APPENDIX 6

ENVIRONMENTAL VALUES OF THE LEEDERVILLE AQUIFER AND THE YARAGADEE AQUIFER

Perth Groundwater Replenishment Scheme

Environmental Values for the Leederville Aquifer and the Yarragadee Aquifer at the Beenyup Site

February 2013

Prepared by:

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Revision History

Version	Prepared By	Date Issued	Issued to	Comments Received from
First draft	Tran Huynh, Michael Martin, Vanessa Moscovis.	21/01/13	***For review,*** Representatives of: DoW: Adrian Parker DoH: Richard Theobald, Clemencia Rodriguez DEC: Ruth Dowd, Bhabesh Das Water Corporation: Nick Turner ***For information,*** additional Technical expertise: DoW: Brad Degens, Cahit Yesertener CSIRO: Brad Patterson; Henning Prommer, Simone Seibert Curtin: Brett Harris Rockwater: Karen Johnston Water Corporation: Simon Higginson	DoW: Adrian Parker, Brad Degens, Matt Viskovich, Nigel Mantle; DoH: Clemencia Rodriguez; DEC: Bhabesh Das
Second draft	Tran Huynh, Michael Martin, Vanessa Moscovis.	07/02/13	As above	DoW: Adrian Parker Brad Degens; CSIRO: Brad Patterson
Final	Tran Huynh, Michael Martin, Vanessa Moscovis.	18/02/13	Representatives of: DoW: Adrian Parker; DoH: Richard Theobald, Clemencia Rodriguez; DEC: Ruth Dowd, Bhabesh Das, Marko Pasalich; Water Corporation: Nick Turner	

Endorsement

This document was developed by representatives from the following Agencies:

1. **Department of Health** of 227 Stubbs Terrace, Shenton Park, Perth, Western Australia

2. **Department of Environment and Conservation**, of 168 St Georges Terrace, Perth, Western Australia

3. **Department of Water**, of 168 St Georges Terrace, Perth, Western Australia

4. **Water Corporation**, of 629 Newcastle Street, Leederville, Western Australia

In endorsing this document, the Department of Health (DoH), Department of Environment and Conservation (DEC), Department of Water (DoW) and the Water Corporation agree on the Environmental Values relevant to the proposed Perth Groundwater Replenishment Scheme – Stage 2A.

Signed for
Department of Health

19/2/13.

Mr Richard Theobald
Manager Water Unit

Date

Signed for
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22/2/2013.

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Acronyms

ADWG – Australian Drinking Water Guidelines

AGWR Phase 2 - Australian Guidelines for Water Recycling: Managed Aquifer Recharge (Phase 2)

ANZECC – Australian and New Zealand guidelines for fresh and marine water quality

AWRP – Advanced Water Recycling Plant

BNYP - Beenyup

EV – Environmental Values

DEC – Department of Environment and Conservation

DoH – Department of Health

DoW – Department of Water

GL - gigalitres

GWR – Groundwater Replenishment

GWR MoU – Memorandum of Understanding between the Department of Health and the Water Corporation for the Groundwater Replenishment Trial

GWRS – Groundwater Replenishment Scheme

RMZ – Recharge Management Zone

RWQI – Recycled Water Quality Indicators

RWQP – Recycled Water Quality Parameters

TRG – Technical Reference Group

WWTP – Wastewater Treatment Plant

yr - year

1 Executive Summary

Groundwater Replenishment (GWR) is the process by which secondary treated wastewater undergoes advanced treatment to produce water which meets Australian guidelines for drinking water prior to being recharged to an aquifer for later use as a drinking water source.

The Water Corporation is progressing planning for a Perth Groundwater Replenishment Scheme (GWRS) which will recharge up to 28 gigalitres (GL) per year (yr) to the Leederville aquifer and the Yarragadee aquifer. An Advanced Water Recycling Plant (AWRP) will further treat treated wastewater from the Beenyup Wastewater Treatment Plant to drinking water standards prior to recharge.

The Perth GWRS will be staged as described in Table 1 -1 to allow flexibility to meet future water supply demand. Approvals for the Perth GWRS will be undertaken in accordance with the GWR Regulatory Framework (IAWG, 2012).

Table 1-1: Stages of the Perth GWRS

Stage	Activity
Stage 1	Construct a 7GL AWRP at the Beenyup site. Recharge via the existing Leederville aquifer recharge bore and one new Yarragadee aquifer recharge bore located at the Beenyup site.
Stage 2A	Construct an additional 7GL AWRP at the Beenyup site (to provide a total of 14GL recycled water). Maximise recharge to Leederville and Yarragadee aquifer recharge bores.
Stage 2B	Construct a pipeline and two new Leederville aquifer recharge bores (if required) located off the Beenyup site, to the east of Lake Joondalup to recharge the additional 7GL produced by the Stage 2A AWRP.
Stage 3	Construct an additional 14GL AWRP at the Beenyup site (to provide a total of 28GL recycled water). Extend pipeline and construct two additional Leederville aquifer recharge bores and two additional Yarragadee aquifer recharge bores to recharge the additional water.

In order to progress approvals for Stages 1 and 2A of the Perth GWRS, the Corporation has requested that the Department of Health (DoH), Department of Environment and Conservation (DEC) and Department of Water (DoW) to undertake Step 2 of the GWR Regulatory Framework; to define the relevant Environmental Values (EVs)[1] and subsequent water quality guidelines required to protect the EVs that the recycled water must meet at the point of recharge.

This report:

- Provides details of the aquifer characteristics required by the DoH, DEC and DoW to identify the relevant EVs (Step 1);
- Identifies EV's of the Leederville aquifer and the Yarragadee aquifer relevant to a GWR Scheme recharging up to 14 GL/yr at the Beenyup site (Step 2a);
- Identifies the management objectives for the EV's (Step 2b); and
- Identifies the water quality guidelines required to protect the EV's (Step 2c).

[1] EV's are defined as the "particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits".

Groundwater from the Leederville aquifer is currently used by the Water Corporation (public supply), local government, horticulture and industry. Groundwater from the Yarragadee aquifer is also used by the Water Corporation, and to a lesser extent industry and local government. Uses include public water supplies and heating public swimming pools (geothermal bores). Whilst further development of water from these aquifers for horticulture and industry may be currently constrained due to cost, water quality and availability of groundwater allocation, maintaining water quality that is adequate for these uses is required.

Therefore based on these current and potential future uses, the Drinking Water EV, Primary Industry EV and Industrial use EVs are applicable the Leederville and Yarragadee aquifer. The Cultural and Spiritual EV is also required to be maintained.

Groundwater monitoring will occur within the Recharge Management Zone (RMZ) of each recharged aquifer to confirm that recycled water moving horizontally through the Leederville and Yarragadee aquifers will continue to meet water quality guidelines at a specified point from recharge and ensure these EVs remain protected.

Given the location and characteristics of the Leederville and Yarragadee aquifers, the Recreation and Aesthetics EV and aquatic ecosystems EV were not considered relevant.

The likelihood of vertical flow to the Superficial aquifer was also assessed. The Groundwater Technical Reference Group (TRG) considered a number of recharge rates to the Leederville aquifer, based on an analytic model developed using data obtained from the GWR Trial. The outcomes of the modelling are provided in Table 1-2.

Table 1-2: Estimated travel times for water recharged at the Beenyup site to move to the base of the Superficial aquifer

GWR Scheme	Recharge to the Leederville aquifer		Travel Time (years)
	GL/yr	ML/day	
Stage 1	3.5	9.6	1500
	7	19.2	600
Stage 2A	10	27.4	440
	14	38.4	250

Note: These values underestimate travel time as the method does not consider lateral flow which will reduce likelihood of water movement to the Superficial aquifer.

These long travel times are attributed to the Pinjar aquitard, which forms an effective seal between the Superficial aquifer and the recharge interval (i.e. the vertical depth over which the water is recharged) within the Leederville Formation.

In considering upward flow from the Yarragadee aquifer into the Superficial aquifer, the TRG advised of the thick and extensive nature of the low permeability sediments that overlie the Yarragadee aquifer. If conditions allowed for recharged water from the Yarragadee to flow upwards, it would have to first flow through the overlying Leederville aquifer before reaching the base of the Superficial aquifer. Travel times even under extreme head conditions would be in the order of tens of thousands of years.

Based on this information, the DoH, DEC and DoW have confirmed that EVs for the superficial aquifer do not need to be identified.

In summary, the DoH, DEC and DoW have EVs have identified the EVs and water quality guidelines for the Leederville and Yarragadee aquifer for the relevant to Perth GWRS Stage 2A. They are provided in Table 1-3;

The management objective of the identified EV's is to "maintain for current and future use".

Table 1-3: Water Quality Guidelines for the identified EV's

Environmental Value	Leederville aquifer	Yarragadee aquifer
Drinking Water	• Recycled Water Quality Indicators • Recycled Water Quality Parameters As defined by the GWR MoU	
Primary Industries	• As per Drinking Water EV	
Industrial Water	• As per Drinking Water EV	
Cultural and Spiritual	• Consultation with Indigenous Community	

Note: The water quality guidelines for drinking water are based on health guidelines provided in the ADWG (ADWG, 2004), AGWR Phase 2 (NRMMC-EPHC- NHRMC, 2009) and results from the Premiers Collaborative Research Project (DoH et al, 2009). These water quality guidelines are tailored to the Beenyup wastewater catchment.

2 Introduction

Groundwater Replenishment (GWR) is the process by which secondary treated wastewater undergoes advanced treatment to produce water which meets or exceeds the Australian guidelines for drinking water prior to being recharged to an aquifer for later use as a drinking water source.

The Water Corporation completed the Groundwater Replenishment Trial in December 2012, demonstrating that advanced water treatment processes can successfully deliver a safe, reliable and sustainable water source option that adequately protects human health and the environment.

The Water Corporation's groundwater security strategy is part of the Water Corporation's *"Water Forever Whatever the Weather"* (Water Corporation, 2012) the 10 year strategy to drought-proof Perth. It involves the transfer of groundwater abstraction from the superficial aquifer(s) to the deeper Leederville and Yarragadee aquifers and a staged expansion of the Perth Groundwater Replenishment Scheme.

The GWR Regulatory Framework (IAWG, 2012) was established to define the approvals pathway required to develop a GWR scheme, approve commencement of recharge and provide ongoing regulation. An overview of the GWR Regulatory Framework is provided in Figure 3-1.

The GWR Regulatory Framework applies only where recycled water will be used as a drinking water source. It does not apply to other wastewater reuse applications.

The Water Corporation is progressing with the 28 GL/yr Perth Groundwater Replenishment Scheme (GWRS) at the Beenyup site. Delivery will be in 3 stages; Stage 1 - 7 GL/yr, Stage 2 - 14 GL/yr and Stage 3 - 28 GL/yr. The Corporation will seek the necessary approvals for each stage of the Perth GWRS as outlined in the GWR Regulatory Framework.

The first three steps of the GWR Framework involves collaboration between the Departments of Health (DoH), Environment and Conservation (DEC), Water (DoW) and Water Corporation to identify the uses or the "environmental values" of the groundwater environment in the vicinity of the groundwater replenishment scheme and determine the water quality requirements of the recycled water to ensure protection of the groundwater environment. This information then informs Step 4; a risk assessment for the GWR Scheme. Undertaking these four steps prior to entering into each Agency's formal approval process ensures a consistent approach between the regulators to groundwater replenishment.

3 Report Purpose

The GWR Regulatory Framework required the DoH, DEC, DoW and the Water Corporation to identify the Environmental Values (EV's) applicable to the proposed GWR Scheme.

This report:

- Provides details of the aquifer characteristics required by the DoH, DEC and DoW to assist with identifying the relevant Environmental Values (EV's) (Step 1);
- Identifies EV's of the Leederville aquifer and the Yarragadee aquifer relevant to a GWR Scheme recharging up to 14 GL/yr at the Beenyup site (Step 2a);
- Identifies the management objectives for the EV's (Step 2b); and
- Identifies the water quality guidelines required to protect the EV's (Step 2c).

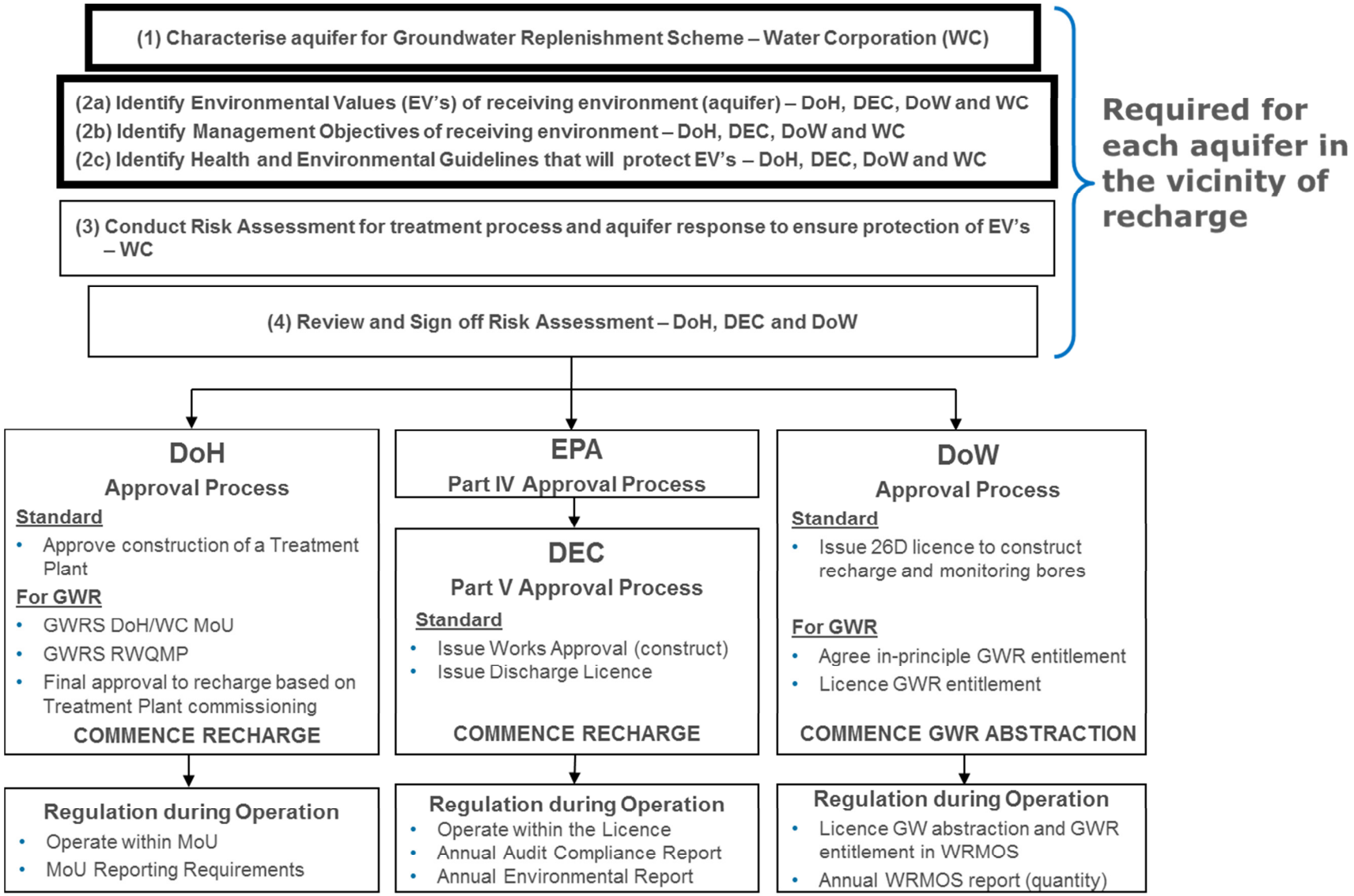

Figure 3-1: Groundwater Replenishment Framework

4 Groundwater Replenishment Scheme

The Water Corporation is progressing development of the 28 GL/yr Perth GWRS at the Beenyup site in Craigie, in Perth's northern suburbs. Delivery of the Perth GWRS is planned in three stages, described in Table 4-1.

The development of the Perth GWRS includes construction of an Advanced Water Recycling Plant (AWRP) using the same technology utilised in the Groundwater Replenishment Trial. Secondary treated wastewater from the Beenyup Wastewater Treatment Plant (WWTP) will undergo advanced treatment by ultra-filtration followed by reverse osmosis and ultra violet treatment. Recycled water that has met all treatment performance requirements will then be recharged into the Leederville and Yarragadee aquifers.

Table 4-1 Stages of the 28 GL/yr Perth GWRS

Stage	Due	Activity
1	2015	Construct a 7GL AWRP at the Beenyup site. Recharge via the existing Leederville aquifer recharge bore and one new Yarragadee aquifer recharge bore located at the Beenyup site.
2	2018	Construct an additional 7 GL AWRP at the Beenyup site (to provide a total of 14 GL recycled water) Construct a pipeline and two new Leederville aquifer recharge bores (if required) located off the Beenyup site, to the east of Lake Joondalup to recharge the additional 7GL produced by the Stage 2A AWRP.
3	2022	Construct an additional 14GL AWRP at the Beenyup site (to provide a total of 28GL recycled water). Extend pipeline and construct two additional Leederville aquifer recharge bores and two additional Yarragadee aquifer recharge bores to recharge the additional water.

A staged delivery allows a flexible approach to meet water demand in the Integrated Water Supply Scheme. Dates are based on predictions of future water demand and an assumption of supply contribution from surface water sources. If surface water inflows are less it may be necessary to accelerate the delivery of the future stages of the Perth GWRS.

4.1 Perth GWRS Stage 2 - Accelerated scope

In order to maintain supply against a background of a drying climate, the Water Corporation is considering accelerating the delivery of Stage 2 of the Perth GWRS.

Given potential delays in constructing a large pipeline under major transport infrastructure and alongside a regionally significant environmental site the Water Corporation has reviewed the scope of Stage 2.

The two recharge bores required for Perth GWRS Stage 1 were identified as being potentially capable of greater recharge rates than had been initially planned.

Based on these potential constraints and solutions, the Water Corporation will progress the delivery of Stage 2 in two parts as detailed in Table 4-2.

Table 4-2 Accelerated delivery of the Perth GWRS - Stage 2

Stage	Activity
Stage 2A	Construct an additional 7GL AWRP at the Beenyup site (to provide a total of 14GL recycled water). Maximise recharge to Leederville and Yarragadee aquifer recharge bores.
Stage 2B	Construct a pipeline and two new Leederville aquifer recharge bores (if required) located off the Beenyup site, to the east of Lake Joondalup to recharge the additional 7GL produced by the Stage 2A AWRP.

Whilst maximum recharge rates for each bore can be estimated, this will not be confirmed until they can be tested under pumping and recharge conditions.

The Perth GWRS Stage 1 AWRP will have a capacity of 7GL/yr. This should provide sufficient recycled water to test recharge rates to each aquifer to a maximum rate of 7GL/yr and inform the design requirements for Perth GWRS Stage 2A.

Approvals for Perth GWRS Stage 2B will be progressed with Perth GWRS Stage 3 and will be commenced in sufficient time to meet the forecast demand. Figure 4-1 illustrates the staging options of the 28 GL/yr GWRS including acceleration of GWRS Stage 2.

The Water Corporation has requested that the DoH, DEC and DoW identify the EV's for Perth GWRS Stage 2A; recharging up to a total of 14GL to the Leederville and Yarragadee aquifers at the Beenyup site.

4.2 Recharge Management Zone

The Interagency Working Group[2] was required to define the minimum distance between recharge and abstraction as an outcome of the GWR Trial. The IAWG sought technical advice from the Groundwater Technical Reference Group (TRG)[3] to understand the groundwater system and aquifer response to recharge.

Based on the Groundwater TRG advice, the IAWG established that the minimum distance between recharge and abstraction will be defined by a Recharge Management Zone (RMZ). Groundwater monitoring must occur to ensure that the groundwater meets the health and environment related guidelines at the boundary of the zone. This distance should be defined based on knowledge of the local aquifer characteristics and response to recharge. Further details on the RMZ requirements can be found in the GWR Regulatory Framework.

The RMZ for the confined aquifers at the Beenyup site, that is the Leederville and the Yarragadee aquifers, is a radial distance of 250m from the point of recharge. This was based on information provided by the Groundwater TRG (Groundwater - TRG, May 2012), and confirmed in writing by the DoH, DoW and DEC (Water Corporation, 28 June 2012) (DEC, 23 July 2012) (DoW, 31 July 2012).

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[2] Inter-agency Working Group (IAWG) – consisting of representatives from the DoW, DoH, DEC and the Water Corporation, was formed to oversee the GWR Trial with the intention of developing policy and regulation for groundwater replenishment.

[3] Groundwater Technical Reference Group (TRG) consists of groundwater expertise from CSRIO, Curtin University, Department of Water, Rockwater Hydrogeological Consultants and the Water Corporation.
Initially formed to inform the objectives of the Groundwater Replenishment Trial, including monitoring and assessment the aquifer response when recharged with recycled water, the TRG remains to assist in the development of the Perth GWRS.

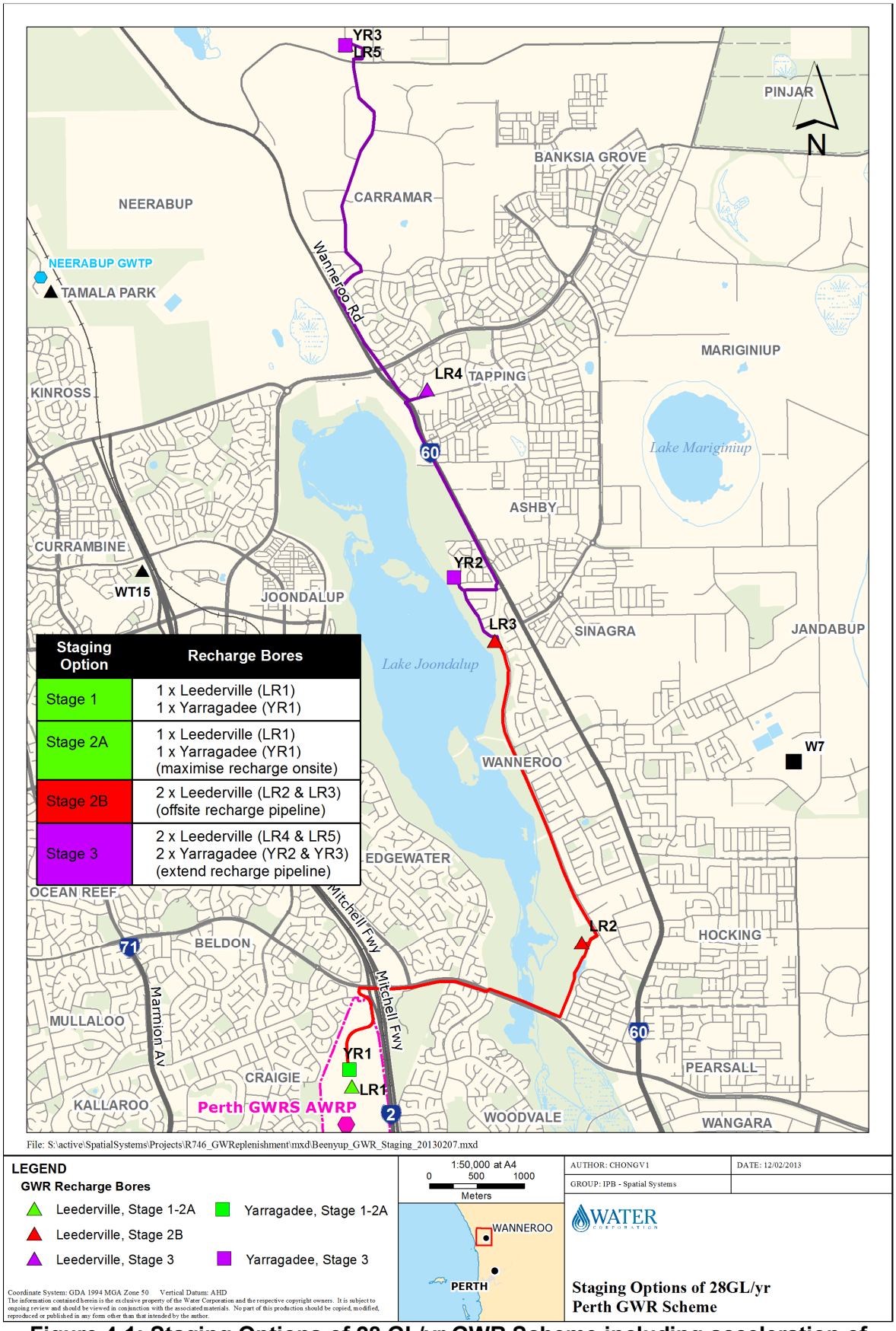


Figure 4-1: Staging Options of 28 GL/yr GWR Scheme including acceleration of Stage 2

5 Step 1: Characterising the aquifer to allow identification of Environmental Values

Step 2 of the GWR Framework requires the DoH, DEC, DoW and Water Corporation to identify the uses of each aquifer that is effected by a groundwater replenishment scheme. These *uses* are defined as "Environmental Values" (EV's) by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000a) (ANZECC Guidelines) and are taken to mean "the particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits." When identifying the EVs, existing and future uses of the groundwater must be considered.

An understanding of the groundwater system in the vicinity of the GWRS is required to identify the EVs. This includes an understanding of how water flows within the aquifer that is being recharged (horizontal flow) as well as if it will flow from the aquifer that is recharged to adjacent aquifers (vertical flow).

The Perth GWRS Stage 2A will recharge the Leederville and Yarragadee aquifers at the Beenyup site. Groundwater monitoring will occur within the RMZ and will confirm that recycled water moving horizontally through the aquifer will continue to meet health and environmental water quality guidelines at a specified point from recharge and ensure the identified EV's remain protected.

The likelihood of recycled water moving upwards into the Superficial aquifer is also considered. If water is shown to flow from the recharged aquifer, specifically the Leederville aquifer, to the superficial then the EVs of the Superficial aquifer must also be identified.

The Groundwater TRG investigated the likelihood of vertical flow from the Leederville aquifer to the Superficial aquifer based on information gained from the Groundwater Replenishment Trial. A process of investigation was developed to guide decision making by Agency representatives. Outlined in Appendix 1, the evaluation process can be summarised as follows:

1) How long will it take for recycled water to move through the Leederville aquifer and Pinjar aquitard to the base of the Superficial aquifer?
2) If recycled water was to reach the base of the superficial aquifer how much recycled water would be entering the aquifer? and
3) What would the resulting groundwater chemistry be when the recycled water mixes in the Superficial aquifer?

Information pertaining to the Leederville and Yarragadee aquifers at the two recharge bores located at the Beenyup site is provided in the following section.

5.1 Aquifer Characteristics

Investigations to determine the suitability of the Beenyup site for GWR began in 2004. Initial studies were conducted to understand the aquifers to the top of the Yarragadee aquifer at the Beenyup site. Findings from these initial investigations were summarised in the "Groundwater Replenishment Trial Site Evaluation Report – Aquifer Assessment (Rockwater Pty Ltd, 2008)"

This was followed by a comphrensive study to characterise the Leederville aquifer as part of the Groundwater Replenishment Trial (Water Corporation, 2009), (Water Corporation, 2011), (Water Corporation, 2012).

The stratigraphy at the Beenyup site has been defined based on the lithological description and geophysical logs from two cored boreholes; BYNP1/07 (Leederville) and BNYP1/12 (Yarragadee) and correlated against previous interpretations of Artesian Monitoring Bore AM 27 (Water Corporation, 2009) about 1 km to the north-east; the Cragie Geothermal Bore, about 1.2 km to the south and Yarragadee production bore WT97, 3 km south. Additional information used to characterise the Yarragadee aquifer for the purposes of identifying the EVs includes information from a Yarragadee bore at Beatty Park (Rockwater Pty Ltd, 2011). Current Yarragadee investigations at the Beenyup site includes detailed seismic, and analysis of core samples retrieved from BNYP1/12. A correlation between sites proximal to Beenyup based on this information is shown in Figure 5-1 and the hydro-stratigraphy is summarised in Table 5-1. The recharge interval of the Leederville aquifer (identified as the Wanneroo Member) is overlain by up to 30 m of siltstone with minor thin sandstone beds which separates the recharge zone from the overlying aquifer units (Water Corporation, 2009).

Siltstone and mudstone of the Mariginiup Member and South Perth Shale forms a lower seal more than 100 m thick at the base of the recharge interval. The Mariginup Member contains a few thin sandstone beds and the South Perth Shale is predominantly siltsone and shale and both are regarded as an aquitard[4], which is a confining unit that retards the flow of water to or from an adjacent aquifer. The Yarragadee aquifer is effectively isolated from the overlying aquifers in this area by the Mariginiup Member and South Perth Shale (Water Corporation, 2009).

[4] Aquitard – A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water (AGI, 1980).

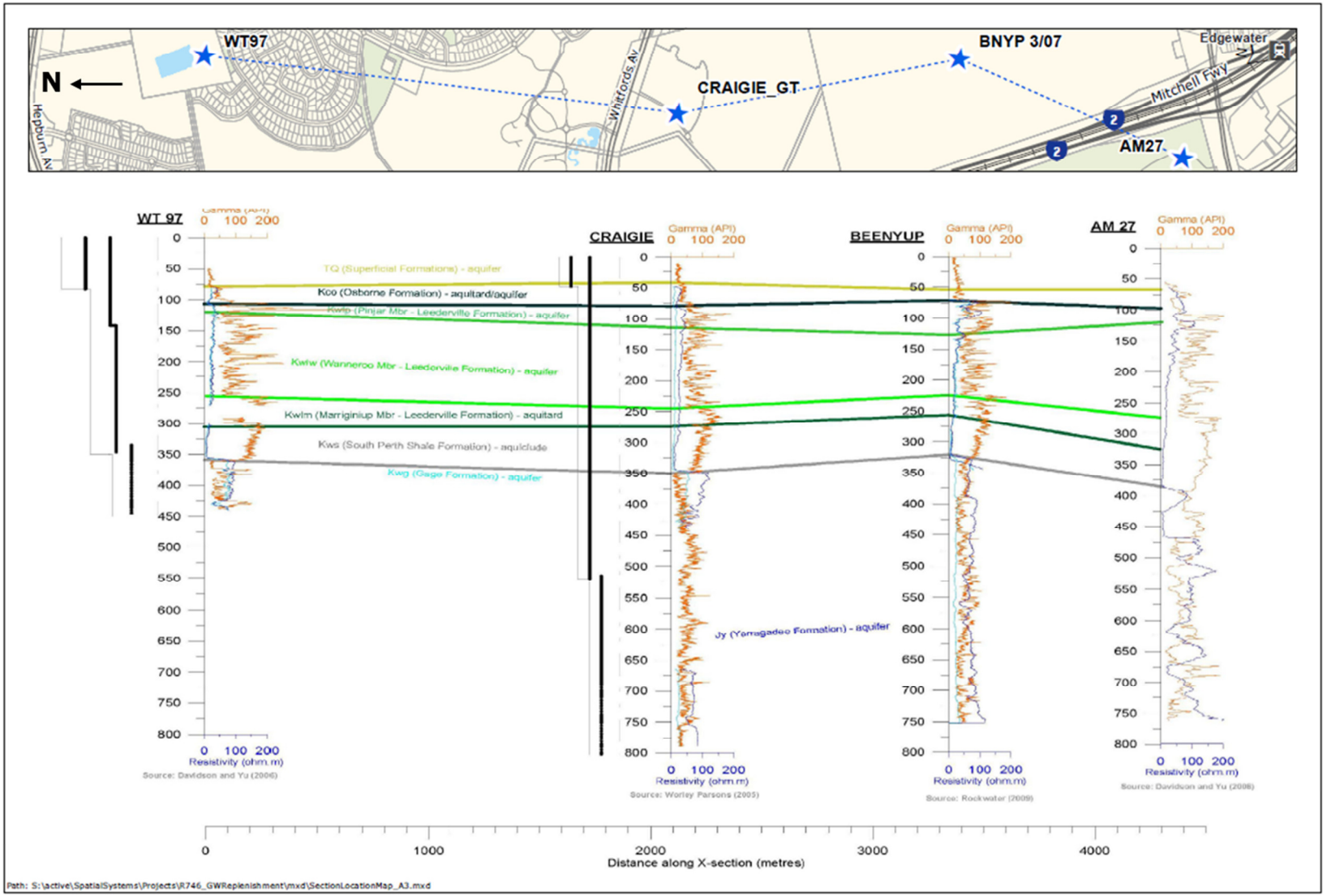


Figure 5-1: Hydrostratigraphic correlation for the Beenyup site

Table 5-1: Hydro-stratigraphic summary for the Beenyup Site

Summary Depth (m)		Description	Geological Unit	Hydrogeology
From	To			
0	20	Sand, medium to coarse grained quartz and limestone grains	Tamala Limestone	Superficial aquifer
20	50	Limestone	Tamala Limestone	Superficial aquifer
Unconformity				
50	65	Sandstone, silty, medium to coarse grained quartz and glauconite with silt and shale beds.	Osborne Formation	Mirrabooka aquifer Kardinya Shale aquitard
Unconformity				
65	95	Sandstone, fine to coarse grained, moderately sorted, sub-rounded quartz with thin dark grey siltstone beds	Leederville Formation (undifferentiated)	Leederville aquifer
95	125	Siltstone and shale	Leederville Formation	aquitard
125	175	Sandstone, fine to coarse grained quartz with thin siltstone and mudstone beds	Leederville Formation: Wanneroo Member	Leederville aquifer
175	190	Siltstone, mudstone and poorly sorted sandstone.	Leederville Formation: Wanneroo Member	Intra-formational siltstone
190	225	Sandstone, fine to coarse grained quartz with thin siltstone and mudstone beds	Leederville Formation Wanneroo Member	Leederville aquifer
225	260	Siltstone and mudstone	Leederville Formation: Mariginiup Member	aquitard
260	320	Siltstone and mudstone	South Perth Shale	aquitard
Unconformity				
320	390	Sandstone and siltstone	Gage Formation	Yarragadee aquifer
390	>750	Sandstone and siltstone	Yarragadee Formation	Yarragadee aquifer

Note: yellow shading highlights the recharge zone for the Leederville bore.
After (Water Corporation, 2012)

5.2 Leederville Aquifer

A schematic of the groundwater movement in the vicinity of the Leederville recharge bore has been illustrated in Figure 5-2 (Water Corporation, 2009). Due to the hydro-stratigraphy of the site, the recycled water remains in the Wanneroo Member which is the main transmissive part of the Leederville aquifer and moves slowly (over decades) towards the nearest abstraction bore or the ocean.

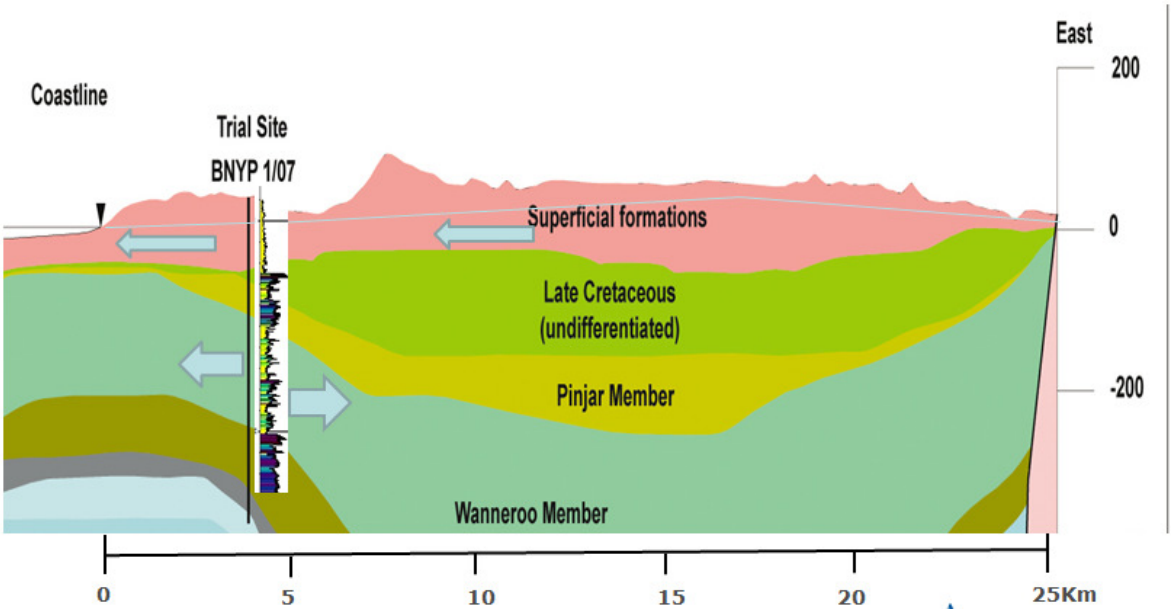


Figure 5-2: Groundwater movement in the vicinity of the Leederville recharge bore

5.2.1 Uses of the Leederville aquifer

Groundwater from the Leederville aquifer is currently used by the Water Corporation, industry and local government for public water supplies, irrigation, horticulture and industry. These uses will continue into the future.

5.2.2 Upward flow into the Superficial aquifer

As described in Table 5-1, up to 30 m of siltstone and shale forms an effective seal between the recharge interval of the Leederville aquifer and the overlying sediments, including the Mirrabooka and Superficial aquifers.

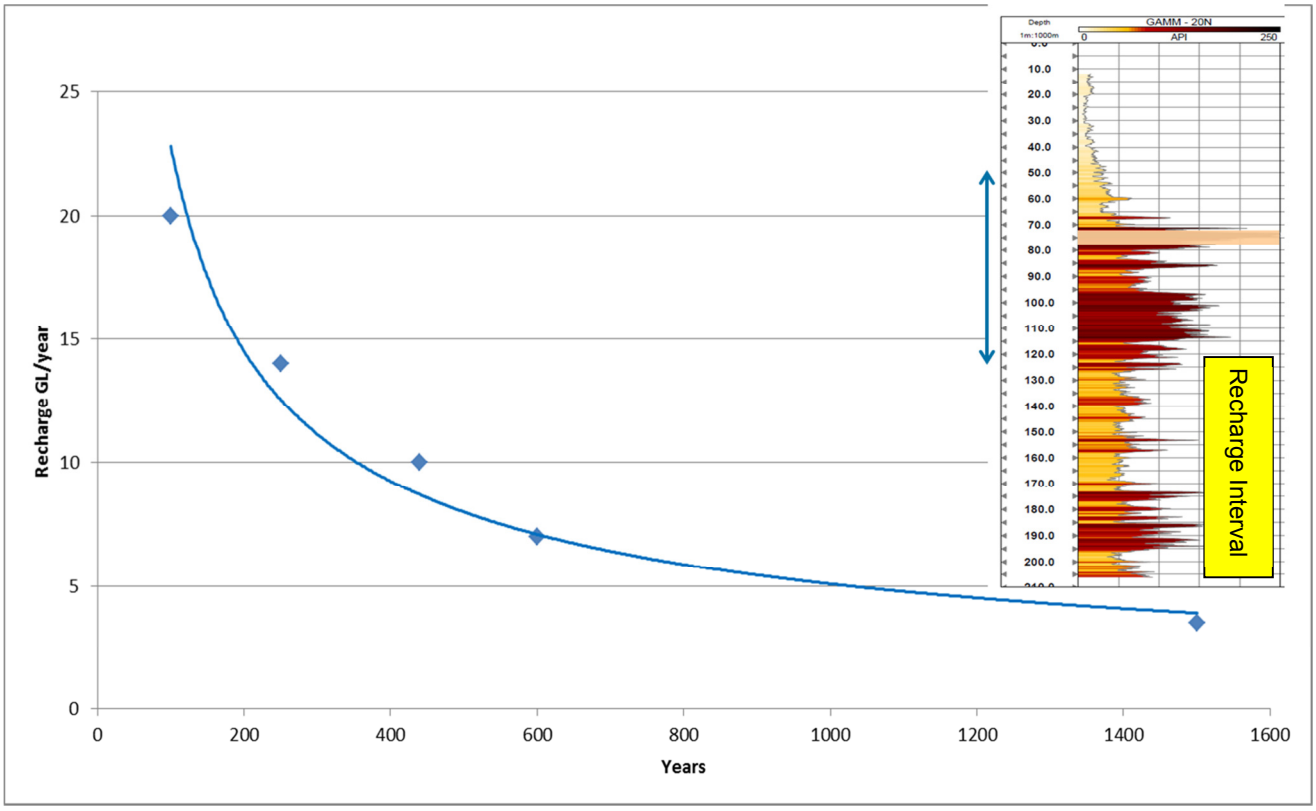
The likelihood of upward flow is directly related to recharge rates and aquifer pressure. During the GWR Trial, a total of 1.27 GL had been recharged to the Leederville aquifer by February 2012 at an average recharge rate of 2.83ML/day. The potentiometric (pressure) head in the recharge zone (Wanneroo Member) was maintained below the potentiometric head in the overlying sediments for much of the recharge period, and there was no net potential for upward flow of recycled water to the Superficial aquifer (Water Corporation, 2012).

As the rate of recharge increases there is an increased potential for the recharge water from the recharge zone to enter the overlying aquifers and possibly reach the Superficial aquifer due to an increase in recharge pressures. Hydro-stratigraphic logs from the site indicate that the sediments which lie between the recharge interval and the Superficial aquifer is up to 75m thick at the Beenyup site (Table 5-1). Any upward flowing recharge water would need to move through these layers before reaching the Superficial aquifer.

The first step in the evaluation of upward flow is to determine how long it will take for recharged water to move through the overlying sediments to the base of the Superficial aquifer (see Appendix 1). If necessary, further evaluation is required to quantify the volume of water and predict changes to water quality.

The Perth Regional Aquifer Modelling System (PRAMS3.4) is an appropriate modelling tool for assessment at a regional scale, but does not provide the required detail for local scale assessments. An analytic model, based on first principles, was developed by the Groundwater TRG to enable assessment at a local scale, and is applicable for a range of potential recharge rates (Figure 5-3). The model utilises the observed strata from a site, and can be quickly reconfigured for a new site as information from drilling and testing becomes available.

The model provides a conservative prediction (underestimate) of travel time as it only considers vertical flow and does not take into account head reduction due to additional abstraction of the recharged volume or lateral flow due to spreading or regional through flow in the overlying sediments which may significantly reduce the likelihood of recharged water reaching the superficial aquifer.



Note: insert at top right of Figure 5-3 is a representation of the strata at the Beenyup site from the geophysical log of the Leederville recharge bore. The interval between the recharge zone and base of superficial aquifer is shown by the blue arrow. The dark lines represent the low permeability siltstone strata that impede upward movement of recharged water. Spreading may occur in the sandy (light coloured) layers.

Figure 5-3: Travel Time for upward flow into the Superficial aquifer

The Groundwater TRG considered a number of Leederville aquifer recharge rates up to 14GL/yr, i.e. the entire AWRP production volume associated with Stage 2. It is not intended to construct more than one Leederville and one Yarragadee bore at the Beenyup site, and the recharge capacity will be confirmed following pump tests.

Evaluation of the 14 GL/yr recharge ensures the scenario with the greatest pressure with respect to upward flow is assessed.

The travel times for recycled water to reach the Superficial aquifer was predicted by applying the recharge scenarios to the analytic model presented in Figure 5-3. The predicted travel times are summarised in Table 5-2.

Table 5-2: Predicted travel times for water recharged at the Beenyup site to move to the base of the Superficial aquifer

GWR Scheme	Recharge to the Leederville aquifer		Travel Time (years)
	GL/yr	ML/day	
Stage 1	3.5	9.6	1500
	7	19.2	600
Stage 2A	10	27.4	440
	14	38.4	250

Specific to Perth GWRS Stage 2A where recharge into the Leederville aquifer could reach up to 14 GL/yr at the Beenyup site, the travel time for the recycled water to reach the base of the Superficial aquifer is estimated to be greater than 250 years.

While there is a possibility for upward flow further from the recharge bore, this is mitigated by the reduced head difference with distance from the bore, the horizontal travel time within the aquifer, and the extent and thickness of sediments overlying the recharge zone. At a distance of 250m – 500m from the recharge bore, the estimated vertical travel time would increase to 400years if recharge continued at 14 GL/yr. The potential for regional movement of recharged water to the Superficial aquifer will be confirmed using the PRAMS model and documented as part of the Aquifer Risk Assessment.

5.3 Yarragadee aquifer

As described in Table 5-1, there is a regionally extensive layer that separates the Leederville and Yarragadee aquifers (Davidson W.A. & Yu X., 2008). This layer consists of the Mariginiup aquitard and South Perth Shale aquitard and is more than 100m thick at the Beenyup site.

5.3.1 Uses of the Yarragadee aquifer

Groundwater from the Yarragadee aquifer is also used by the Water Corporation, and to a lesser extent industry and local government. Uses include public water supplies and heating public swimming pools (geothermal bores). Whilst further development of water from this aquifer for horticulture and industry may be currently constrained due to cost, water quality and availability of groundwater allocation, maintaining water quality that is adequate for these uses is required.

5.3.2 Upward flow into the Superficial aquifer

Because of the thick and extensive nature of the low permeability sediments that overlie the Yarragadee aquifer, it is considered that upward flow of recharge water across this layer is unlikely.

If conditions allowed for recharged water from the Yarragadee to flow upwards, it would have to first flow into the Leederville aquifer, through the Pinjar aquitard and overlying aquifers before reaching the base of the Superficial aquifer. Travel times even under extreme head conditions will be in the order of tens of thousands of years.

6 Environmental Values (EV's)

The Groundwater TRG have provided information on the Leederville aquifer and Yarragadee aquifer characteristics at the Beenyup site to the DoH, DEC and DoW representatives to allow identification of the relevant Environmental Values (EV's).

6.1 Step 2a: Identifying the EVs of the receiving environment (Leederville and Yarragadee aquifers)

The ANZECC Guidelines recognises there are six EV's to consider; aquatic ecosystems, primary industries, recreation and aesthetics, drinking water, industrial water and cultural and spiritual issues, which fall into two categories; ecological values and social values. An "**ecological value"** means the intrinsic natural values of ecosystems which require protection against the effects of pollution, environmental harm, waste discharges and deposits, while a **"social value"** means a particular value or use of the aquatic environment that is important for public benefit, welfare, safety or health and which requires protection from the effects of pollution, environmental harm, waste discharges and deposits.

The DoH, DEC and DoW have advised that management of the Leederville and Yarragadee aquifers are to be maintained for both current and future uses.

The following section considers each value described in the ANZECC Guidelines and assesses its relevance for the Leederville and Yarragadee aquifers in the vicinity of the Beenyup site.

6.1.1 Drinking Water (a social value)

The ANZECC guideline references the Australian Nation Health and Medical Research Council *Australian Drinking Water Guidelines* (ADWG, 2004) to provide guidance on what constitutes good quality drinking water (ANZECC and ARMCANZ, 2000a).

Guidance on producing drinking water using recycled water as a source is provided in the *Australian Guidelines for Water Recycling: Managed Aquifer Recharge (Phase 2) (AGWR Phase 2)* (NRMMC-EPHC- NHRMC, 2009).

Both ADWG and AGWR Phase 2 cover a wide range of measurable characteristics which fall into two categories. A **health-related guideline value** is the concentration or measure of a water quality characteristic that, based on present knowledge, does not pose any significant risk to the health of the consumer over a lifetime of consumption. An **aesthetic guideline value** is the concentration or measure of a water quality characteristic associated with good quality water. The ADWG emphasises that health-related guidelines define water which, based on current knowledge, is *safe* to drink over a lifetime: that is, it constitutes no significant risk to health (ANZECC and ARMCANZ, 2000a).

The Beenyup site falls within the Perth Coastal Underground Water Pollution Control Area which the DoW has designated a Priority 3 source protection area.. Priority 3 source protection areas are defined to manage the risk of pollution to the water source

from catchment activities. Protection of these areas is achieved through guided or regulated land use activities. The existing and future use of the Leederville and Yarragadee aquifers for the purpose of providing a raw drinking water resource should therefore be maintained. The DoH, DEC and DoW agrees that the Drinking Water EV must therefore be protected.

6.1.2 Primary Industries (a social value)

The ANZECC Guidelines have amalgamated agriculture, aquaculture and human consumption of aquatic foods and water for irrigation into one environmental value called 'Primary Industries'. Both the quality and the quantity of water resources are critical issues for agriculture and aquaculture in Australia. Water quality is also of major importance for the protection of human consumers of food products. Growth of these major primary industries, together with expanding urbanisation and other industrial development, has increased the demand for good quality water but at the same time exerted escalating pressures on the quality of the water resources that are available. Therefore, to assess water for primary industries, not only must productivity issues be considered but also the possible adverse effects of these enterprises on downstream water quality and activities (ANZECC and ARMCANZ, 2000a).

For the purposes of identifying EVs, irrigation for landscaping in urban areas for public recreation, including playing fields and parks and gardens has been included in Primary Industries.

There are a number of bores currently used for the purpose of primary industry in the Leederville aquifer and there is potential for further bores to be licensed for this purpose. Therefore the DoH, DEC and DoW agree that the Primary Industry EV should be maintained for the Leederville aquifer.

There are currently no licenced Yarragadee bores in the vicinity of the Beenyup site providing water for Primary Industry. However with a growing population and increasing pressures to gain access to this water source for the purpose of Primary Industry, current constraints may be overcome and future use for primary industry is possible. Therefore the DoH, DEC and DoW agree that the Primary Industry EV should apply to the Yarragadee aquifer.

6.1.3 Industrial Water (a social value)

The ANZECC guidelines recognise that water for industrial use is an environmental value that has a high economic benefit to the community.

There are bores present in the Leederville and Yarragadee aquifer that provide water for industrial water purposes therefore the DoH, DEC and DoW agree that the Industrial Water EV must be maintained.

6.1.4 Cultural and Spiritual Issues (a social value)

The ANZECC Guidelines recognise cultural and spiritual values are important, particularly for indigenous people. No specific guidance for protection of these values is provided but the ANZECC Guidelines indicates that planning and management must consider cultural issues.

Consultation will continue with members of the Aboriginal community including members from the South West Aboriginal Land and Sea Council (SWALSC) and Indigenous Water Policy Group.

6.1.5 Aquatic Ecosystems (an ecological value)

The objective of the aquatic ecosystem environmental value adopted by the ANZECC Guidelines is "to maintain and enhance the 'ecological integrity' of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes".

Leederville aquifer - The GW TRG have advised that for recharge up to 14 GL/yr to the Leederville aquifer, it is estimated that it will take more than 250 years for the recharged water to first move into the low permeability sediments above the recharge zone before reaching the Superficial aquifer. Lateral flow within the overlying sandy sediments will further reduce the likelihood of recharge water reaching the Superficial aquifer. Monitoring the aquifer pressures within the RMZ will confirm the low risk of upward flow into the Superficial aquifer. Based on this information, the DoH, DEC, DoW have confirmed that the Aquatic Ecosystems EV will not be considered for the Leederville aquifer.

Yarragadee aquifer - The DoH, DEC and DoW note that water recharged to the Yarragadee aquifer must first flow into the Leederville aquifer and Pinjar aquitard prior to flowing into the Superficial aquifer. Therefore the DoH, DEC and DoW agree that the Aquatic Ecosystems EV will not be considered for the Yarragadee aquifer.

6.1.6 Recreation and Aesthetics (a social value)

The ANZECC Guidelines intends that the Recreation and Aesthetics EV maintains the ability of the resource to accommodate recreational activities such as swimming, boating or fishing as well as visual amenity, such as ensuring that the water body is a pleasant place to be near or look at.

Local governments in Perth often use groundwater to maintain water levels in ornamental lakes for aesthetic purposes. The water can potentially be sourced from the Leederville and Yarragadee aquifers. While this use could potentially be considered to have an aesthetic value, they have not been identified within the vicinity of the Beenyup site.

Irrigation of landscaping in urban areas for public recreation, including playing fields and parks and gardens for the purpose of recreation or aesthetics is considered in the Primary Industries EV (section 6.1.2).

The recharge interval of the Leederville aquifer commences below 120m depth and the Yarragadee aquifer commences below 320 m, both these aquifers are not accessible for recreation purposes.

The DoH, DEC and DoW agrees that the Recreation and Aesthetics EV does not apply to the Leederville and Yarragadee aquifers.

In summary, the EV's that are applicable to the Leederville and Yarragadee aquifers in the vicinity of the Beenyup site are listed in Table 6-1.

Table 6-1: EV's for the Leederville aquifer and Yarragadee aquifer at Beenyup site

Environmental Value	Leederville aquifer	Yarragadee aquifer
Drinking Water	✔	✔
Primary Industries	✔	✔
Industrial Water	✔	✔
Cultural and Spiritual	✔	✔
Aquatic ecosystems	✘	✘
Recreation and Aesthetics	✘	✘

applicable ✔
not applicable ✘

6.2 Step 2b: Establish a broad management objective for the relevant EVs

The establishment of a management objective is to reflect the desired state of the EV's identified as relevant to the receiving environment.

The DoH, DEC and DoW have agreed that the management objectives of the EV's defined in Table 6-1 will be maintained for current use.

Managing access to the groundwater in the future is the role of the DoW as the State's water resource manager. To this end, the DoW has developed a position for the take and use of groundwater from the Leederville and Yarragadee aquifers which is documented in the *"Gnangara groundwater areas allocation plan"* (DoW, 2009). The DoW has advised of the limited water availability with both aquifers currently being over allocated.
However there may come a time in the future where this position is amended therefore water quality should be protected for future uses.

6.3 Step 2c: Determine Appropriate Water Quality Guidelines

The DoH, DEC, DoW and Water Corporation have agreed that the water quality guidelines required to protect the identified EVs must be met at the point of recharge. The water quality guidelines applied to the Leederville and Yarragadee aquifers will be the same.

6.3.1 Drinking Water EV

The DoH has confirmed the water quality guidelines required to protect human health and the drinking water resource as part of the Groundwater Replenishment Trial. The guidelines are based on health guidelines provided in the ADWG, AGWR Phase 2 and results from the Premiers Collaborative Research Project (DoH et al, 2009). These water quality guidelines are tailored to the Beenyup wastewater catchment. Regular risk assessments ensure that the health guidelines are still relevant.

These guidelines are referred to as Recycled Water Quality Parameters (RWQP) and recycled Water Quality Indicators (RWQI) and are defined in Schedule 1 of the *Memorandum of Understanding between the Department of Health and the Water Corporation for the Groundwater Replenishment Trial* (GWR MoU).

The RWQP and RWQI defined in the GWR MoU (as amended from time to time) will be applied at the point of recharge to protect the Drinking Water EV.

6.3.2 Primary Industry EV and Industrial Water EV

There is a wide range of uses of water in the EV's of Primary Industries and Industrial Water; given that there is unrestricted access to potable (drinking) water for the purpose of Primary Industry and Industrial Water, the Drinking Water EV water quality guidelines will be applied for these two EVs.

6.3.3 Cultural and Spiritual EV

There is no specific guidance for the protection of the Cultural and Spiritual EV's however the Water Corporation will continue to liaise with the relevant stakeholders in the Indigenous Community to discuss any cultural issues with respect to recharging into the Leederville and Yarragadee aquifers.

7 Conclusion

The DoH, DEC and DoW have established the relevant EV's and water quality guidelines for the Perth GWRS Stage 2A, recharging to the Leederville aquifer and Yarragadee aquifer based on:

- Advice on the characteristics of the Leederville and Yarragadee aquifers provided by the Groundwater TRG; and
- Evaluation of the six environmental values described in the ANZECC guidelines.

The relevant EVs and water quality guidelines are provided in Table 7-1:

Table 7-1: The identified EV's and water quality guidelines for GWRS Stage 2A

Environmental Value	Water Quality Guidelines for Leederville and Yarragadee aquifer – GWRS Stage 2A
Drinking Water	• Recycled Water Quality Indicators • Recycled Water Quality Parameters As defined by the GWR MoU
Primary Industries	• As per Drinking Water EV
Industrial Water	• As per Drinking Water EV
Cultural and Spiritual	• Consultation with Indigenous Community

The DoH, DEC and DoW have also advised that the management objective of the identified EV's is to "maintain for current and future use".

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