow 1500m from the confluence with the Blackwood River.	Construct well into Leederville Formation and supplement summer flows to reinstate habitat area
Reedia Wetland water levels and habitat	Analysis of groundwater level monitoring indicates any groundwater level changes that are attributable to proposal	Decrease Water Corporation abstraction from Yarragadee Unit 3 and increase abstraction from Unit 1. Continue monitoring and evaluate to observe effects and determine cause. Develop response options in consultation with regulatory agencies if impact prognosis is likely to be unacceptable

	Monitoring of vegetation changes indicate water-stress related change is occurring inconsistent with control sites	Develop response options in consultation with regulatory agencies if impact prognosis is likely to be unacceptable and changes are clearly attributable to proposal

*Acceptable vegetation change to be characterised by:

- retention of full range of vegetation types (upland to wetland) although areas may change
- continuum of vegetation types is maintained without significant areas of vegetation being in poor health, compared to control sites.

7. OTHER MANAGEMENT ACTIONS

7.1 SOUTH WEST YARRAGADEE MONITORING REVIEW GROUP

A stakeholder based South West Yarragadee Monitoring Review Group will be formed and will have a pivotal role in the adaptive management process (Strategen 2006 Volume 1 Chapter 8 Section 3.2.3). The proposed terms of reference for this group are to independently review and provide public advice and recommendations to the Water Corporation and other relevant Government agencies on:

1. Management objectives and social, economic and environmental performance indicators as proposed by the Water Corporation.
2. Monitoring programs and results including the South West Yarragadee Sustainability Initiative.
3. Proposed contingency measures in the event of unforeseen adverse impacts.
4. The performance of the Water Corporation in meeting objectives and performance standards as presented in the proposed annual Sustainability Report.

The group will be provided with administrative support and financial resources to provide access to independent technical support and expertise where necessary to conduct the reviews.

The membership of this group is to be determined in consultation with the stakeholders, but is proposed to be based on the following elements:

- maximum membership of 12
- independent chair from within region
- membership will for three years on a rotational basis, with members being able to apply for re-appointment
- membership based on interests and expertise rather than being representative of a constituency
- membership will have a majority of community members (agency membership limited to non-regulatory agencies).

The regulatory agencies will not be represented on the group because of a potential conflict of interest. The arrangements for the committee will be reviewed after three years and modified if necessary. It is anticipated that the group will meet two or three times per year.

The Water Corporation response to the review by the monitoring review group will form part of its annual Sustainability Report to Government. The proponent also commits to establish a South West Yarragadee Interpretive Centre in the South West to provide information to the community and visitors about development of the aquifer. This centre could be utilised by the Monitoring Review Group as one of several avenues to make its advice public.

7.2 SOUTH WEST YARRAGADEE SUSTAINABILITY INITIATIVE

The Water Corporation will implement a South West Yarragadee Sustainability Initiative intended to enhance the information base and to provide for maximisation of water availability in the region (Strategen 2006 Volume 1 Chapter 7 Section 4.1.1). This initiative will provide information on key ecological and social aspects and risk areas to complement the information already made available through development of the proposal.

The South West Yarragadee Sustainability Initiative will be an element of the proposed adaptive management framework (Strategen 2006 Volume 1 Chapter 7 Section 4.1.1) and involves commitment to a range of actions to obtain information to refine the existing models of the groundwater system and associated dependent ecosystems and to achieve net benefit outcomes.

Activities undertaken under the initiative will include:

1. A major biodiversity study of groundwater dependent ecosystems of the Scott and Swan Coast Plains and the Blackwood River area potentially affected by the development, which will enhance the baseline against which changes can be assessed.
2. Supporting investigations into the potential for acidification from acid sulphate soils and potential means of management.
3. Research into the magnitude and possible means of management of irrigation return water.
4. Investigations into the effects of changing land use on water demand, availability and quality.

The initiative will be funded through a capital investment of $2 million with the capital and any interest made available to the initiative over a period of ten years.

7.3 ANNUAL SUSTAINABILITY REPORT

The Water Corporation will prepare and publish an annual Sustainability Report outlining the following:

- compliance with statutory requirements of environmental approval and the water licence for abstraction from the Yarragadee aquifer
- assessment of performance against key performance indicators
- implementation of Water Corporation commitments
- summary of environmental and socio-economic monitoring information
- progressive results from the proposed biodiversity study
- stakeholder engagement.

This report will be submitted to the Stakeholder Monitoring Review Group for review before presentation to relevant Government agencies with a response to advice from the monitoring group (Strategen 2006 Volume 1 Chapter 8 Section 3.2.4).

Appendix 2

Wetland Management Plan

South West Yarragadee Water Supply Development

Wetland Management Plan

September 2006

Prepared for
Water Corporation
by Strategen

strategen

WATER CORPORATION

South West Yarragadee Water Supply Development

Wetland Management Plan

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13 September 2006

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Client: Water Corporation

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SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT

WETLAND MANAGEMENT PLAN

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SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT

WETLAND MANAGEMENT PLAN

1. CONTEXT AND SCOPE

The pipeline route has been aligned to avoid wetlands of conservation significance with the exception of the Preston River. Most of the wetlands that may be affected by infrastructure are palusplain wetlands in agricultural areas of the Swan Coastal Plain. Palusplain wetlands are seasonally waterlogged areas and those along the pipeline route are mostly highly degraded and many have been cleared. The pipeline route extends through some wetlands classified as multiple use wetlands.

1.1 PURPOSE AND SCOPE

The purpose of the plan is to provide for the management of construction activities in or adjacent to wetland areas. The actions outlined in this plan are aimed at minimising potential impacts on wetlands, particularly vegetated wetlands, to achieve the environmental objectives for wetlands outlined below.

This plan applies to all wetlands of conservation significance. This plan should be read in conjunction with the Weed Management Plan, Forest Diseases Management Plan, Dewatering Management Plan and Acid Sulphate Soils Management Plan that are included in the SE/ERMP.

For the purposes of this plan, wetlands do not include watercourses. The pipeline crosses the Capel, Ferguson, Preston, Collie and Brunswick Rivers. These are all registered as Aboriginal heritage sites or proposed to be registered (Capel River). The method of pipeline construction across watercourses depends on the outcome of the Aboriginal heritage surveys to be carried out by the Water Corporation. Watercourse crossings will require approval from the Department of Water pursuant to the *Rights in Water and Irrigation Act 1914*.

2. OBJECTIVES

The environmental objectives and key performance indicators are included in Table 2.1.

Table 2.1 Environmental objectives and key performance criteria

Issue	Environmental objective	Performance Indicator
Disturbance to wetlands	To minimise and manage disturbance to wetlands and wetland buffer areas from construction activities.	No wetland dependent vegetation outside approved areas is cleared or destroyed.
Wetland water quality and water regimes	To prevent adverse changes to wetland water quality or flow regimes resulting from construction activities.	No permanent impact on wetland values during construction or following rehabilitation. No adverse change in the water quality of wetlands following rehabilitation. No change in wetland water level regimes following rehabilitation.

3. POTENTIAL IMPACTS

Construction of the pipeline has the potential to affect wetlands located within and adjacent to the corridor alignment in a number of ways including:

- damage or destruction of wetland vegetation
- spread of weeds or disease (e.g. dieback)
- fragmentation of habitat (temporary) and loss of habitat (generally temporary, however, some permanent loss of habitat will occur where removal of large habitat trees is necessary for construction to occur)
- affecting wetland hydrological regimes through increased water runoff flows into wetlands.

Trench dewatering and discharge may affect wetlands through potentially altering hydrological regimes. Changes to the hydrological regimes of wetlands may result from any activities that cause the interception of surface and groundwater flows or through increased water/runoff flows into wetlands. Inappropriate disposal of trench dewater, and surface runoff may lead to the deterioration of surface water quality in wetlands.

Consequently, appropriate management is required to ensure that the environmental risk associated with construction of the pipeline through wetland areas is undertaken to minimise potential detrimental impacts.

4. MANAGEMENT ACTIONS

The management actions for wetland areas are outlined in Table 4.1.

Table 4.1 Management actions for wetland areas

Activity	Action	Timing
Planning	All wetlands and their appropriate buffers (200 m) within and immediately adjacent to the construction corridor shall be identified and recorded prior to construction.	Prior to construction activities
	All activities with potential to affect wetlands shall be scheduled to be undertaken during statistically dry periods.	Prior to construction activities
	All service locations, re-fuelling and fuel storage sites, and infrastructure such as turn around and turkey nests shall be at least 200 m from the nearest wetland and/or within cleared areas.	Prior to construction
Clear and grade	Where vegetation within a wetland or its associated buffer area is required to be disturbed to enable construction, the width of the construction corridor shall be reduced to 20 m to minimise the disturbance.	During clear and grade activities
	Within a wetland or its associated buffer area, all construction activities shall remain within the designated construction corridor.	During clear and grade activities
	Stockpiles shall not be located in wetlands and associated buffer areas.	During clear and grade activities
Trenching and excavation	If Acid Sulphate Soils are identified, trenching and excavation shall be undertaken in accordance with the Acid Sulphate Soil Management Plan (SE/ERMP Volume 2 Chapter 9 Section 20).	During trenching activities
	Disposal of dewater shall be undertaken in accordance with the Dewatering Management Plan (SE/ERMP Volume 2 Chapter 9 Section 15).	During trenching activities

Activity	Action	Timing
Backfill and rehabilitation	Backfill and other disturbed areas within wetlands shall be graded and shaped to be consistent with the pre-existing contours and drainage patterns of wetland area.	During backfilling operations
General	Weeds, pests and dieback shall be managed according to the Weed Management Plan and Forest Diseases Management Plan (SE/ERMP Volume 2 Chapter 8 Sections 11 and 13)	Rehabilitation and cleanup
	Fuel storage and refuelling shall be consistent with the Spills Management Plan (SE/ERMP Volume 2 Chapter 9 Section 18)	At all times
	No storage or handling of fuel or hydrocarbons shall occur within 50 m of a wetland.	At all times

5. MONITORING AND RECORDING, REPORTING AND RECORDING

Monitoring of dewatering discharge will be undertaken as described in the Dewatering Management Plan (SE/ERMP Volume 2 Chapter 9 Section 15).

Monitoring will be undertaken of all clearing activities and compared with approved clearing limits.

Rehabilitation within wetland areas will be undertaken in accordance with the Rehabilitation Management Plan (SE/ERMP Volume 2 Chapter 9 Section 22).

Visual monitoring of soil erosion will be undertaken in wetland areas within or adjacent to the construction corridor. Visual inspection will be carried our weekly during construction.

All information and data recorded through monitoring shall be recorded by the Construction Contractor.

6. CONTINGENCIES

Contingency actions for wetland areas are outlined in Table 6.1. Contingency actions for dewatering discharge are outlined in the Dewatering Management Plan (SE/ERMP Volume 2 Chapter 9 Section 15).

Table 6.1 Contingency actions

Trigger	Action	Responsibility
Wetland areas cleared outside of approved construction areas	Investigate the activity that caused the clearing and determine responsibility. Review Wetland Management Plan. Undertake rehabilitation measures after contacting DEC and obtaining advice regarding rehabilitation measures for wetlands.	Construction Contractor
Soil erosion in wetland areas	Investigate cause Install bunds and drainage measures to reduce impact. Review surface drainage contours.	Construction Contractor

Appendix 3

Watercourse Crossing Management Plan

South West Yarragadee Water Supply Development

Watercourse Crossing Management Plan

September 2006

Prepared for
Water Corporation
by Strategen

strategen

WATER CORPORATION

South West Yarragadee Water Supply Development

Watercourse Crossing Management Plan

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SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT

WATERCOURSE CROSSING MANAGEMENT PLAN

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SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT

WATERCOURSE CROSSING MANAGEMENT PLAN

1. CONTEXT AND SCOPE

The rivers and other watercourses of the Swan Coastal Plain drain towards the coast in a generally westerly direction. The pipeline extends in a generally north-south alignment from the wellfield at Jarrahdale to Harvey and crosses the east-west flowing drainage systems including the Capel, Ferguson, Preston, Collie and Brunswick Rivers. These are all registered as Aboriginal heritage sites or proposed to be registered (Capel River).

The Preston River has been recognised as a wetland of conservation significance.

Watercourses provide habitat for flora and fauna and some are known to have significance to persons of Aboriginal descent. In addition, construction activities at watercourses have the potential to disrupt natural water flows and add suspended materials (particulates) to the water column.

1.1 PURPOSE AND SCOPE

The purpose of the plan is to provide for the management of construction of the pipeline across watercourses to minimise impacts on water quality and riparian zones.

This plan applies to all watercourse crossings along the pipeline route between the wellfield and Harvey. This plan should be read in conjunction with the Weed Management Plan, Forest Diseases Management Plan, Dewatering Management Plan and Acid Sulphate Soils Management Plan that are included in the Sustainability Evaluation/ERMP.

2. OBJECTIVES

The environmental objectives and key performance indicators are included in Table 2.1.

Table 2.1 Environmental objectives and key performance criteria

Issue	Environmental objective	Performance Indicator
Disturbance to watercourses	Minimise and manage disturbance of watercourses.	No long term diversion of watercourses No significant erosion of the watercourse intersecting or adjacent to the pipeline construction corridor. Indicated by visual inspection
Water quality	Prevent contamination of watercourses from construction activities.	No direct discharge of dewatering water to watercourses. Management actions have been implemented. No significant (in excess of 80 litres within 200m of a watercourse) spills or leaks of hydrocarbons during construction and rehabilitation operations outside of areas designated for maintenance, refuelling or storage.

3. POTENTIAL IMPACTS

Three methods are proposed to be undertaken to cross watercourses, with the methods adopted based on the geotechnical characteristics of the site, the environmental significance of the watercourse, the potential for environmental impacts as a result of the activity and expected water flow during construction. The methods proposed involve:

- open trenching
- construction of the pipeline over the watercourse
- horizontal directional drilling (HDD).

Construction of the pipeline across watercourses has the potential to:

- affect water quality through dewatering discharge, erosion or fuel spills
- temporarily alter the direction and volume of flows.

4. MANAGEMENT ACTIONS

The management actions for wetland areas are outlined in Table 4.1.

Table 4.1 Management actions for wetland areas

Activity	Action	Timing
General requirements	River, creek and drain crossings shall be scheduled during dry conditions or low flow periods wherever practicable by observing weather forecasts.	During construction
Access and limits of disturbance	The total area of disturbance shall be marked out with survey pegs so as to delineate the areas of construction activity. If vehicles have to go beyond the marked disturbance areas near watercourses, existing tracks should be used.	Prior to construction
	Habitat trees to be kept shall be marked (flagged).	Prior to construction
Trenching method	For flowing watercourses using the open trenching construction method, the flow will be diverted by channel or by a diversion pipeline. If the watercourse is not flowing, the watercourse will be dammed.	During construction
	Trenches in watercourses shall not be left open during construction breaks that exceed three days duration.	During construction
Drilling	HDD drill site, entry and exit points shall be located away from watercourse banks and riparian areas, as far as practicable.	During construction
	The drilling site shall be completely contained within an appropriate earthen bund. Topsoil must not be used in the construction of the bund.	During construction
	Only water based drilling fluids shall be used.	During construction
Soil, landform and vegetation	Management of soil, landform and vegetation shall be in accordance with the Rehabilitation Management Plan.	During and after construction
	Excavated soil should be stored beyond the riparian vegetation zone to minimise disturbance.	During construction
	Following construction, the banks of the watercourse will be returned to its original alignment and profile and will be rehabilitated	After construction
	Cleared and pruned vegetation shall be stockpiled on-site for later use in bank stabilisation and rehabilitation.	During construction

Water quality	If construction is being carried out in or near a flowing watercourse, a continuous row of un-oaten straw bales will be placed downstream of the construction works for sediment filtration and flow velocity reduction. The bales will be fixed using stakes to the base of the watercourse during construction, and removed following construction.	During construction

5. MONITORING AND RECORDING, REPORTING AND RECORDING

Monitoring of dewatering discharge will be undertaken as described in the Dewatering Management Plan (Sustainability Evaluation/ERMP Volume 2 Chapter 9 Section 15).

Monitoring will be undertaken of all clearing activities and compared with approved clearing limits.

Rehabilitation within wetland areas will be undertaken in accordance with the Rehabilitation Management Plan (Sustainability Evaluation/ERMP Volume 2 Chapter 9 Section 22).

Visual monitoring of soil erosion at watercourse crossings will be undertaken weekly during construction. Drilling sites will be inspected to ensure that mud and drilling fluid is not discharged to the watercourse.

All information and data recorded through monitoring shall be recorded by the Construction Contractor.

6. CONTINGENCIES

Contingency actions for watercourse crossings are outlined in Table 6.1. Contingency actions for dewatering discharge are outlined in the Dewatering Management Plan (Sustainability Evaluation/ERMP Volume 2 Chapter 9 Section 15).

Table 6.1 Contingency actions

Trigger	Action	Responsibility
Erosion/sedimentation	Initiate control measures to prevent further erosion/sedimentation.	Construction Contractor
	Undertake remedial action.	Construction Contractor
	Investigate and update plan as required.	Construction Contractor
Uncontrolled release of drilling mud or fluid	Cease operations	Construction Contractor
	Stop mud entering watercourse.	Construction Contractor
	Investigate cause.	Construction Contractor
	Undertake required remedial action.	Construction Contractor
	Investigate and update plan as required.	Construction Contractor

Appendix 4

Hydrogeology of Blackwood River valley and tributaries and Swan Coastal Plain – report by URS Australia

SWAN COASTAL PLAIN SECTIONS

Background

The area of consideration extends to the Swan Coastal Plain down-slope of the Whicher Scarp. Beneath most areas of the Swan Coastal Plain, where the Guildford Formation is predominate, the superficial formations form a comparatively poor, low transmissivity aquifer. Commonly, the superficial formations comprise a multiple layered stratigraphy. Where the Guildford Formation is present, clay beds are common. The clay beds usually form confining layers that limit vertical groundwater flows. Experience in the mineral sands mining operations in the vicinity and east of Capel provides indications of the effective transmissivity of the superficial formations being typically low. The larger transmissivity domains occur in dunal terrain and reworked Tamala Limestone beds to the north and west of Capel. Lower values occur at South Capel.

There is also demonstrable evidence that the clay beds of the Guildford Formation at Yoganup West (southeast of Capel) are of comparatively low lateral and vertical hydraulic conductivity. In this setting the clays mitigate the propagation of drawdown that arises from pit dewatering abstractions from the Yoganup Formation and Leederville Formation, limiting impacts on the water table environment.

The Yarragadee Formation is known to subcrop beneath the superficial formations on the Swan Coastal Plain. The areas of subcrop are not widespread, occurring only in a coastal/near-shore strip to the south of Bunbury and in a zone to the east of Capel that is transacted by the Capel River. It is expected that drawdown due to abstraction from the Yarragadee Formation would be preferentially manifest in these subcrop zones and in the superficial formations overlying these zones.

The South West Yarragadee Aquifer Peer Review Panel Report on the South-West Aquifer Modelling System (Water Corporation, 2005) indicates that the drawdowns in Layer 1 (superficial formations) beneath the Swan Coastal Plain predicted by the SWAMS2 model are conservatively high, providing an over-estimation of potential drawdown impacts. The Panel indicates that the over-estimation of the predicted drawdowns is linked to under-estimation of potential rainfall recharge in settings where the aquifer systems are full and excess rainfall (rejected recharge) is shed by overland flow. As such, if drawdown of the water table did occur in these settings, the additional storage provided above the water table would be seasonally filled by the infiltration of rainfall that would normally have been rejected.

Development of Swan Coastal Plain Conceptual Hydrogeological Cross-Sections

URS was engaged by the Water Corporation to develop three conceptual hydrogeological cross-sections (Tutunup, Ludlow and Preston) of the superficial formations and regional aquifer systems beneath the Swan Coastal Plain. The cross-sections are intended to provide a view on how pressure changes in the deeper Yarragadee Formation might translate to the surface. The sections, Preston, Ludlow, and Tutunup are named after the nearest river or wetland. They originate off-shore (Figure H2) and terminate near the Whicher Scarp that separates the Blackwood Plateau from the Swan Coastal Plain.

It is intended for the cross-sections to enhance the interpretation of both the local hydrogeology and risks to the water table posed by proposed abstraction from the Yarragadee Formation by the Water Corporation. The sections are developed from the form of the SWAMS2 model, the known and available hydrogeological data and our experience on superficial formations settings of the Swan Coastal Plain in areas between Bunbury and Busselton. Notwithstanding, the sections are interpretive and subject to future revision in the light of additional information.

The sections explore and develop the interpretations of aquifer system distributions, the vertical and lateral differences in simulated hydraulic conductivity, water table and potentiometric surfaces elevations, regarding recharge and discharge zones and mechanisms for propagation of drawdown from the Yarragadee Formation to the water table. The sections are based on recent groundwater level data and as such are not intended to represent natural baseline conditions, but rather a modified setting wherein existing stressors may have altered groundwater levels and flow nets.

Beneath the Swan Coastal Plain the uppermost aquifer is the superficial formations. The Tamala Limestone, Spearwood Dunes, Yoganup Formation and to a certain extent the Bassendean Sand are the more transmissive of superficial formations; the clay and silt beds of the Guilford Formation are typically of low transmissivity. Either the Leederville (Vasse Member) or the Yarragadee Formation subcrop below the superficial formations. Although both formations host aquifers, clayey beds, in particular in the Vasse Member of the Leederville Formation, can limit groundwater flow. The Bunbury Basalt forms an aquiclude that subcrops near and southeast of Bunbury. It is the only aquiclude recognised beneath the Swan Coastal Plain. Aquitards, such as the Parmelia Formation and Mowen Member of the Leederville Formation that occur beneath the Blackwood Plateau, are absent beneath the Swan Coastal Plain.

Recharge to the superficial formations is from diffuse rainfall and upward leakage from the Leederville Formation and the Yarragadee Formation near the coast. Discharge from the superficial formations is to the extensive network of drains and watercourses; and also by evapotranspiration. Downward leakage (recharge) to the Leederville Formation and Yarragadee Formation occurs near the Whicher Scarp. Near the coast, a salt water wedge occurs.

The Vasse Member of the Leederville Formation and the Yarragadee Formation are recharged by diffuse rainfall on the Blackwood Plateau. Discharge from the Vasse Member and Yarragadee Formation is offshore and to the superficial formations near the coast (Hirschberg 1987).

Horizontal groundwater flow is from the Blackwood Plateau towards the coast in all formations. In general, vertical hydraulic gradients indicate downward groundwater flow potentials near the Whicher Scarp and upward near the coast.

Topography is projected to the cross-sections from a 100 m by 100 m Digital Terrain Model supplied by Water Corporation. The sections were created using data imported from a Microsoft Access database supplied by Water Corporation, and bore records obtained from the Department of Water (waterinfo@water.wa.gov.au, 2006). These data include coded geology and time-series groundwater level observations for the Bunbury (BUNx) and Busselton (BUSx) areas.

The vertical elevation range used for the sections, -140 m to +120 m AHD, indicates only local- to intermediate-scale groundwater flows. Previous drilling programmes and regional hydrogeological investigations describe the structure and regional hydrogeology of the Bunbury – Busselton area. These reports include Appleyard (1991), Baddock (1994), Commander (1982 and 1984), Hirschberg (1987), Smith (1984), and Wharton (1981 and 1982). Deep regional flow patterns are explained in Hirschberg (1987). There are numerous additional and site specific investigations of the superficial formations commissioned by private companies (mineral sands mining and processing, horticulturalists and so on) that provide relevant experience regarding the hydrogeology of the Swan Coastal Plain. Most of the site specific investigations are comparatively recent and include project areas such as Capel, South Capel, North Capel, Tutunup, Yoganup North, Yoganup West, Cloverdale, Elgin, Stratham West and Ludlow.

Wherever possible, April 2004 groundwater levels were used to construct the vertical isouipotentials. These represent end-of-the season low groundwater levels. Groundwater levels from years different to 2004 were only incorporated to the sections where the time series data did not show significant fluctuations. The annual range of fluctuations between high (spring) and low (autumn) levels is around 2m for the water table in the Swan Coastal Plain. The annual range for potentiometric level fluctuations for confined aquifers is similar.

Vertical gradients measure the hydraulic connection between different aquifers. High vertical gradients (both downward and upward) between the superficial formations and Yarragadee Formation provide indications of low vertical hydraulic connection. Furthermore, high vertical gradients can be considered an indication for likely small changes in vertical gradients and flow within the superficial formations due to drawdown within the Yarragadee Formation. On the other hand small vertical gradients are the measure of good hydraulic connection and increased potential for both flow and the propagation of drawdown impacts from the Yarragadee Formation
It is understood that the use of vertical gradients alone is not an appropriate tool to interpret the potential water table impacts associated with drawdown of the Yarragadee Formation beneath the Swan Coastal Plain. Other factors such as lateral groundwater flow characteristics in the superficial formations, recharge and discharge zone distributions and rejected recharge occurrences will also contribute to outcomes.

SECTION PRESTON (Figure H3)

Horizontal through-flow occurs from the Blackwood Plateau, beneath DNB2 and DNB1. Downward vertical gradients between the superficial formations and the Yarragadee Formation prevail beneath the Swan Coastal Plain west of DNB1. The potentiometric surface for the Yarragadee (2 or 3) Formation is below the water table along the entire section, demonstrating it currently forms a recharge area for the Yarragadee Formation.

The Bunbury Basalt near BUN27 influences the groundwater flow paths, mounding potentiometric surfaces and creating a local discharge area in the Vasse Member of the Leederville Formation. The potentiometric surface for the Vasse Member is marginally above the water table in the vicinity (BL3 to BUS3) of the basalt subcrops.

West of BL3 pronounced downward gradients are the indication of recharge from both the superficial formations and the Vasse Member towards the Yarragadee (2) Formation. Near BUN8, the basalt again creates steep downward gradients and recharge from the superficial formations to the Yarragadee (3) Formation.

The regional flow is horizontal in the deeper part of the Yarragadee Formations (not displayed in Figure H3). Downward vertical gradients in BUN22, BUN26, and BL3: diminish from 0.15 between the superficial formations and Yarragadee (2) Formation to 0.035 (between Vasse Member and Yarragadee (3) Formation) and 0.01 (through the Yarragadee (3) Formation).

Lakes Beridup-Waneragup Area.

These lakes overlie 20 m of superficial formations and up to 60 m of the Vasse Member of the Leederville Formation. Near Lake Beridup about 70 m of Bunbury basalt was encountered in BUN8. A large downward vertical gradient of 0.15 to 0.18 was measured, as shown in Figure H3, between the superficial formations and the Yarragadee Formation. Locally, the Bunbury Basalt forms an effective barrier to groundwater flow, potentially limiting the transmitting of any changes in groundwater levels between the Yarragadee Formation and superficial formations.

Muddy Lakes

Muddy Lakes are situated over 10 to 15 m of superficial formations that directly overlie the Yarragadee (3) Formation. Although Muddy Lakes are situated west of the Bunbury Basalt subcrop, small downward vertical gradients between the superficial formations and the Yarragadee Formation persist to the coast: downward 0.02 at BUN7 and downward 0.03 at BUN9.

The potential for upward propagation of drawdown from the Yarragadee (3) Formation to the superficial formations may exist at Muddy Lakes and could be manifest by additional (induced) downward leakage in the summer.

The nearest well-logs (Department of Water (DOW) sites 23019013, 23019863, 23019289, 23019290) all indicate the occurrence of fine organic matter and peat beds to a depth of 1 or 2 m beneath Muddy Lakes. These beds may be of comparatively low transmissivity and limit the vertical flow of water from the lakes to underlying superficial formations. As such, the lakes may be perched and not directly connected to the permanent water table.

Water tables are very shallow in the vicinity of Muddy Lakes, being (0.1 at 23019013, 0.5 at 23019289, and 0.7 m at 23019290 in September 2004) below ground level. The off-setting of potential winter drawdowns by increased diffuse rainfall recharge (‘rejected recharge’) therefore is likely in the vicinity of the lakes because of the shallow water table.

SECTION LUDLOW (Figure H4)

The Vasse Member is draped over the Darradup Fault (west of BUS12, Hirschberg 1987). The Vasse Member is up to 100 m thick near the coast.

Significant (0.07 to 0.15) downward hydraulic gradients exist between the superficial formations, Vasse Member and Yarragadee Formation beneath the footslopes of the Whicher Scarp, between TUCKPB and YB1. These gradients are linked to Bunbury Basalt imposing a local influence on groundwater flow, causing upwelling of potentiometric heads on its eastern, upstream side. The vertical hydraulic gradients reduce to the west of the basalt, being 0.04 downward at BUS11. Horizontal flow prevails at BUS10. Near the coast a small upward gradient of 0.02 occurs at BUS4.

Forest Area Between BUS4 and BUS5

The forested area between BUS4 and BUS5 is situated over potentially transmissive limestone and sand beds of the superficial formations. BUS10 is situated further south of the Ludlow River (Figure H2). The vertical differences in water table and potentiometric levels are small, being 0.03 downward at BUS5, 0.01 downward at BUS10 and 0.02 upward at BUS4. The data at BUS4 are indicating the development of a coastal discharge zone for the Yarragadee Formation.

The small vertical gradients indicate that the groundwater flow is predominantly horizontal beneath the forest and near-coast transects. If the head in the Yarragadee Formation declines, either increased downward flow within or a upward flow could develop through the transmissive superficial formations.

Previously rejected winter recharge from rainfall could replenish the superficial formations and water table. Such processes could be manifest by an increased annual range (seasonal fluctuation) in hydrographs. In the summer, with no recharge, the water table could decline with declining head in the Yarragadee Formation. In the winter, the lowered water table may induce increased recharge, partially or wholly off-setting potential drawdown. Monitoring, especially winter peak groundwater levels in the superficial formations and drain flows, are therefore recommended.

Yarragadee Subcrop – Beneath Tiger Gully and West Of BUS12

Beneath Tiger Gully (a tributary of the Ludlow River that transects cleared arable land at Yoganup) the Yarragadee (1) Formation directly underlies the superficial formations. In this setting, drawdown within the Yarragadee Formation has the potential to propagate directly into the superficial formations. The superficial formations in this setting, however, predominantly comprise the Guildford Formation, with subordinate Yoganup Formation (in discrete strands). Evidence in local mineral sands mining operations is that local clay beds of the Guildford Formation are of comparatively low hydraulic conductivity and do not propagate significant drawdown impacts from pit dewatering to the water table. Locally, therefore, the potential for drawdown of the water table due to lowering of potentiometric levels in the Yarragadee Formation is considered to be low. Elsewhere above the Yarragadee Formation subcrop zone, the clay beds and/or sand beds of the Guildford Formation may be of higher transmissivity. In such areas, there will be greater potentials for drawdown within the Yarragadee Formation to propagate to the water table.

SECTION TUTUNUP (Figure H5)

A significant downward hydraulic gradient of 0.15 at BUS22 is translated further west to essentially horizontal flow at BUS10 and BUS21. Near the coast, an upward gradient of 0.05 exists between the Yarragadee Formation and the superficial formations. The potentiometric surface for the Yarragadee (1) Formation intersects the water table near Q5, separating the downward hydraulic gradient recharge areas east of Q5 from the upward hydraulic gradients to the west.

The potentiometric surface for the Vasse Member is similar to the water table, except beneath YB1-BP06 where it is between the water table and the potentiometric surface for the Yarragadee (1) Formation. This indicates local recharge from the water table to the Vasse Member.

In Section H5 most of the interpreted hydraulic gradient evidently occurs through the Vasse Member of the Leederville Formation and the top part of the Yarragadee Formation. The proximity of Bunbury Basalt is, however, understated and may also contribute to the interpreted gradients. Wharton (1981) indicates an outcrop of Bunbury Basalt nearby and basalt was encountered in Q6 (Figure H2 and H5) of the Section Ludlow.

Vasse-Wonnerup Wetlands

The Vasse-Wonnerup Wetlands are situated at low elevations with a hydraulic connection to the sea. There is a high salinity contrast between the two groundwater samples obtained from the local superficial formations (Hirschberg, 1987). Near BUS9, beneath the wetlands, there is a moderate upward gradient of 0.05 from the Vasse Member to the superficial formations. The wetlands are situated above the transmissive sand and Tamala Limestone beds of the superficial formations. In addition, the groundwater levels shown locally within the superficial formations are nearly identical, indicative of strong connection. Therefore the upward gradient must occur through the Vasse Member. Hirschberg (1987) recognised that clay contents in the Vasse Member increased from the east to the west and this characteristic may explain the occurrence of the hydraulic gradient.

Potential groundwater level changes induced by drawdowns in the Yarragadee Formation may at this site be largely suppressed by the close presence and connection of the sea. An indication for suppression is given on Figure 9, Hirschberg (1987): BUS9 has by far the smallest annual water table variation (0.1m) in the entire Dunsborough –Bunbury area.

The Vasse-Wonnerup wetlands are influenced by the presence of the sea. A potential exists for salinity increase in the wetlands, due to lowered heads in the Yarragadee Formation, but this potential is unlikely to be significant.

Tutunup Wetlands

The Tutunup Wetlands are situated near BUS22. Under the wetlands, sandy (BUS22) or silty (YP3), or clayey (TPB1, situated about 4 km to the south) superficial formations overlie the Vasse Member and the Yarragadee Formation. Locally, there is a significant 0.10 to 0.15 downward hydraulic gradient between the superficial formations/Vasse Member and the Yarragadee Formation. This significant downward hydraulic gradient is interpreted to limit the potentials for propagation of drawdown in the Yarragadee Formation to the water table.

CONCLUSIONS

Three conceptual hydrogeological cross-sections beneath the Swan Coastal Plain developed. Each section incorporates the interpreted hydrogeology, including hydrostratigraphic distributions of aquifer systems, groundwater levels and potentiometric surfaces, equipotentials and flow nets. Groundwater levels from April 2004 have predominantly been used in the interpretations, providing a current snap-shot of the water table and groundwater flow potentials. The sections do not describe a baseline nor do they attempt to identify current stressors that may influence the April 2004 groundwater levels.

The interpreted equipotentials, flow nets and vertical hydraulic gradients provide a guide to the potential vulnerability of the water table to drawdown propagation from the Yarragadee Formation.

The areas wherein drawdown in the Yarragadee Formation may be manifest at the water table are interpreted to potentially occur predominantly where the Yarragadee Formation subcrops directly beneath the superficial formations and the Yarragadee Formation discharges into the superficial formations. Both of these situations occur beneath the Swan Coastal Plain. The Yarragadee Formation subcrops directly beneath the superficial formations on both the Preston and Ludlow cross-sections. Yarragadee Formation discharge areas are also interpreted in western and near-coastal transects of the Ludlow and Tutunup cross-sections. In the discharge zones, the potentiometric surfaces of the Yarragadee Formation are commonly very similar to local water table elevations and vertical hydraulic gradients are comparatively small. These aspects indicate hydraulic connection between the Yarragadee Formation and the water table.

Based on the cross-section and interpreted hydrogeology, the drawdown of the Yarragadee Formation may be manifest at the water table in settings similar to those at Muddy Lakes, Forest and other shallow water table zones up to five or six kilometres from the coast. Further inland, the potentials for drawdown of the water table are less, except perhaps in the vicinity of the subcrop zone on the Ludlow section where the Guildford Formation is not comprised predominantly of clay beds or is comparatively transmissive.

BLACKWOOD RIVER VALLEY SECTIONS

MILYEANNUP BROOK)

Milyeannup Brook is incised into both superficial formations and the Yarragadee Formation. The superficial formations are comprised of valley-fill erosional and fluvial deposits of limited distribution adjacent to the water course. Groundwater flow occurs locally from the Yarragadee Formation into the brook. The potentiometric levels in the Yarragadee Formation are upward in the vicinity of Milyeannup Brook, as shown by the piezometers at site BP38. For example in April 2006 potentiometric levels were 33.6 m in the 161 - 167 m screen interval; 33.2 m in the screen interval 56-62 m; and 32.3 m in the screen interval 16-19 m. Horizontal flow is interpreted to be into the section line (towards the viewer).

The superficial formations in the valley of the brook are generally clayey and occur above the interpreted permanent water table. As such, the vegetation that occurs at higher elevations (outside of the current incised channel) along the brook is expected to be predominantly maintained by soil moisture that is replenished by winter rainfall. Near the base of the river valley, close to the watercourse, this is however, increased potential that vegetation would be dependent (in-part) on the water table.

For the most part the superficial formations are in the unsaturated zone. In these areas, there is a low risk of potentiometric level changes in the Yarragadee Formation adversely influencing plant available water. On the valley floor, however, drawdown of the Yarragadee Formation would influence depth to the water table and stream flow. As such, vegetation on the valley floor that is dependent on the water table and/or stream flow may be at risk.

Vertical gradients diminish with depth into the Yarragadee Formation indicating a horizontal flow system (not displayed in Figure H1) at depth.

HYDROSTRATIGRAPHY OF THE ST JOHN BROOK AREA SECTIONS H7 AND H8

St John Brook is located towards the eastern side of the Bunbury Trough URS (2004). The area is underlain in a downward succession by the Leederville Formation, Parmelia Formation and Yarragadee Formation. The Leederville Formation is divided to Members Quindalup, Mowen, and Vasse. The Quindalup Member consists of interbedded clay, silt, and sandy clay. The Mowen Member is mainly sandy or silty clay. The Vasse Member consists of interbedded clayey sand, shale and sand. The Leederville Formation unconformably overlies the Parmelia Formation, being comprised of clayey sandstone, siltstone and shale. The Bunbury Basalt, where present, occupies paleovalleys within the Yarragadee Formation. The Yarragadee Formation is divided to four units (1, 2, 3 and 4) and consists mainly of sand. The uppermost Yarragadee (1) Formation consists of interbedded sands and clays; the Yarragadee (3) Formation is considered the most transmissive.

The Quindalup and Vasse Members of the Leederville Formation and the Yarragadee Formation are considered aquifers; the Mowen Member and Parmelia Formation aquitards, and the Bunbury Basalt is considered an aquiclude.

Previous Work

URS (2004) describes groundwater flow and groundwater – surface water interaction for the lower St John Brook area. The area of interest for the current report is situated about 10 km to the north of the section of St John Brook previously investigated by URS (2004). Figure H6 indicates the locations of the cross-sections created for the current project as well as those by URS (2004).

The lower section of the St John Brook is deeply incised 70 to 80 m into the Leederville Formation and below the surrounding landscape. On the higher ground URS (2004) found pronounced downward vertical hydraulic gradients. Near St John Brook, however, flow was horizontal or slightly up within the Leederville Formation and downward within the Yarragadee Formation. Therefore, it is interpreted that baseflow into St John Brook is predominantly sources from the Leederville Formation.

Data Used For Constructing The Cross-Sections

Encoded geology and groundwater level data, supplied by Water Corporation for the Blackwood Plateau and Cowaramup Line (Bores BPx and CLx), were used to construct Cross-section H7 and H8. Results of a bore search by the Department of Water were also considered but did not yield significant additional information. A 20 m by 20 m digital terrain model, supplied by Water Corporation, was used to project topography and watercourse elevations to the cross-sections.

Section H7

This section runs from CL6 in the southwest to BP07 in the northeast. Horizontal flow is generally out of the section line (towards the viewer). The entire section is characterized by persistent and large downward vertical hydraulic gradients, particularly within the Mowen Member. Downward vertical hydraulic gradients between the surface (Quindalup or Mowen members of Leederville Formation) and the underlying Vasse Member are in excess of 0.20. The largest downward vertical hydraulic gradient was measured in BP07 as 0.5 between the Quindalup and Mowen Members of the Leederville Formation. Downward vertical gradients, within the Leederville Formation, between the Mowen and Vasse Members, are between 0.1 and 0.4. In comparison downward vertical gradients between the various Yarragadee Formation units are 0.02 (CL6 and CL7, between Yarragadee (1and 3) Formation) or 0.005 between Yarragadee (3) and the Cockleshell Gully Formation. These hydraulic gradients indicate vertical flow within the Leederville Formation changing eventually to horizontal flow deep within the Yarragadee Formation (below -300m AHD, thus not displayed in Figure H7). These aspects indicate the interpreted hydrogeological cross-sections and conceptual hydrogeological model are not entirely compatible. The sections demonstrate that the interpreted vertical hydraulic gradients within the Mowen Member are inconsistent. For example, in the vicinity of CL7 the Mowen Member is comparatively thick but the interpreted vertical hydraulic gradient is comparatively low. At BP07, however, the vertical hydraulic gradients are four or five times steeper.

An alternative interpretation would impose a perched water table within Mowen Member and overlying Quindalup Member successions, as interpreted elsewhere beneath the Blackwood Plateau.

The upper reaches of St Paul, St Joseph, and St John Brook are interpreted to be above the water table. The range of annual water table fluctuations since 2004 is less than 1 m in BP08 and BP09, the closest bores. These data indicate that the brooks are losing water (recharging groundwater) most of the year.

Section H8

This section runs west to southeast and intersects St John Brook just below the St Paul Brook confluence. Horizontal flow is out of the section line (towards the viewer). The potentiometric surface for the Yarragadee (1) Formation is at least 30 m below the interpreted water table. Interpreted vertical hydraulic gradients between the Leederville Formation and Yarragadee Formation are very large and downward through the entire cross-section, except in the vicinity of St John Brook. Here, the water table (in the Mowen Member of the Leederville Formation) and the brook intersect - as predicted by URS (2004).

Vertical downward hydraulic gradients within the Leederville Formation are large, in excess of 0.2; vertical downward hydraulic gradients between the Leederville Formation and the top of the Yarragadee (1) Formation are between 0.15 and 0.5. An alternative interpretation would impose a perched water table within Mowen Member and overlying Quindalup Member successions, as interpreted elsewhere beneath the Blackwood Plateau.

The interpreted vertical hydraulic gradients change markedly (decrease by an order of magnitude) within the Yarragadee (1 to 3) Formation, being 0.015 (CL8), 0.026 (CL6), and 0.029 (CL7). Similar to Figure H7, these hydraulic gradients indicate vertical flow in the Leederville Formation turning to horizontal flow in the deeper parts of the Yarragadee Formation.

Evaluation

Observations by URS (2004) and Strategen (2006) indicate the upper reaches of perennial baseflow in St John Brook occur several hundred meters downstream of the confluence of St Paul Brook. Cross-section H7 and H8, north of the perennial section of the stream, support this interpretation, indicating that St John Brook is locally a losing stream (stream level is higher most of the year than groundwater level). Figure 6 of URS (2004) indicates that St John Brook as a gaining stream (baseflow from groundwater) in the vicinity of the St Paul Brook confluence.

The large downward vertical hydraulic gradients displayed in Sections H7 and H8 would appear to be an effective barrier to transmitting potentiometric level changes between the Yarragadee Formation and Leederville Formation to the water table. The occurrence of perched water table zones is considered likely and this occurrence would further mitigate any potential impacts in near surface, shallow profiles.

ROSA BROOK (SECTIONS H10, H11 AND H12)

Rosa Brook is a southward flowing tributary of the Blackwood River. Rosa Brook typically flows only from early-winter to late-spring each year (Strategen, 2006).

Hydrostratigraphy

The Rosa Brook area is underlain in downward succession by the Mowen and Vasse Members of the Leederville Formation, and Yarragadee Formation. In the upper Rosa Brook catchment, the Mowen Member outcrops; lower in the catchment, the Vasse Member becomes exposed. The Quindalup Member is exposed only in the Blackwood River Valley.

The Quindalup Member consists of interbedded clay, silt, and sandy clay. The Mowen Member is mainly sandy and silty clay. The Vasse Member consists of interbedded clayey sand, shale and sand. The Quindalup and Vasse Members of the Leederville Formation, and the Yarragadee Formation are considered aquifers; the Mowen Member is an aquitard.

Data Used For Constructing The Cross-Sections

Encoded geology and groundwater level data, supplied by Water Corporation for the Blackwood Plateau (Bores BPx) were used to construct Figures H10, H11 and H12. A 20 m by 20 m digital terrain model, supplied by Water Corporation, was used to project topography and watercourse elevations to the cross-sections. The location of the cross-sections is shown in Figure H9.

Section Rosa Brook North - H10

This section runs from bp22 in the west to bp43 in the east. Horizontal flow is generally out of the section line (towards the viewer).

A perched water table is interpreted in the Mowen Member of the Leederville Formation. There is no direct hydraulic connection between the potentiometric surface in the Yarragadee Formation and the perched water table.

Although little data are available, the permanent water table appears to be in the Vasse Member and Yarragadee (1) Formation. There is little information to quantify vertical hydraulic gradients. A downward vertical gradient of 0.03 to 0.06 is however interpreted through the Vasse Member and 0.003 to 0.004 through the Yarragadee (2) Formation. These interpretations indicate downward flow through the Vasse Member changing to horizontal flow in the Yarragadee Formation. Most of the cross-section is indicative of a recharge area for the Yarragadee Formation (downward leakage from the Vasse Member); with horizontal flow in the east due to the transmissivity of the sub-crop zones of the Yarragadee Formation.

Section Rosa Brook South - H11

This section is characterised by complex vertical isopotentials and groundwater flow lines. These characteristics are in-part due to the cross-section following and intersecting the Blackwood River in several locations and the strong groundwater – surface water interaction east of BP25. Horizontal flow is into the cross-section from both the rear and front view.

The western part of the cross-section is characterised by small, 0.006 to 0.01, upward vertical hydraulic gradients and discharge from the Yarragadee Formation to the Vasse Member. The Vasse Member also receives groundwater from the Mowen Member (upward vertical hydraulic gradient of 0.05 to 0.1). Therefore, a recharge area local to BP62 is underlain by a discharge area. The area adjacent to BP27 is a groundwater discharge zone for both the Vasse Member of the Leederville Formation and the Yarragadee Formation. East of BP25 strong and complex groundwater-surface water interaction and horizontal groundwater flow/recharge to the Yarragadee Formation are indicated. Due to this complex pattern, an additional cross-section, Rosa Brook Longitudinal (Figure H12) was created to represent vertical flow better and simpler near the confluence of Rosa Brook and the Blackwood River.

Section Rosa Brook Longitudinal - H12

This cross-section runs parallel with Rosa Brook and groundwater flow is downstream in horizontal sense, from BP13 to the Blackwood River Valley. In the upper Rosa Brook catchment the interpreted water table is situated in the Vasse Member, deep under the perched groundwater in the Mowen Member. A small vertical downward hydraulic gradient must exist but is difficult to quantify. Horizontal groundwater flow prevails from SWY4 to Rosa Brook; the vertical hydraulic gradient in this area is 0.003 downward in the Yarragadee Formation. The Blackwood River near BP27 is indicated as a discharge zone from both the north (BP27) and south (BP55). This is indicated by the 0.04 upward vertical hydraulic gradient between the Vasse and Quindalup Members measured in BP55 and the interpreted upward groundwater flow lines from the Yarragadee Formation.

Summary

Rosa Brook only flows from early-winter to late-spring and is distinctly situated above the permanent water table. These aspects indicate that it is a losing stream (where surface water recharges the water table), except perhaps near the confluence with the Blackwood River. Vegetation along the Rosa Brook, except in reaches nearing the Blackwood River confluence, is interpreted to be predominantly maintained by soil moisture that is replenished by rainfall, rather than depending solely on the water-table.

The upper catchment of the Rosa Brook intersects the Mowen Member wherein a perched water table is interpreted. The lower catchment intersects the Vasse Member and receives recharge from the underlying Yarragadee Formation.

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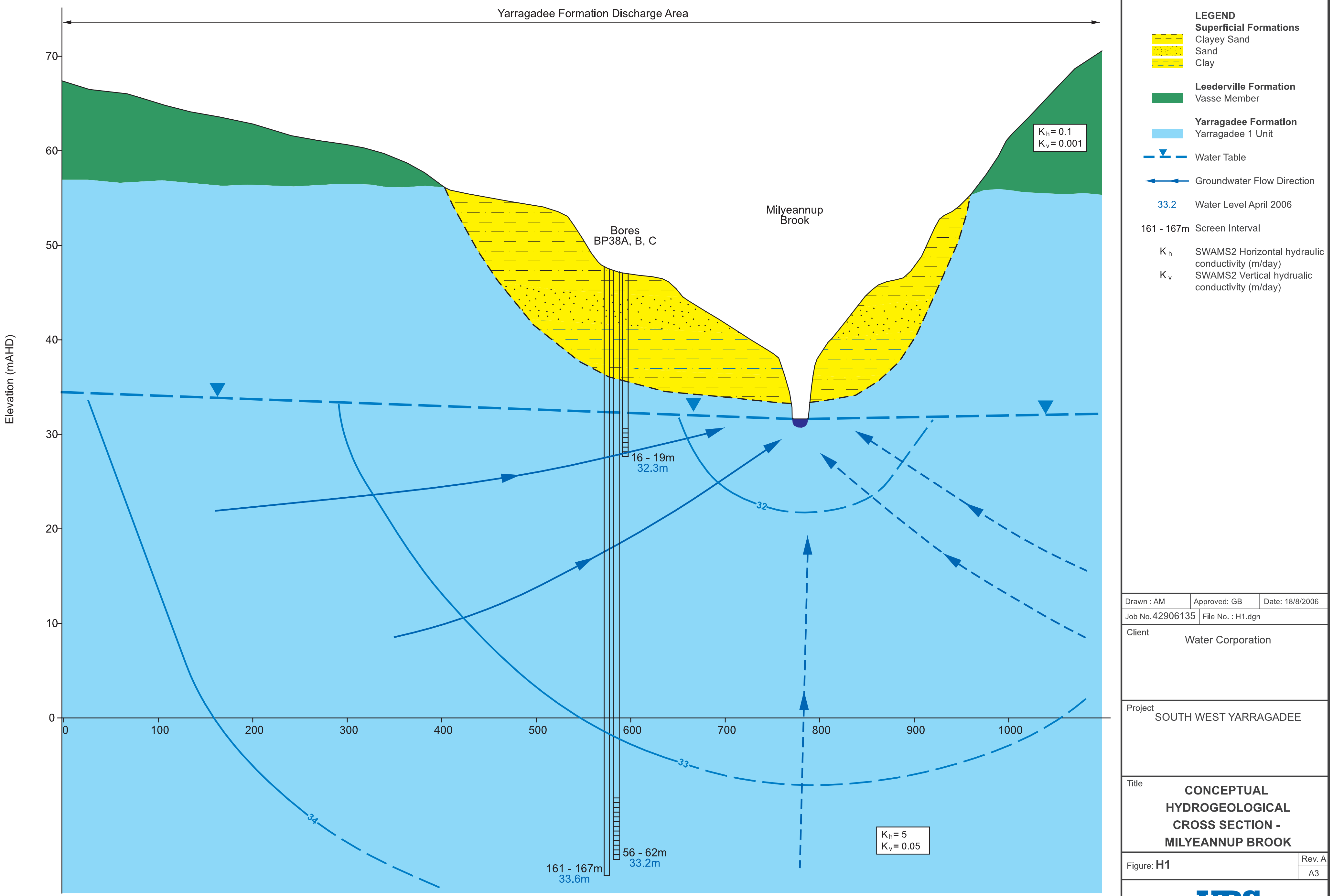


Drawn : AM	Approved: GB	Date: 18/8/2006
Job No.42906135	File No. : H1.dgn	

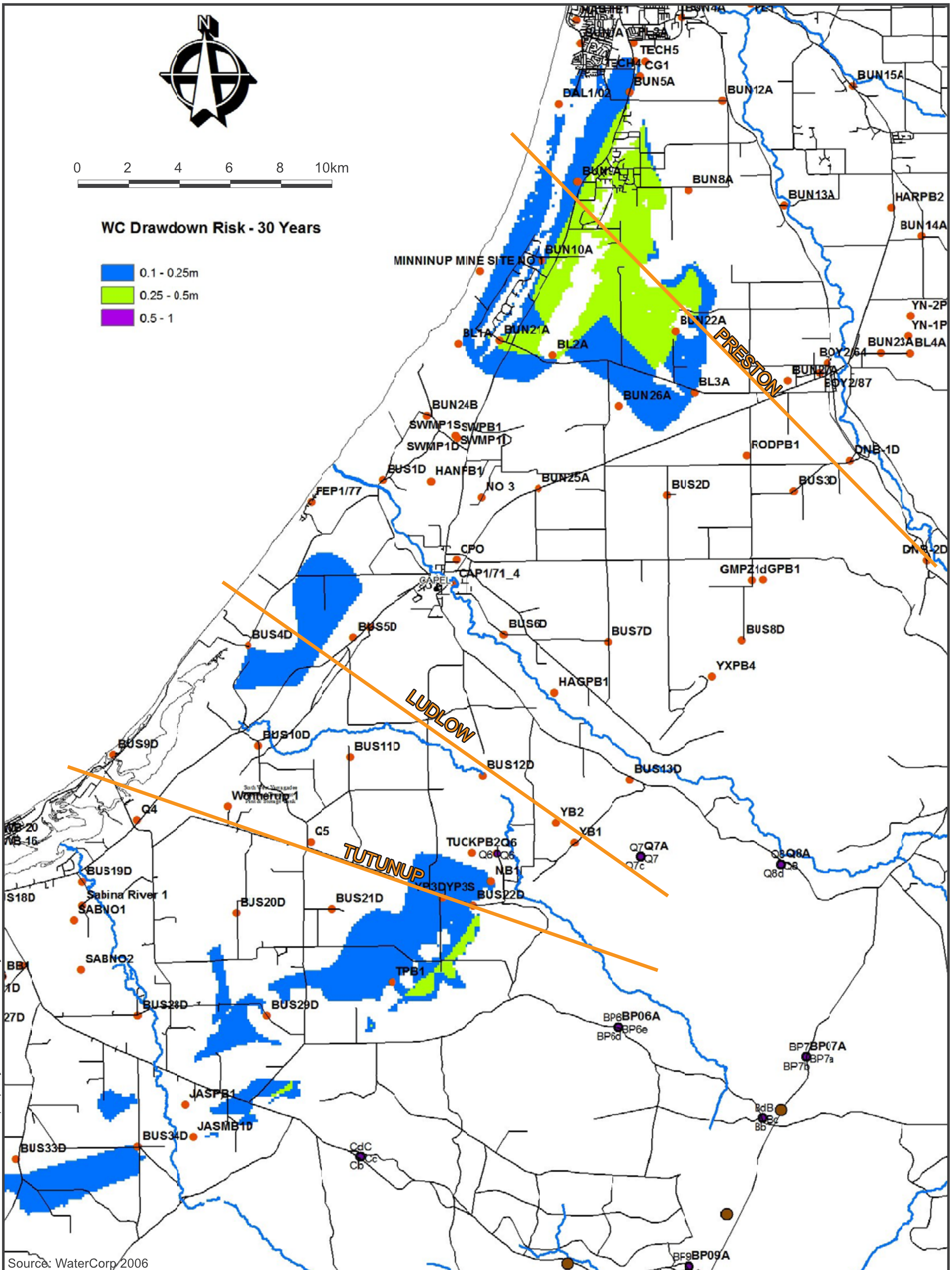
Client: Water Corporation

Project: SOUTH WEST YARRAGADEE

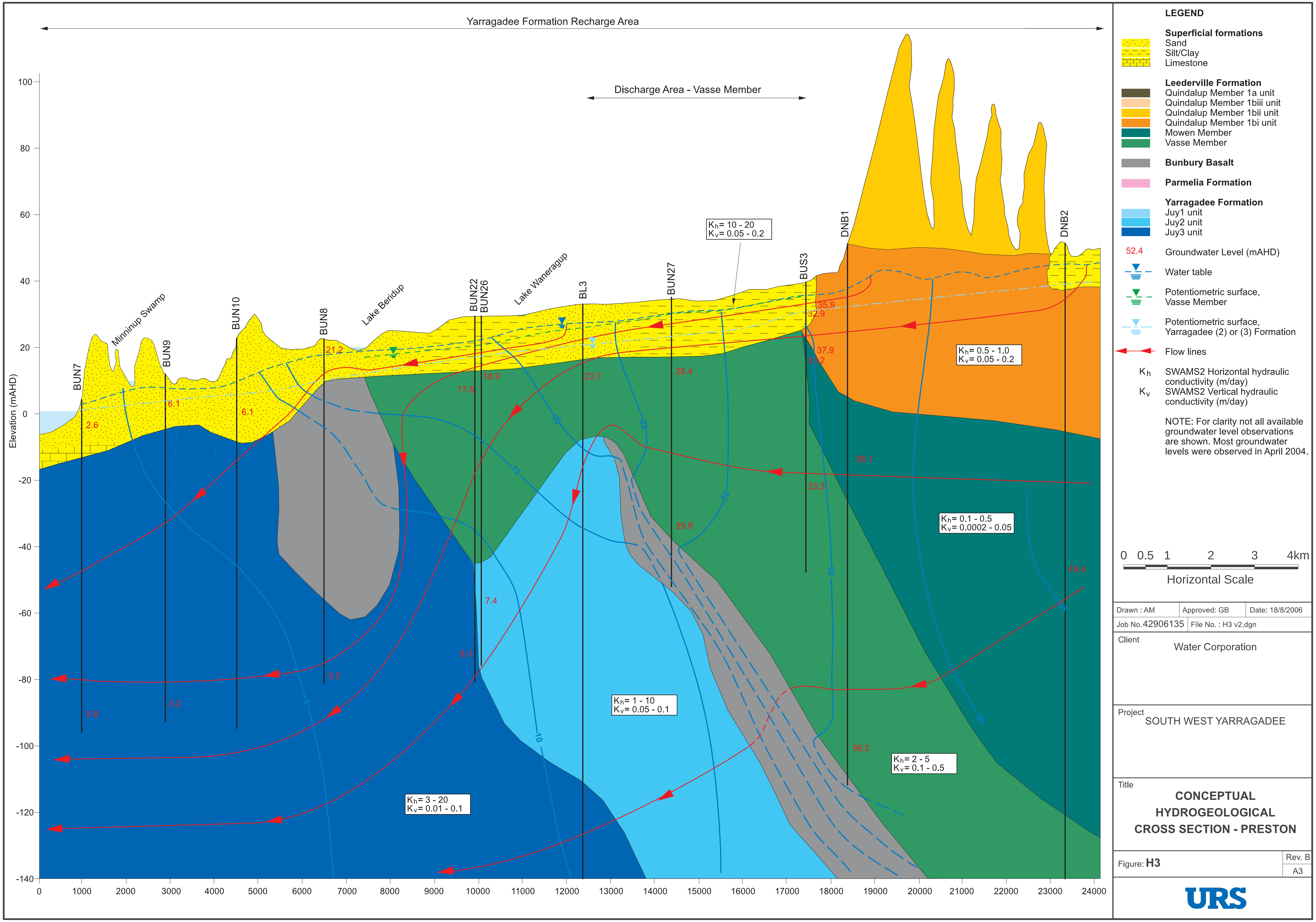
Title: **CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - MILYEANNUP BROOK**

Figure: **H1** — Rev. A — A3

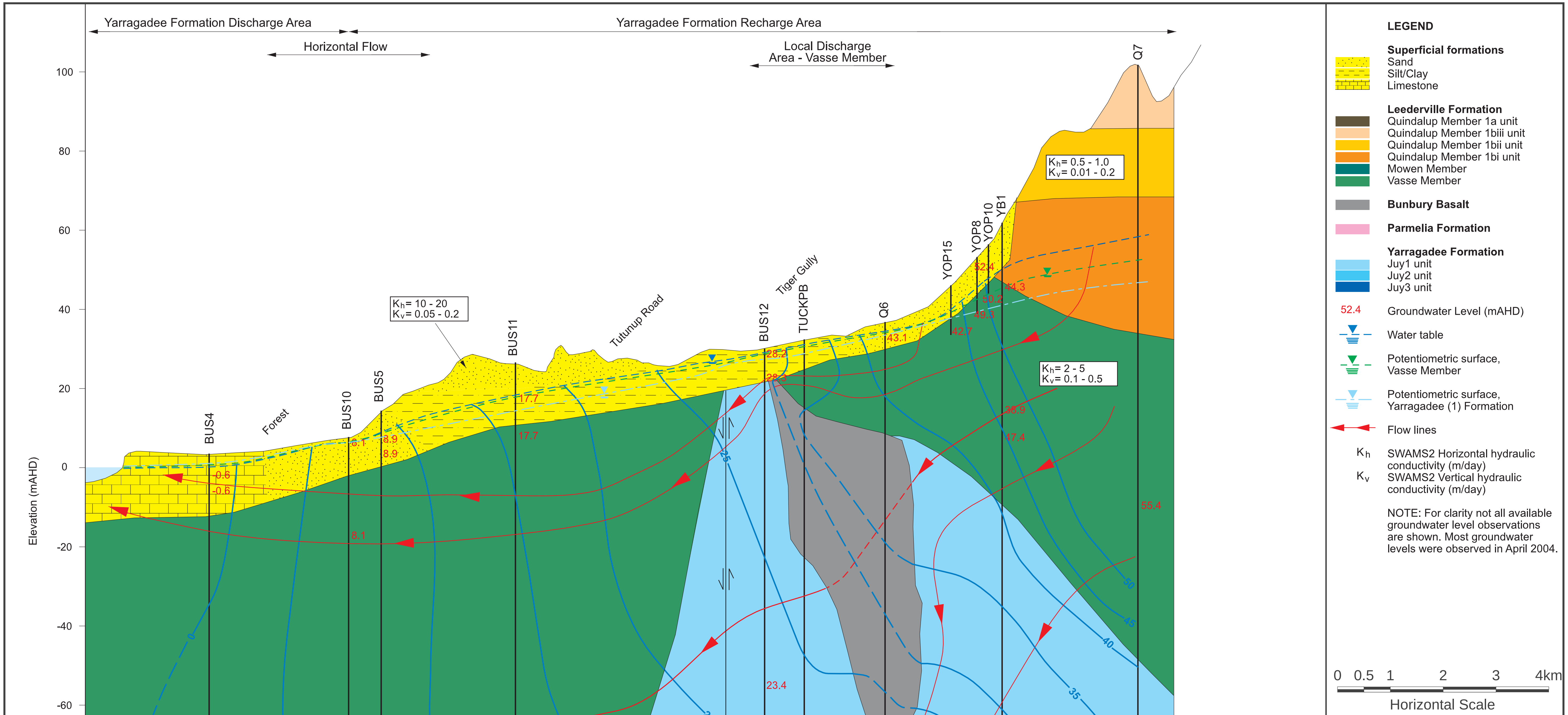
URS



Client	Project	Title
Water Corporation	SOUTH WEST YARRAGADEE	**LOCATION MAP**
URS	Drawn: AM / Approved: GB / Date: 26/7/2006	Figure: **H2** / Rev. A
	Job No.: 42906135 / File No.: H2.dgn	A4



Yarragadee Formation Recharge Area
Discharge Area - Vasse Member
Elevation (mAHD)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
20000
21000
22000
23000
24000
BUN7
Minninup Swamp
BUN9
BUN10
BUN8
Lake Beridup
BUN22
BUN26
Lake Waneragup
BL3
BUN27
BUS3
DNB1
DNB2
Kh= 10 - 20
Kv= 0.05 - 0.2
Kh= 0.5 - 1.0
Kv= 0.05 - 0.2
Kh= 0.1 - 0.5
Kv= 0.0002 - 0.05
Kh= 1 - 10
Kv= 0.05 - 0.1
Kh= 2 - 5
Kv= 0.1 - 0.5
Kh= 3 - 20
Kv= 0.01 - 0.1
2.6
6.1
6.1
21.2
17.8
18.9
23.7
28.4
35.9
32.9
37.9
33.2
38.1
33.3
29.9
45.6
7.4
5.0
5.2
0.8
3.2
36.2
LEGEND
Superficial formations
Sand
Silt/Clay
Limestone
Leederville Formation
Quindalup Member 1a unit
Quindalup Member 1biii unit
Quindalup Member 1bii unit
Quindalup Member 1bi unit
Mowen Member
Vasse Member
Bunbury Basalt
Parmelia Formation
Yarragadee Formation
Juy1 unit
Juy2 unit
Juy3 unit
52.4 Groundwater Level (mAHD)
Water table
Potentiometric surface, Vasse Member
Potentiometric surface, Yarragadee (2) or (3) Formation
Flow lines
Kh SWAMS2 Horizontal hydraulic conductivity (m/day)
Kv SWAMS2 Vertical hydraulic conductivity (m/day)
NOTE: For clarity not all available groundwater level observations are shown. Most groundwater levels were observed in April 2004.
0 0.5 1 2 3 4km
Horizontal Scale
Drawn : AM
Approved: GB
Date: 18/8/2006
Job No.42906135
File No. : H3 v2.dgn
Client
Water Corporation
Project
SOUTH WEST YARRAGADEE
Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - PRESTON
Figure: H3
Rev. B
A3
URS



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Job No. 42906135 | File No. : H4 v2.dgn

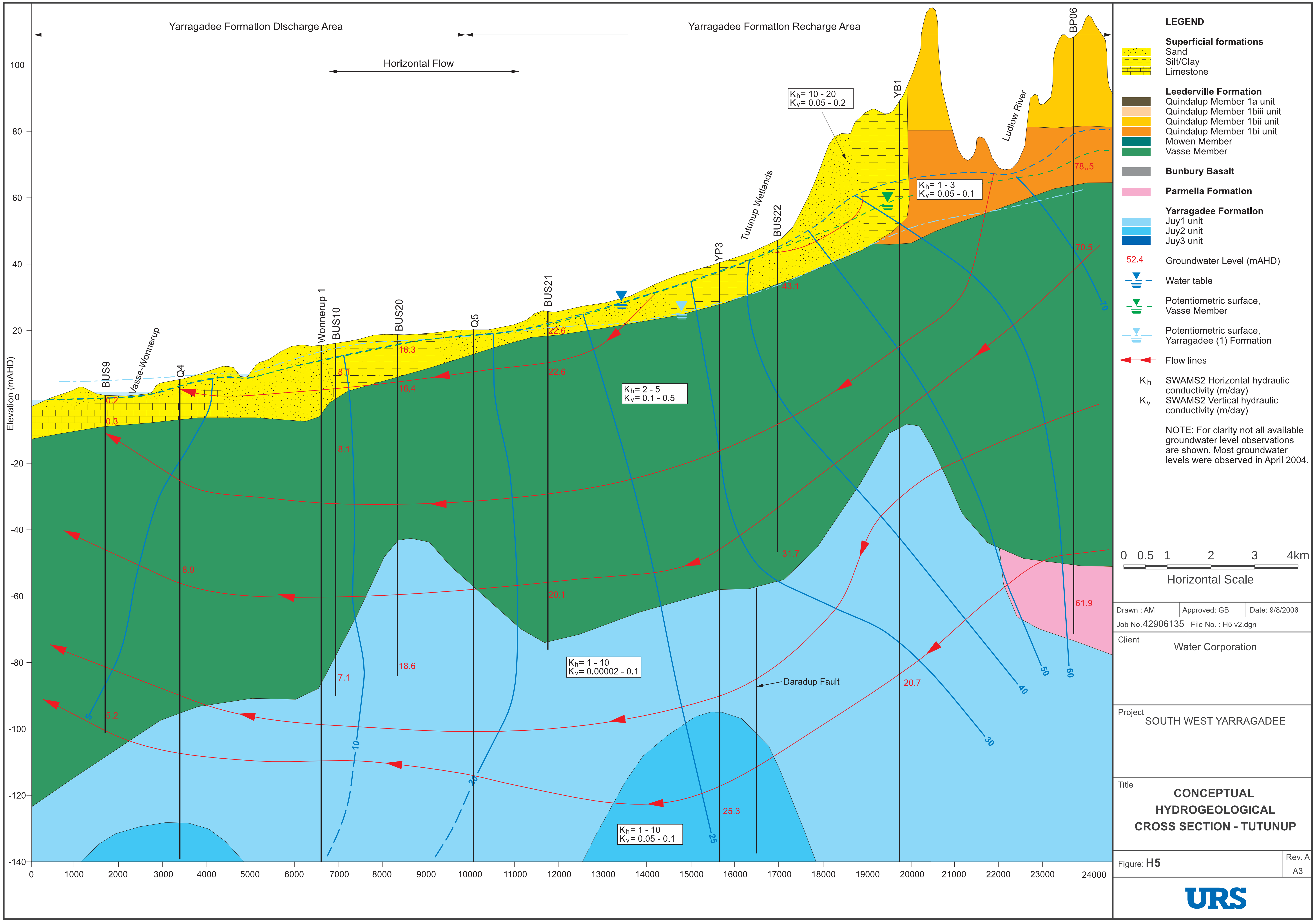
Client: Water Corporation

Project: SOUTH WEST YARRAGADEE

Title: **CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - LUDLOW**

Figure: **H4** | Rev. B | A3

URS



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Job No. 42906135 | File No. : H5 v2.dgn

Client
Water Corporation

Project
SOUTH WEST YARRAGADEE

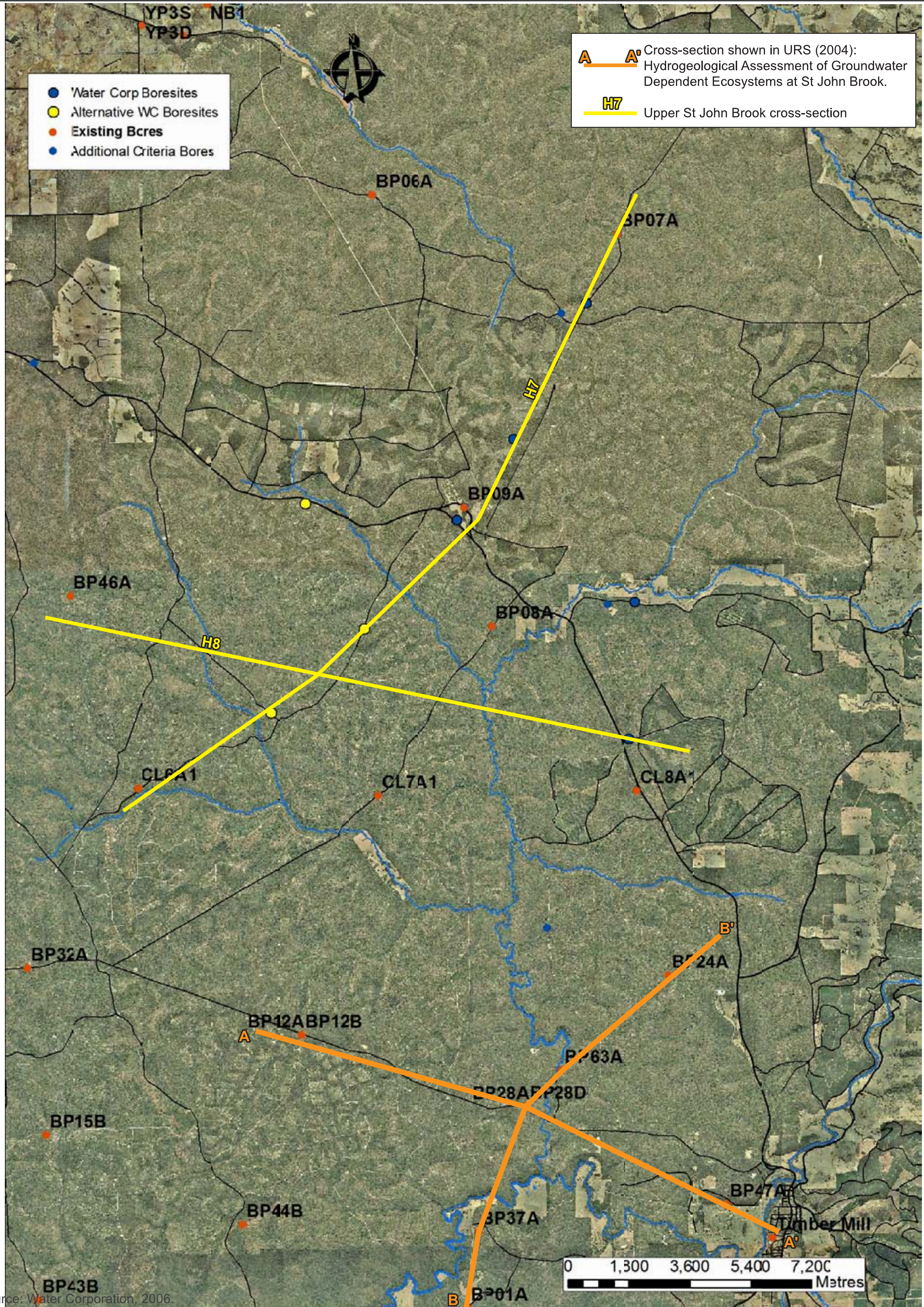
Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - TUTUNUP

Figure: **H5**

Rev. A

A3

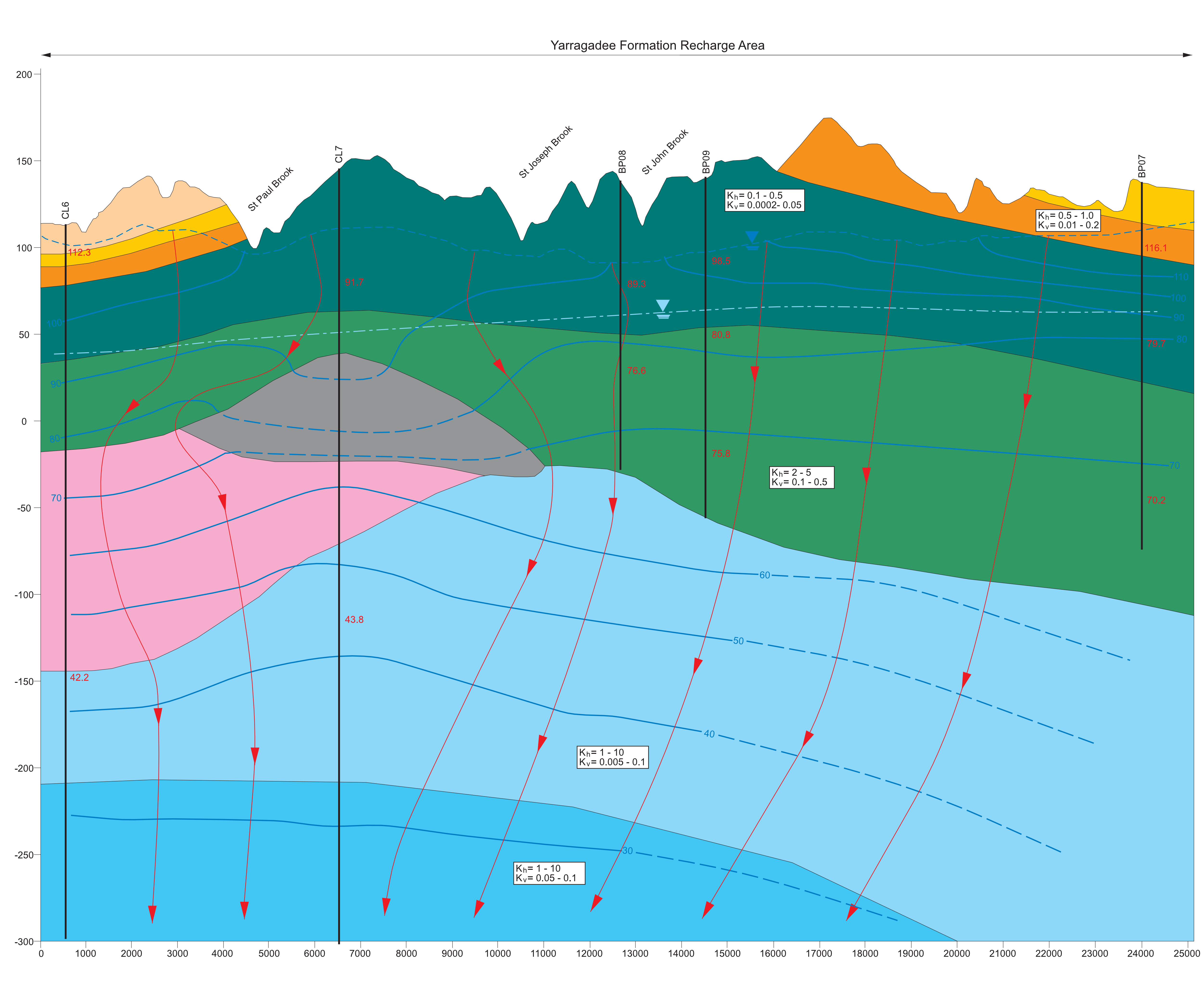
URS

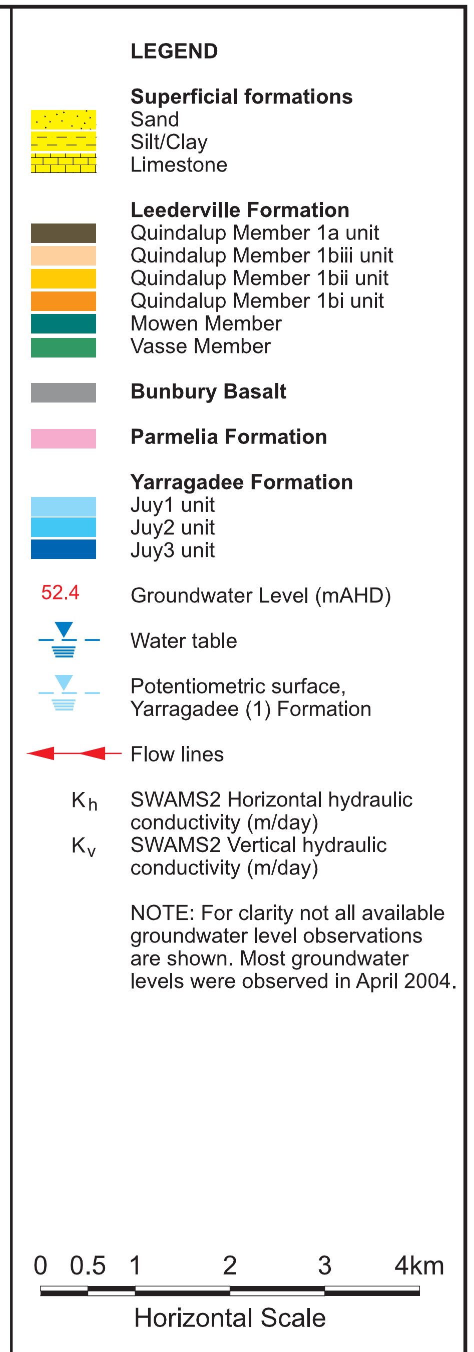


Source: Water Corporation, 2006.

Client	Project	Title
Water Corporation	SOUTH WEST YARRAGADEE	XXXXXX

Drawn: AM	Approved: GB	Date: 4/8/2006	Figure: H6	Rev. A
Job No.:42906135	File No.: H6.dgn			A4





Drawn : AM	Approved: GB	Date: 18/8/2006
Job No. 42906135	File No. : h7.dgn	

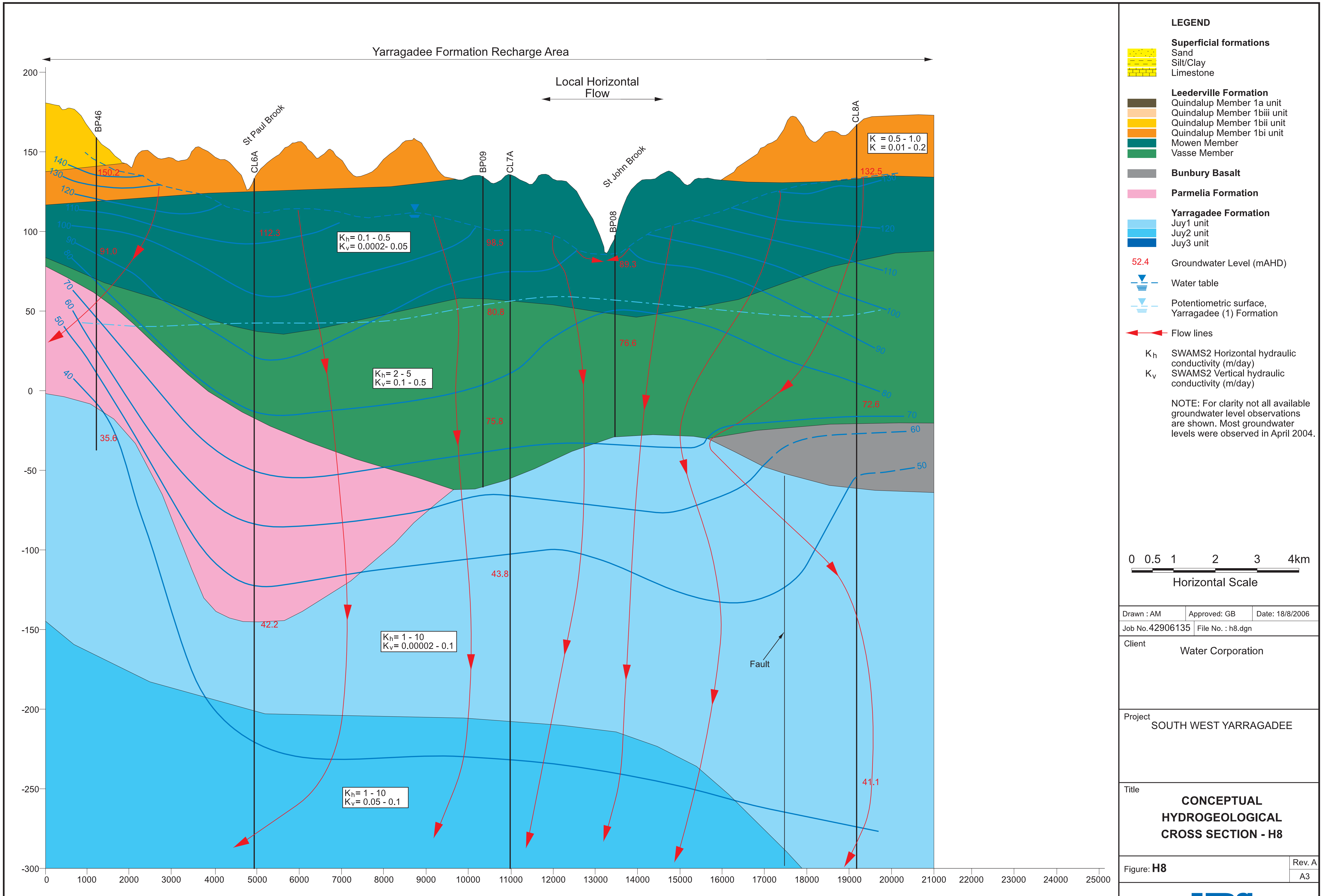
Client
Water Corporation

Project
SOUTH WEST YARRAGADEE

Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - H7

Figure: **H7** | Rev. A | A3

URS



Drawn : AM | Approved: GB | Date: 18/8/2006

Job No. 42906135 | File No. : h8.dgn

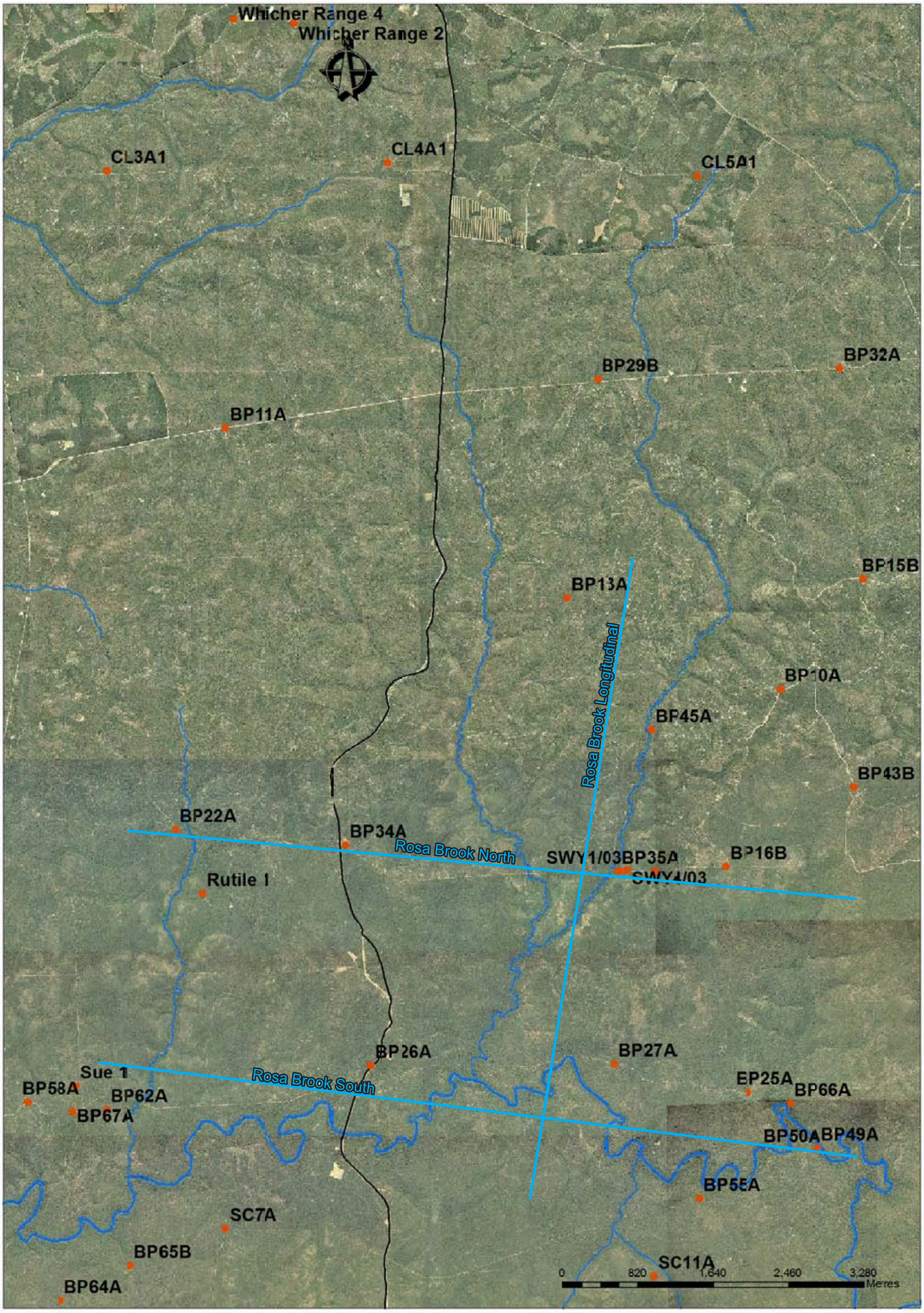
Client: Water Corporation

Project: SOUTH WEST YARRAGADEE

Title: **CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - H8**

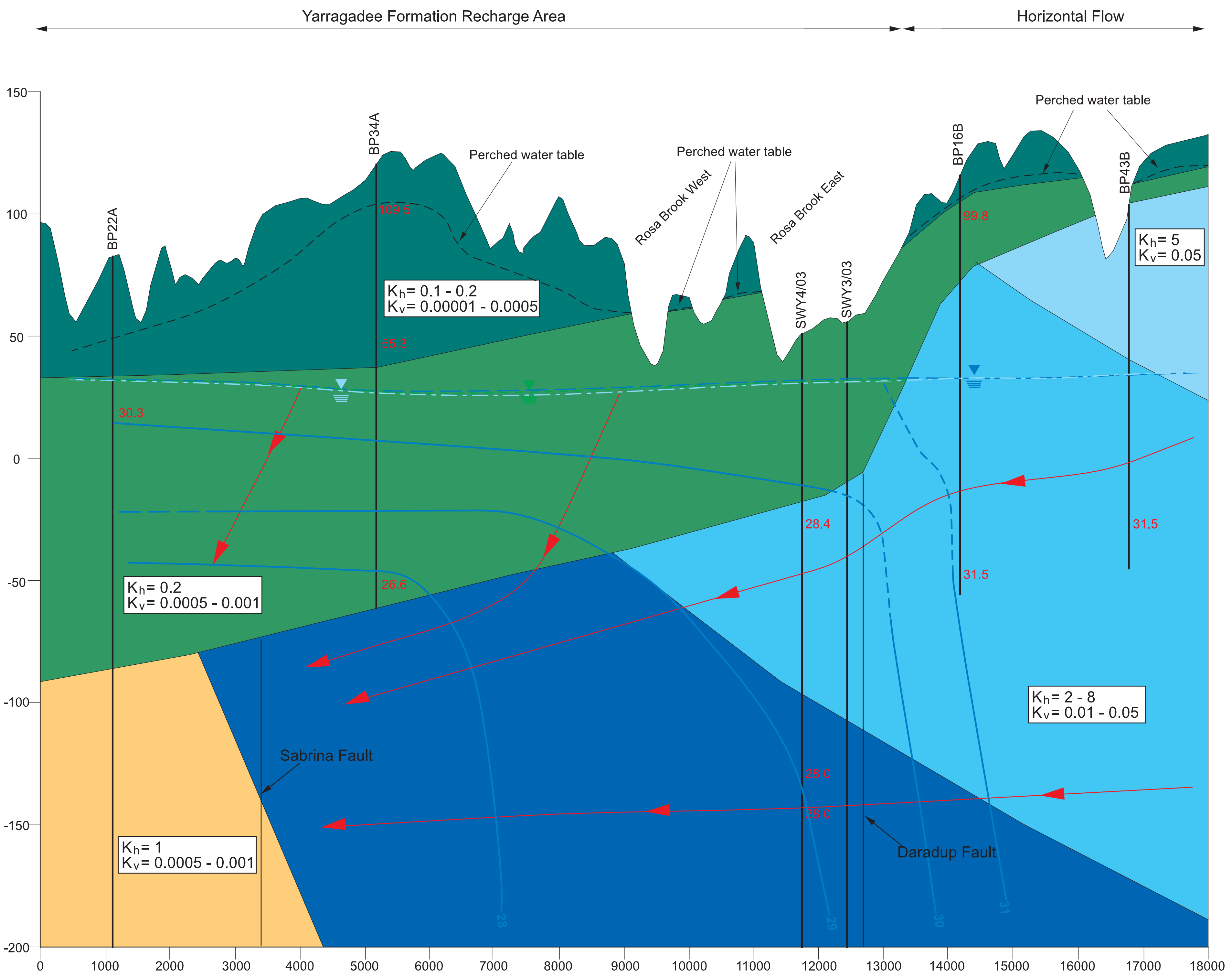
Figure: **H8** | Rev. A | A3

URS



Source: Water Corporation, 2006.

Client	Project	Title
Water Corporation	SOUTH WEST YARRAGADEE	**ROSA BROOK CROSS-SECTION LOCATIONS**
URS	Drawn: AM / Approved: GB / Date: 17/8/2006	Figure: **H9** / Rev. A
	Job No.:42906135 / File No.: H9.dgn	A4



LEGEND

Superficial formations
Sand
Silt/Clay
Limestone

Leederville Formation
Quindalup Member 1a unit
Quindalup Member 1biii unit
Quindalup Member 1bii unit
Quindalup Member 1bi unit
Mowen Member
Vasse Member

Bunbury Basalt

Parmelia Formation

Yarragadee Formation
Juy1 unit
Juy2 unit
Juy3 unit

Cockleshell Gully Formation

52.4 Groundwater Level (mAHD)

Water table

Potentiometric surface, Vasse Member

Potentiometric surface, Yarragadee (2) & (3) Formation

Flow lines

K_h SWAMS2 Horizontal hydraulic conductivity (m/day)

K_v SWAMS2 Vertical hydraulic conductivity (m/day)

NOTE: For clarity not all available groundwater level observations are shown. Most groundwater levels were observed in April 2004.

0 0.5 1 2 3 4km

Horizontal Scale

Drawn : AM	Approved: GB	Date: 18/8/2006
Job No.42906135	File No. : H10 v2.dgn	

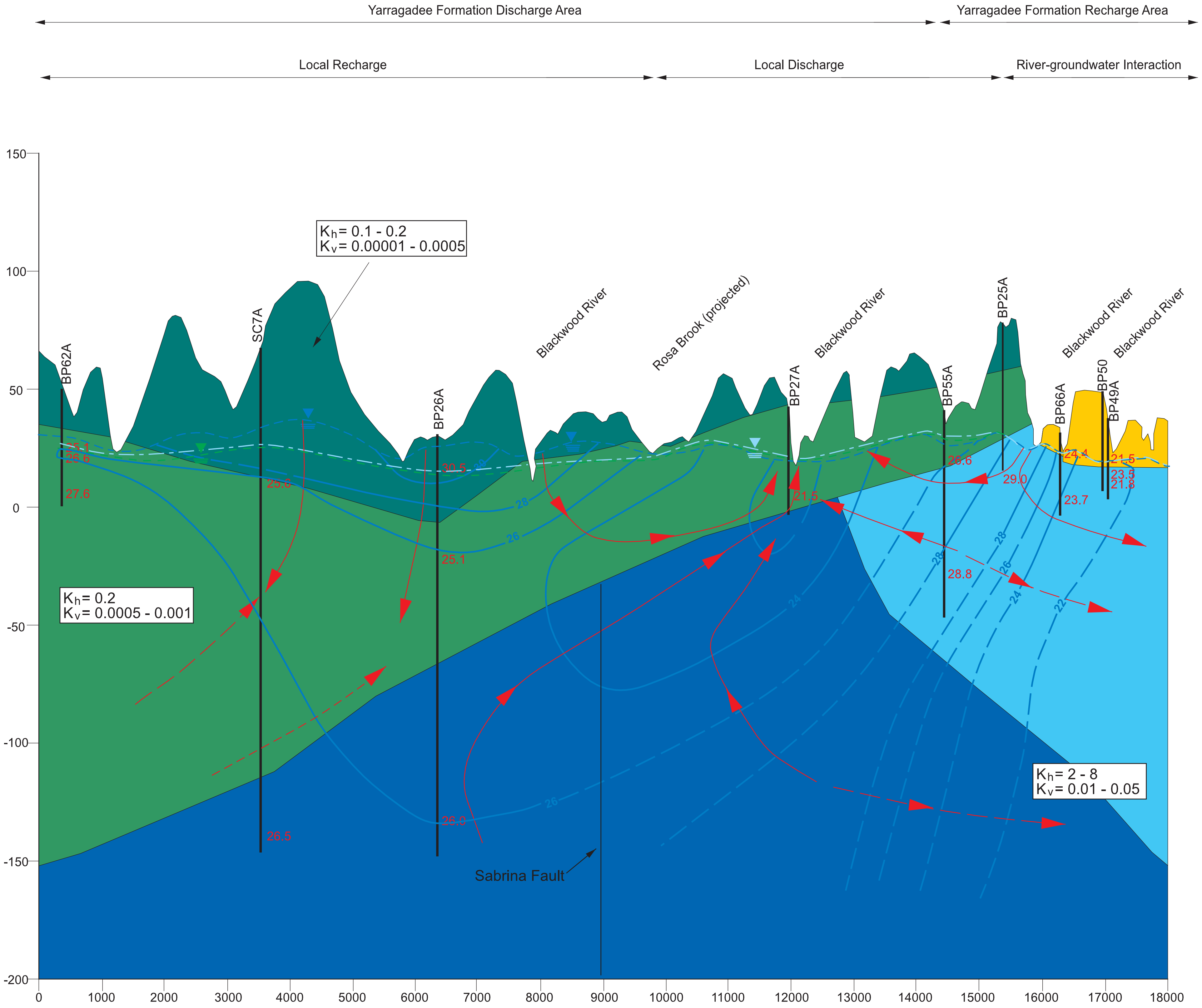
Client
Water Corporation

Project
SOUTH WEST YARRAGADEE

Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - ROSA BROOK NORTH

Figure: **H10** Rev. A A3

URS



LEGEND

Superficial formations
Sand
Silt/Clay
Limestone

Leederville Formation
Quindalup Member 1a unit
Quindalup Member 1biii unit
Quindalup Member 1bii unit
Quindalup Member 1bi unit
Mowen Member
Vasse Member

Bunbury Basalt

Parmelia Formation

Yarragadee Formation
Juy1 unit
Juy2 unit
Juy3 unit

52.4 Groundwater Level (mAHD)

Water table

Potentiometric surface, Vasse Member

Potentiometric surface, Yarragadee (2) & (3) Formation

Flow lines

K_h SWAMS2 Horizontal hydraulic conductivity (m/day)

K_v SWAMS2 Vertical hydraulic conductivity (m/day)

NOTE: For clarity not all available groundwater level observations are shown. Most groundwater levels were observed in April 2004.

0 0.5 1 2 3 4km

Horizontal Scale

Drawn : AM	Approved: GB	Date: 18/8/2006
Job No. 42906135	File No. : H11 v2.dgn	

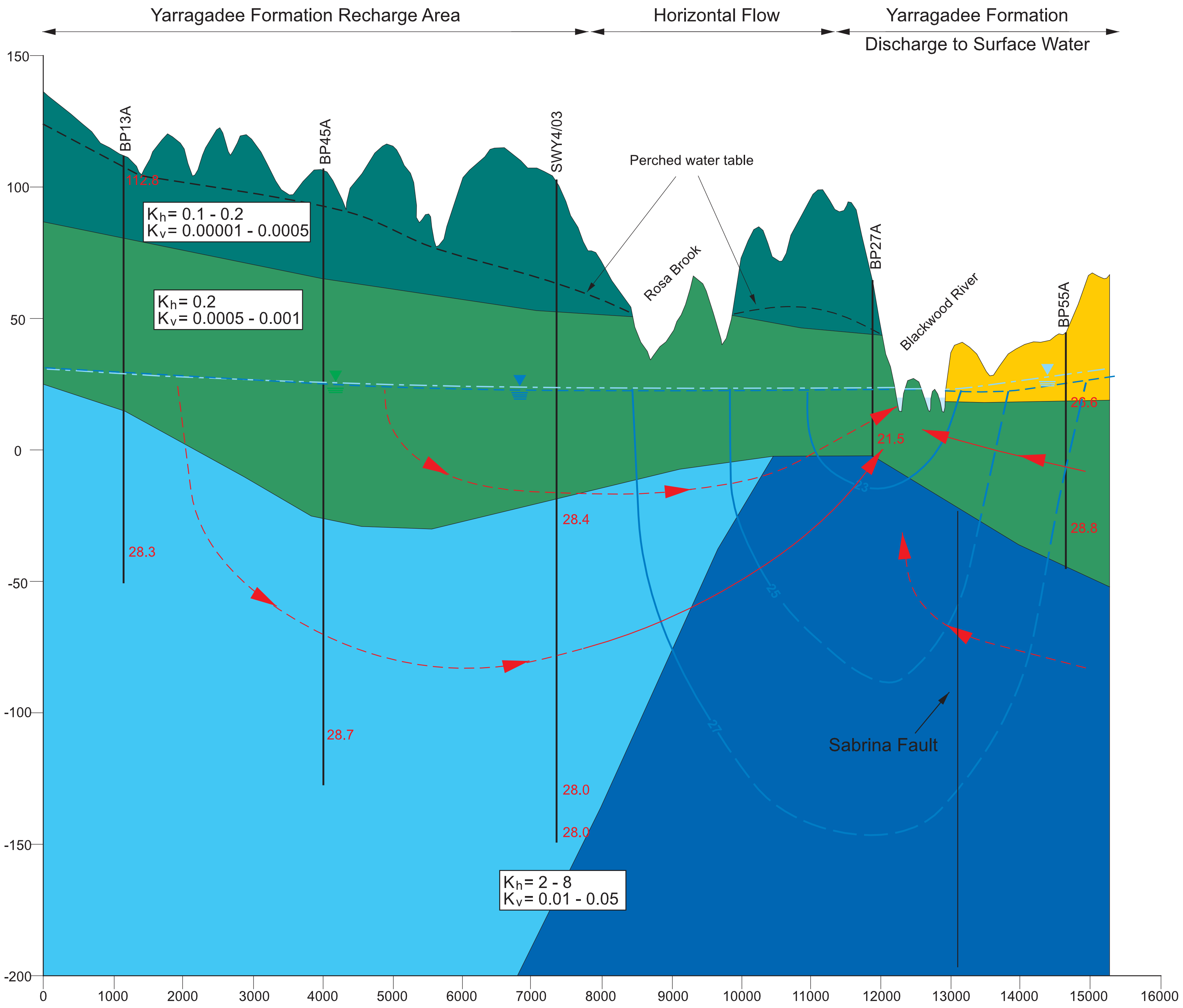
Client
Water Corporation

Project
SOUTH WEST YARRAGADEE

Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - ROSA BROOK SOUTH

Figure: **H11** Rev. A A3

URS



LEGEND

Superficial formations
Sand
Silt/Clay
Limestone

Leederville Formation
Quindalup Member 1a unit
Quindalup Member 1biii unit
Quindalup Member 1bii unit
Quindalup Member 1bi unit
Mowen Member
Vasse Member

Bunbury Basalt

Parmelia Formation

Yarragadee Formation
Juy1 unit
Juy2 unit
Juy3 unit

52.4 Groundwater Level (mAHD)

Water table

Potentiometric surface, Vasse Member

Potentiometric surface, Yarragadee (2) Formation

Flow lines

K_h SWAMS2 Horizontal hydraulic conductivity (m/day)
K_v SWAMS2 Vertical hydraulic conductivity (m/day)

NOTE: For clarity not all available groundwater level observations are shown. Most groundwater levels were observed in April 2004.

0 0.5 1 2 3 4km
Horizontal Scale

Drawn : AM	Approved: GB	Date: 18/8/2006
Job No.42906135	File No. : H12 v2.dgn	

Client
Water Corporation

Project
SOUTH WEST YARRAGADEE

Title
CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION - ROSA BROOK LONGITUDINAL

Figure: **H12** Rev. A
A3

URS

Appendix 5

Supplementation feasibility – letter report by URS Australia

URS

7 September 2006

Ref: 42906135/629-F7815

Water Corporation
629 Newcastle Street
West Leederville
W.A. 6902

Attention: Mark Leathersich
Principal Engineer

Dear Sir,

Subject: BLACKWOOD RIVER AND TRIBUTARIES SUPPLEMENTATION BORES

URS has been asked, to provide an assessment of the feasibility of supplementing the Blackwood River and tributaries at key locations to make up for the potential reductions in base-flow resulting from the proposed 45 GL/annum abstraction from the Yarragadee Formation. This letter summarises our supplementation assessments. Groundwater quality, temperature, pH, dissolved oxygen (DO), power requirements in operating the bores and engineering concepts are discussed.

1. Background

The Water Corporation is currently in the process of providing a response to submissions to the South West Yarragadee ERMP. Modelling studies conducted to date have shown that the base-flow contributions to the Blackwood River and tributaries may be reduced by the proposed abstractions. As such, the Water Corporation is assessing the feasibility of supplementing the Blackwood River and tributaries, St John Brook and Milyeannup Brook, with abstracted groundwater from selected local production bores sites.

Four supplementation bores, to augment the base-flow of Blackwood River (two sites: Yarragadee Formation and Leederville Formation) and St John Brook and Milyeannup Brook are proposed. It is expected that a three-month supplementation campaign will be needed at 10 l/s for the two Blackwood River schemes; 5 l/s for Milyeannup Brook; and 2 l/s for St John Brook. The source of the supplementary groundwater will be four new bores drilled to the Yarragadee Formation.

2. Hydrostratigraphy

The Blackwood River and its tributaries are deeply incised into the Blackwood Plateau, being characterised by steep-sided valleys below the plateau surface. The Blackwood River has locally eroded the Leederville Formation and traverses, along different reaches, Bunbury Basalt, Parmelia Formation and Yarragadee Formation. Perennial pools maintained by base-flow occur in the low gradient sections of the watercourse and in scoured pools. Flows are confined to narrow channels.

The Yarragadee Formation is the preferred source of groundwater for supplementation because:

- It can easily yield the required amounts of groundwater;
- In many places it is predominantly disconnected from the water table by the Mowen Member of the Leederville Formation, and/or the Parmelia Formation; and
- Abstraction from the Yarragadee Formation will have minimal impacts at the water table.

The areas preferably identified as possible sites for installing the production bores for supplementation are where the Mowen Member is present as confining beds. The Mowen Member is predominantly formed of clay and is considered an aquitard. The shale of the Parmelia Formation (where it is present) also forms an aquitard between the Leederville Formation and the Yarragadee Formation. Drawdown from the Yarragadee Formation supplementation abstractions will predominantly be attenuated by these aquitards. The hydrostratigraphy of the Blackwood River and its tributaries is therefore such that it suits the supplementary scheme. This is supported by preliminary predictive modelling results that indicate:

- Drawdown from the supplementation bores would be predominantly limited to the Yarragadee Formation.

- There is no year-to-year accumulation of drawdown from the proposed three-monthly supplementation campaigns.

- Further reduction in base-flow in the Blackwood River and tributaries is not expected as a result of the supplementary scheme.

3. Production Bore Sites

The production bore sites for supplementation were selected based on the following criteria, designed to minimise drawdown impacts. These criteria include:

1. Minimum depth to water table of 15 m. It is generally accepted that ecosystem dependency decreases with increasing depth-to-water table, and terrestrial fauna and flora rely mostly on groundwater with less than 10 m depth to water table.
2. Minimum depth to top of Yarragadee Formation of 100 m.
3. Target screen zone situated in the deeper, interpreted horizontal flow zones of the Yarragadee Formation. Combined with criteria 2, these ensure an adequate separation between the water table and the target screened zone in the Yarragadee Formation.
4. Sufficient thickness below Mowen Member and Vasse Member of the Leederville Formation. The Mowen Member is an aquitard that potentially will limit the propagation of drawdown between from the Yarragadee Formation to the water table.
5. Absence of Bunbury Basalt. Drilling through the basalt, while possible, may add unnecessary costs to the project.

A GIS tool was developed to search the numerical groundwater flow model for locations that meet these criteria. Table S1 and Figure S1 outline the recommended production bore sites and specifications. Relevant information is derived from the data that forms the SWAMS2 model (Water Corporation, 2005) and hydrogeological classifications of the nearest monitoring well (supplied by Water Corporation, 2006).

Table S1. Supplementary Production Bore Details and Specifications.

Scheme and total volume of water pumped* (ML)	Flow rate (L/s)	Grundfos Pump and Power Rating	Target Coordinates (MGA 94)	Estimated Ground Elevation (m AHD)	Target Depth (m)	Target Aquifer	Target Screen Interval (m AHD)	Target SWL (m AHD)	Target Lift** (m)	Salinity*** (mg/L TDS)	Base of Yarragadee Formation*** (m AHD)	Nearest Applicable Monitoring Well**** and Summary Log (m AHD)
St John Brook 15.5	2	SP14A 7.5 kW SP17 5.5 Kw	379099; 6246681	143	263-303	JUY1	-120- to -160	74	90	300-500	JUY1 -200 JUY2 -500	BP28 95.6 80.6 1BII 80.6 62.6 1BI 62.6 37.6 2AI 37.6 7.6 2B 7.6 -25.3 2C -25.3 -196.3 JUY1 -196.3 -252.3 JUY2
Milyeannup Brook 38.8	5	SP14A 7.5 kW SP17 7.5 kW	368182; 6220275	124	224-264	JUY2,3	-100 to -140	53	90	200-400	JUY1 -25 JUY2 -175 JUY3 -550	BP38 46.4 34.8 Qund 34.8 -133.5 JUY3
Blackwood River (Yarragadee Formation) 77.8	10	SP46 18.5 kW	375025; 6230440	119	229-269	JUY1,2	-110 to -150	42	120	200-400	JUY1 -175 JUY2 -450	BP05 88.3 58.3 2AI 58.3 32.3 2C 32.3 5.3 3A 5.3 -31.7 3B -31.7 -55.7 3C -55.7 -79.7 JUY1
Blackwood River (Leederville Formation) 77.8	10	SP46 13 kW	378572; 6239650	60	210-250	JUY1	-150-190m	33	70	200-400	JUY1 -200 JUY2 -500	BP37 73.1 48.1 2AII 48.1 41.1 2 AI 41.1 -22.9 2B -22.9 -31.9 2C -31.9 -201.9 JUY1 -201.9 -340.9 JUY2

* Assuming a three-months long supplementation scheme
** Estimated for 20 m above ground elevation, 50% well loss, and a specific discharge of 200 m^3/day/m.
***Source for information: Water Corporation, 2005. South West Yarragadee Hydrogeological Investigations and Evaluation, Southern Perth Basin.
**** Source for information: Water Corporation database, 2006

The total amount of groundwater to be abstracted, assuming a three-month supplementary campaign, is 210 ML/year or below 0.5% of the proposed 45 GL/year abstraction.

The described target depths represent the minimum depths. The information in Table S1 is indicative only, being based on general information. Site-specific testing (pumping and groundwater quality) are recommended to confirm local conditions. For water treatment options, a field-trial or pilot study is recommended before actual treatment systems are designed.

3.1 Water Quality

The watercourses nearest to the production bore sites for the Blackwood River, St John Brook, and Milyeannup Brook are perennial, being Yarragadee Formation discharge areas where most of the summer stream flow is supplied by groundwater.

Target surface water quality, in terms of salinity, temperature, dissolved oxygen (DO), and manganese, are those listed in the ANZECC guidelines (Tables 3.3.1, 3.3.6, and 3.3.7, 2000) for freshwater ecology:

Salinity	120-300 µS/cm (approximately 80 - 200 mg/L TDS)
Temperature	20-80 percentile of reference data
Dissolved oxygen	80 -120% saturation or the 20 percentile of reference data
Manganese	1.2 mg/L (99% protection) and 3.6 mg/l (80% protection).

The ANZECC guidelines (2000) for freshwater ecology do not specify iron thresholds. The ANZECC guidelines values can be changed to suit local ecosystems and reference data. The unconditional adoption of the above salinities, for example, for the largely brackish environment of the Blackwood River, would be inappropriate. Conversely, a target is set for dissolved manganese that is lower than the ANZECC guidelines because of aesthetic reasons.

Few observations by Department of Water data indicate total iron levels of 0.3 mg/l to 0.6 mg/l at Hut Pool, Blackwood River (Site.No.16144). It is generally accepted, however, that for aesthetic reasons, iron concentrations should be less than 0.3 mg/L, while manganese concentrations should be less than 0.05 mg/L. Dissolved iron and manganese concentrations in the abstracted groundwater are likely to exceed these aesthetic values. Once groundwater comes into contact with oxygen from the air, oxidation causes the formation of rust coloured ferric and brownish-black manganic particles. Treatment is required and it is recommended to target iron and manganese concentrations of 0.3 mg/L and 0.05 mg/L respectively for the supplementation scheme.

Baddock (1994) also noted comparatively high dissolved iron and manganese concentrations (14 to 33 mg/L for iron and 0.11 to 0.84 mg/L for manganese) in the Yarragadee Formation. The pH of the Yarragadee Formation in the vicinity of the supplementation schemes is 5.3 to 6.5 (Baddock, 1994). Department of Water records indicate a pH range (20 to 80 percentile) of 4.8 to 6.2 (162 samples). Appleyard (1991) indicated that the chemistry of groundwater from the Yarragadee Formation appears to be uniform over the Swan Coastal Plain and the Blackwood Plateau.

The pH for the Blackwood River ranges from 6.8 to 7.3, with Milyeannup Brook and St John Brook being more acidic in April 2005 (pH 5.7 to 5.8 and pH 5.9 to 6.2, respectively).

3.2 Groundwater salinity

The salinity of the Yarragadee Formation groundwater is estimated from 130 to 590 mg/L (URS 2004), and 100 to 400 mg/L (Davies and Price, 2003). The median salinity of 171 Yarragadee

Formation groundwater samples is 330 mg/L; with a 20 to 80 percentile range of 204 to 555 mg/L TDS (data supplied by Department of Water, 2006). Salinities from Water Corporation reports, listed in Table S1 indicate a similar range. Overall, groundwater from the supplementation production bores will be similar in salinity to the natural base-flow that sustains the Blackwood River and tributaries during the summer months.

Salinity generally decreases with increasing depth within the Yarragadee Formation. The supplementation production bores will have the option of targeting groundwater quality that is compatible with the base-flow conditions.

3.3 Yarragadee Formation Groundwater Temperature

The ANZECC guidelines (Table 3.3.1, 2000) for aquatic ecosystem protection recommend default trigger values for temperature as the 20 and 80 percentile of reference (monitoring) data. Several sources of surface water temperature data are discussed below. The sources for these data include URS (2004), and the Department of Water database. Figure S2 shows the locations of observation sites.

Department of Water temperature data obtained by URS in 2006 indicate (Table S2) that the temperatures of surface waters to be supplemented are within the 10 to 21 degree C range (20 to 80 percentile). Summer temperatures are expected in the range of 15 to 25 degree C. As the supplementation is intended for summer only, target temperatures of 15 to 25 degree C are adopted.

The temperature of groundwater from Yarragadee Formation in the target screen intervals of -100 to -200 mAHD is estimated to be between 17 and 25 degree C. This estimate is based on published temperature profiles and geothermal gradients by Appleyard (1991), Baddock (1994), Commander (1982 and 1984), Hirschberg (1987), Smith (1984), and Wharton (1981 and 1982), mainly beneath the Swan Coastal Plain.

Interpretations for the stratigraphy beneath the Swan Coastal Plain extent beneath the Blackwood Plateau. The Karridale Line (Baddock, 1994; 'KL bores') and Cowaramup Line (Appleyard, 1991; 'CL bores') border the areas proposed for the supplementation production bores. Bores KL5 and KL6 (Baddock, 1994) indicate temperatures of 17 to 22 degree C; CL6 (Appleyard, 1991) around 20 to 25 degree C. Further north, bores Q6-Q8 of the Quindalup Line (Wharton, 1982) indicate temperatures of 22 to 24 degree C.

Table S2. Summary of summer temperatures and annual pH values in the Blackwood River and its tributaries.

	Time-Series Data	Estimated Summer Range (Degree C)	pH (20 to 80 Percentile)
609003 St Paul Brook*	1974 to 1995	15 to 25	5.9 to 6.7
609018 St John Brook*	1983 to 2005	15 to 25	6.2 to 7.1
609019 Blackwood River*	1983 to 2006	17 to 25	7.0 to-7.6
6091008 Milyeannup Brook*	1971 to 1977	15 to 21	5.8 to 7.6
Yarragadee Formation*	n/a	15-25	4.8 to 6.2 (162 samples)
Yarragadee Formation**	n/a	17-25	n/a

*Data obtained from Department of Water, 2006.
**Data from Appleyard (1991), Baddock (1994), Commander (1982 and 1984), Hirschberg (1987), Smith (1984), and Wharton (1981 and 1982).

The range for groundwater (17 to 25 degree C) and summer surface water temperature (15 to 25 degree C) in the Blackwood River and its tributaries overlap. Hence no significant impacts are expected within the proposed three-month summer campaign.

3.4 Dissolved Oxygen (DO)

Low dissolved oxygen (DO) concentrations may effect aquatic organisms (fish, invertebrates and microorganisms, ANZECC, 2000).

The concentration of DO is dependent on temperature, salinity, biological activity (microbial, primary production) and rate of transfer from the atmosphere. Under natural conditions, DO may change, sometimes considerably, over a daily period (ANZECC, 2000).

Department of Water data indicate a median DO concentration of 7.1 mg/L (~75% saturation) based on 215 samples at Hut Pool, Blackwood River (Site No.16144). The range between 20 to 80 percentiles for this site is 6.0 to 8.6 mg/L (~65% to 85% saturation). A total of 37 samples are available for St John Brook, Barrabup Pool, Site 16143, indicating a range of 5.1 mg/L to 8.8 mg/L (20 to 80 percentile) and a median of 7.6 mg/L. Therefore the target DO concentration for supplementation for the Blackwood River and tributaries is 6 mg/L.

There are limited data on DO concentrations within the groundwater of the Yarragadee Formation. The high dissolved iron and manganese concentrations (14 to 33 mg/L for iron and 0.11 to 0.84 mg/L for manganese) reported by Baddock (1994) in the Yarragadee Formation indicate that DO concentrations may be generally less than 2 mg/L. Therefore groundwater would require treatment to increase DO concentrations.

4. Engineering Concepts

4.1 Power Supply

The total power consumption, based on Table S1, will be just over 100 MWh annually assuming three month supplementary campaign. Estimated power costs will therefore be around $ 10,000 annually. It is recommended that power supply to the two Blackwood River supplementation pumps be sourced from the power grid as power requirements are beyond that which is capable through solar panels.

Power availability is confirmed for the Blackwood River (Leederville Formation supplementary bore) by a power line indicated at approximately 0.7 km distance (Cambray Map 2030-3). No power is available in the vicinity of the other sites. The other supplementation site with large power requirement, Blackwood River (Yarragadee Formation supplementary bore) is just over 1 km from the Brockman Highway, along Larsen Road. A generator, as an alternative to the grid power supply, may be used for the three sites with no power available in the vicinity.

4.2 Water treatment options

There are a number of methods available for the treatment of water with elevated iron and manganese concentrations. The effectiveness and efficiency of these methods depends on the chemistry of the groundwater in terms pH, Eh (redox potential), temperature, concentration and form of the iron and manganese. For example, whether the iron and manganese is in a dissolved, particulate or colloidal form. The most commonly used method to treat/remove iron and manganese from groundwater is by a process of oxidation from either aeration or chemical addition, followed by precipitation, usually achieved by filtration.

Oxidation followed by filtration is a relatively simple process. The oxidant chemically oxidizes the iron or manganese (forming a particle), and kills iron bacteria and any other disease-causing bacteria that may be present. The filter then removes the iron or manganese particles.

Dissolved oxygen can be increased by aeration to the target 6mg/l concentrations or more. Oxidation of iron and manganese can also be achieved through aeration. Aeration if often achieved a tray tower in which water flows down the trays.

In order to achieve the iron and manganese targets (concentrations of 0.3 mg/L and 0.05 mg/L respectively) for the supplementation sand filtration after the aeration will be required. It will be advisable to further aerate the water after filtration to ensure target DO concentrations are achieved. This can be done using a spillway. It is recommended that laboratory testing be conducted to aerate or alternately dose groundwater samples with oxidants to indicate the effectiveness of proposed DO treatments and indicate the residual dissolved iron and manganese concentrations.

The groundwater has a pH that may indicate the occurrence of dissolved carbon dioxide. If this is the case the tray aeration tower will strip out the carbon dioxide, with a resultant increase in pH. Similarly if there is dissolved sulphide in the groundwater this can be stripped or oxidised. It is recommended that the odour of the groundwater be assessed when sampling and if sulphide seems to be present, the concentration determined.

4.3 Erosion Control

Based on the bore production rates of between 2 and 10 L/s, it is envisaged that with a pumped transfer system, the discharge pipeline to the river will be between 50 mm and 100 mm diameter and that discharge velocities will be no more than 1.5 m/s. These are relatively low discharge rates and accordingly there is not a great deal of energy to dissipate.

As the bed of the Blackwood River is relatively sandy it is likely to be erodable. Accordingly discharge velocities need to be minimised (0.2 to 0.5 m/s) or rock areas chosen for the location of discharge points. Both Milyeannup and St John have steep banks with clayey and rocky beds. The rocky beds provide ideal discharge points to minimise erosion.

There are a number of relatively low-cost erosion control techniques that could be used. A selection of these includes:

- Locate discharge outlet below the permanent waterline of the river or into a permanent pool, if there is one.
- Discharge into a vertically placed concrete pipe (say 300 mm diameter) on the river bank surrounded by graded rock of size and layer thickness sufficient to resist being washed away during floods. The water will cascade over the rim of the pipe and flow over the rocks, into the river.
- Outlet the discharge pipe in the river bank and provide a Reno-mattress rock chute, underlain with a synthetic geotextile, down to the water edge.

The main principles that should be considered when designing river outlets are:

- Arrangement should be physically flexible to move with any soil movement and erosion. For this reason rock chutes are favoured over concrete chutes.
- Works need to dissipate discharge energy by spreading the flow.
- Structures and rock rip-rap within the waterway needs to be designed to withstand floods.
- Outlets should be situated in sheltered locations and avoid protruding into the waterway.

5. Operating Costs

The operating costs for the supplementation scheme would involve:

- Power supply;
- Water treatment;
- Maintenance of pumps; and
- Maintenance of discharge points.

The estimated power consumption of the pumps is listed in Table S1. Assuming the pumps operate continuously for three months and the cost of power is 10 cent per kilowatt, the costs for each of the pumped sites are:

St John Brook	$ 1,500
Milyeannup Brook	$ 1,500
Blackwood River (Yarragadee aquifer)	$ 4,000
Blackwood River (Leederville aquifer)	$ 3,000
Total	$10,000

The costs of pump maintenance, water treatment, and discharge points maintenance are not included.

6. Conclusions

Supplementation production bore sites, to augment the summer base-flow of the Blackwood River and selected tributaries were chosen based on criteria that ensure no or minimal impact at the water table. The areas identified as possible sites for installing the supplementation production bores are underlain by the aquitard beds of the Mowen Member. It is intended that drawdown from the Yarragadee Formation will be attenuated by the presence of the aquitards. This is confirmed by preliminary modelling results that indicate drawdown from the supplementation bores would be predominantly limited to the Yarragadee Formation. No significant further reduction in discharges to the Blackwood River and tributaries is expected as a result of the supplementary scheme.

The salinity and temperature ranges of Yarragadee Formation groundwater and the receiving surface waters overlap, particularly in summer. As such, no significant temperature impacts are expected within the proposed three-month summer supplementation periods.

Once Yarragadee Formation groundwater comes into contact with oxygen from the air, the high dissolved iron and manganese concentrations are likely to form ferric and manganic particles.

A number of relatively low-cost erosion control techniques, that could be utilised in the Blackwood Project are discussed with the principles of designing river outlets.

The sites selected for the base-flow supplementation scheme and engineering designs are conceptual. Based on our current information, the supplementation of Blackwood River and its tributaries is feasible. The practical aspects will depend on the drilling results at these sites.

The costs of operating the supplementation scheme should be small relative to the proposed public water supply from the Yarragadee Formation.

7. Recommendations

The selected sites are in principle feasible for the installation of production bores. This feasibility, however, will have to be confirmed based on actual site investigations. The sites were selected based on current information and interpretations of the hydrostratigraphy. It is recommended that the detailed design aspects of the supplementation be supported by aquifer tests to determine local aquifer properties, and by groundwater sampling for temperature and groundwater quality measurements.

It is recommended that power supply to the two Blackwood River supplementation pumps be sourced from the power grid as power requirements are beyond that which is capable through solar panels. Power availability is confirmed by for the Blackwood River (Leederville Formation supplementary bore) by a power line indicated at approximately 0.7 km distance on the Cambray Map (2030-3). No power is available in the vicinity of the other sites. The other supplementation site with large power requirement, Blackwood River (Yarragadee Formation supplementary bore) is just over 1 km from the Brockman Highway, along Larsen Road. A generator, as an alternative to the grid power supply, may be used for the three sites with no power available in the vicinity. The systems implemented should be able to turn on and off manually if and when required.

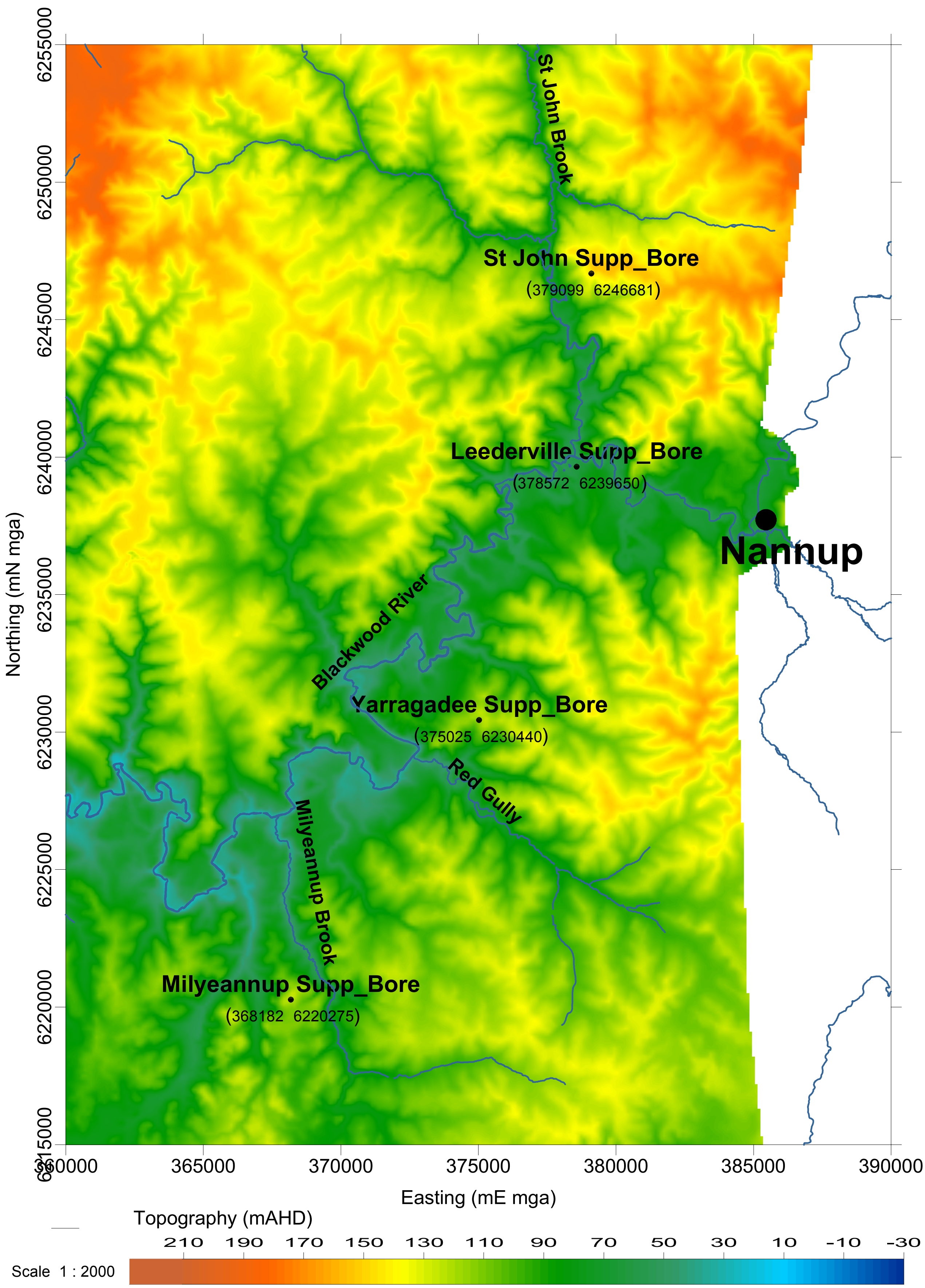
8. References

All references made in this letter will be appended to the groundwater modelling report.

Yours faithfully
URS AUSTRALIA PTY LTD

Gabor Bekesi
Associate Hydrogeologist

Eddy Lim
Principal Hydrogeologist



Job No.	42906135	
Prep. By	ECPL	24 Aug '06
Chk'd By	IGB	
Revision No.		0

Water Corporation

BLACKWOOD RIVER VALLEY MODEL

LOCATION OF PROPOSED SUPPLEMENTATION BORES

Figure S1

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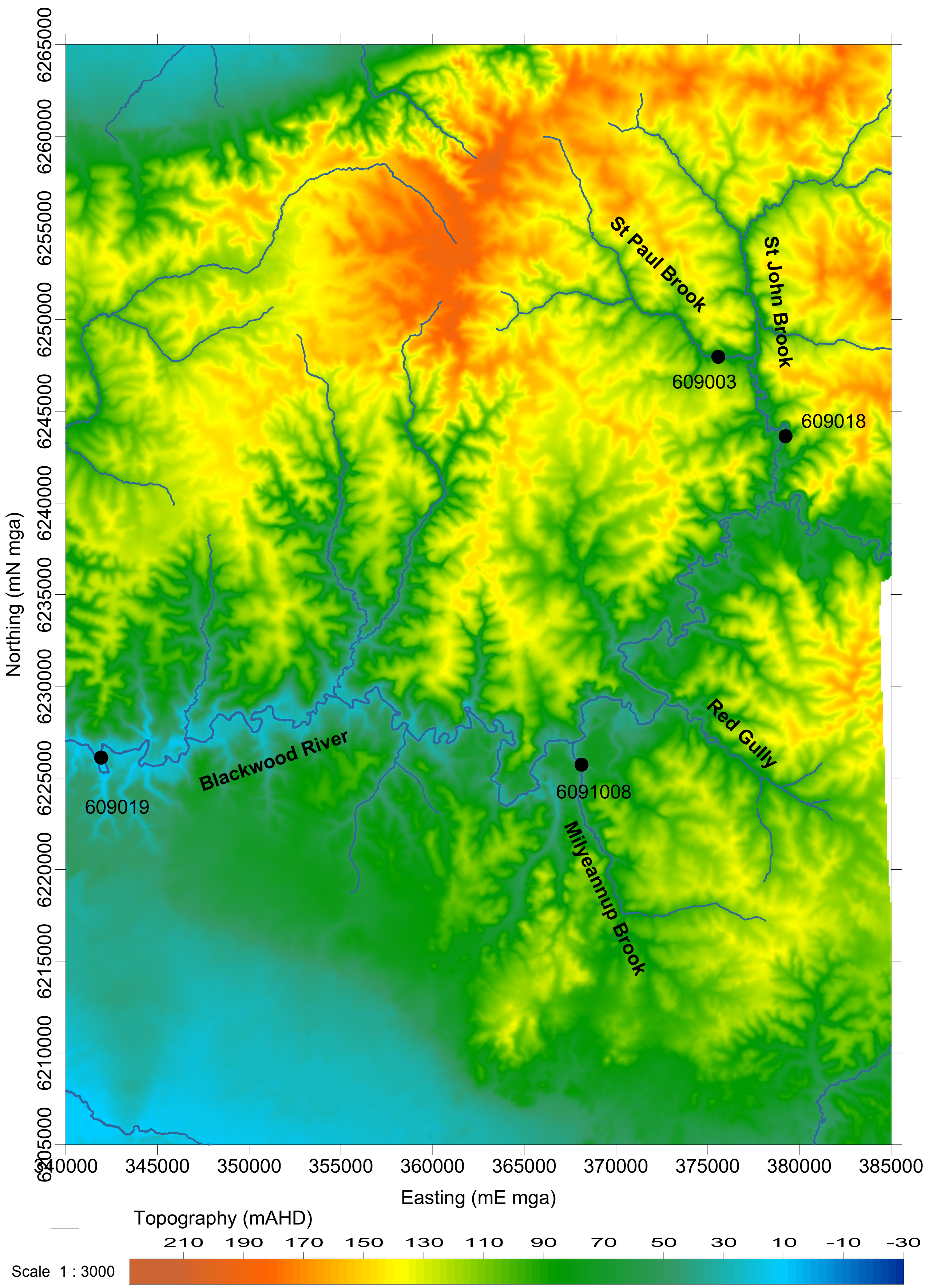

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Water Corporation

BLACKWOOD RIVER VALLEY MODEL

LOCATION OF SURFACE WATER MONITORING SITES

Figure S2

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FigureS2.srf

Appendix 6

Distribution and abundance of Balston's perch in Milyeannup Brook – report by the Centre of Excellence in Natural Resource Management

WATER

CORPORATION

DISTRIBUTION AND ABUNDANCE OF BALSTON'S PERCH IN MILYEANNUP BROOK

CENRM REPORT 14/06V3

AUGUST 2006

©	Centre of Excellence in Natural Resource Management, The University of Western Australia
TITLE	Distribution and abundance of Balston's Perch in Milyeannup Brook
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PRODUCED FOR	WATER CORPORATION OF WESTERN AUSTRALIA
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DISCLAIMER

Cover photograph: Milyeannup Brook, July 2006.

SUMMARY

The Water Corporation of Western Australia has applied for a license to operate a 45GL/annum borefield, abstracting from the south west Yarragadee aquifer, in the vicinity north of the Blackwood River adjacent to Rosa Brook in south-western Australia. Subsequent studies on environmental water requirements and potential ecological risks as a consequence of abstraction have highlighted the importance of freshwater tributaries for maintenance of native aquatic fauna.

Native fish are a conspicuous component of the fauna of freshwater tributaries and elevated salinity levels in the Blackwood River may exceed individual species' tolerances levels and inhibit the movement of fish amongst tributaries. Balston's Perch (*Nannatherina balstoni*) has been assessed from a range of tributaries and is almost totally concentrated in Milyeannup Brook. This species is considered the rarest freshwater fish in southwestern Australia and is currently listed as "Priority 1" by the Western Australian Department of Conservation and Land Management as it represents "*a taxon with few, poorly known populations on threatened lands*".

The abundance and distribution of this species was assessed at Milyeannup Brook. At the time of the survey (July 2006), continuous flows were limited to a position approximately 2km upstream from the confluence with the Blackwood River. Some small pools were also present in the upper reaches of the catchment in the vicinity of Milyeannup Rd crossing. Low flows were considered a consequence of low rainfall; recent records emphasised the extreme conditions with the lowest values on record, with (to July 30^{th} 2006), only ~20% of the long-term average being received.

Fish surveys were undertaken at five sites on Milyeannup Brook. Four sites were sampled in the downstream reach (MBD1-4). A single site (a small pool) was sampled in the upstream reach (MBU1). Quantitative sampling from these sites resulted in a total of ~500 native fish, representing four species, being collected over two days of sampling. The introduced Mosquitofish (*Gambusia holbrooki*) was observed only in the upper reaches of the catchment. Under certain conditions, the Mosquitofish can out-compete, and locally extirpate, the native species.

Specimens of the Perch were collected (measured and released) from both the downstream (MBD1 and MBD2) and upstream (MBU1) reaches of Milyeannup Brook where it represented the most abundant species collected. *Galaxias occidentalis* (Western Minnow) was the second most abundant species overall: they were collected at all sites and common in downstream reaches. Both *Edelia vittata* (Pygmy Perch) and *Bostockia porosa* (Nightfish) were collected in low numbers and *Galaxiella munda* (Mud Minnow) was sampled from a single site located in the upper reaches of the Brook.

Assessments based on the quantitative sampling and weighted for habitat, give approximate population number of Balston's Perch of ~1000 in Milyeannup Brook; all probably from a single size class (about one year old). These numbers are considerably greater than previous estimates, and would typically indicate a healthy, breeding population. The extreme drought conditions resulted in the "concentration" of fish in the lower reaches and would represent population minima as a consequence of natural conditions. Under more typical flows in Milyeannup Brook, a statistical significant departure from this minimum number could be used to define an "impact" (or if due to abstraction, when supplementation is warranted). As a conservative approach (which could be changed when more details are known of genetic structure), a reduction of 20% (or more) from this initial population estimate should be used to initiate supplementation. This should only occur, if it can be clearly established that abstraction resulted in lower flows as supplementation in addition to natural flows may help the spread of exotics (*e.g.* Mosquitofish).

Although the fish were concentrated and surviving in the lower reaches, it is unknown if individuals migrate to upstream reaches to spawn and develop. Balston's Perch spawns during winter and spring, attaching eggs trailing vegetation and riparian vegetation inundated by seasonally high flows. These habitats were not well-represented in the lower reaches, which were generally characterised by a deeply incised stream channel and high bank gradients. Consequently, sampling to date, cannot clarify if the species can complete a reproductive cycle solely within the lower reaches.

Small samples of fins of Balston's Perch (a non-lethal technique) were collected for genetic analyses (DNA and allozyme electrophoresis). Initial DNA analysis shows a well-mixed population and would indicate a degree of genetic "mixing" in the population and would indicate individuals are moving though-out the Brook. In contrast, were the population highly genetically differentiated, then this would characterize more isolated sub-populations.

If abstraction from Yarragadee results in changes to hydraulic connectivity, particularly an increase in the duration of zero flow and discontinuity in aquatic habitat, and a delay in the initiation of winter flows, there are potential risks to the maintenance of Balston's Perch in Milyeannup Brook. However, flows in winter are predominantly the consequence of rainfall and it should be noted, the relationship between groundwater and surface flows was outside the scope of this report. The following analysis addresses the major issues associated with the maintenance of the Perch in Milyeannup. It should be noted, this assessment was based on recent analysis of groundwater-surface water interactions (see Appendices 1 and 2).

Fish life cycle issue	Potential impacts by abstraction from Yarragadee	Assessment	Risk (qualitative)
Reproductive migration	Changing the timing of the initiation of winter flows	Species typically migrate late winter/ early spring (Morgan *et al.* 1998). Consequently, during this time, flows will be dominated by rainfall and runoff.	Likelihood=medium Consequence=low
Reproductive migration	Lack of suitable spawning habitat in lower reaches	Species typically migrate late winter/ early spring (Morgan *et al.* 1998). Consequently, during this time, flows will be dominated by rainfall and runoff.	Likelihood=low Consequence=medium
Reproductive migration	Loss of hydraulic connectivity	Late winter/early spring rainfall and subsequent runoff will override any groundwater-surface water inputs. The clay soils result in a degree of "perching" of surface waters (Strategen 2006)	Likelihood=low-medium (see URS 2004) Consequence=medium
Reproductive migration	Loss of initial winter flush (an initial stimulus for onset of migration)	Late winter/early spring rainfall and subsequent runoff will override any groundwater-surface water inputs.	Likelihood=low Consequence=low

Fish life cycle issue	Potential impacts by abstraction from Yarragadee	Assessment	Risk (qualitative)
Density-dependent effects	Concentration of individuals in lower Brook pools	Little evidence of density-dependent effects (competition, predation). Concentration occurs at present due to "drought"	Likelihood=high Consequence=low
Habitat	Point of initiation of flow moves downstream and fish are concentrated in lower pools	Did occur during early 2006 as a consequence of drought conditions. Fish numbers high in lower pools.	Likelihood=medium Consequence=high

Other risks to the maintenance of the Perch in Milyeannup Brook include a continued drought, loss of pool water quality in these refugial habitats and loss of riparian vegetation leading to high water temperatures (most native aquatic fauna are cold-water stenotherms).

Monitoring and Assessment

Specifically for the purposes of monitoring the Perch in Milyeannup Brook, before and after groundwater abstraction, it is recommended that additional (~ 5-6) survey reaches be established upstream of MBU1 (see Table 1). Biological monitoring should be undertaken at these sites in combination with the seven sites (MBD1-6 and MBU1) established during the present study.

The monitoring program should be undertaken seasonally (both before and after abstraction) to allow for interpretation of any seasonal impacts of water abstraction on Balston's Perch or critical ecological processes that directly or indirectly impact on the Milyeannup population. The monitoring program should collect the following information:

- Quantitative estimates of population size of the Perch using non-destructive methods;
- Quantitative assessment of habitat use with in Milyeannup Brook by Balston's Perch, especially the requirements for spawning and recruitment of early life stages;
- Water quality, particularly physicochemical parameters including dissolved oxygen, salinity, conductivity, colour, turbidity, temperature, pH; and
- Seasonal variations in stream discharge and habitat availability both in the Brook
- Rules for supplementation (to mimic the historic hydrograph).
- As regional controls, a detailed biophysical monitoring program should be conducted in Spearwood and Adelaide creeks. This monitoring program should include physical attributes (channel cross sections, pool aggradation), water quality (nutrients, salinity, pH, temperature, redox, colour, turbidity, dissolved oxygen) and aquatic fauna (macroinvertebrates and fish).

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INTRODUCTION

Background

The Water Corporation of Western Australia has applied for a license to operate a 45GL/annum borefield, abstracting from the south west Yarragadee aquifer, in the vicinity north of the Blackwood River adjacent to Rosa Brook in south-western Australia. Subsequent studies on environmental water requirements and potential ecological risks as a consequence of abstraction highlighted the importance of freshwater tributaries for maintenance of aquatic fauna (CENRM 2005).

These tributaries contain endemic fish species including Balston's Perch, *Nannatherina balstoni* (cited as *N. balstoni)* which is considered the rarest freshwater fish endemic to southwestern Australia (Morgan *et al*. 1998). The species is currently listed as "Priority 1" by the Western Australian Department of Conservation and Land Management because it represents "*a taxon with few, poorly known populations on threatened lands*" (CALM 2005). The species has been suggested for inclusion under the *Environmental Protection and Biodiversity Act 1999* as "*Vulnerable*", due to its restricted distribution and considerable contraction of range over the past century.

On a regional scale, threatening processes likely to impact directly on *N. balstoni* have been suggested to include:

- habitat alteration;
- alteration to natural flow regime;
- increasing salinisation and eutrophication, and;
- impact of introduced species (Morgan *et al*. 1998).

The vulnerability of *N. balstoni* to threats is escalated by their relatively short life cycle, low fecundity, annual spawning, low population sizes and specialised dietary requirements (Morgan *et al*. 1998).

A description of the historical and current distribution of *N. balstoni* has been recently provided (WRM 2006). Historically, the species geographical range extended from the Moore River in the North, to the Goodga River in the southwest (Allen *et al*. 2002).

Currently, populations of *N. balstoni* are highly fragmented, and the distributional range has contracted to the far southwest between Margaret River and the Goodga River (Allen *et al.* 2002). Within the Blackwood River catchment, recent fish surveys suggested that the distribution of *N. balstoni* is largely restricted to Milyeannup Brook (CENRM 2005; Morgan and Beatty 2005). Only a single specimen has been reported from both Red Gully and from the Blackwood River main channel at Denny Road crossing (downstream of the Yarragadee discharge area) (Morgan and Beatty 2005).Consequently, Milyeannup Brook could represent an important refuge habitat for a sub-regional population of *N. balstoni.*

Objectives

1. To undertake a snapshot survey of Balston's Perch along the length of Milyeannup Brook during winter/spring.

2. To describe the distribution, abundance and size structure of Balston's Perch during the winter/spring (typically high flow) period in Milyeannup Brook. Generally, this would be the period of spawning for the Perch.

3. To collect data on structural habitat attributes of Milyeannup Brook that support Balston's Perch.

4. To suggest appropriate molecular techniques (allozyme electrophoresis and DNA) suitable to gain an understanding on "mixing" and consequently movement of the Perch.

MATERIALS AND METHODS

Study sites

Milyeannup Brook can be divided into two reaches on the basis of catchment physiography and aquatic habitat (Davies, 2005). The downstream reach extends from the Milyeannup Brook – Blackwood River confluence upstream to Milyeannup Brook Road (~19km upstream) and is comprised of second- and third-order stream channels with higher gradients. This is in contrast to the upstream reach. Aquatic habitats were dominated by pool/glide habitats separated by relatively short riffle habitats (Davies, 2005). The upstream reach extended upstream of Milyeannup Brook Rd and is comprised predominantly of first order streams that flow over low gradient swamplands (Davies, 2005).

Six survey sites have been established in the lower reach and included two previously-sampled sites (Morgan and Beatty, 2005) near the confluence of the Blackwood River and upstream of the Brockman Highway. A single survey site was established in the upstream reach (MBU1) immediately upstream of Milyeannup Rd.

Table I. Location of sampling sites on Milyeannup Brook*

Site	Reach Description	Latitude	Longitude	Distance upstream from Blackwood River (km)
MBU1	U/s of Milyeannup Rd	34.17439	115.53187	20.4
MBD1	U/s from confluence with Blackwood River	34.09288	115.56553	0.7
MBD2	U/s Brockman Hwy	34.09888	115.56950	2.2
MBD3	2.1Km D/s from Blackwood Rd	34.10444	115.57004	4.1
MBD4	1.4Km D/s from Blackwood Rd	34.10915	115.56895	5.3
MBD5	0.8Km D/s from Blackwood Rd	34.11490	115.56760	6.9
MBD6	U/s of Blackwood Rd	34.12340	115.56988	9.3

* U/s: Upstream; D/s: Downstream

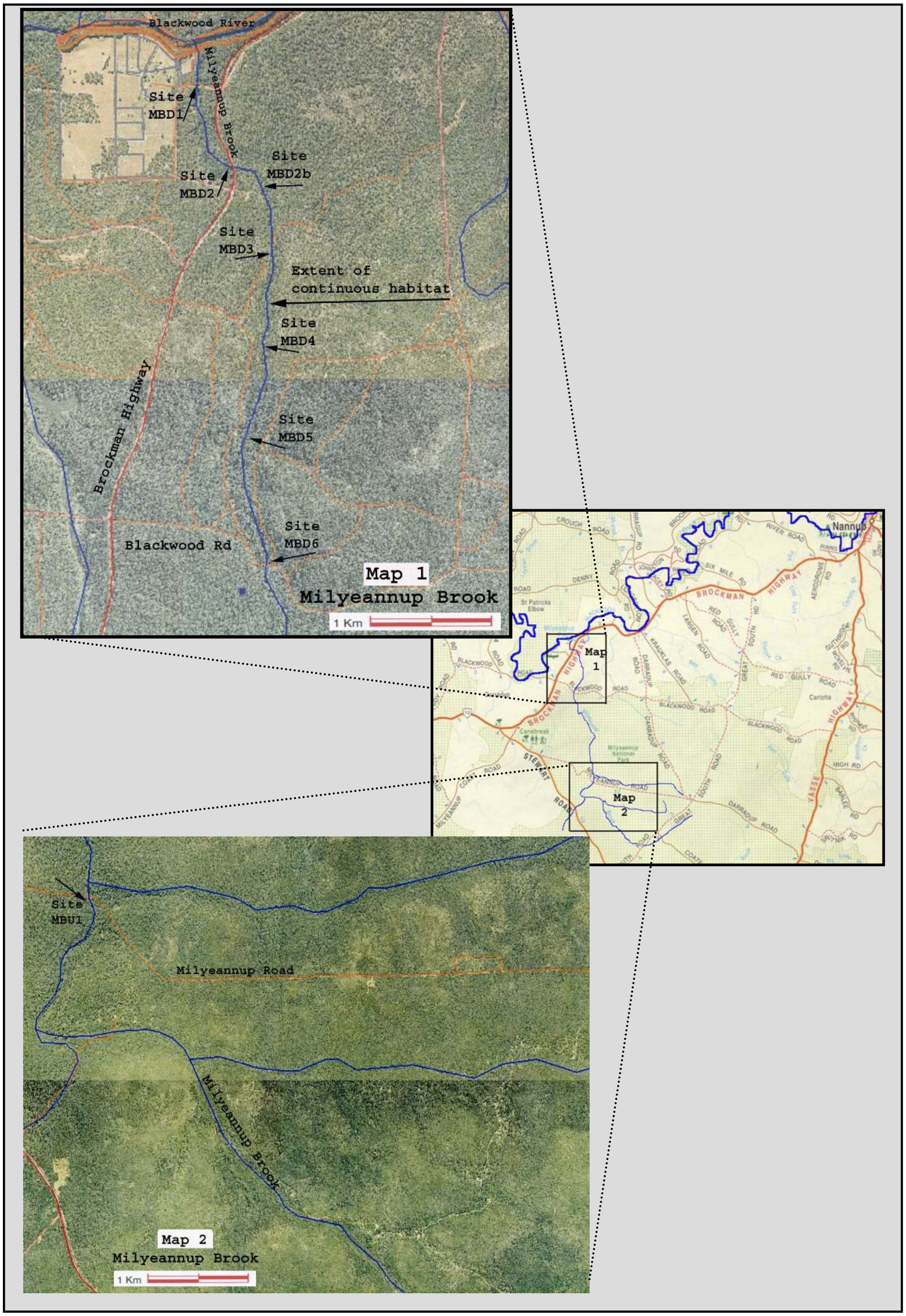

Figure 1. Location of survey sites in upstream (Map 2) and downstream (Map 1) reach of Milyeannup Brook. Inset provides sub-regional context.

Fish Collection and Sample Processing

Due to the limited extent of available habitat and water, fish surveys were undertaken at only five of the seven sites established on Milyeannup Brook (see Table 1). Four sites were sampled in the downstream reach (MBD1-4). A single site was sampled in the upstream reach (MBU1). Sampling was conducted using a variety of netting techniques including baited traps, Fyke nets and dip nets (*i.e.* non-destructive methods). Sampling was conducted during both daylight and overnight during July 2006. The duration of sampling (hours of wetted net time) was recorded for each net type at each site. All collected fish were identified, enumerated and measured for standard length (SL, nearest 1 mm). Taxonomic nomenclature (naming) follows Allen *et al.* (2002) and Paxton and Eschmeyer (1998). The total catch of each species from each net type were converted to relative abundances and expressed as Catch per Unit Effort (CPUE = Fish/hr).

Water Quality Measurements

In situ measurements of water quality parameters were made at sites MBD1-3 and MBU1 (sites with adequate water). Measurements were recorded at surface (<0.1m) waters. Water temperature (°C), total dissolved solids ($mg.L^{-1}$), dissolved oxygen (% saturation and $mg.l^{-1}$), turbidity (NTU[1]) and pH were measured with a YEO-KAL (model 611) portable water quality analyser.

Quantification of in-stream habitat

The relative abundance (% wetted area) of hydraulic biotypes and structural habitat attributes was estimated only for fish survey sites (MBD1-4 and MBU1). Hydraulic units were defined using the categories: cascade; riffle; glide; run; pool; backwater. The relative abundance of dominant cover elements was also recorded and defined as: substratum, large and small woody debris; leaves and other organic matter; overhanging bank; overhanging vegetation; submerged vegetation and; emergent vegetation.

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[1] Nephelometric turbidity units

Riparian vegetation

Qualitative assessments of foreshore vegetation were recorded in conjunction with fixed point photography. Assessments were made using the rapid assessment methodology of Pen and Scott (1995). Vegetation condition was categorized according to dominant plant species and relative degree of disturbance such as weed invasion, the proportion of exposed soils along banks, areas of erosion and sedimentation.

Channel form and bank stability

Streambed geology was described in terms of percentage composition of various substrata based on particle size: bedrock (>512 mm); rock (128-512 mm); cobble (64-128 mm); gravel (32-64 mm); fine gravel (8-32 mm); sand (0.5-8 mm); mud/silt (unconsolidated <0.5mm) and clay (consolidated < 0.5 mm).

RESULTS

Extent of aquatic habitat

Initial reconnaissance along the length of Milyeannup Brook identified suitable aquatic habitat extended for only approximately 2km upstream from the confluence of Milyeannup Brook with the Blackwood River (Figure 1). Between sites MBD3 and MDB4, aquatic habitat became discontinuous and confined to small, bedrock-controlled pools (see MBD3b Figure 2). Milyeannup Brook was completely dry between of MBD4 and MBD6. Suitable aquatic habitat was also present immediately upstream and downstream of Milyeannup Rd crossing (site MBU1). The extent of aquatic habitat upstream of Milyeannup Rd crossing and between site MBU1 and MBD6 limited.

Physicochemistry

Water quality parameters were similar among all four sites (Table II). Water temperature ranged from 10.95°C at site MBD3 to 11.8°C at MBD1. Water was relatively fresh at all sites: electrical conductivity ranged from 317-391µS/cm and salinity from 0.19-0.22‰. Dissolved oxygen levels ranged from 6.6mg/L (60.9%) at site MBD3 to 7.9mg/L (73.6%) at MBU1. The pH tended to be slightly acidic and ranged from 5.22 at site MBD3 to 5.83 at site MBD1.

Table II. Channel characteristics, water quality and structural habitat (instream and riparian) at four locations on Milyeannup Brook.

	Site			
Site Characteristics	**MBD1**	**MBD2**	**MBD3**	**MBU1**
Reach characteristics				
Mean width (m)	2.5	2	2	N/A
Mean depth (m)	0.6	0.2	0.4	N/A
Estimated flow (ML/d)	2.0	1-2	0	<1
Water Quality				
Temperature (°C)	11.8	11.31	10.95	11.35
Electrical conductivity ($\mu S.cm^{-1}$)	357	382	391	317
Salinity (%)	0.22	0.22	0.23	0.19
Dissolved Oxygen (% sat)	73	70.6	60.9	73.6
Dissolved Oxygen ($mg.L^{-1}$)	7.8	7.6	6.6	7.9
Turbidity (NTU)	10.3	3.5	2.8	6.3
pH	5.83	5.55	5.22	5.72
ORP (mV)	337	338	355	381
Substratum composition (% wetted area)				
Bed rock	-	-	5	-
Boulder	5	5	5	-
Cobble	-	-	-	-
Pebble	-	-	-	-
Gravel	-	-	-	-
Sand	80	90	70	50
Silt	15	5	-	5
Clay	-	-	20	45
Instream cover (% wetted area)				
Substrate	-	-	2	-
Large woody debris	2	10	5	5
Small woody debris	15	5	75	25
Leaves and organic debris	15	75	20	50
Bank overhang	20	5	40	-
Vegetation overhang	20	25	60	20
Submerged vegetation	-	-	-	-
Emergent vegetation	5	2	5	80
Hydraulic habitat (% wetted area)				
Rapid/cascade	-	-	-	-
Run	95	-	-	-
Riffle	5	5		-
Glide	-	65		-
Pool	-	20	100	-
Backwater	-	-	-	-
Forshore condition assessment				
Bank slope (°)	45-60	60	>60	10
Erosion (%)	5	2	2	-
Slumping (%)	-	-	-	-
Sedimentation	5	-	-	-
Riparian leaf litter cover (%)	75	75	75	40
Foreshore Assessment Grading	A3	A2	A1	A1

Structural and hydraulic habitats

The mean wetted channel widths were similar among all sites (Table II). The stream channel was generally highly incised at sites in the downstream reach (MBD1-3) with bank slopes of more than 60° (Table II, Figure 2). Mean water depths tended to be greater at sites MBD1 and MBD3 due to relatively higher proportion of pool type habitats at these sites (Table II). In comparison, site MBD2 was dominated by "glide" type habitat and had relatively shallow water depths (Table II). The stream substratum at each site was dominated (>50%) by sand. The relative contribution of coarse substrates including boulders and bedrock was low and restricted to sites in the downstream reach (Table II). Instream structural habitat was abundant and diverse at all sites (Table II, Figure 2). Leaves and organic debris, small woody debris and overhanging vegetation were generally abundant at all sites (Table II, Figure 2). Downstream reaches possessed overhanging bank habitats that were not represented in the upstream sites. In contrast, structural habitats at the upstream site were strongly dominated by emergent aquatic vegetation (Table II, Figure 2).

Distribution and abundance of fish.

A total of 501 native fish, representing four native species, were collected from four survey sites on Milyeannup Brook over two days of sampling. Fish were collected from three sites (MBD1-3) in the downstream reach and also from the single site (MBU1) located in the upstream reach. No fish were collected between MBD4 and MBU1. No introduced fish species were collected, although some Mosquitofish (*Gambusia holbrooki*) were observed at MBU1.

Nannatherina balstoni were the most abundant species collected representing 54.7% of the total number of fish collected (Table III). *Nannatherina balstoni* were collected from both the downstream (MBD1 and MBD2) and upstream (MBU1) reaches. The majority (91.2%) of *N. balstoni* were collected at site MBD1 in the Fyke net (Table III, Figure 3). In contrast 22 *N. balstoni* were collected in bait traps (Table III, Figure 3). Similar numbers of *N. balstoni* were collected from MBD1and MBD2 using bait traps. *Galaxias occidentalis* was the second most abundant species overall. A total of 194 *G. occidentalis* were collected representing 38.7% of the total catch of fish from Milyeannup Brook. *Galaxias occidentalis* were collected at all sites although were most abundant in the downstream reaches (MBD1-3) (Table III). A total of 43 *G. occidentalis* were collected using the Fyke net at site MBD1, representing 14.3% of the total catch from this net (Table III, Figure 3). In contrast 151 *Galaxias occidentalis* were collected in bait traps representing 71.4% of the total catch using this method (Table III, Figure 3). *Edelia vittata* were collected in low numbers from three sites located in both the downstream (MBD1 and MBD3) and upstream (MBU1) reaches. *Bostockia porosa* was only collected from two sites. (MBD1 and MBD3) located in the downstream reach (Table III). Nine *Galaxiella munda* were collected from the single site located in the upstream reach (Table III).

Figure 2. Sampling sites on Milyeannup Brook

Table III. Total Number and (Catch per Unit Effort [fish/hr]) of fish species from five sites on Milyeannup Brook.

Site	Date	Method	Nb	Go	Ev	Bp	Gm
MBD1	27/07/06	Bait Trap	8 (0.27)	64 (2.13)	1 (0.03)	-	-
	28/07/06	Bait Trap	2 (0.1)	6 (0.3)	-	-	-
	28/07/06	Fyke Net	252 (12.6)	43 (2.15)	3 (0.15)	8 (0.4)	-
MBD2	27/07/06	Bait Trap	10 (0.33)	45 (1.5)	3 (0.1)	-	-
	28/07/06	Bait Trap	1 (0.01)	8 (0.08)	-	-	-
MBD3	28/07/06	Bait Trap	-	27 (0.25)	-	1 (0.01)	-
MBU1	28/07/06	Bait Trap	1 (0.01)	1 (0.01)	8 (0.8)	-	9 (0.10)

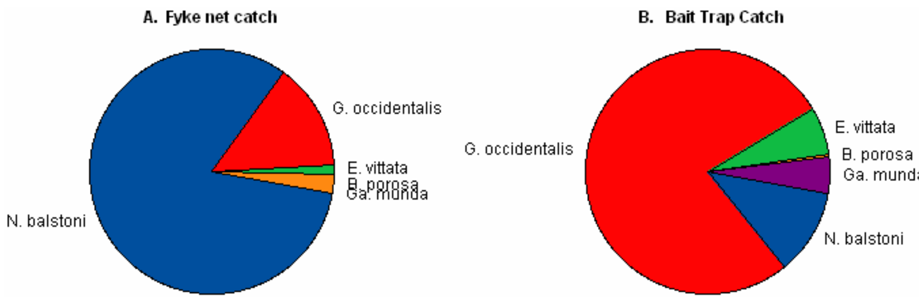

Figure 3. Relative contributions of each species to the total catch of fish from Fyke net and bait traps

Size Structure of fish populations

Length frequency distributions for the four species: *N. balstoni*, *G. occidentalis*, *E. vittata*, *B. porosa* and *Ga. munda*, are shown in Figure 4. The minimum, maximum and mean measurements of standard length for each species are provided in (Table IV). The distribution of size classes indicates *N. balstoni* from Milyeannup are probably all the same age and the results from spawning in the previous year. This species is considered an annual breeder (Morgan and Beatty 2005).

Table IV. Minimum, maximum and mean measurements of standard length (mm) for *Galaxias occidentalis*, *Nannatherina balstoni*, Bostockia porosa, *Edelia vittata*, and *Galaxiella munda*.

	Standard length (mm)			
	n	min	max	mean
Galaxias occidentalis	188	50	120	76.3
Nannatherina balstoni	66	40	81	57.4
Bostockia porosa	9	60	110	92.8
Edelia vittata	15	21	50	31.7
Galaxiella munda	8	30	39	34.5

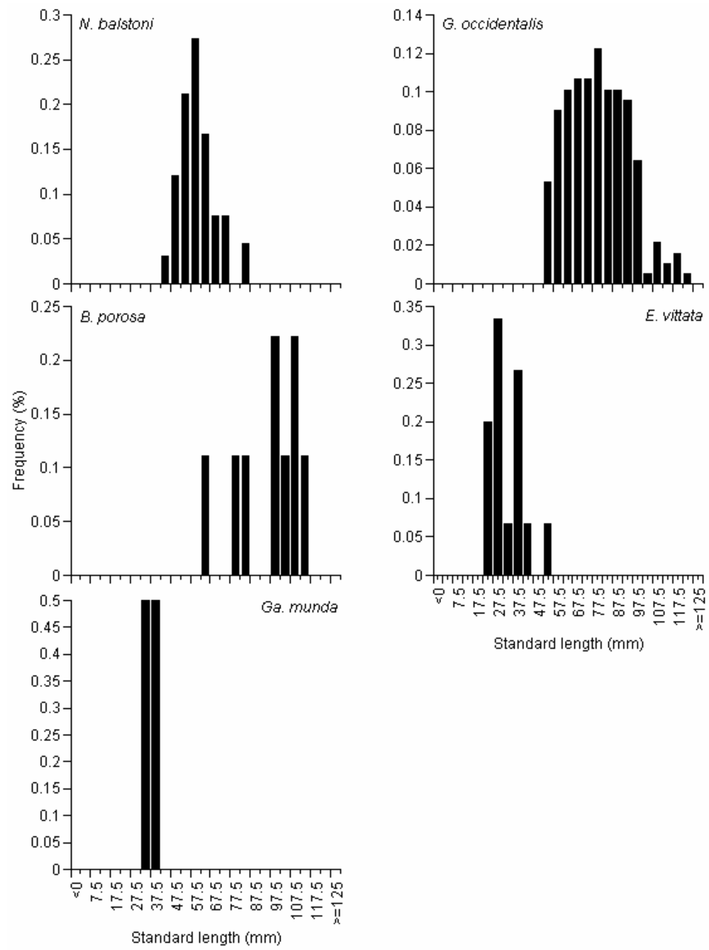

Figure 4. Length frequency distributions for fish species collected from all survey sites on Milyeannup Brook.

Discussion

Extent of aquatic habitat

At the time of survey (July 2006) aquatic habitat in Milyeannup Brook extended only for approximately 2km upstream from the confluence of Milyeannup Brook with the Blackwood River. Wetted aquatic habitat was present in limited pools in the upper reaches of the catchment in the vicinity of Milyeannup Rd crossing. The observation of *Baumea vaginalis* in the mid reaches of Milyeannup Brook (see Figure 5) also suggests that aquatic habitat is usually present within this reach of the catchment as this species of emergent sedge is usually associated with permanent water (Wheeler *et al.* 2002). Recent rainfall records have been estimated to represent only *c.* 20% of the long-term rainfall average (Figure 6). The substantial restriction of available habitat under these conditions is an important observation and may represent risk to sustainability of *N. balstoni*.

Figure 5. *Baumea vaginalis* overhanging dry channel at MBD4 27 July 2006.

Distribution and abundance of fish.

All species collected in this study have been previously recorded from Milyeannup Brook (Morgan and Beatty 2005). However, fish surveys have only previously been reported from two sites in the lower reaches of the Brook (MBD1 and MBD2): the collection of *N. balstoni* from the upper reaches represents an important finding. Swamp-like habitats upstream of Milyeannup Road may represent important refugia for *N. balstoni*, and also *Ga. munda*, especially during current climatic conditions that have result in substantial loss of aquatic habitat from the mid- to lower-reaches of the catchment.

The abundance of fish species reported here, particularly the high numbers of *N. balstoni* and *G. occidentalis*, contrasts with relatively low abundances reported from early sampling events (Morgan and Beatty 2005). The high densities of *N. balstoni* and *G. occidentalis* are likely a result of concentration into the restricted available habitat.

The limited extent of flows in Milyeannup Brook was surprising given the season. Flows were expected from the first-order swamps through to the Blackwood River. The concentration of water into lower reaches was undoubtedly the consequence of the extended low rainfall conditions. The three months to July 2006 were the lowest on record for rainfall in southwestern Australia (Figure 6). Consequently, it was difficult to assess how Balston's Perch would utilize upstream reaches.

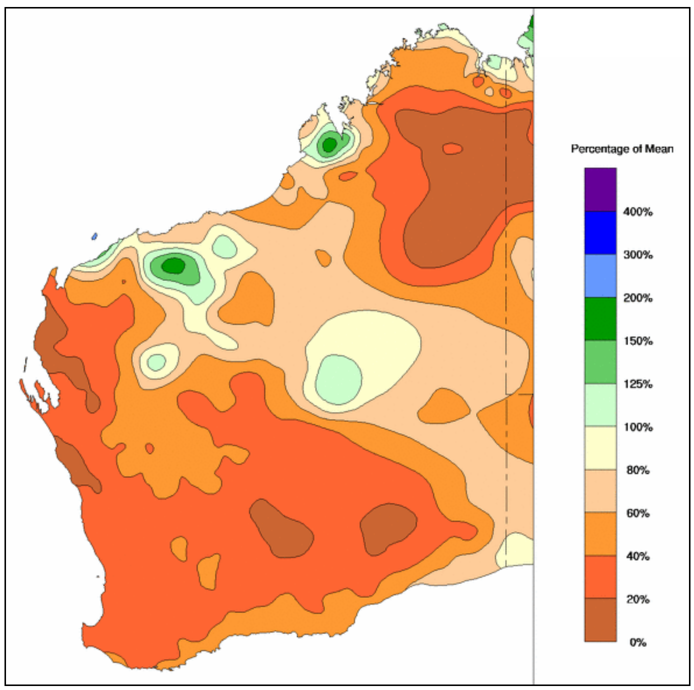

Figure 6. Wet season rainfall (1 April to 31 July 2006) relative to long term (1961-1990) seasonal mean rainfall (source: Commonwealth of Australia 2006, Australian Bureau of Meteorology http://www.bom.gov.au, accessed 31/07/2006).

Risk Assessment

Based on the life history of the Perch and potential impacts as a consequence of abstraction from Yarragadee a number of issues require assessment. This species is typically annual (gill & Morgan 1998) and undergoes a reproductive migration. Any changes to hydraulic connectivity may therefore restrict this movement. The following assessment (Table V) is based on current understanding on the surface water-groundwater interactions (Appendix 1) and the nature of the clay soils which would tend to support surface water "perching" (Appendix 2). The assessment is qualitative and risk is considered in two components and overall as likelihood x consequence.

The main issues of hydraulic connectivity timing on the initiation of flow in the Brook are considered to be primarily a consequence of winter/spring rainfall rather than controlled by groundwater levels.

Other risks to the maintenance of the Perch in Milyeannup Brook include a continued drought, loss of pool water quality in these refugial habitats and loss of riparian vegetation leading to high water temperatures (most native aquatic fauna are cold-water stenotherms).

Monitoring and Assessment

Due to some level ecological uncertainties and risk, a detailed monitoring program is recommended in an adaptive framework. Specifically for the purposes of monitoring the Perch in Milyeannup Brook, before and after groundwater abstraction, it is recommended that additional (~ 5-6) survey reaches be established upstream of MBU1 (see Table 1). Biological monitoring should be undertaken at these sites in combination with the seven sites (MBD1-6 and MBU1) established during the present study.

The monitoring program should be undertaken seasonally (both before and after abstraction) to allow for interpretation of any seasonal impacts of water abstraction on Balston's Perch or critical ecological processes that directly or indirectly impact on the Milyeannup population. The monitoring program should collect the following information:

- Quantitative estimates of population size of the Perch using non-destructive methods;
- Quantitative assessment of habitat use with in Milyeannup Brook by Balston's Perch, especially the requirements for spawning and recruitment of early life stages;
- Water quality, particularly physicochemical parameters including dissolved oxygen, salinity, conductivity, colour, turbidity, temperature, pH; and
- Seasonal variations in stream discharge and habitat availability both in the Brook
- Rules for supplementation (to mimic the historic hydrograph).
- As regional controls, a detailed biophysical monitoring program should be conducted in Spearwood and Adelaide creeks. This monitoring program should include physical attributes (channel cross sections, pool aggradation), water quality (nutrients, salinity, pH, temperature, redox, colour, turbidity, dissolved oxygen) and aquatic fauna (macroinvertebrates and fish).

Supplementation

The population size of the Perch, measured during mid-2006, should be considered a minima. The "drought" and consequently reduced river flows are amongst the lowest recorded and therefore, as a consequence of impacts non-abstraction related, the population size measured of 1000 individuals is considered an appropriate baseline. A departure of 20% (or more) from these estimates should be used as the guide to initiate supplementation.

Rules of supplementation should be based on historic flows (magnitude and duration) and the artificial flows should be staged up and down (to minimize bed erosion and bank slumping respectively). Supplementation should also trigger increased intensity of monitoring of fish, flows and water chemistry.

Supplementation should not be considered if the flow regime remains largely unaltered. Elsewhere, modified flows have favoured exotic species over natives, and as the Mosquitofish is already present in Milyeannup, its current distribution should not be increased as a consequence of a modified flow regime.

Table V. Risk assessment of important flow related issues interacting with the life history traits of the Perch.

Fish life cycle issue	Potential impacts by abstraction from Yarragadee	Assessment	Risk (qualitative)
Reproductive migration	Changing the timing of the initiation of winter flows	Species typically migrate late winter/ early spring (Morgan *et al.* 1998). Consequently, during this time, flows will be dominated by rainfall and runoff.	Likelihood=medium Consequence=low
Reproductive migration	Lack of suitable spawning habitat in lower reaches	Species typically migrate late winter/ early spring (Morgan *et al.* 1998). Consequently, during this time, flows will be dominated by rainfall and runoff.	Likelihood=low Consequence=medium
Reproductive migration	Loss of hydraulic connectivity	Late winter/early spring rainfall and subsequent runoff will override any groundwater-surface water inputs. The clay soils result in a degree of "perching" of surface waters (Strategen 2006)	Likelihood=low-medium (see URS 2004) Consequence=medium
Reproductive migration	Loss of initial winter flush (an initial stimulus for onset of migration)	Late winter/early spring rainfall and subsequent runoff will override any groundwater-surface water inputs.	Likelihood=low Consequence=low
Density-dependent effects	Concentration of individuals in lower Brook pools	Little evidence of density-dependent effects (competition, predation). Concentration occurs at present due to "drought"	Likelihood=high Consequence=low
Habitat	Point of initiation of flow moves downstream and fish are concentrated in lower pools	Did occur during early 2006 as a consequence of drought conditions. Fish numbers high in lower pools.	Likelihood=medium Consequence=high

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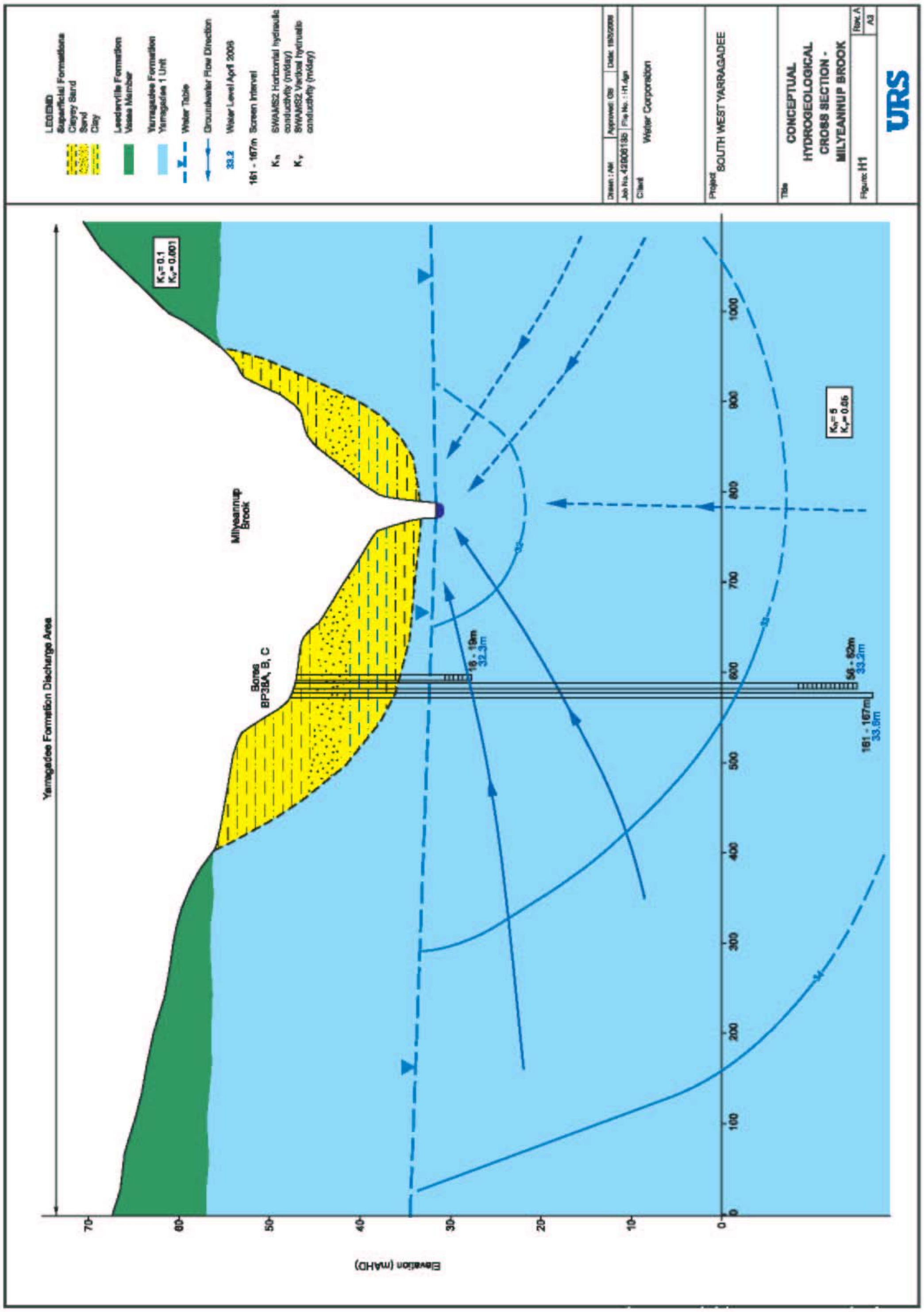
Appendix 1. Reprinted after URS (2004).



Appendix 2. Reprinted from the ERMP.

BLACKWOOD RIVER VALLEY SECTIONS

MILYEANNUP BROOK)

Milyeannup Brook is incised into both superficial formations and the Yarragadee Formation. The superficial formations are comprised of valley-fill erosional and fluvial deposits of limited distribution adjacent to the water course. Groundwater flow occurs locally from the Yarragadee Formation into the brook. The potentiometric levels in the Yarragadee Formation are upward in the vicinity of Milyeannup Brook, as shown by the piezometers at site BP38. For example in April 2006 potentiometric levels were 33.6 m in the 161 - 167 m screen interval; 33.2 m in the screen interval 56-62 m; and 32.3 m in the screen interval 16-19 m. Horizontal flow is interpreted to be into the section line (towards the viewer).

The superficial formations in the valley of the brook are generally clayey and occur above the interpreted permanent water table. As such, the vegetation that occurs at higher elevations (outside of the current incised channel) along the brook is expected to be predominantly maintained by soil moisture that is replenished by winter rainfall. Near the base of the river valley, close to the watercourse, this is however, increased potential that vegetation would be dependent (in-part) on the water table.

For the most part the superficial formations are in the unsaturated zone. In these areas, there is a low risk of potentiometric level changes in the Yarragadee Formation adversely influencing plant available water. On the valley floor, however, drawdown of the Yarragadee Formation would influence depth to the water table and stream flow. As such, vegetation on the valley floor that is dependent on the water table and/or stream flow may be at risk.

Vertical gradients diminish with depth into the Yarragadee Formation indicating a horizontal flow system (not displayed in Figure H1) at depth.

Appendix 7

Review of extent of occurrence of Balston's pygmy perch and the mud minnow – report by Wetland Research & Management

Review of extent of occurrence of Balston's pygmy perch and the mud minnow

prepared for

strategen

by

Wetland Research & Management

June 2006

Review of extent of occurrence of Balston's pygmy perch and the mud minnow

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Report

June 2006

Frontispiece: (left to right): Balston's pygmy perch, *Nannatherina balstoni* (photo taken from Department of Fisheries 2005); mud minnow, *Galaxiella munda* (photo taken from Department of Fisheries 2005).

Recommended Reference Format

WRM (2006). Review of extent of occurrence of Balston's pygmy perch and the mud minnow. Unpublished report by Wetland Research & Management to Strategen. June 2006.

Disclaimer

BACKGROUND

Groundwater abstraction from the fresh South West Yarragadee Aquifer in Western Australia has been proposed as a possible means of addressing water shortage issues in the southwest of the State. Studies are currently being undertaken to examine the potential effects of this abstraction on the surrounding environment, particularly the wetlands and river systems. Some sections of the Blackwood River and a number of its tributaries have perennial flows which appear to be dependent on groundwater inflows (discharge), particularly in summer. Therefore, groundwater abstraction may consequently reduce surface flows in the river and its tributaries, affecting salinities and potentially resulting in some systems drying.

As part of the assessment of the South Wester Yarragadee Water Supply Development Project, Strategen contracted WRM to undertake a review of the extent of occurrence of both Balston's pygmy perch and the mud minnow in southwestern Western Australia, particularly in relation to their occurrence in the area potentially affected by groundwater drawdown. Both these fish species are endemic to the southwest of Western Australia and hold conservation significance (as evidenced by listings with various agencies). They are known to occur in tributaries of the Blackwood River and therefore may be adversely affected by groundwater abstraction. This report documents the occurrence of the two species in the Blackwood and its tributaries, relative to the overall occurrence within the southwest.

NANNATHERINA BALSTONI REGAN 1906

Balston's pygmy perch, *Nannatherina balstoni*, is the rarest of all southwest endemic freshwater fishes (Morgan *et al.* 1998). Allen *et al.* (2002) suggest they occur in acidic, tannin-stained freshwater pools, streams and lakes in sandy areas within 30 km of the coast, although more inland occurrences are known (WRM 2005) *N. balstoni* are typically found amongst inundated riparian vegetation, particularly in spring where they presumably feed and spawn (Morgan *et al.* 1998). The larvae prefer shallow water (<10 cm), but as they grow they gradually move into deeper waters.

Their life cycle typically lasts one year (Morgan *et al.* 1995), with only one spawning event which occurs in the breeding season between June and September (Morgan *et al.* 1998). Spawning peaks in mid-July to early August, when water levels are at a maximum (Morgan *et al.* 1998). Balston' pygymy perch are also known to breed in response to flooding. Females lay between 500 and 1600 eggs, and adults die shortly after spawning (Allen *et al.* 2002)

As the rarest freshwater fish in Western Australia, it has been awarded conservation status, of differing levels, with a number of agencies. *N. Balstoni* is listed under the IUCN Redlist of Threatened Species as 'Data Deficient' (World Conservation Centre 1996). In 1999 it was listed as 'Vulnerable' with the Australian Society for Fish Biology, however, this was amended to 'Data Deficient' in 2001. More recently, it was nominated in February 2005 for inclusion as 'Vulnerable' under the Environment Protection and Biodiversity Act 1999. Their nomination was primarily based on their restricted distribution and considerable contraction of range over the past century. CALM (2005) have also listed *N. balstoni* on their List of Priority Fauna as 'Priority 1'. The criterion for inclusion in this Priority category is "taxa with few, poorly known populations on threatened lands" (CALM 2005).

The major threats to the status of Balston's pygmy perch are from habitat alteration, including changes to flow regimes (regulation and abstraction) and increasing salinisation, siltation and eutrophication, and the introduction of exotic species (Morgan *et al.* 1998). Their vulnerability is compounded by their short life-cycle, low fecundities, single breeding event, low population sizes (approx. <1000 mature per river system), predation from introduced fish (evidenced by lack of co-occurrence) and an inability to tolerate marginally saline or eutrophic waters (characteristic of the larger rivers and wetlands of southwestern Australia).

Historically, *N. balstoni* had a distribution extending from the Moore River (Gingin Brook) in the north to Two Peoples Bay (Goodga River, near Albany) in the southwest (Museum Records, Morgan *et al.* 1998). However, due to anthropogenic disturbance and habitat degradation (salinisation, damming, eutrophication and dewatering), their range now consists of highly fragmented populations in the extreme southwest of the State, between Margaret River and Two Peoples Bay. It has been suggested that they have been lost from freshwater systems in the northern half of their original range (Anon. 2005a) and recent surveys failed to record them in the Moore River (Morgan *et al.* 2000, Strategen 2006) or Collie River (Morgan *et al.* 1998). Museum records of 1981 indicated the presence of Balston's pygmy perch in Gingin Brook of the Moore River catchment. However, more recent surveys (1996-1998, 2003, & 2005) of over 70 sites on the Moore River and its tributaries (including

Gingin Brook) failed to locate any *N. balstoni* (Morgan *et al.* 2000, Strategen 2006). Morgan *et al.* (1998) reported this species from the Collie River (L. Pen pers. comm. to Morgan *et al.* 1998), but it does not seem to still occur there, perhaps due to elevated salinities and habitat degradation. Furthermore, it is also likely that this species has been lost from rivers and lakes on the Swan Coastal Plain south of Perth (Anon 2005a).

Within its current range, Balston's pygmy perch has become extremely rare or lost from many rivers, including the Blackwood River, Frankland River, Margaret River and King River (Morgan *et al.* in press). It is confined to drainages and wetlands near the south-western coastline (Allen *et al.* 2002). The centre of the present distribution is in the peat flats of the Doggerup, Gardner and Shannon River watersheds (Morgan *et al.* 1998). Over part of its range, *N. balstoni* co-occurs with the western pygmy perch, *Edelia vittata* (its closest relative), but it is generally more scarce (Allen *et al.* 2002). In fact, this species is often only recorded in low abundances (<10 fish), despite a large sampling effort (Morgan *et al.* 1995).

The extent of their occurrence within this known range can be documented by reviewing studies undertaken since 1990. Pusey & Edward (1990) surveyed the fish fauna of the southern acid peat flats in south-western Australia. A total of nine sites were sampled including both temporary and permanent water. Over 3700 fish were collected, representing six species and three families (Pusey & Edward 1990). Although *N. balstoni* was the most infrequently encountered species, it was present at all sites except number 6 (a permanent water site). It had previously been recorded from this site in 1981 (Pusey unpub. data). Balston's comprised 4.8% of the total fish fauna collected from temporary water sites and 3.7% from permanent water sites (Pusey & Edward 1990).

Twenty-seven wetlands between Cape Naturaliste and Albany, within 20 km of the coast, were sampled by Jaensch (1992). *N. balstoni* were recorded from nine sites, including Quitjup Lake, Lake Smith, Doggerup Lake, Lake Florence, Gardner River Lake, Maringup Lake, the lake east of Broke Inlet, Owingup Swamp, and Boat Harbour Lake 1.

Morgan *et al.* (1998) studied the distribution of freshwater fishes throughout south-western Australia between 1994 and 1996. Balston's were found to be moderately abundant in a number of ephemeral shallow pools and creeks between Windy Harbour and Walpole. They were captured in very low number in the major rivers, Margaret, Scott, Donnelly, Shannon, Gardner, Deep, Kent and Denmark rivers. A number of lake systems supported Balston's pygmy perch, albeit in low numbers, such as Lake Quitjup, Lake Smith, Doggerup Lake, Maringup Lake and Moates Lake (Morgan et al. 1998). The authors also presented museum records of known occurrences, including Grasmere 1947, Albany 1976, Northcliffe 1981, Northcliffe 1986 (Warren River), Nannup 1986 (Blackwood River), Nelson Rd 1986 (Shannon River), Mt Chudalup 1986, Walpole 1986 (Weld River), Walpople 1986 (Inlet River), Denmark 1992, Broke Inlet 1992, Manjimup 1992, and Nannup 1992. Christensen (1982, cited in Morgan et al. 1998) recorded *N. balstoni* from Bevan Rd (Kent River), Kordabup Rd/South West Hwy, and the Muir Hwy.

Between 1996 and 1998 an extensive survey of the fish fauna of the Moore River catchment was undertaken by Morgan *et al.* (2000). This involved the sampling of over 50 sites along the Moore River, Gingin Brook, Lennard Brook, Ellen Brook and associated wetlands around the Gingin region (Morgan *et al.* 2000). Despite Museum Records indicating their presence in Gingin Brook, no Balston's were collected during the surveys. Seven sites on the Moore River and Gingin Brook were again sampled in 2004 by the Aquatic Research Laboratory, UWA, using a variety of methods as part of an Environmental Water Requirements (EWR) study (Strategen 2006). Five species of freshwater fish were collected but no *N. balstoni* (Strategen 2006).

The fish fauna of the highly salt-affected Blackwood River catchment has been surveyed numerous times. Morgan *et al.* (2003) sampled 151 sites using a range of techniques which yielded over 12700 fish. Balston's were found to be very rare and were only collected from a single low salinity site in the Scott River catchment (Morgan *et al.* 2003). The Blackwood River catchment was again sampled in 2004 as part of an EWR study for the main river system (CENRM 2005). Sites were located in the main river channel and a number of fresher tributaries, including Ballan Creek, Rosa Brook, Adelaide Brook, Spearwood Creek, Layman Brook, Milyeannup Brook, Poison Gully, Sollya Creek, Red Gully, McAfee Brook, Sturcke Creek and St John Brook (CENRM 2005). Only one Balston's pygmy perch was collected at one location on the Blackwood River (CENRM 2005). Then, during early April 2005, six sites were sampled in the main channel and tributaries between the river's junction with Great North Road and Agg Road as part of a study aiming to determine the dependence of fish on the Yarragadee Aquifer (Morgan & Beatty 2005a). Tributaries included in the study were Adelaide Brook, Rosa Brook, Layman Brook, Poison Gully, Milyeannup Brook, Red Gully, Sturcke Creek, McAfee Brook and St John Brook (Morgan & Beatty 2005a). *N. balstoni* were collected from four sites (one in the main Blackwood River channel downstream of the Yarragadee discharge area, two in Milyeannup Brook, and one in Red Gully) (Morgan& Beatty 2005a). Milyeannup Brook appears to be an important refuge for this fish, with 90% of all captures being from this tributary (densities were 15-30 times greater from this system than any other tributary) (Morgan & Beatty 2005a). Milyeannup Brook is a tributary which receives direct flows from the Yarragadee, and as such surface flows would be affected by groundwater abstraction and the lowering of water tables (Morgan & Beatty 2005). Since *N. balstoni* are no longer found anywhere else in the Blackwood (as suggested by Morgan & Beatty 2005a), the robust population recorded from Milyeannup Brook is of conservation importance. Morgan & Beatty suggested that "reductions in flows and depths by reducing aquifer input to Milyeannup Brook may be detrimental to the maintenance of this population". Balston's pygmy perch of Milyeannup Brook were located near the Blackwood River (i.e. site MB1 – near confluence with main channel; site MB2 – Brockman Highway) (Morgan & Beatty 2005a). No sampling sites were located in the headwaters of Milyeannup Brook (see Figure 1).

In a study designed to monitor fish usage of the Goodga River fishway, Morgan & Beatty (2005b), recorded *N. balstoni* from the Angove River. This capture represented an extension to their range, since previous to this study they were only known from streams and lakes west of the Goodga River.

Finally, as part of a study assessing the nature conservation values of wetlands from the Muir-Byenup peat swamp system near Manjimup, south-western Australia, WRM (1998) sampled fish fauna from 27 sites. A number of methods were utilised, including electrofishing, box-traps, seine nets, dip nets and rotenone. Sampling was undertaken over three seasons. Of the 27 sites, only four supported Balston's pygmy perch (WRM 1998). These were Bokarup Swamp, Kulunilup Lake, Mulgarnup Swamp, and Lake Unicup (WRM

2005). The same suite of sites were again sampled in 2004 over three seasons, and *N. balstoni* was collected from the same four locations (WRM 2005).

This review indicates there are a number of seemingly stable populations of Balston's pygmy perch exist within the south-west of Western Australia. In the Blackwood River catchment, they are most abundant in Milyeannup Creek. Whilst Balston's pygmy perch appears to be quite widespread, there are no large or extensive populations and they are generally recorded in low numbers despite a large sampling effort. They are therefore prone to progressive losses and, in the extreme case, local extinctions may result. Given their conservation status, and relative rarity, individual populations warrant protection, and every effort must be taken to ensure their continued survival.

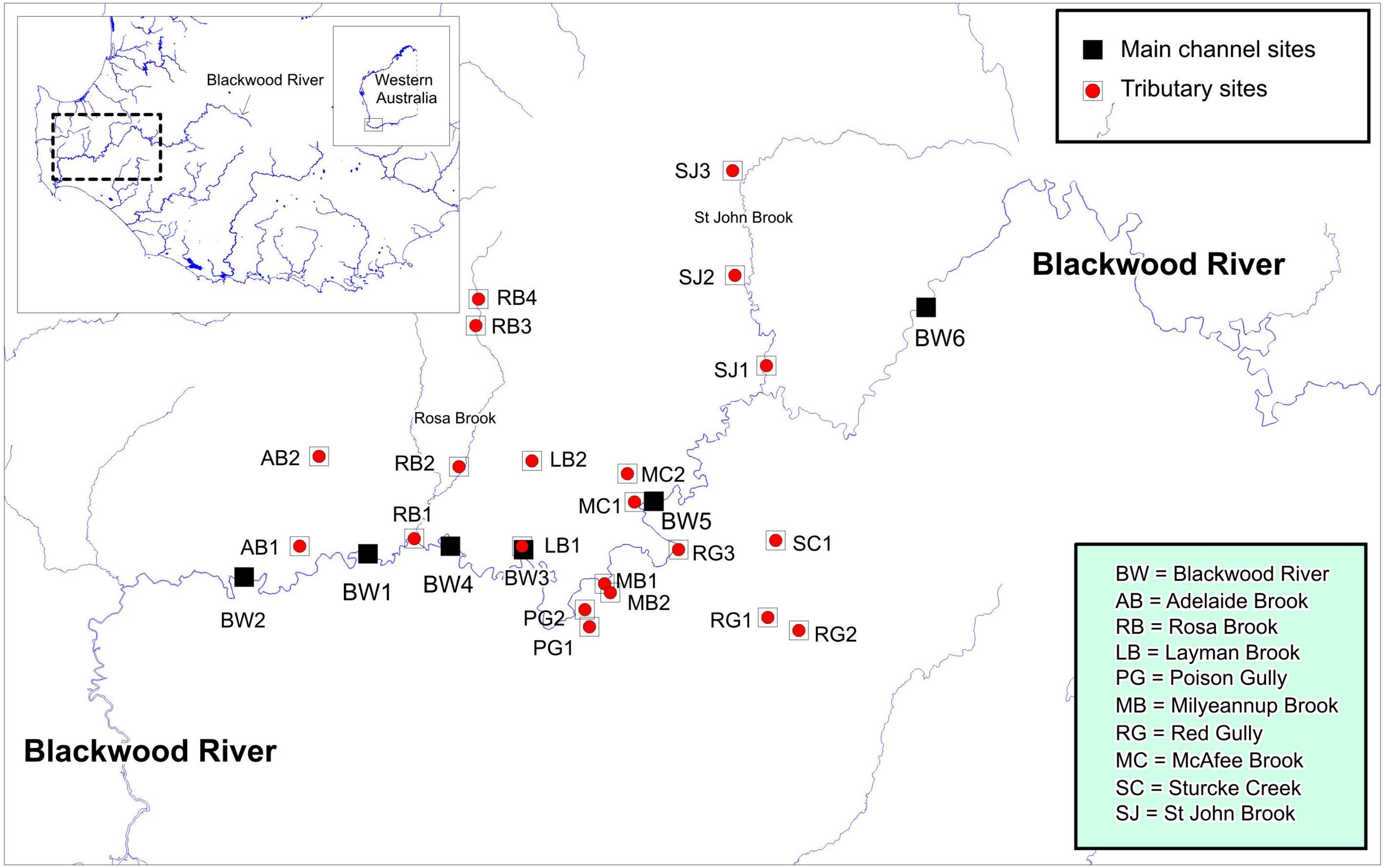

Figure 1. The sites sampled in the Blackwood River and its tributaries during April 2005. N.B: - Adelaide Brook, Rosa Brook and Layman Brook were sampled during the summer of 2003/4. Taken from Morgan & Beatty (2005a)

GALAXIELLA MUNDA MCDOWALL 1978

The mud minnow, *Galaxiella munda*, is commonly found to inhabit waters which are darkly tannin-stained and acidic (pH 3.0-6.0) (Morgan *et al.* 1998, Allen *et al.* 2002). Morgan *et al.* (1998) also suggest they occur in waters which experience marked seasonal temperature fluctuations (11-35°C). They are typically found in small flowing streams near submerged vegetation; occasionally in still water of ponds, swamps and roadside drains (Allen *et al.* 2002). Adults tend to live close to riparian vegetation in streams and in the open water of pools. Larvae generally feed in the very shallow water of pools (<10 cm) amongst flooded riparian vegetation. As they grow, they gradually move into the deeper water of pools and then into the streams to which these pools are connected (Morgan *et al.* 1998).

Spawning in *G. munda* occurs between July and October (Morgan *et al.* 1998, Allen *et al.* 2002). Similar to Balston's pygmy perch, their life cycle typically lasts for one year, and peak spawning is prompted by the rise of water temperature and day length (Morgan *et al.* 1998, Allen *et al.* 2002). However, unlike *N. balstoni*, the mud minnow is a multiple spawner. Females deposit several clutches of eggs over a protracted period of a few weeks in flooded vegetation (Allen *et al.* 2002). Spent adults usually die a few months after spawning (Allen *et al.* 2002).

The conservation status of mud minnow has also been listed with a number of agencies. It is listed as 'Restricted' by the Australian Society for Fish Biology (2001) and 'Lower Risk – Near Threatened' on the IUCN Redlist of Threatened Species (Wager 1996). The latter listing means that the mud minnow is considered a species which does not qualify for 'Conservation Dependent', but is close to qualifying for 'Vulnerable' (Wager 1996). This species is also listed as Priority 4 on CALM's List of Priority Fauna, suggesting it is a taxon in need of monitoring (CALM 2005). Furthermore, in February 2005, *G. munda* was also nominated for inclusion as 'Vulnerable' under the EPBC Act 1999. Its nomination was based on the substantial reduction in numbers over the past century, coupled with its restricted distribution (Anon. 2005b). According to its nomination form, the mud minnow has undergone a loss of populations from all rivers between Moore River and Margaret River (Anon. 2005b). Populations have also become severely fragmented or lost from many of the rivers within its current distribution (i.e. Blackwood and Margaret rivers) due to loss of habitat (salinisation, damming, eutrophication and dewatering) and introduced species (Anon. 2005b). A number of rivers in which it is currently found also support the introduced fishes known to predate on *G. munda*.

The major threats to the status of the mud minnow are similar to those affecting Balston's pygmy perch. That is, habitat degradation and the introduction of exotic species. In south-western Australia, habitat degradation is likely to occur through alterations to flow regimes (regulation and abstraction), increased salinisation, siltation and eutrophication, which occur through dam construction, groundwater extraction and agricultural/forestry practices in the uppermost catchment (Morgan *et al.* 1998). Morgan *et al.* (1998) cite habitat alteration (through dam construction) and the introduction of *Perca fluviatilis* and *Gambusia holbrooki* as the possible cause for the virtual disappearance of *G. munda* from the headwaters of Bog

Brook. Pen *et al.* (1991) collected viable populations of mud minnows from these waters, but Morgan *et al.* (1998) found very few.

Like *N. balstoni,* the mud minnow has undergone a considerable reduction in range (Anon. 2005b, Morgan & Beatty 2005), and has also been lost from the northern half of its range – with the exception of the Gingin Brook population (Anon. 2005b). In addition, this species has been lost from rivers and lakes on the Swan Coastal Plain south of Perth (i.e. between the Moore River and Margaret River), which is now a network of drains (Anon. 2005b). It has been suggested that rural development and degradation of aquatic habitats have severely impacted on the original population (Morgan *et al.* 1998, Allen *et al.* 2002).

Currently, *G. munda* is essentially restricted to the extreme south-west corner of the State, between the Goodga and Margaret rivers, with an isolated population at Gingin, approximately 100 km north of Perth (Morgan *et al.* 1998, Allen *et al.* 2002). However, this population consists of very few individuals which are restricted to a small spring in Gingin Brook. Its centre of distribution is in the small lakes and streams around Windy Harbour in the D'Entrecasteaux National Park (Morgan *et al.* 1998). Morgan *et al.* (1998) reported that this species was occasionally abundant in the headwaters and tributaries of rivers and in a number of shallow pools connected to streams. These authors also suggested that *G. munda* penetrated further into the forested areas than *N. balstoni*, *Galaxiella nigostriata* and *Lepidogalaxias salamandroides* (Morgan *et al.* 1998). Within the Margaret River mud minnows are essentially restricted to a few pools in the upper reaches, habitats that were previously free from introduced fishes (Morgan & Beatty 2003).

The extent of their occurrence within this known range can be documented by reviewing studies undertaken since 1990. Pusey & Edward (1990) recorded mud minnows from both temporary (9.4% of the total fish fauna) and permanent (6.5% of the total fish fauna) peat wetlands in south-western Australia. Interestingly, Pusey & Edward (1990) provided information to refute Allen's (1992) suggestion that *G. munda* are able to aestivate to avoid drought. Their data indicated that mud minnows in fact move out of temporary waters prior to their desiccation (Pusey & Edward 1990). Pusey & Edward (1990) reported that *G. munda* use the southern acid peat flats during the wet season and move seasonally between temporary and permanent waters.

Of the 27 sites between Cape Naturaliste and Albany sampled by Jaensch (1992), mud minnows were only collected from one location. This was within Lake Samuel (Jaensch 1992).

Morgan *et al.* (1998) recorded *G. munda* from the watersheds of the Margaret River, Warren River, Lake Muir, Doggerup Creek, Gardner River, Shannon River, Broke Inlet, Deep River, Frankland River, Bow River, Kent River, Denmark River, Hay River, Torbay Inlet, King River and Two Peoples Bay. It was found to be most abundant in creeks and streams of the Gardner River and Shannon River watersheds. In Boorara Brook (a tributary of the Gardner River), for example, over 100 fish were caught in a small pool, measuring 3 m by 1 m (Morgan *et al.* 1998). Museum Records and Christensen (1982, cited in Morgan *et al.* 1998) also indicate mud minnows have previously been collected from the Blackwood and Donnelly River watersheds. Other Museum Records cited in Morgan *et al.* (1998) include Northcliffe 1960, Fish Creek Pool 1964, Pemberton 1958, Mt Chudalup 1977, Walpole 1977, Cane Break Creek 1976, Warren 1981, Jeffrey Rd 1981, Shannon 1982, Gardner River 1982 & 1986, Blackwood River 1986, Doggerup Creek 1986, Nelson Rd 1986 (Shannon River), Shannon River 1986, Weld River 1986, Inlet River 1986, Lake Powell 1986, Quinnup 1978, Northcliffe 1978, Shannon 1977, Crystal Springs 1977, Shannon 1978, Denmark 1978, Mt Frankland 1978, Nile Creek 1978, and Gardner River 1988. *G. munda* was the most abundant species collected by Christensen (1982, cited in Morgan *et al.* 1998), and it was recorded from: Nelson Rd, Deeside Coast Rd, South West Hwy, Cripple Rd (Quininup Brook), Wheatley Coast Rd, Richardson Rd, Thompson Rd, Bevan Rd (Deep River), Muir Hwy (Tone River), Denbarker Rd (Mitchell River), Gurnsey Rd (Meerup River), Rifle Range Rd, Pneumonia Rd, Beardmore Rd (Deep River), Middle Rd, Middle Rd (Bow River), Break Rd, Stewart Rd, Fouracres Rd, Scott Rd, Nornalup Rd, Basin Rd (Kent River), Kordabup Rd/South West Hwy, Kockelup Rd, Stan Rd, and Court Rd.

The fish fauna of the Moore River catchment has been surveyed on a number of occasions by different scientists. Morgan *et al.* (2000) sampled 57 sites along the Moore River, Gingin Brook, Lennard Brook, Ellen Brook and associated wetlands around the Gingin region between 1996 and 1998. *G. munda* were only caught in very low numbers from one site in the fresh waters of Lennard Brook (Morgan *et al.* 2000). Then in November 2003, eight sites were sampled in Gingin Brook (upstream and downstream) of dams (Beatty & Morgan 2004). Over 700 fish from eight species were collected. This included six species of freshwater fish endemic to the south-west. The mud minnow was the least abundant/common species recorded (Beatty & Morgan 2004). It was found at only one site at a density of 0.24/m^2 (total number = 22). Beatty & Morgan (2004) reported that *G. munda* has been lost from the main channel (Moore River) and is now essentially restricted to the 'fresh' tributaries. The authors therefore suggested that this isolated population is of high conservation importance (Beatty & Morgan 2004). When the system was sampled again in 2004, by the Aquatic Research Laboratory, UWA, no mud minnows were collected (Strategen 2006).

As mentioned previously, the fish fauna of the highly salt-affected Blackwood River catchment has also been surveyed numerous times. During extensive sampling of over 150 sites, mud minnows were only captured from Rosa Brook (Morgan *et al.* 2003). Mud minnows were also captured by CENRM (2005) in the Blackwood catchment, again from only one locality. In this study, they were collected from Poison Gully (location: WGS84 34°07'47.6"S, 115°34' 11.7"E, near the Brockman Highway; CENRM 2005), although there is some confusion as to their identification due to difficultly in differentiating between them and the black-stripe minnow (*Galaxiella nigostriata*). In early April of 2005, Morgan & Beatty (2005) sampled six sites in the main Blackwood River channel and nine tributaries. Mud minnows were collected from 11 sites, including Poison Gully (site PG2 - near confluence with main channel), Milyeannup Brook (MB1 - near confluence with main channel), Layman Brook (site LB1 - Denny Road), Rosa Brook (site RB1 – Denny Road, RB2 – Crouch Road, RB3 – Lawson Road, RB4 – Mowen Road), Red Gully (RG1 – waterpoint on Gt. Southern Rd), McAfee Brook (site MC2 – Crouch Rd), Sturcke Creek (SC1 – waterpoint on Gt. Southern Rd), and St John Brook (site SJ3 – Baker Rd) (see Figure 1). According to Morgan & Beatty (2005) they were well represented in tributaries but were never encountered in the main channel. Mud minnows were also captured in waterpoints that were water reserves for fire fighting, i.e. sites that were otherwise dry aside from the presence of waterpoints (Morgan & Beatty 2005). A high percent of spinal deformity (33%) was recorded from mud minnows collected from Red Gully, suggesting this population may be inbreeding within a small gene pool (Morgan & Beatty 2005).

In a study of the Vasse River (including two sites in the Vasse River Diversion Drain) during December 2003 and March 2004, 7895 fish were collected (Morgan & Beatty 2004). The mud minnow was collected from only site in the headwaters of the Vasse River (at Sturt Rd) and was collected from a waterpoint (Morgan & Beatty 2004). This site was located in the forested upper catchment, and therefore the most undisturbed section of the Vasse River. The abundance of *G. munda* was very low, with only 5 individuals being captured at a density of 0.125/m^2 (Morgan & Beatty 2004). This was the first record of the mud minnow in the Vasse River.

The nature conservation values of wetlands in the Muir-Byenup peat swamp system were assessed by WRM (1998 and 2005). Twenty-seven sites were sampled over three seasons in 1996/97 and again in 2004. *G. munda* was collected in 1996/97 from Poorginup and Myalgelup Road swamps, where they were abundant, and specimens were again recorded from the same sites in 2004 (WRM 1998 and 2005). In these studies, *G. munda* and *G. nigostriata* were the most infrequently encountered native species (WRM 2005).

Finally, Beatty *et al.* (2006) sampled ten sites in the southwest of WA in September 2005. Systems surveyed included, Wilyabrup Brook, Jingarmup Brook, Dugulup Creek, Dandatup Brook and Meelup Brook. The only fish fauna collected during this study were western pygmy perch and western minnows from Wilyabrup Brook, although landholders indicated that mud minnows had previously been sighted from the system (Beatty *et al.* 2006).

This review suggests that *G. munda* is quite widespread throughout the south-west of Western Australia, but tends to have small populations in disjunct occurrences. It is relatively common to the fresh tributaries of the Blackwood River catchment. *G. munda* is generally collected in higher abundances than *N. balstoni*. The peat wetlands from the Byenup-Muir catchment also represents apparently stable populations of *G. munda*. Given their listing as 'Restricted' (Australian Society for Fish Biology 2001) and 'Near Threatened' on the IUCN Redlist of Threatened Species (Wager 1996), effective management is also required for mud minnows to ensure their conservation, and individual populations warrant protection.

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Appendix 8

Response to Department of Environment and Heritage submission

RESPONSE TO DEPARTMENT OF ENVIRONMENT AND HERITAGE SUBMISSION

The Department of the Environment and Heritage (DEH) submitted comments on the South West Yarragadee Water Supply Development in May 2006. DEH requested specific information to be provided and these requests are addressed in the following sections.

Flora and fauna surveys of the pipeline route

The pipeline route and wellfield as presented in the Sustainability Evaluation/ERMP has been planned to avoid all nationally significant areas wherever possible utilising the latest in GIS database planning tools. A small amount of clearing is unavoidable and the Water Corporation has made a commitment in the Sustainability Evaluation/ERMP to undertake the following surveys along the pipeline route:

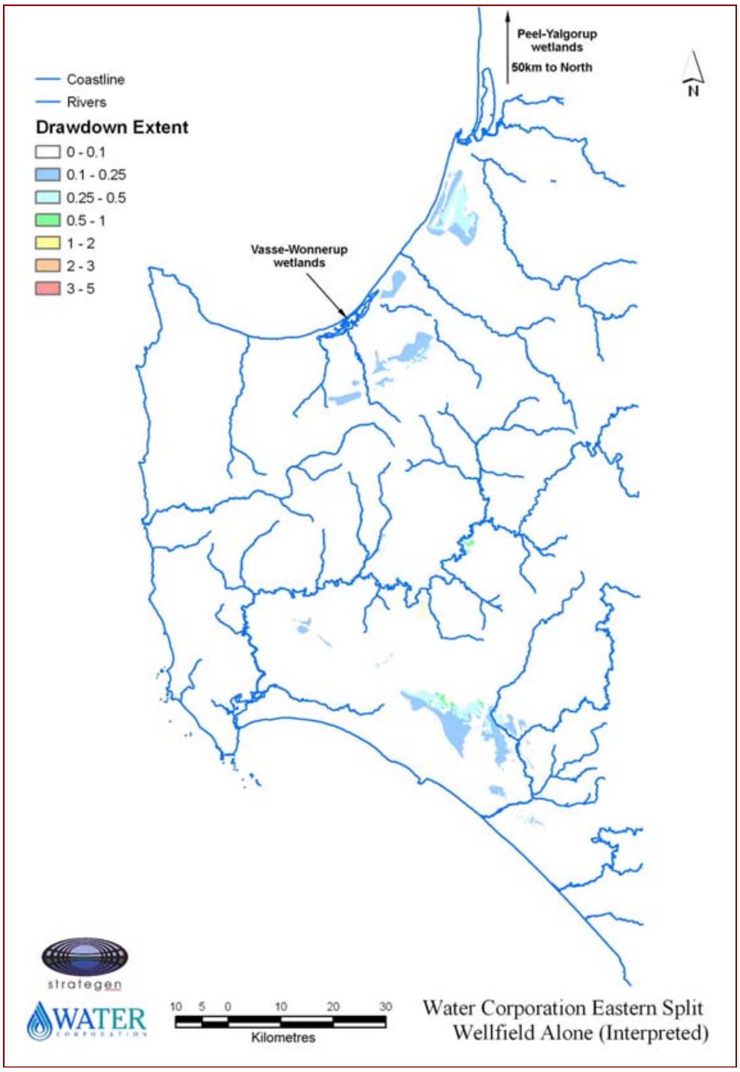
- a soil sampling program to further define the risk of exposure of acid sulphate soils
- a detailed flora and fauna habitat survey to identify species and communities of conservation significance.

The flora and fauna habitat survey will meet all requirements of the *Environmental Protection and Biodiversity Act 1999*.

Ramsar Wetlands

No Ramsar wetlands are within the areas potentially affected by groundwater drawdowns from the Water Corporation proposal. The Peel–Yalgorup wetlands are more than 50 km to the north of the potentially affected areas. The Vasse–Wonnerup wetlands are relatively close to areas of groundwater drawdown (Figure 1) but the wetlands are connected to the ocean and their minimum water levels are controlled by sea level and will not be affected by the proposal. The hydrogeology of the Vasse–Wonnerup wetland system is described in Volume 2 Chapter 5 Section 4.9.1 of the Sustainability Evaluation/ERMP.

Figure 1 Ramsar wetlands and proximity to areas of potential groundwater drawdown



Matters of national significance

DEH requested that the ERMP contain a separate section relating to matters of national environmental significance. A revised ERMP is not being produced and all changes to the proposal and further information is presented in this response to submissions. The matters of national environmental significance are discussed in this section.

Mattiske (2005b) conducted a search of the Department of Environment and Conservation (then CALM) databases to identify the flora species and threatened ecological communities (TECs) of conservation significance that may occur in each area potentially affected by groundwater drawdown from the proposal. Each species was then given a likely groundwater dependence based on life form and information on habitat preference in relation to groundwater depth. This information is shown below in relation to each area potentially affected by the proposal.

Bamford (2005) identified fauna species that were likely to occur in each area potentially affected by the proposal. The EPBC listed fauna species and their likely groundwater dependence (Bamford 2003) are shown in the following tables.

There are no EPBC listed threatened ecological communities (TECs) on the Blackwood Plateau (includes Rosa Brook, St John Brook, Poison Gully and Milyeannup Brook) or the Scott Coastal Plain.

Poison Gully and Milyeannup Brook

The EPBC listed flora species that may occur in Poison Gully and Milyeannup Brook are shown in Table 1. *Daviesia elongata* subsp. *elongata* was recorded in the survey of Milyeannup Brook and Poison Gully (11 transects). The species was found in the upper reaches of Poison Gully, on lower slopes in seasonally moist, leached grey sands. The species is a small herbaceous plant existing in an area of greater than 10 m depth to groundwater and is therefore unlikely to be groundwater dependent, relying on soil moisture rather than groundwater.

Table 1 Summary of EPBC flora species that may occur in Poison Gully and Milyeannup Brook and their potential groundwater dependence

Genus	Species	EPBC Status	Likely Groundwater Dependence
Caladenia	*huegelii*	Endangered	Low
Daviesia	*elongata* subsp. *elongata*	Vulnerable	Low
Drakaea	*Elastica*	Endangered	Medium
Drakaea	*Micrantha* (ms)	Vulnerable	Medium
Dryandra	*Mimica*	Endangered	Medium
Dryandra	*nivea* subsp. *uliginosa*	Endangered	Medium
Dryandra	*Squarrose* subsp. *argillacea*	Vulnerable	Medium
Laxmannia	*Jamesii*	Vulnerable	Low
Verticordia	*plumosa* var. *vassensis*	Endangered	High

The EPBC listed fauna species that may occur in Poison Gully and Milyeannup Brook are shown in Table 2. None of these species have a high likelihood of being groundwater dependant. Therefore, there is likely to be no impact on EPBC listed fauna species in this area.

Table 2 EPBC listed fauna species likely to occur in Poison Gully and Milyeannup Brook, and their groundwater dependence (GD)

Species	EPBC Status	GD[1]	Occurrence
FISH	None		
FROGS	None		
REPTILES	None		
BIRDS			
Apus pacificus (migratory)	Listed	Low	Likely
Falco peregrinus	Specially protected for other reasons	Low	Likely
Calyptorhynchus latirostris	Endangered	Low	Likely
Calyptorhynchus baudinii	Vulnerable	Low	Likely
Merops ornatus (migratory)	Listed	Low	Likely
MAMMALS			
Dasyurus geoffroii	Vulnerable	Moderate	Likely
Pseudocheirus occidentalis	Vulnerable	Low	Uncertain
Setonix brachyurus	Vulnerable	Moderate	Likely

Adapted from Bamford (2005)
[1] Likelihood of being groundwater dependent

Milyeannup Brook is deeply incised and the superficial formations in the valley of the brook are generally clayey and above the water table, demonstrating that the vegetation along the brook is maintained by soil moisture replenished from winter rainfall rather than being highly dependent on the water table. Therefore, there is unlikely to be any significant impact on EPBC species that potentially utilise the area.

There is expected to be a small impact on groundwater dependent vegetation on the lower slope in Poison Gully. The changes are likely to be a slight shift in site vegetation types down the slope in the lower valley. The area of changes would be localised and the full range of vegetation types would still be present on the slope. Therefore, the full range of habitats and vegetation types would still exist and there is unlikely to be any significant impact on EPBC species that may utilise the area.

Rosa Brook

The EPBC listed flora species that may occur in Rosa Brook are shown in Table 3. Mattiske (2005a) did not record any of these species in the three cross-sectional transects surveyed along Rosa Brook.

Table 3 Summary of EPBC flora species that may occur in Rosa Brook and their potential groundwater dependence

Genus	Species	EPBC Status	Likely Groundwater Dependence
Caladenia	*huegelii*	Endangered	Low
Drakaea	*elastica*	Endangered	Medium
Drakaea	*micrantha* (ms)	Vulnerable	Medium
Dryandra	*mimica*	Endangered	Medium
Dryandra	*nivea* subsp. *uliginosa*	Endangered	Medium
Dryandra	*squarrosa* subsp. *argillacea*	Vulnerable	Medium
Laxmannia	*jamesii*	Vulnerable	Low
Verticordia	*plumosa* var. *vassensis*	Endangered	High

The EPBC listed fauna species that may occur in Rosa Brook are the same as for Poison Gully and Milyeannup Brook (Table 2). None of these species have a high likelihood of being groundwater dependant. Therefore, there is likely to be no impact on EPBC listed fauna species in this area.

The potential drawdowns in Rosa Brook are <0.5 m and are not expected to cause measurable changes to the ecosystem or any EPBC listed species that may occur in the area.

St John Brook

The EPBC listed flora species that may occur in St John Brook are shown in Table 4. Mattiske (2005a) did not record any of these species in the two areas surveyed along St John Brook.

Table 4 Summary of EPBC flora species that may occur in St John Brook and their potential groundwater dependence

Genus	Species	EPBC Status	Likely Groundwater Dependence
Caladenia	*huegelii*	Endangered	Low
Drakaea	*elastica*	Endangered	Medium
Drakaea	*micrantha* (ms)	Vulnerable	Medium
Dryandra	*mimica*	Endangered	Medium
Dryandra	*nivea* subsp. *uliginosa*	Endangered	Medium
Dryandra	*squarrosa* subsp. *argillacea*	Vulnerable	Medium
Laxmannia	*jamesii*	Vulnerable	Low
Verticordia	*plumosa* var. *vassensis*	Endangered	High

The EPBC listed fauna species that may occur in St John Brook are the same as for Poison Gully and Milyeannup Brook (Table 2). None of these species have a high likelihood of being groundwater dependant. Therefore, there is likely to be no impact on EPBC listed fauna species in this area.

St John Brook is a narrow deeply incised valley with fertile soils that have a high moisture retention capacity. Only a very narrow band of vegetation would be expected to be groundwater dependent as the depth to groundwater increases very quickly up the slope. There may be a very slight shift down slope of the lower slope vegetation types but the changes would be small and the full range of site vegetation types would still exist. Therefore, the full range of habitats and species would still exist and there is unlikely to be any significant impact on EPBC species that may utilise the area.

Scott Coastal Plain

The EPBC listed flora species that may occur on the Scott Coastal Plain are shown in Table 5. Mattiske (2005a) did not record any of these species in the five transects surveyed on the Scott Coastal Plain.

Table 5 Summary of EPBC flora species that may occur on the Scott Coastal Plain and their potential groundwater dependence

Genus	Species	EPBC Status	Likely Groundwater Dependence
Caladenia	*harringtoniae*	Vulnerable	Medium
Dryandra	*nivea* subsp. *uliginosa*	Endangered	Medium
Grevillea	*brachystylis* subsp. *australis*	Vulnerable	High
Lambertia	*orbifolia* subsp. Scott River Plains (L.W. Sage 684) (pn)	Endangered	Medium
Leptomeria	*dielsiana*	Vulnerable	
Meziella	*rifida*	Vulnerable	High

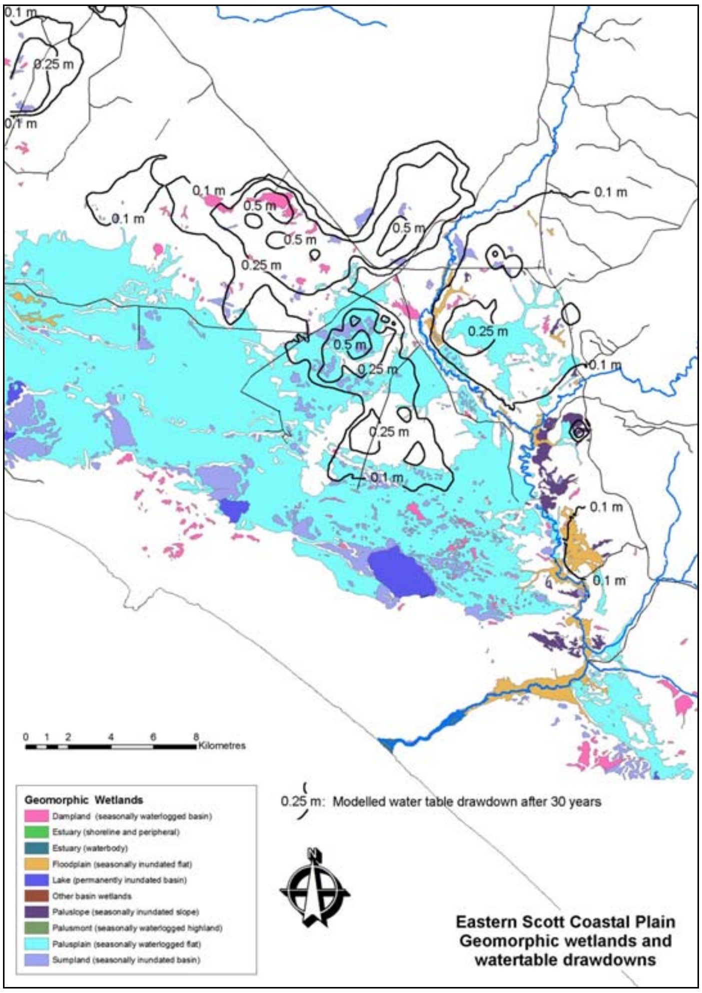
The EPBC listed fauna species that may occur on the Scott Coastal Plain are shown in Table 6. All the species with high or very high potential to be groundwater dependent are the migratory birds. These species are likely to be dependent on seasonal or permanent wetlands that may be groundwater dependent. No impact is expected on the permanent wetlands of the Scott Coastal Plain as these are outside of the potential area of drawdowns.

Table 6 EPBC listed fauna species likely to occur on the Scott Coastal Plain and their groundwater dependence (GD)

Species	EPBC Status	GD	Occurrence
FISH	None		
FROGS	None		
REPTILES	None		
BIRDS			
Ardea alba (migratory)	Listed – marine overfly area	Very high	Likely
Calidris acuminata	Migratory	Very high	Likely
Calidris ferruginea	Migratory	Very high	Likely
Haliaeetus leucogaster	Migratory	Very high	Likely
Tringa nebularia	Migratory	Very high	Likely
Tringa glareola	Migratory	Very high	Likely
Sterna bergii	Migratory	High	Likely
Apus pacificus	Listed	Low	Likely
Merops ornatus	Listed	Low	Likely
Leipoa ocellata	Vulnerable	Low	Uncertain
Falco peregrinus	Specially protected for other reasons	Low	Likely
Calyptorhynchus latirostris	Endangered	Low	Likely
Calyptorhynchus baudinii	Vulnerable	Low	Likely
Pezoporus wallicus	Endangered	Moderate	Uncertain
MAMMALS			
Dasyurus geoffroii	Vulnerable	Moderate	Likely
Pseudocheirus occidentalis	Vulnerable	Low	Likely
Setonix brachyurus	Vulnerable	Moderate	Likely

The predicted drawdown areas (Aquaterra 2006) have been overlaid on mapping of the geomorphic wetlands in the area (Figure 2) and the majority of the drawdown area does not coincide with any wetland areas. The one exception is a small seasonal wetland in the north that appears to be perched as described. Therefore, there is unlikely to be any change in water availability for EPBC listed migratory birds.

Figure 2 Predicted groundwater drawdowns and geomorphic wetlands of the Scott Coastal Plain



In the north east Scott Coastal Plain, the predicted water table drawdowns are between 0.1 and 0.75 m after 30 years (Aquaterra 2006).

To maintain terrestrial groundwater dependent ecosystems at a low level of risk, Froend & Loomes (2006) recommend that the following maximum drawdowns are not exceeded:

- 0-3 m depth to groundwater category: 0.75 m maximum drawdown
- 3-6 m depth to groundwater category: 1 m maximum drawdown.

The predicted drawdowns of 0.1 to 0.75 m after 30 years on the Scott Coastal Plain are within these limits and, therefore, not expected to have a measurable impact on the terrestrial ecosystems in the area. The Scott Coastal Plain ecosystems are adapted to high seasonal water level variation and Froend & Loomes (2006) recommends that the maximum drawdowns are not exceeded for more than two years.

Swan Coastal Plain

The EPBC listed flora species that may occur on the Swan Coastal Plain are shown in Table 7.

Table 7 Summary of EPBC flora species that may occur on the Swan Coastal Plain and their potential groundwater dependence

Genus	Species	EPBC category	Likely Groundwater dependence
Grevillea	*maccutcheonii*	Endangered	High
Petrophile	*Latericola* (ms)	Endangered	High
Lambertia	*echinata* subsp. *occidentalis*	Endangered	High
Lambertia	*orbifolia* subsp. Scott River Plains (L.W. Sage 684) (pn)	Endangered	High
Verticordia	*densiflora* var. *pedunculata*	Endangered	High
Verticordia	*plumosa* var. *ananeotes*	Endangered	High
Verticordia	*plumosa* var. *vassensis*	Endangered	High
Caladenia	*Busselliana*	Endangered	Medium
Drakaea	*Elastica*	Endangered	Medium
Dryandra	*Mimica*	Endangered	Medium
Dryandra	*nivea* subsp. *uliginosa*	Endangered	Medium
Caladenia	*caesarea* subsp. *maritima*	Endangered	Low
Caladenia	*Huegelii*	Endangered	Low
Eleocharis	*Keigheryi*	Vulnerable	High
Grevillea	*Elongata*	Vulnerable	High
Tetraria	*Australiensis*	Vulnerable	Medium
Diuris	*Drummondii*	Vulnerable	Medium
Drakaea	*micrantha* (ms)	Vulnerable	Medium
Dryandra	*squarrosa* subsp. *argillacea*	Vulnerable	Medium
Brachysema	*Modestum*	Vulnerable	Medium
Daviesia	*elongata* subsp. *elongata*	Vulnerable	Low

Table 8 shows the EPBC listed TECs that exists on the Swan Coastal Plain and its potential to be influenced by groundwater drawdowns. As the drawdowns are expected to be between 0.1 and 0.25 m after 30 years, the potential impact is low, with no measurable change expected.

Table 8 EPBC listed TECs within predicted drawdown areas on the Swan Coastal Plain

TEC	Location	EPBC category	Water Corporation predicted drawdown	Impact on TEC
Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)	Five known areas on the Southern Swan Coastal Plain, east of Busselton	Endangered	Two sites: 0.1 – 0.25 m	Low

The EPBC listed fauna species that may occur on the Swan Coastal Plain are shown in Table 9. All the species with high or very high potential to be groundwater dependent are the migratory birds. Permanent and seasonal wetlands on the Swan Coastal Plain are not expected to be affected due to the overall low levels of drawdown and the fact that these are not likely to coincide with wetland areas as described in Section 4.6.

Table 9 EPBC listed fauna species likely to occur on the Swan Coastal Plain and their groundwater dependence (GD)

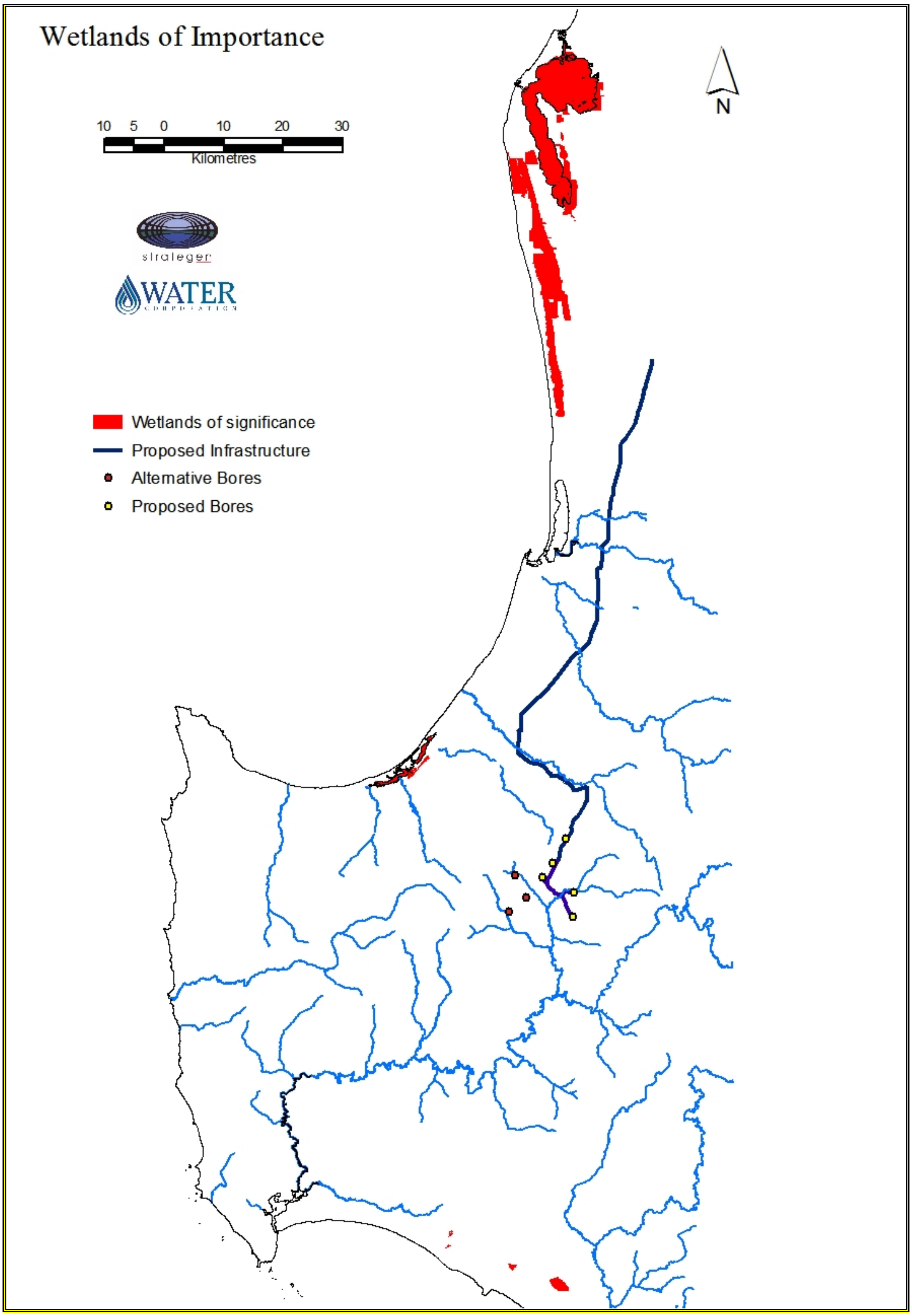
Species	EPBC status	GD	Likely Occurrence
FISH			
FROGS			
REPTILES			
BIRDS			
Ardea alba (migratory)	Listed – marine overfly area	Very high	Likely
Ardea ibis (migratory)	Listed – marine overfly area	Very high	Likely
Haliaeetus leucogaster	Migratory	Very high	Likely
Tringa nebularia	Migratory	Very high	Likely
Tringa glareola	Migratory	Very high	Likely
Calidris acuminata	Migratory	Very high	Likely
Calidris ferruginea	Migratory	Very high	Likely
Rostratula benghalensis australis	Vulnerable	Very high	Likely
Sterna bergii	Migratory	High	Likely
Merops ornatus (migratory)	Listed – marine overfly area	Low	Likely
Apus pacificus (migratory)	Listed – marine overfly area	Low	Likely
Falco peregrinus	Specially protected for other reasons	Low	Likely
Calyptorhynchus latirostris	Endangered	Low	Likely
Calyptorhynchus baudinii	Vulnerable	Low	Likely
MAMMALS			
Dasyurus geoffroii	Vulnerable	Moderate	Likely
Pseudocheirus occidentalis	Vulnerable	Low	Likely
Setonix brachyurus	Vulnerable	Moderate	Certain

On the Swan Coastal Plain, the drawdowns from the Water Corporation abstraction are predicted to be very low (<0.5 m) and would not result in a measurable change in the ecosystems of the area or the EPBC species that potentially occur there.

Areas of significance to migratory shorebirds

Figure 3 shows the locations of wetlands of significance to migratory shorebirds relative to the proposal infrastructure, demonstrating that separation distances exceed 10 km.

Figure 3 Locations of wetlands of significance to migratory shorebirds

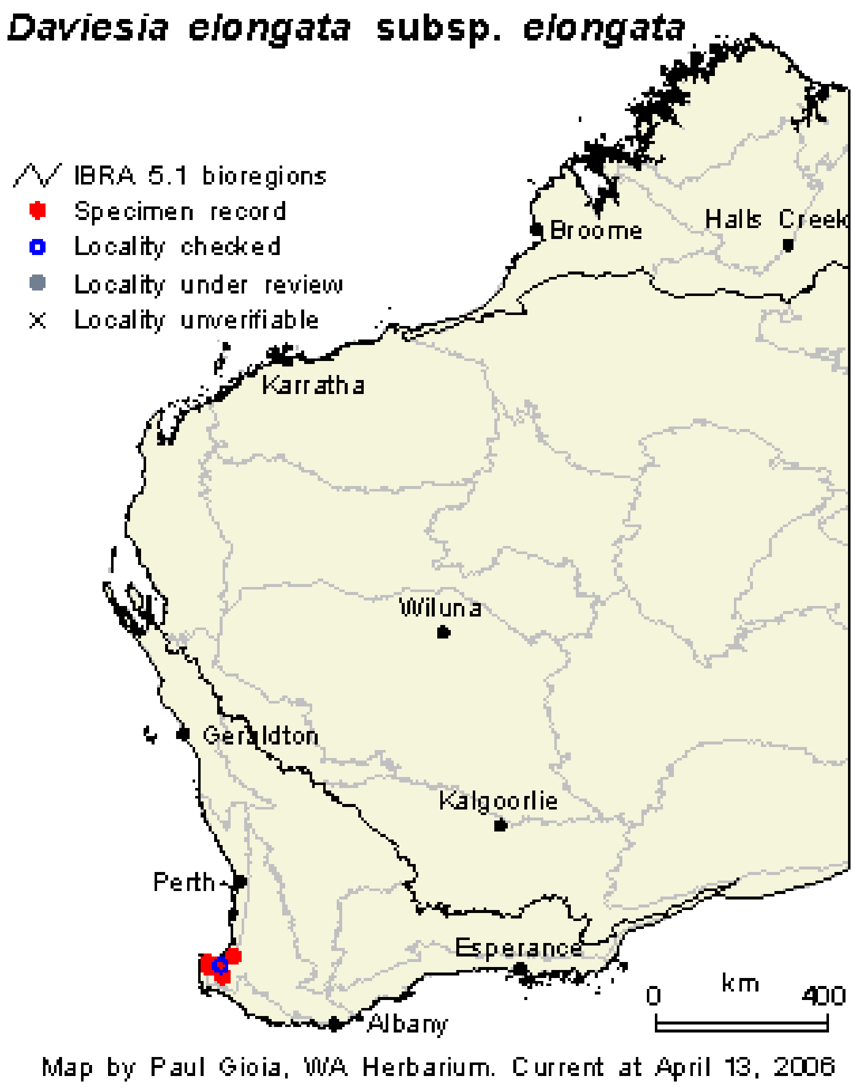


Threatened species distribution maps

Distribution maps of the nationally threatened frogs and mammals are not available from either national or state agency websites. The published information sources that were used in determining which nationally threatened species may occur in each area of interest for the proposal are listed in Appendix 28 of the Sustainability Evaluation/ERMP (Bamford 2003). In addition, local DEC officers (then CALM) were consulted regarding the exact locations of the white-bellied frog and the orange-bellied frog that both occur in a highly localised area within the Reedia wetlands.

The requested maps of the distribution of *Daviesia elongata* subsp. *elongata, Corymbia calophylla – Xanthorrhoea perrsii* woodlands and shrublands of the Swan Coastal Plain and Shrublands on southern Swan Coastal Plain ironstones are shown in Figure 3, Figure 4 and Figure 5 respectively.

Figure 3 Distribution of Daviesia *elongata* subsp. *elongate*



Sourced from Florabase (DEC 2006)

Figure 4 Distribution of the TEC *Corymbia calophylla – Xanthorrhea preissii* woodlands and shrublands of the Swan Coastal Plain

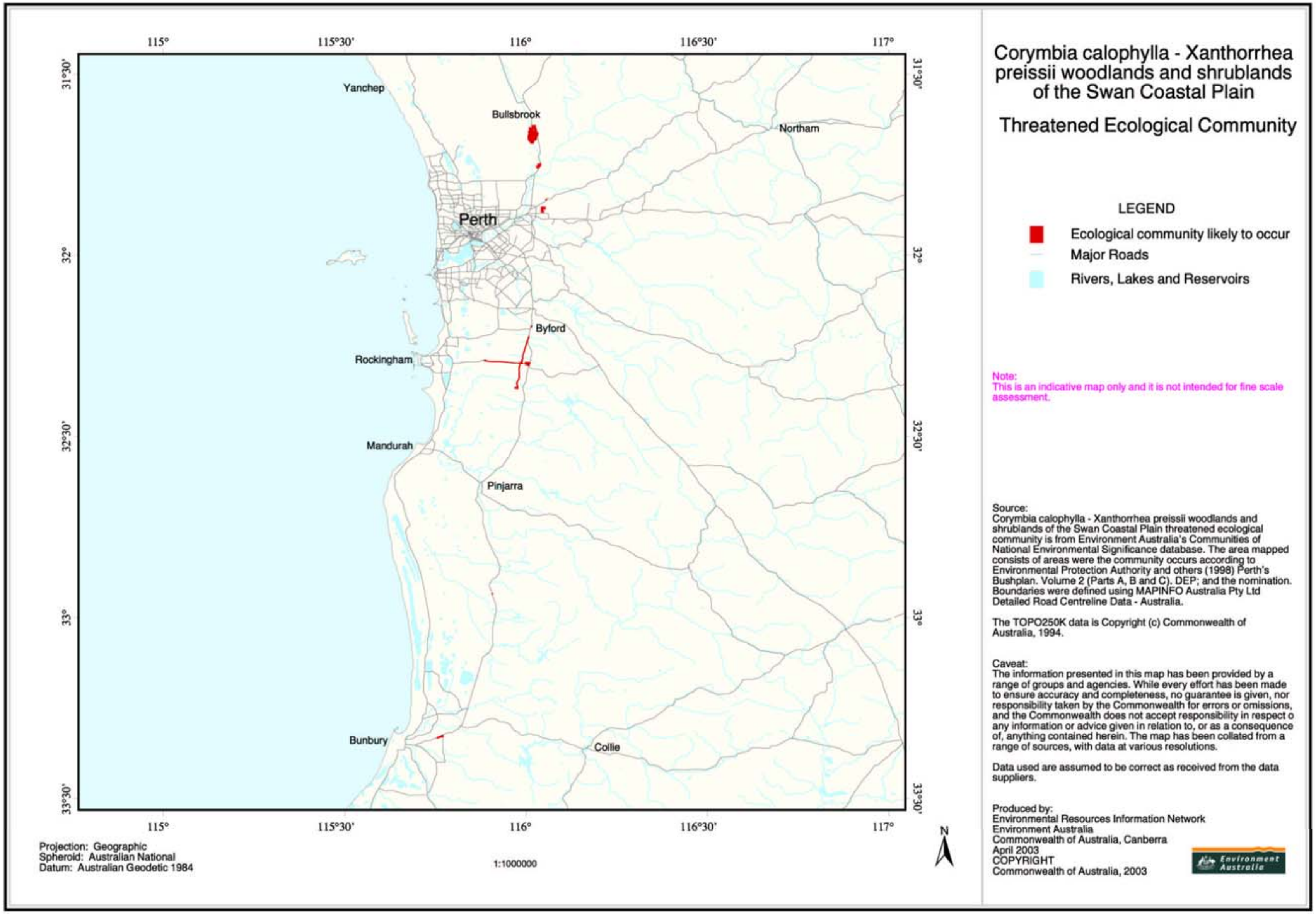
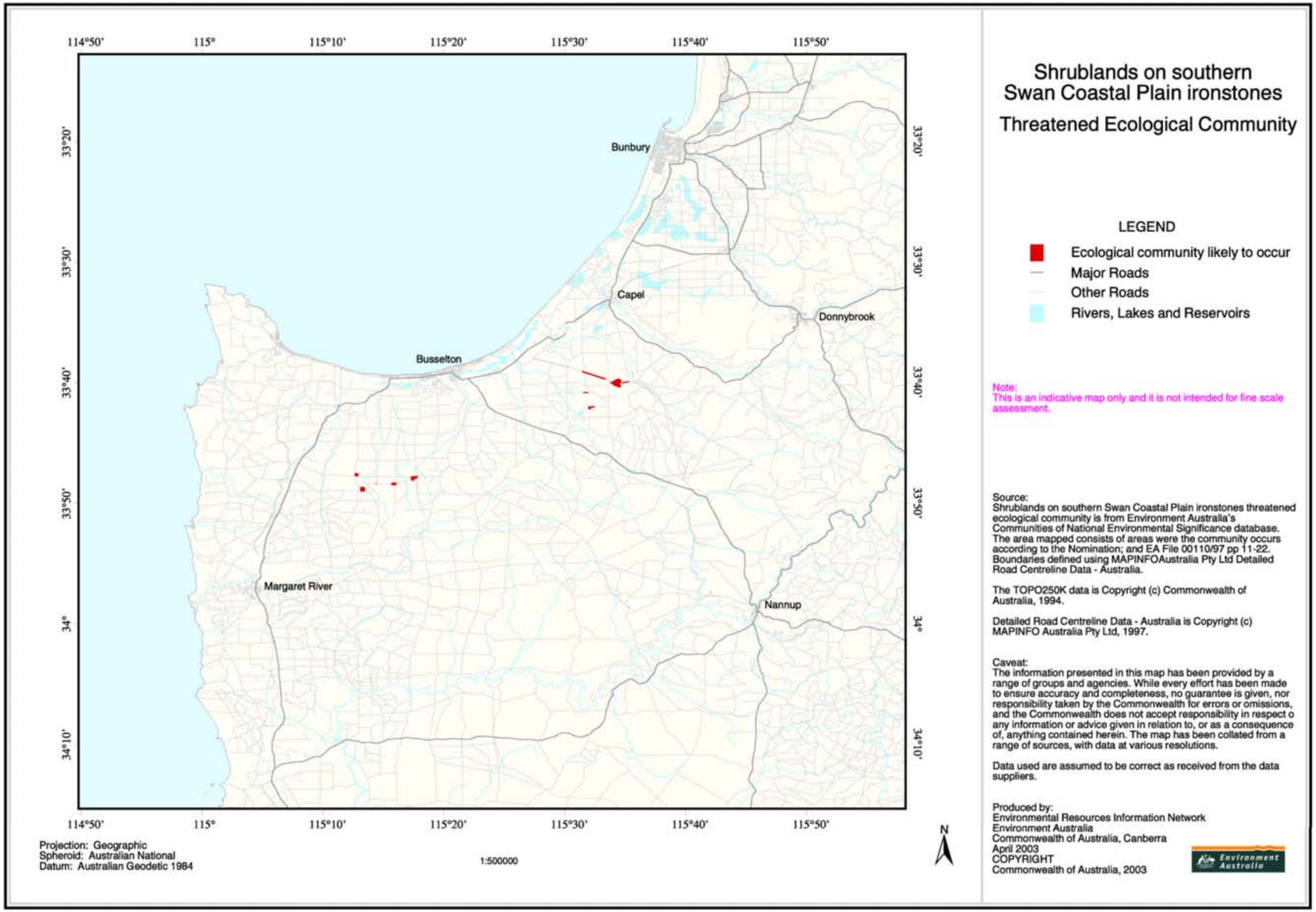


Figure 5 Distribution of the TEC Shrublands on southern Swan Coastal Plain ironstones



Maps of infrastructure

The final alignment of the pipeline route through the Swan Coastal Plain is still subject to consultation with the potentially affected landholders. The alignment through the State Forest has not changed since the Sustainability Evaluation/ERMP was produced and the vegetation communities that are affected by the infrastructure (including the wellfield, storage tank and treatment plant) are all listed in Volume 2 Chapter 8 of the Sustainability Evaluation/ERMP. This information includes the clearing area, the percentage remaining of the pre-European extent of each vegetation complex and the percentage of the remaining that will be disturbed by the proposal.

References

Department of Environment and Conservation (DEC) 2006, *Florabase* [Online], Available online from http://florabase.calm.wa.gov.au/ [16 August 2006].

Department of Environment and Heritage (DEH) 2006, *Ecological community description,* [Online], Available from http://www.deh.gov.au/cgi-bin/sprat/public/publiclookupcommunities.pl [16 August 2006]

Appendix 9

Response to EPA letter of 29 June 2006

Environmental Protection Authority

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Attention: Mr Mark Leathersich

SOUTH WEST YARRAGADEE WATER SUPPLY DEVELOPMENT (ASSESSMENT NO. 1552)

I would like to express the Environmental Protection Authority's (EPA) appreciation for the assistance and information provided by the Water Corporation on 12 and 13 June 2006 during its inspection of some of the key areas associated with the South West Yarragadee proposal.

During that inspection, the EPA indicated that it would be seeking further information in relation to a number of matters of interest to the EPA and to people who made submissions on the proposal ERMP. This letter identifies those matters upon which the EPA requests further information. This is in addition to the matters raised in submissions, although the EPA is aware that many of the matters listed in this letter have also been raised in submissions.

Groundwater information

Given the regional nature of the groundwater resource and the wide distribution of sites identified by the South-West Aquifer Modelling System (SWAMS), it is important to use the best information to get a good understanding of the areas potentially affected and to have an appropriate degree of confidence about of the level of risk to environmental values.

Some work has already started on obtaining better information. The EPA is aware that the Department of Water (DoW) has already undertaken development of a local area groundwater model for the eastern Scott Coastal Plain.

During the site visit, the EPA was advised that the Water Corporation is preparing a local area model for a portion of the Blackwood Valley, that this would use existing information and additional drilling was not proposed. The EPA understands that the DoW intends to prepare a further local area groundwater model for the southern Swan Coastal Plain later this year.

The improved predictive capacity that local area models have is acknowledged by the Expert Peer Review Panel, within the limits of model parameters and data used. The EPA believes that the local area models for the Blackwood Valley and Swan Coastal Plain would considerably inform the assessment and decisions related to the South West Yarragadee proposal. The October 2005 Panel Report recommends additional work is undertaken in these areas.

In relation to the Blackwood local model, the EPA would appreciate advice on the adequacy of using existing geological and hydrological information to develop and validate the model over what is expected to be an area with a complex set of relationships and generally a short duration of record.

The EPA also believes that a local area model covering the western Scott Coastal Plain would assist in addressing understanding of the relationship between surface water and groundwater, and subsequent predicted changes in groundwater levels and their implications in that area. These include potential acidification of groundwater and surface waters under a range of land use and abstraction scenarios.

While there has been specific examination of the hydrogeology of the lower St John's Brook, the ERMP does not discuss in any detail the implications of the proposed borefield on the upper portion of the Brook and its tributaries. While Figures 5.25 and 5.27 indicate 3-5 m watertable drawdowns, these are reduced to zero in Fig 55.31 following interpretation. The EPA considers that there is the need for a more detailed explanation of the geology and hydrogeology in the proposed borefield area and the implications on St John's Brook and its tributaries, including those upstream of Vasse Highway. This should refer to watercourses and wetlands in the catchment. It is noted that the 2005 Expert Panel Report points to the need for a local model in this area.

The proposal refers to adaptive management options should impacts be greater than predicted, including relocating bores. However, the ERMP contains virtually no details of alternative bore layouts in the Jarrahwood area, and whether a changed layout would effectively address unexpected impacts. It is understood that adopting a different abstraction split from that proposed could have different impacts. Given that the Expert Panel raised concerns about water quality implications at the proposed borefield, a better understanding of these matters needs to be provided during the assessment process.

A key issue for the assessment is the implications on environmental values of the combined effects of abstraction and climatic variation. When the EPA assessed the Forest Management Plan 2004-2014, the interactions between forest management and climate change on environmental values was a major issue and has been reflected in the approved Plan. The South West Yarragadee proposal clearly has implications to CALM Act land under a range of tenures, all of which are subject to the Plan. An assessment of the implications on CALM Act land, as well as land management objectives in the approved Plan, would greatly assist the EPA in this assessment.

The Expert Panel points to the importance of rainfall, recharge and evapotranspiration as some key parameters in terms of the groundwater resource. It is acknowledged that the existing SWAMS 2 model uses average annual rainfall over the period 1980 to 2003, thus incorporating the recent period of declining rainfall (9%), and that one of the scenarios includes a further 5% decline over the next 30 years. It is understood that this scenario uses a reduced recharge estimate of 10 per cent. The EPA would appreciate a detailed explanation of why recharge might decline by only 10 per cent when surface flows have been affected much more significantly during recent decades.

Much has been made about the volume of water in storage in the Yarragadee aquifer. However, the sensitivity of the modelled drawdown predictions and interpreted results to differing levels of rainfall and recharge can be expected to be important factors to the robustness of the proposal. This is pertinent to areas where there is close interaction between surface and groundwater levels, and between the overlying Leederville and superficial aquifers that might be influenced by changing pressures in the Yarragadee aquifer. The Expert Panel made comments about these relationships and the EPA believes that the matters that they raise need to be resolved before the assessment of the proposal is completed.

As you are aware, the implications of the proposal on the seawater interface along the Bunbury to Dunsborough coast has been raised in submissions. This issue is clearly important in the Bunbury area, but concern has also been raised about wetlands and private bores located close to the coast in other areas. While commitments have been given to Aqwest in relation to Bunbury's water supply, it is unclear about the extent to which other groundwater users and uses could be affected. The southern Swan Coastal Plain local model mentioned above would be expected to assist in understanding the implications of the proposal, in combination with other, including existing, allocations, especially as the surface water – groundwater interaction is not accounted for in the SWAMS 2 model.

<u>Management/ Mitigation</u>

A key issue for management and mitigation of impacts arising from the proposal will be the capacity to identify impacts and to distinguish their causes. It is critical that there be an adequate and comprehensive range of monitoring to allow for the cause(s) of impacts to be defined in areas such as the Blackwood Valley Swan and Scott Coastal Plains, where there is complexity in land use and historical impacts. ERMP Vol 1 Table 5.14 acknowledges in a number of places that this will be a challenge. However, deferral of responses to impacts while the cause is clearly identified is likely to be unacceptable where significant values are placed at higher risk.

This issue is of considerable concern to the EPA. There are a number of agencies with statutory responsibilities related to matters likely to be affected. These include the Department of Water and Conservation Commission/ Department of Conservation and Land Management. The EPA believes that the governance arrangements associated with the management of potential impacts need to be developed further and clearly articulated. While the EPA encourages the Water Corporation to further examine this issue, the EPA intends to bring key agencies together during the assessment to improve governance arrangements that might be applied should the proposal proceed.

The ERMP identifies (eg section 8.7.3) a number of management responses to possible impacts that could arise from implementation of the proposal. There are also a number of general commitments given in the ERMP. The EPA believes that it is important to have confidence that management and mitigation measures proposed will achieve their intended environmental objective.

An example relates to supplementation of some Blackwood tributaries to mitigate environmental and social impacts (ERMP Vol 2, Table 9.3). The extent to which supplementation would be effective where environmental values are threatened is unclear at this time, in part because many of the parameters that support those specific values are not known. These parameters will undoubtedly relate to matters beyond just water availability. This is one of the issues where the level of risk to significant environmental values in the long term will need to be predicted with a reasonable level of confidence.

The identification of trigger's for management action, including monitoring, would also contribute to the EPA's understanding of proposed management and mitigation measures.

The Water Corporation has set an objective of "a net increase in ecological function or biological diversity in the region, with particular emphasis on critical assets" for biodiversity and ecological integrity. The ERMP does not clearly indicate how an increase would be obtained by this proposal, nor does it clearly state how this will be achieved for significant environmental values, eg Balston's Pigmy Perch or the Blackwood River.

The EPA requires further information on the proposed management and contingency actions and their likely success in achieving the environmental objectives set out in the ERMP.

There are several issues in the ERMP where the loss of environmental or economic values is intended to be offset. Clearing associated with the borefield infrastructure is one of these. The Water Corporation should provide clear information on how it intends to deliver on its proposed offsets, in terms of type, scale, quality and location.

Vegetation

One of the decision rules that the Water Corporation has applied to identifying areas at risk is to focus on areas where vegetation has depth to groundwater of less than 10 m. The EPA would appreciate comment on the relevance of that rule on the Blackwood Plateau when there is information to indicate that tall vegetation in the forest access groundwater from much greater depth.

The DoE, with CALM and the DPI, has commenced the Swan BioPlan study, which aims to identify significant vegetation on the Swan Coastal plain south of Perth. Those areas of already identified significant vegetation, such as threatened ecological communities (TEC's), will undoubtedly continue to be important, and areas of existing vegetation can be expected to be given a priority for protection. In this context, the southern Swan Coastal plain local model mentioned above will be important to enable better judgements on the threat from this proposal and other, including existing, allocations.

Pipeline

It is understood that the Water Corporation is only now approaching private landowners along the pipeline route from Jarrahwood to Harvey. You may be aware that a number of submissions were received from landowners. To what extent is the pipeline route shown in the ERMP 'indicative' and therefore subject to revision? In asking this question, the

EPA is cognisant that the final pipeline route might be different to the route assessed. It is therefore important to provide information to the EPA during the assessment on any changes to the alignment in the ERMP.

While your response to that matters raised in this letter should be incorporated in the response to submissions, it would be appreciated if the information was also provided separately to the EPA.

Should you require clarification on these matters, please consult with Colin Murray (6364 7151).

Dr Andrea Hinwood
DEPUTY CHAIRMAN

29 June 2006

[CMu]

cc: Paul Frewer	A/Director-General, Department of Water
cc: Michelle van der Voort	Department of the Environment and Heritage
cc: Keiran McNamara	Executive Director, Department of Conservation & Land Management

RESPONSE TO EPA ISSUES

The following is submitted in response to issues raised in the letter from the Environmental Protection Authority of 29 June 2006, included below.

General

Based on the information obtained from the extensive investigations undertaken to support the evaluation and preparation of the SE/ERMP, the Water Corporation is confident that the proposal will not result in significant adverse impacts to environmental values in the region. Key aspects that provide this confidence are:

1. The highly developed understanding of the conceptual hydrogeology/hydrology of the region based on extensive drilling, testing and monitoring programs undertaken over several decades. This understanding has been adopted into a best practice three-dimensional model of the groundwater system, used to evaluate regional scale responses to the various scenarios of future abstraction and changes to recharge because of further future climate change. While being limited to providing a regional scale evaluation of drawdown impacts, the model is conservatively based in respect of several key parameters. These include the extensive volumes of water held in storage in clayey horizons that would be released as a result of drawdowns in the Yarragadee Formation and recovery of "rejected recharge" on the coastal plains (as acknowledged by the Peer Review Panel).
2. The development of a local scale model for the Eastern Scott Coastal Plain and the detailed examination of the hydrogeology and hydrostratigraphy of the Blackwood River and tributaries and the Swan Coastal Plain has confirmed the regional scale modelling results as being conservative.
3. The physical magnitude of the resource includes an extensive storage that that provides considerable buffering against the effects of changes in the system stressors such as recharge and abstraction. The recharge estimates are considerably higher than expected future abstraction levels, and have been conservatively derived.
4. The Water Corporation wellfield is located in an area remote from any existing and expected future abstractions by other parties, such that the Water Corporation proposal is effectively not competing with existing and future regional users. On the coastal plains, where the majority of existing and future abstractions are located, the Water Corporation drawdowns are expected to be minor compared to the effects of local abstraction.
5. The proposed approach to adaptive management within a comprehensive hydrological/biological monitoring and response framework, with identified triggers, and availability of demonstrably feasible contingency actions provides an assurance that any unexpected impacts can be detected and managed.

The following comments are made in respect of the specific issues raised in the letter of 29 June 2006.

Swan Coastal Plain local scale model

The Department of Water is understood to be undecided on the development of a local scale model of the Swan Coastal Plain because there is uncertainty on the extent to which such work would add value. The area has been extensively investigated in respect of many of the current abstraction projects that exist in this area which provide a good conceptual hydrogeological model to be developed. The presence of extensive clay horizons through the superficial formations, are expected to have a substantial mitigating effect on drawdowns in underlying formation propagating to the watertable. URS Australia (2006a) has prepared a report on the hydrogeology and hydrostratigraphy of the Swan Coastal Plain (Appendix 4) that demonstrates the relationships between groundwater in the various formations, and groundwater dependent surface features. This work supports the proposition that abstraction from the Yarragadee Formation by the Water Corporation will have little to no effect on the Swan Coastal Plain

Adequacy of Blackwood local model

URS Australia has been commissioned to develop a local scale model of the Blackwood River and tributaries to improve the estimates of drawdown in these areas, and consequent impact on streamflows and groundwater dependent ecosystems. The complexity of this modelling is such that the results were not available within sufficient time to be incorporated in this report. However, the results will be made public, and the proposal modified accordingly if those results suggest that the potential environmental impacts will be greater than currently expected and likely to cause significant additional impact. Preliminary results are confirming the results of the SWAMS V2.0 modelling presented in the Sustainability Evaluation/ERMP.

The monitoring network established during the project and on which the modelling is based, is extensive, with no obvious gaps in coverage identified in the work to date. The sub-regional Blackwood Valley model will be useful in identifying where there are gaps in knowledge.

Local model of western Scott Coastal Plain

The Water Corporation wellfield is located approximately 70 km from the western Scott Coastal Plain, with the Busselton Fault forming an intervening hydraulic barrier, and no impact from the proposal is consequently expected in this area. Drawdowns on the eastern Scott Coastal Plain have been demonstrated by the Department of Water local scale modelling to be minor and limited to the northern area of the plain immediately south of the proposed wellfield. This is supported by the understanding of the conceptual hydrogeology, which has been reviewed by the Peer Review Panel. This supports the expectation that the Water Corporation will have no impact on the western Scott Coastal Plain. Therefore, the Water Corporation does not propose to develop a local scale model of this area. Drawdown impacts on the western Scott Coastal Plain will be largely the result of abstraction in the area, and is a matter for the Department of Water to consider.

Impacts on St Johns Brook

St John Brook is being included into the local scale modelling being undertaken by URS Australia, as discussed above.

URS Australia (2006a) reviewed the hydrogeology of the St John Brook at a local scale to produce several cross-sections with flow nets (Figure 4.3). The cross-sections showed that north of the St Paul Brook confluence, St John Brook is a losing stream (stream level is higher most of the year than groundwater level) and is not groundwater dependent. This supports the observations in the Sustainability Evaluation/ERMP that the upper end of perennial baseflow in St John Brook is several hundred meters below the confluence of St Paul Brook. In addition, the large downward vertical gradient measured in the wells in the area and illustrated in the cross sections appears to be an effective barrier to transmitting changes between the Yarragadee and Leederville Formations.

The summer flows in the mid to lower reaches of St John Brook are naturally very low and there is potential that the permanent summer groundwater discharge (permanent stream length) will slowly migrate downstream over a small section in the upper reaches of the brook near the junction with St Paul Brook. This section of the brook is a first order stream and a survey by the Centre of Excellence in Natural Resources Management (CENRM) determined it to have low habitat diversity (CENRM 2005b).

CENRM concluded that if a previously perennial first order stream became ephemeral, the risk to regional aquatic biodiversity would be considered low, for the following reasons:

- first order streams have low flows, with gentle channel slope, and lack the pool and riffle zones that provide important aquatic habitats in second and third order streams
- fish biodiversity is concentrated in pool habitats in second and third order streams
- any macroinvertebrates in the first order reaches would also be found downstream.

However, if the baseflow falls below the recorded historical flow rate (there is an established gauging station on St John Brook), a well into the Yarragadee Formation with appropriate treatment, can be used to supplement summer flows. The predicted impacts on St John Brook are considered acceptable but if unexpected reductions in flow occur, summer flows will be supplemented as a contingency. An investigation into the feasibility of supplementation of St John Brook has been undertaken by URS Australia. This work has concluded that a well taking water at 2 L/s from the Yarragadee Formation in that location would be capable of ensuring flows are maintained at the required levels (15.5 ML/yr). Such supplementation would only be required during low rainfall summer periods. Treatment may be required to meet the water quality guideline levels in respect of iron, manganese and dissolved oxygen

Alternative wellfield layouts

Alternative well sites are presented in the SE/ERMP (Volume 1 Figure 1.9) to provide for the possibility that all abstractions would need to be taken from a single hydrogeological unit (the deeper Yarragadee Unit 3), rather than split between two units as proposed in the preferred option. Alternative wellfield configurations would be assessed and possibly modified, based on information to become available following initial pumping, monitoring and review. It is not possible to provide more detail until such testing is carried out as part of the wellfield construction and testing process.

The water quality aspects of the proposed wellfield raised by the Peer Review Panel related to the potential for groundwater from the upper Yarragadee Units to be more saline than the lower units, where the upper units are overlain by the Leederville Formation. While this is true, the salinity of the upper units is still within the limits required for potable supplies and will not be an issue for the Water Corporation.

The environmental impacts of the eastern split wellfield (Yarragadee Units 1 and 3) compared with the eastern wellfield option (Yarragadee Unit 3 only) were modelled and these options are the primary means of adjusting pumping regimes in the Jarrahwood area. The latter option showed potentially less impact on the watertable in the St John Brook area, but with increased potential for higher drawdowns at a distance in the vicinity of the Blackwood River, Poison Gully and Milyeannup and Rosa brooks. The modelled impacts on St John Brook are not expected to occur to the same extent as indicated by the regional modelling and this has been confirmed by the detailed examination of the local hydrogeology and hydrostratigraphy. Operation of the scheme as proposed, with appropriate monitoring will allow a more accurate evaluation of the effects of possible future abstraction regimes in terms of impacts on key risk areas than can be achieved from any further theoretical modelling examination.

Implications on CALM Act land

The SE/ERMP has considered the impacts on all land, irrespective of tenure, with land with high depths to the water table filtered out because of the inferred lack of groundwater dependent ecosystems. Where an impact on environmental values on CALM Act land is expected, this has been included in the SE/ERMP. It should be noted that management of CALM Act land will also have some influence on groundwater recharge and the hydrology of the region.

The Forest Management Plan 2004-2013 commits to "*working with the Water Corporation and the Water and Rivers Commission on proposals they have to access land in the plan area to assess and utilise surface and subsurface water for public water supply and to use targeted timber harvesting to enhance water run-off.*"

Relationship between rainfall and recharge under climate change

The extent to which groundwater recharge will respond to changes in rainfall is complex, and is expected to vary depending on a number of factors, of which the hydrogeology and biological transpiration responses are considered to be important.

Net groundwater recharge can be expected to reduce in volume if and as rainfall over the region reduces, and this is clearly acknowledged in the SE/ERMP. The relationship between rainfall and recharge under climate change is discussed in depth in Volume 1 Chapter 7 Section 2.1.4. The presumption that groundwater recharge will diminish at a rate disproportionately greater than the rate of rainfall reduction is unfounded. Surface flows have declined disproportionately to the recent reductions in rainfall in the south west of Western Australia, however, examination of water balance data presented in the Bari *et al*. (2004) study showed that the disproportionately reduced surface flows in the Stirling Dam catchment have been partly offset by increases in percentage groundwater recharge rates. Given that a drier climate is likely to cause a biological response with vegetation shifting to a species with lower transpiration rates, there is no basis for assuming that evapotranspiration would increase to any significant extent, even under high air temperatures and correspondingly higher evaporation rates. As outlined in the SE/ERMP (Volume 2 Chapter 5 Section 2.6), Tick Flat on the Gnangara Mound is an example of vegetation, with predominantly wetland characteristics, gradually changing to vegetation characteristic of upland areas since the 1970s, with lower dependencies on groundwater. The only influence on vegetation type in this area that could have caused this change is the drier climate experienced in the region over recent decades.

In considering the potential impacts of a drier climate on groundwater recharge, the local hydrogeology would be an important factor. On the coastal plains, where the groundwater systems are essentially "full", a relatively large proportion of rainfall runs off as rejected recharge. It would be expected that reductions in rainfall in these areas would only result in a reduction in the volume of rejected recharge (manifesting as a reduction in streamflow). That is, net recharge volumes on the coastal plains would remain unchanged, unless the rainfall reduction was of a similar magnitude to the amount of rejected recharge. This would require a reduction in rainfall of about 300 mm/yr (33%) on the Swan Coastal Plain and 240 mm/yr (about 20%) on the Scott Coastal Plain before absolute recharge rates were affected.

On the Blackwood Plateau, the area of outcropping Yarragadee Formation would be expected to experience an immediate reduction in recharge in response to reduced rainfalls. In the short term, the proportionate reduction in recharge may exceed the reduction in rainfall, at least until the biological response has an effect in reducing transpiration. However, recharge through the outcropping Yarragadee Formation is a relatively small component of the total recharge over the Southern Perth Basin (between 10 and 20%).

The remaining area of the Blackwood Plateau is overlain by Leederville Formation, with extensive areas of Mowen Formation, in which there are predominantly downward head gradients between the surface and the Yarragadee Formation of up to 100 m or more. It could be expected that changes in recharge rates into the upper Leederville Formation would respond in similar fashion to the outcropping Yarragadee Formation, with an immediate reduction in recharge and consequent lowered water levels in the upper Leederville Formation. However, the changes to the downward head gradients (particularly in the areas with high gradients) would be marginal, and the consequential changes in recharge rates to the Yarragadee Formation would be small and occur at a slow rate.

The SE/ERMP discusses the expected long term impacts of a drier climate on groundwater recharge at length, taking the lagging biological responses into account. This suggested that over time, the resulting % reductions in groundwater recharge would closely match any % reductions in rainfall and given the above assessment, is considered a conservative assumption.

Therefore, it is a reasonable assumption that the recharge values adopted in the climate change scenarios, of 5% and 10% progressive reductions in recharge, correspond with rainfall rates at least 5% and 10% lower respectively, than those used in the primary modelling scenarios. If these climate change results are added to the primary scenarios as is suggested in the SE/ERMP, these would represent recharge rates of approximately 15% and 19% lower than the historical average. CSIRO studies suggest that a 20% reduction is the most extreme outcome of the various modelling studies undertaken for the south west. Given the approximate nature of both regional climate and regional groundwater modelling, it is felt that the scenario with a further 10% reduction in recharge represents a strong indication of the extents of drawdown that might be expected as the most extreme outcome (20% reduction in rainfall).

Interactions between watertables and underlying formations

The physical magnitude of the resource includes an extensive storage that provides considerable buffering against the effects of changes in the system stressors such as recharge and abstraction. The extensive volumes of water stored in clay horizons within the Leederville and Yarragadee Formation will be released as a consequence of any drawdowns from the proposal and will serve to attenuate the drawdown effects in the Yarragadee and Leederville formations as modelled. This point was clearly made by the Peer Review Panel in supporting the notion that the regional scale modelling is highly conservative in nature.

The local scale modelling is largely aimed at considering the interactions between the various formations, with an emphasis on the local scale impacts on the water table of lowering pressures in underlying aquifers.

Seawater intrusion

The impacts of seawater intrusion on other than Aqwest water supply in the Bunbury area is expected to be minimal, as impacts on the shallow aquifers will be small to zero, and there are no other users close to the coast in the deeper aquifers. The movement of the saltwater interface resulting from the proposal will occur very slowly and at depth. The only wells at risk are those in the deeper formations near the coast (in the Yarragadee Formation and in the Leederville Formation where present). No domestic wells fall into this category. Watertable wells in the superficial formations would not be affected.

No seawater intrusion will occur into any coastal wetlands, as any interface movement would be in aquifer formations at depths considerably lower than the base of any coastal wetlands. The coastal wetlands are all located in the superficial formations, which are not expected to experience any seawater intrusion effects.

Monitoring to identify impacts and distinguish causes

The Groundwater Abstraction Management Plan has been redrafted (Appendix 1) to include more detail on the proposed monitoring program to identify impacts, and provides trigger values for response actions to be initiated. The management plan now incudes details of the location of proposed control sites to be used to assist in differentiating causes of any observed impacts. The approach involves a comprehensive program of monitoring both hydrological and biological responses, and reacting in the event of untoward performance of either factor. Trigger values for groundwater drawdown have been established for a number of key locations in both the Yarragadee Formation and the superficial formations. These locations, referred to as criteria monitoring sites, include both the Blackwood Valley, tributaries and the coastal plains.

Governance

The Water Corporation acknowledges the governance issues associated with the project. To assist this, the Water Corporation has proposed that it take full responsibility offsetting and management in those areas where the Water Corporation is the major contributor to the drawdown effect and only take responsibility for monitoring and reporting in other areas. This effectively means the Corporation will be responsible for offsetting all groundwater drawdown impacts on the eastern Blackwood Plateau. The Corporation does not propose to take responsibility for managing the drawdown impacts of regional users on the Swan and Scott coastal plains or west of the Busselton Fault on the Blackwood Plateau.

However, the Water Corporation would be willing to participate in discussions with the relevant agencies to assist the EPA to develop a more robust alternative approach if considered necessary.

Confidence in proposed management and mitigation measures

The streamflow supplementation contingency options have been evaluated by URS Australia (report at Appendix 5) and shown to be feasible and the Water Corporation is committed to implementing these if required. Further work has been undertaken by the Centre of Excellence in Natural Resources Management in understanding the aquatic fauna and habitat requirements of Milyeannup Brook (Appendix 5) to provide an improved basis for application of a contingency measure. This has resulted in a clear contingency triggering value for this system being included in the revised Groundwater Abstraction Management Plan.

Adjustment of the abstraction regime is a demonstrably feasible contingency, if deemed necessary, including the potential for temporary or permanent reductions in abstraction, if so required by the DoW. The Water Corporation has a history of substantially modifying and reducing groundwater abstractions from its wellfields on the Gnangara Mound in order to contribute to offsetting the environmental impacts of falling watertables, even though the impacts have largely been the result of a drier climate and pumping by other private users.

Any adjustment of the abstraction regime would need to be tailored to mitigate the specific impacts that are observed, and at this time, it is not possible to be definitive on the details of the adjustments that might need to be made. Changing the distribution of abstraction between the two Yarragadee Units proposed for screening (Units 1 and 3) is a relatively simple process that can largely be accommodated by changing pump duties in the various wells. The selection of contingency well sites to modify the geographic location of abstraction is notional at this time, and may need to be modified if monitoring results and subsequent modelling indicate that alternative locations are necessary. This can only be determined at that time.

Clearly, the option to completely shut down the wellfield would be a last resort action if all other measures fail, and it is only expected to be required if the impacts of the proposal are so adverse as to justify such an action. In this event, alternative sources would be sought to provide the required water in order to protect the investment in the water transfer infrastructure. Alternative sources could involve the development of surface water sources in the region, such as the Donnelly River, subject to the required approvals being obtained.

The other mitigation measures, including offsets such as the Sustainability Initiative, sponsorship of a program to reduce major threatening process such as feral pigs, are believed to be demonstrably practical and achievable.

Management action triggers

The revised Groundwater Abstraction Management Plan (Appendix 1) identifies a range of specific hydrological and biological triggers for management. Specific criteria locations and rates of change have been included to provide greater definition to the proposed triggers. These may be refined further on the basis of results from the local scale modelling of the Blackwood River and tributaries currently being undertaken.

Increasing ecological function or biological diversity

The key program to achieve increasing ecological function or biological diversity is sponsorship of a high profile project to manage a priority threatening process (feral pigs) in areas that may be affected by the proposal. This approach has been discussed with DEC. The Water Corporation sponsorship will involve the provision of annual funding to the agreed project of up to $150 000 per year for up to 10 years. This is a considerable increase on the proposed contribution as presented in the SE/ERMP. This has been included in the response report as a modified commitment.

Information on proposed management and contingency actions

The revised Groundwater Abstraction Management Plan (Appendix 1) provides substantially more detailed information on proposed management and contingency actions, to the extent of detail possible at this time, given that some flexibility will be necessary to allow tailoring of contingency actions to address specific issues, if and as they arise.

Information on delivery of offsets

The Water Corporation is currently negotiating the clearing offsets with the DEC. It is not possible to provide more detail on the offsets until these negotiations are complete.

Vegetation dependence on deep groundwater

Vegetation in areas with high depths to groundwater (< 10 m) primarily relies on the high moisture holding capacity of soil profiles upon the Blackwood Plateau and reliable annual wetting of the soil profile. The extent to which such wetting will continue will be largely a function of future climate regimes and will independent of groundwater abstraction impacts.

While tall vegetation may have roots that penetrate to close to the water table, they are not phreatophytes and are not watertable dependent, with the possible exception of during extreme droughts when the soil moisture store becomes completely depleted. The water table tends to limit the depth of root penetration of non-phreatophytes. Progressive and slow lowering of the water table would allow these species to progressively extend their roots to greater depth as necessary, without ecological impact.

Pipeline alignment

The pipeline alignment presented in the SE/ERMP is indicative of the preferred alignment. The EPA will be kept informed of changes to the alignment as they result from individual landowner negotiations, with particular reference to any potential consequential environmental impacts.