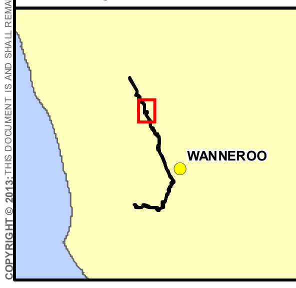
LOCALITY MAP



Legend

- July 2016 Survey Area (30.63 ha)
- June 2016 Survey Area
- Stage 3 Pipeline Preferred Alignment
- Stage 3 Pipeline Alternate Alignment

Surveyed Date

- June 2016
- July 2016

Potential BC Breeding Trees with Suitable Hollows

Species

- *Eucalyptus accedens*
- *Eucalyptus marginata*
- *Corymbia calophylla*
- *Eucalyptus rudis*
- *Eucalyptus gomphocephala*

DATA SOURCES

- CADASTRAL BOUNDARY SOURCED FROM LANDGATE 2009
- VEGETATION MAPPED BY 360 ENVIRONMENTAL 2016 AT A SCALE OF 1:1000
- LOCALITY MAP SOURCED LANDGATE 2006, AERIAL PHOTOGRAPHY SOURCED LANDGATE FEB 2016 (© Western Australian Land Information Authority 2016)

Powered By SLIP ENABLER

NOTE THAT POSITIONAL ERRORS MAY BE >5M IN SOME AREAS

360 environmental
a 10 Bermondsey St, West Leederville, 6007 WA
t (08) 9388 8360 f (08) 9381 2360
w www.360environmental.com.au

people planet professional

WATER CORPORATION

CREATED	CHECKED	APPROVED	REVISION	DATE
JJ/MH	LS	RF	0	26-Aug-16

HORIZONTAL DATUM	PROJECT NO
GDA 1994 MGA Zone 50	1744

0 20 40 80 120 160 200
Meters
1:4,000 @ A3

Water Corporation
Groundwater Replenishment Scheme
Beenyup Stage 3 Pipeline

Flora and Fauna Survey

Figure 3

GRWS Black Cockatoo Potential Breeding Trees with Hollows

K:\Projects\1.0 EBS\1744 GWRS Black Cockatoo Survey\Figures\1744 Figure 3 - Hollows.mxd

APPENDIX A

Black Cockatoo Potential Breeding Trees

ID	Species	DBH	No. of Hollows	Hollow Size	Easting	Northing	Comments
June 2016 Fauna Survey Black Cockatoo Potential Breeding Trees							
1	*Corymbia calophylla*	A	0		385167	6488592	
2	*Eucalyptus marginata*	A	0		385168	6488604	
3	*Eucalyptus marginata (dead)*	A	4		385159	6488608	Hollows don't go anywhere
4	*Eucalyptus marginata*	A	2		385137	6488634	Hollows don't go anywhere
5	*Eucalyptus marginata*	A	0		385151	6488645	
6	*Eucalyptus marginata*	A	1	<100	385141	6488642	
7	*Eucalyptus marginata (dead)*	A	0		385125	6488649	Bees
8	*Eucalyptus marginata*	A	0		385113	6488662	
9	*Eucalyptus marginata*	A	0		385109	6488674	
10	*Eucalyptus marginata*	A	1	<100	385119	6488711	
11	*Eucalyptus marginata*	B	4	<100	385072	6488674	
12	*Eucalyptus marginata*	A	0		385075	6488695	
13	*Eucalyptus marginata*	A	0		385095	6488721	
14	*Eucalyptus marginata*	A	0		385092	6488735	
15	*Eucalyptus marginata*	A	0		385090	6488748	
16	*Eucalyptus marginata*	A	1	<100	385068	6488735	
17	*Eucalyptus marginata*	A	0		385048	6488738	
18	*Eucalyptus marginata*	A	0		385020	6488758	
19	*Eucalyptus marginata (dead)*	A	0		385018	6488766	
20	*Eucalyptus marginata*	A	0		385007	6488775	Splits into two at 2m
21	*Eucalyptus marginata (dead)*	A	0		384968	6488802	
22	*Eucalyptus marginata (dead)*	A	5	<100	384992	6488827	
23	*Eucalyptus marginata*	A	0		385000	6488829	
24	*Eucalyptus marginata (dead)*	A	0		385003	6488822	
25	*Eucalyptus marginata (dead)*	A	0		384996	6488841	Bees
26	*Eucalyptus marginata (dead)*	A	0		384979	6488834	
27	*Eucalyptus marginata (dead)*	A	3	1x100, 2x <100	384945	6488866	Bees

28	*Eucalyptus marginata (dead)*	A	0		384934	6488852	Patch of Marri <500mm
29	*Eucalyptus marginata (dead)*	B	4	1x100, 3x<100	384959	6488900	Bees
30	*Eucalyptus marginata*	A	2	<100	384952	6488935	Bees
31	*Eucalyptus marginata*	A	3	<100	384885	6488947	Bees
32	*Eucalyptus marginata*	A	0		384886	6488932	
33	*Corymbia calophylla*	A	0		384877	6488950	
34	*Eucalyptus marginata*	A	0		384869	6489010	
35	*Corymbia calophylla*	A	0		384876	6489025	
36	*Corymbia calophylla*	A	0		384876	6489025	
37	*Eucalyptus marginata*	A	3	1X150, 2x<100	384864	6489055	
38	*Eucalyptus gomphocephala*	A	0		384851	6489218	
39	*Eucalyptus marginata*	A	0		384753	6489635	
40	*Eucalyptus rudis*	A	0		384763	6489631	
41	*Corymbia calophylla*	A	0		384769	6489627	
42	*Corymbia calophylla*	A	0		384766	6489620	
43	*Eucalyptus rudis*	A	0		384789	6489604	
44	*Corymbia calophylla*	A	0		384774	6489595	
45	*Eucalyptus rudis*	A	0		384840	6489530	Bees
46	*Eucalyptus rudis*	A	0		384838	6489518	
47	*Corymbia calophylla*	A	0		384831	6489520	
48	*Eucalyptus marginata*	A	0		384029	6491022	
49	*Eucalyptus gomphocephala*	A	0		385305.368	6488138.412	
50	*Eucalyptus gomphocephala*	A	0		385266	6488158	
51	*Eucalyptus gomphocephala*	A	0		385267.222	6488218.237	
52	*Eucalyptus gomphocephala*	A	0		385630	6487553	
53	*Eucalyptus gomphocephala*	A	0		385373.031	6488014.412	
54	*Eucalyptus rudis*	A	0		385779	6487447	
55	*Eucalyptus gomphocephala*	A	0		385807	6486637	
56	*Eucalyptus gomphocephala*	A	0		386007.121	6486063.26	
57	*Eucalyptus gomphocephala*	A	0		386013.533	6486048.879	
58	*Eucalyptus gomphocephala*	A	0		386029.3	6486007.969	
59	*Eucalyptus gomphocephala*	A	0		386035.74	6485993.381	
60	*Corymbia calophylla*	A	0		386062.202	6485971.556	

61	*Corymbia calophylla*	A	0		386066	6485924.35	
62	*Eucalyptus ascedens*	A	0		386084.327	6485884.638	
63	*Eucalyptus gomphocephala*	A	0		386096	6485855	
64	*Eucalyptus gomphocephala*	A	0		386105.44	6485833.031	
65	*Eucalyptus rudis*	A	0		386143.206	6485737.44	
66	*Eucalyptus rudis*	A	0		386172.677	6485695.677	
67	*Eucalyptus rudis*	A	0		386385	6485168	
68	*Corymbia calophylla*	A	0		386549	6484797	
69	*Eucalyptus marginata*	A	0		386755.605	6484445.598	
70	*Corymbia calophylla*	A	0		386774.86	6484432.788	
71	*Corymbia calophylla*	A	0		386784.08	6484430.577	
72	*Eucalyptus rudis*	A	0		386631.573	6484190.75	Carnaby's Black Cockatoo flying nearby
73	*Eucalyptus rudis*	A	0		386631	6484160	
74	*Eucalyptus rudis*	A	0		385015	6488697	
75	*Eucalyptus gomphocephala*	C	0	All <100	386519	6483962	
76	*Eucalyptus gomphocephala*	B	1	<100	386103.456	6482970.352	
77	*Eucalyptus gomphocephala*	A	0		386143	6483014	
78	*Eucalyptus gomphocephala*	A	0		386167	6483059	
79	*Eucalyptus gomphocephala*	A	0		386211	6483069	
80	*Eucalyptus gomphocephala*	A	0		386092	6482896	
81	*Eucalyptus gomphocephala*	A	0		386092	6482896	
82	*Eucalyptus gomphocephala*	A	0		386092	6482896	
83	*Eucalyptus gomphocephala*	A	0		386098	6482846	
84	*Eucalyptus gomphocephala*	A	0		386098	6482846	
85	*Corymbia calophylla*	A	0		386092	6482790	
86	*Corymbia calophylla*	A	0		386096	6482763	
87	*Eucalyptus gomphocephala*	A	0		386120	6482720	
88	*Eucalyptus gomphocephala*	A	0		385938	6482658	
89	*Eucalyptus gomphocephala*	A	0		385732	6482602	
90	*Eucalyptus gomphocephala*	A	0		385732	6482602	
91	*Eucalyptus gomphocephala*	A	0		385732	6482602	
92	*Eucalyptus gomphocephala*	A	0		384679	6482683	
93	*Eucalyptus gomphocephala*	A	0		384679	6482683	

94	*Eucalyptus marginata*	A	0		385015	6488647	
95	*Eucalyptus marginata*	A	0		385043	6488693	
96	*Eucalyptus marginata (dead)*	A	0		385053	6488706	
97	*Eucalyptus marginata*	A	0		385073	6488694	
98	*Eucalyptus marginata*	A	0		385072	6488674	
99	*Eucalyptus marginata (dead)*	A	0		385015	6488769	
100	*Eucalyptus marginata (dead)*	A	0		385038	6488707	
101	*Eucalyptus marginata*	A	2	<100	385048	6488736	
102	*Eucalyptus marginata*	A	0		385024	6488758	
103	*Corymbia calophylla*	A	0		384920	6488823	
104	*Corymbia calophylla*	A	0		384921	6488832	
105	*Corymbia calophylla*	A	0		384911	6488847	
106	*Eucalyptus marginata*	A	0		384890	6488858	
107	*Corymbia calophylla*	C	0		385229	6482717	
108	*Corymbia calophylla*	A	0		385156	6482730	
				July 2016 Black Cockatoo Habitat Assessment			
				Potential Breeding Trees			
1	*Eucalyptus marginata*	A			385211	6488646	
2	*Eucalyptus marginata*	A			385211	6488646	
3	*Eucalyptus marginata*	A			385199	6488677	Dead
4	*Eucalyptus marginata*	A			385202	6488688	Dead
5	*Eucalyptus marginata*	A			385191	6488703	Dead
6	*Eucalyptus marginata*	A			385166	6488770	
7	*Eucalyptus marginata*	A			385187	6488776	
8	*Eucalyptus marginata*	A			385184	6488830	
9	*Eucalyptus marginata*	A			385155	6488853	
10	*Eucalyptus marginata*	A			385116	6488855	Bees
11	*Eucalyptus marginata*	A			385129	6488871	
12	*Eucalyptus marginata*	A			385135	6488900	
13	*Eucalyptus marginata*	A			389153	6488898	Dead
14	*Eucalyptus marginata*	A			385156	6488923	Dead
15	*Eucalyptus marginata*	A			385174	6488915	Dead

16	*Eucalyptus marginata*	A			385205	6488916	
17	*Eucalyptus marginata*	A			385209	6488903	
18	*Eucalyptus marginata*	A			385214	6488901	Bees
19	*Eucalyptus marginata*	A			385230	6488872	Dead
20	*Eucalyptus marginata*	A			385222	6488866	
21	*Eucalyptus marginata*	A			385222	6488866	
22	*Eucalyptus marginata*	A			385250	6488859	
23	*Eucalyptus marginata*	A			385261	6488850	
24	*Eucalyptus marginata*	A			385271	6488799	Bees
25	*Eucalyptus marginata*	A			385239	6488761	Bees
26	*Eucalyptus marginata*	A			385263	6488682	Dead
27	*Eucalyptus marginata*	A			385263	6488682	Dead
28	*Eucalyptus marginata*	A			385254	6488668	
29	*Eucalyptus marginata*	A			385292	6488634	
30	*Eucalyptus gomphocephala*	A			385324	6488570	Splits in two at 2m and then splits again
31	*Eucalyptus gomphocephala*	A			385346	6488597	Chewed marri nuts
32	*Eucalyptus marginata*	A			385369	6488593	
33	*Eucalyptus marginata*	A			385399	6488611	
34	*Eucalyptus marginata*	A			385380	6488655	
35	*Eucalyptus marginata*	A	1	> 100	385377	6488658	Possible Cockatoo hollow
36	*Eucalyptus marginata*	A			385383	6488662	
37	*Eucalyptus marginata*	A			385404	6488717	
38	*Eucalyptus marginata*	A			385357	6488709	
39	*Eucalyptus marginata*	A			385357	6488709	
40	*Eucalyptus marginata*	A			385349	6488728	
41	*Eucalyptus marginata*	A			385330	6488642	
42	*Eucalyptus marginata*	A			385318	6488749	
43	*Eucalyptus marginata*	A			385309	6488750	
44	*Eucalyptus gomphocephala*	A			384856	6488764	
45	*Eucalyptus gomphocephala*	A			384848	6488787	
46	*Eucalyptus gomphocephala*	A			384848	6488787	
47	*Eucalyptus gomphocephala*	A	1	> 100	384847	6488789	Possible Cockatoo hollow
48	*Eucalyptus rudis*	A			384840	6488829	Forks low down

49	*Eucalyptus marginata*	A			384849	6488845	
50	*Eucalyptus marginata*	A			384861	6488847	
51	*Eucalyptus marginata*	A	1	> 100	384884	6488881	Possible Cockatoo hollow
52	*Eucalyptus marginata*	A			384901	6488894	
53	*Corymbia calophylla*	A			384897	6488918	
54	*Corymbia calophylla*	A			384878	6488915	Chewed Marri nuts (Carnaby's)
55	*Eucalyptus marginata*	A			384870	6488924	
56	*Eucalyptus marginata*	A			384860	6488980	
57	*Eucalyptus gomphocephala*	A			384821	6489225	
58	*Eucalyptus rudis*	A			384826	6489235	
59	*Corymbia calophylla*	A			384860	6489333	
60	*Eucalyptus rudis*	A			384830	6489344	
61	*Eucalyptus rudis*	A			384827	6489388	
62	*Eucalyptus rudis*	A			384827	6489388	
63	*Eucalyptus rudis*	A			384814	6489419	
64	*Eucalyptus rudis*	A			384821	6489452	
65	*Eucalyptus rudis*	A			384819	6489574	
66	*Eucalyptus rudis*	A			384768	6489566	
67	*Eucalyptus rudis*	A			384768	6489566	
68	*Eucalyptus rudis*	A			384780	6489561	
69	*Eucalyptus rudis*	A			384761	6489592	
70	*Corymbia calophylla*	A			384751	6489627	

APPENDIX B

Black Cockatoo Foraging Evidence

Point	Coordinates GDA 94		Notes
1	385198	6488568	Carnaby's Cockatoo - old evidence of feeding on seeds from *Banksia attenuata.* Forest Red-tailed Black Cockatoo - 2 calling
2	385214	6488619	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia attenuata*
3	385207	6488656	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
4	385206	6488665	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
5	385203	6488667	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
6	385194	6488702	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
7	385193	6488703	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
8	385173	6488756	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia menziesii*
9	385161	6488787	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
10	385150	6488839	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
11	385156	6488862	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
12	385152	6488864	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
13	385133	6488875	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
14	385141	6488900	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
15	385150	6488901	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
16	385168	6488913	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
17	385219	6488911	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
18	385225	6488884	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
19	385232	6488865	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia menziesii*
20	385241	6488867	Carnaby's Cockatoo - recent evidence of feeding on seeds from *Banksia attenuata*
21	385251	6488855	Carnaby's Cockatoo - old evidence of feeding on seeds from *Banksia attenuata*
22	385271	6488830	Carnaby's Cockatoo - recent evidence of feeding on seeds from *Banksia menziesii*
23	385273	6488792	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia menziesii*
24	385269	6488766	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia menziesii*
25	385262	6488750	Forest Red-tailed Black Cockatoo - old evidence of feeding on seeds from *Allocasuarina fraseriana*
27	385259	6488664	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia menziesii*
28	385281	6488635	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia menziesii*
29	385295	6488617	Carnaby's Cockatoo - recent evidence of feeding on nectar from *Banksia menziesii*
30	385339	6488601	Forest Red-tailed Black Cockatoo - old and recent evidence of feeding on seeds from *Corymbia calophylla*

31	385385	6488643	Carnaby's Cockatoo - recent evidence of feeding on nectar from *Banksia menziesii*
32	385396	6488696	Carnaby's Cockatoo - recent evidence of feeding on nectar from *Banksia menziesii*
33	385396	6488702	Forest Red-tailed Black Cockatoo - recent evidence of feeding on seeds from *Allocasuarina fraseriana*
34	385374	6488714	Carnaby's Cockatoo - recent evidence of feeding on grubs from *Banksia attenuata*
35	385308	6488713	Forest Red-tailed Black Cockatoo - recent evidence of feeding on seeds from *Allocasuarina fraseriana*
36	385072	6488562	Forest Red-tailed Black Cockatoo - recent evidence of feeding on seeds from *Allocasuarina fraseriana*
37	384844	6488834	Carnaby's Cockatoo - old and recent evidence of feeding on grubs from *Banksia attenuata*
39	384866	6489005	Carnaby's Cockatoo - old evidence of feeding on grubs from *Banksia attenuata*

Bennelongia Environmental Consultants

Groundwater Replenishment Scheme Stage 2: Subterranean Fauna Desktop Assessment

Prepared for:

Water Corporation

August 2016

Final Version

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Groundwater Replenishment Scheme Stage 2: Stygofauna Desktop Assessment

Bennelongia Pty Ltd
5 Bishop Street
Jolimont WA 6913

P: (08) 9285 8722
F: (08) 9285 8811
E: info@bennelongia.com.au

ACN: 124 110 167

Report Number: 280

Report Version	Prepared by	Reviewed by	Submitted to Client	
			Method	Date
Draft	Renee Young	Stuart Halse	email	17 August 2016
Final	Renee Young	Stuart Halse	email	31 August 2016

K:\Projects\B_WC03\Report\BEC_WC_03_final25viii16

EXECUTIVE SUMMARY

The Water Corporation is proposing to implement an expansion of the Groundwater Replenishment Scheme (Stage 2) including off-site recharge of the confined aquifers. Duplication of the existing Advanced Water Recycling Plant (AWRP) located at the Beenyup Wastewater Treatment Plant (WWTP) and the construction of additional water recharge and conveyance infrastructure will increase the capacity of the project to recharge on average 77 ML/day of recycled water into the Leederville and Yarragadee aquifers. The water will meet drinking water standards prior to being recharged. This report assesses the likelihood of stygofauna being present within the Leederville or Yarragadee aquifers at, or immediately adjacent to, the proposed recharge locations.

Stygofauna are animals that live in groundwater and arid areas of Western Australia are particularly rich in stygofauna. However, knowledge of the subterranean fauna of the Swan Coastal Plain is relatively limited. An unpublished review of stygofauna occurrence in the Gnangara groundwater system suggested that the more frequently recorded groups are copepods, amphipods, syncarids, ostracods and oligochaetes.

Stygofauna may occur in an array of different groundwater habitats including porous, karstic and fractured-rock aquifers, springs and the hyporheos of streams. The groundwater habitats on the Swan Coastal Plain that are likely to support stygofauna include porous alluvium and colluvium, limestone karst, springs and the hyporheos of rivers and streams. In these habitats, both lateral and vertical connectivity of fissures and voids are important for the occurrence of stygofauna. Lateral connectivity enables animals to move about underground, while vertical connectivity through to the surface enables recharge of carbon and nutrients to the stygofauna community. Stygofauna have mostly been recorded in fresh to brackish groundwater but may occur in salinities (expressed as conductivity) of up to 55,000 µS/cm. Irrespective of the prospectivity of the geology, few species and only low numbers of individuals are expected to occur where depth to the watertable is much more than 30 m.

Three regional aquifers occur in the Perth Region: the unconfined superficial aquifer; the confined Leederville aquifer; and the confined Yarragadee aquifer. The superficial aquifer is located close to the surface and is often expressed as wetlands or lakes in low lying areas of land. The Leederville and Yarragadee are mostly confined aquifers that occur much deeper, and are separated from the superficial aquifer and each other by confining materials such as clay and shale. There are small areas north of Perth (and also extensive areas off-shore) where these aquifers come to the surface. Locally, the Mirrabooka aquifer is also used for public supply and was intersected when Bore BNYP 1/07 was drilled in 2007 near near Beenyup and when the pilot hole at the northern recharge site was drilled in 2016.

The geology within the Leederville and Yarragadee aquifers is transmissive and the water is fresh (<500 mg/L TDS); thus both aquifers may provide suitable habitat for stygofauna in this local area where they are unconfined. However, stygofauna are unlikely to occur naturally at the actual point of injection of recycled water, which will be at depths of 140 – 400 m (Leederville) or ~ 1350 m (Yarragadee) and about because levels of carbon and nutrients will be very low. Farther afield, the aquifers quickly become confined with an impermeable layer between the Superficial and the Leederville aquifer (and again between the Leederville and Yarragadee aquifers). In areas where the Leederville and Yarragadee aquifers are confined there is no vertical connectivity with the surface to provide input of carbon and nutrients to the aquifers and stygofauna are very unlikely to occur.

In theory, recharge might have an impact on stygofauna if injection into the underlying Leederville and Yarragadee aquifers leads to upwards movement of the recycled water into the superficial aquifer, where stygofauna are likely to be present. However, owing to mixing of water after injection, it is considered unlikely that there would be any impact on stygofauna in the superficial aquifer from changes in water quality should upward movement of recycled water occur. Furthermore, most species in the Gnangara Mound, where the scheme will operate, appear to have ranges that extend beyond the Mound and the likely extent of any possible water quality changes.

Given that stygofauna are unlikely to occur in the vicinity of reinjection points of recycled water because injection is occurring deep in confined parts of the Leederville and Yarragadee aquifers and that the likelihood of water quality changes in the superficial aquifer appears to very low, no impact on stygofauna conservation values would be expected from Stage 2 of the Groundwater Replenishment Scheme.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Water Corporation is proposing to implement an expansion of the Groundwater Replenishment Scheme (Stage 2) including off-site recharge of the confined aquifers from which scheme water is drawn. Duplication of the existing Advanced Water Recycling Plant (AWRP) located at the Beenyup Wastewater Treatment Plant (WWTP) and the construction of additional water recharge and conveyance infrastructure will increase the capacity of the scheme to recharge into the Leederville and Yarragadee aquifers, on average, 77 ML/day of recycled water. The recycled water will meet drinking water standards.

Recharge of the confined aquifers in specific locations (Figure 1) has potential ecological benefits in aiding the recovery of some sensitive wetlands and groundwater dependent ecosystems (GDEs). The proposed recharge locations have been placed where increase in pressure within the deep aquifer as a result of injecting recycled water will result in upwards water pressure from the deeper aquifers to the superficial aquifer.

This report assesses the likelihood of stygofauna being present within the Leederville or Yarragadee aquifers at, or immediately adjacent to, the proposed recharge locations. It also examines the likelihood of recharge affecting stygofauna in the superficial aquifer but does not consider in detail whether stygofauna communities that may occur near the recharge sites. It takes account of:

- Pre-existing datasets and relevant reference materials;
- Information on the current understanding of aquifers within the Perth Metropolitan area (including conceptual models);
- Site-specific geological data derived from a pilot hole at the proposed northern recharge site; and
- The consultant's experience regarding the likely distribution of stygofauna within the confined aquifers of the Perth Metropolitan area.

2. OVERVIEW OF PERTH'S MAJOR AQUIFERS

Three regional aquifers occur in the Perth Region in the vicinity of the proposed recharge sites. These are the:

- unconfined superficial aquifer;
- confined Leederville aquifer; and
- confined Yarragadee aquifer.

The superficial aquifer is located relatively close to the ground surface and is often expressed as wetlands or lakes in low-lying parts of the landscape. The Leederville and Yarragadee aquifers are confined aquifers that occur much deeper, and are separated from the superficial aquifer and each other by confining materials such as siltstone and shale (Figure 2). Locally, the Mirrabooka aquifer is also used for public supply (Commander 2003) and was intersected when Bore BNYP 1/07 was drilled in 2007, and when the pilot hole at the northern recharge site was drilled in 2016, in addition to the three aforementioned aquifers (Rockwater 2008). Thus, the Mirrabooka aquifer is also described in this report.

2.1 Superficial Aquifer

The superficial aquifer is a complex, unconfined multilayered aquifer which extends throughout the Swan Coastal Plain, west of Gingin and the Darling Scarps. It supports a mix of ephemeral, seasonal and perennial wetlands, and in areas of urban development with shallow water tables much of it has

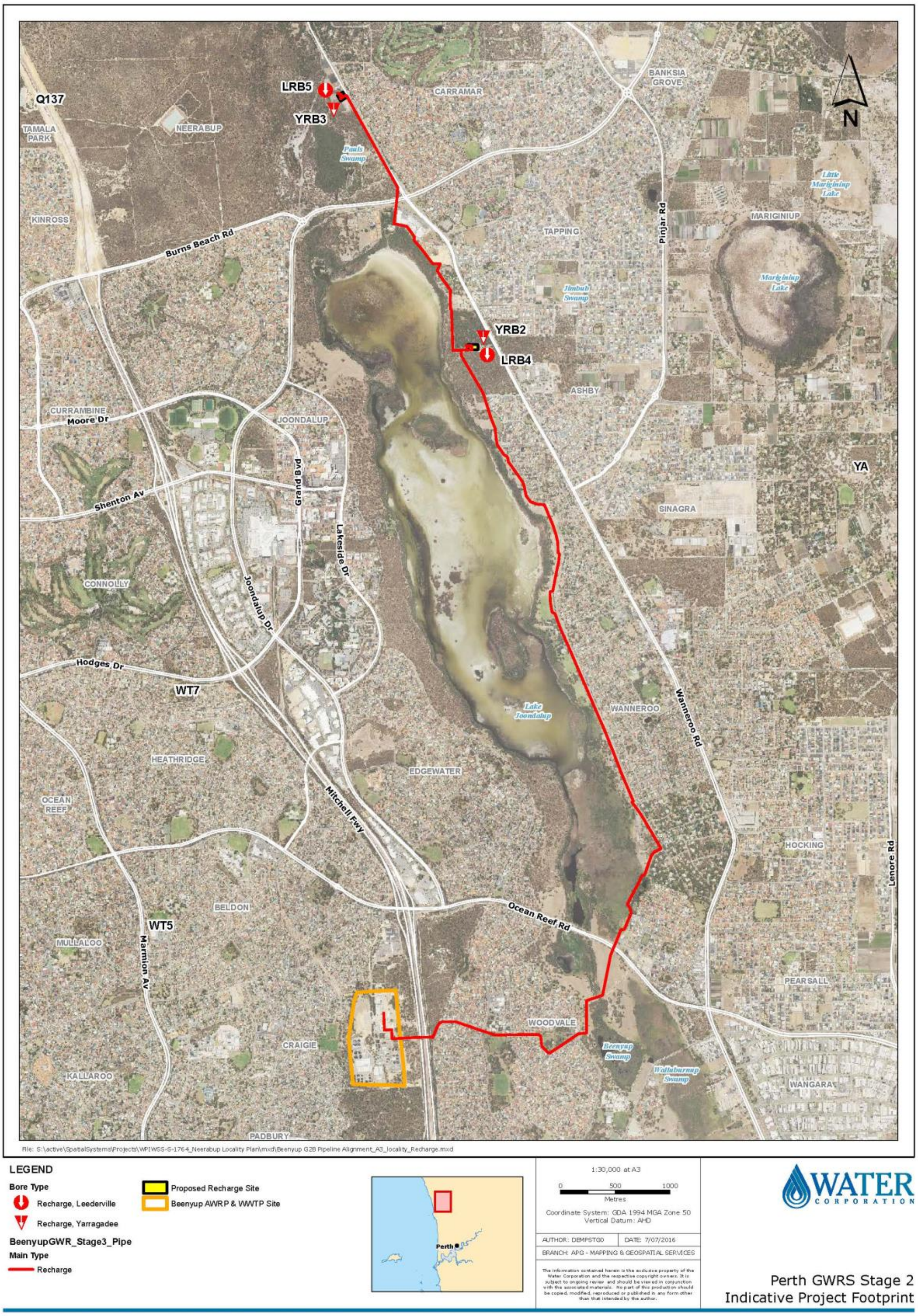


Figure 1. Perth GWRS Stage 2 Indicative Project Footprint.

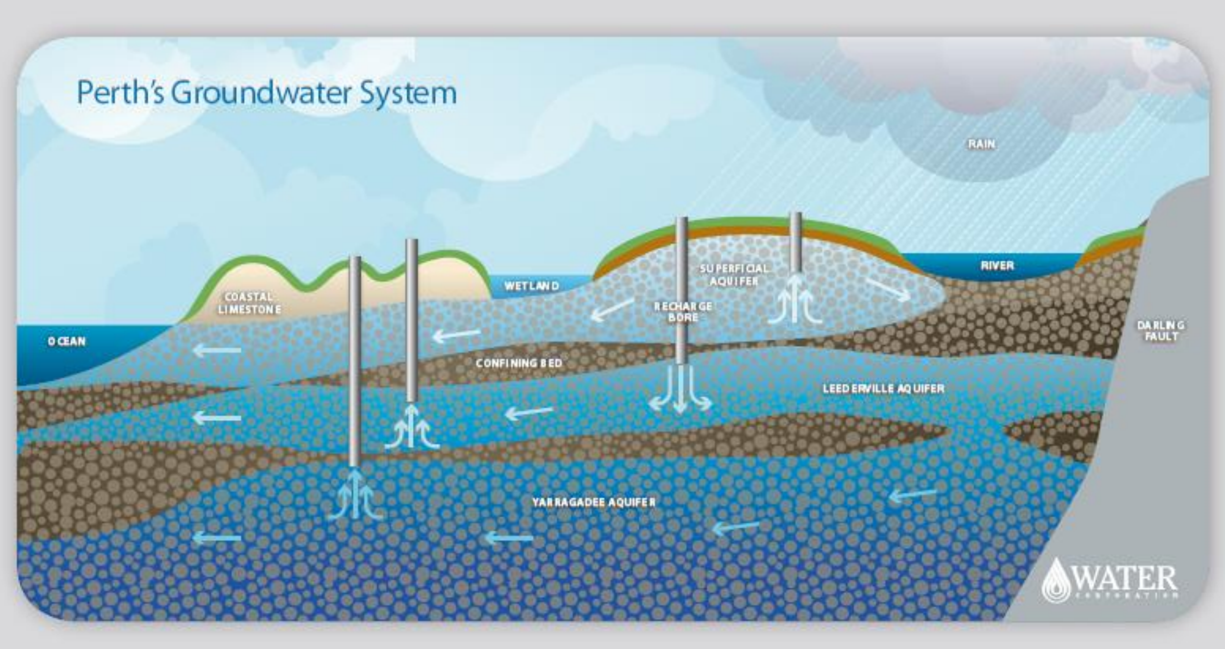


Figure 2. Schematic diagram of Perth's groundwater system (Water Corporation).

been drained (Halse 1989). The sediments which constitute the superficial aquifer range from predominantly clayey (Guildford Clay) in the east adjacent to the Darling Fault, through a sandy succession (Bassendean Sand and Gnangara Sand) in the central coastal plain area, to sand and limestone (Safety Bay Sand, Becher Sand and Tamala Limestone) within the coastal belt. The superficial aquifer has a maximum thickness of about 70 m, but average thicknesses of 45 and 20 m in the northern and southern Perth Region respectively (Davidson 1995).

Groundwater recharge occurs mostly from winter rainfall and is highest in the central and western parts of the coastal plain where the superficial formations are sandy and runoff is minimal. Seasonal water table fluctuations range from less than 0.5 m in the Tamala Limestone, 1-1.5 m in the Bassendean Sand and 3 m in the Guildford Clay, reflecting transmissivity of the sediments (Commander 2003).

The groundwater salinity is less than 250 mg/L in the Gnangara and Jandakot Mounds and typically rises to 600–800 mg/L along the coast (Davidson, 1995). Pockets of high salinity occur in groundwater discharge areas (Maddington, Serpentine Flats). Lakes Coogee, Cooloongup and Walyungup in coastal areas south of Perth are fed by groundwater and are saline.

2.2 Mirrabooka aquifer

The Mirrabooka aquifer is a semi-confined, or locally confined, aquifer that exists only in the northern Perth area. It is a predominantly sandy, major semi-confined aquifer and comprises the Poison Hill Greensand, Gingin Chalk, Molecap Greensand, and Mirrabooka Member. The extent of the Mirrabooka aquifer is quite widespread in the northern Perth area, where it is in hydraulic continuity with the superficial aquifer (Davidson 2005).

Groundwater from the Mirrabooka aquifer ranges in salinity from 130 to 350 mg/L TDS. The lowest salinity water is generally found in the recharge area and at the top of the aquifer, where it is in direct hydraulic contact with the groundwater in the superficial aquifer.

2.3 Leederville aquifer

The Leederville Aquifer is located between the superficial aquifer and the Yarragadee aquifer. While smaller than the Perth Yarragadee, it is still very large and in some areas it connects with the surface.

The Leederville aquifer is a major confined aquifer spanning the Perth Region. It overlaps the Darling Fault south of the Dandaragan Plateau and extends both north and south of the area. This aquifer is present beneath the entire coastal plain except near the Swan Estuary, where it has been eroded out prior to deposition of the Kings Park Formation, and in the southeast corner where the superficial formations rest directly on the Cattamarra Coal Measures. The Leederville aquifer is a multilayer groundwater-flow system consisting of discontinuous interbedded sandstones, siltstones and shales of the Henley Sandstone Member (Osborne Formation) and the Wanneroo and Mariginiup Members (Leederville Formation) (Davidson 2005).

The Leederville aquifer has a maximum thickness of more than 550 m in the Yanchep Syncline. In the northern part of the Swan Syncline and in the Wanneroo area it is about 500 and 400 m thick, respectively. Across the Pinjar Anticline the aquifer has a minimum thickness of about 50 m. South of Perth, the Leederville aquifer ranges in thickness from about 50 m in the southeast to about 300 m in the Jandakot area.

Groundwater salinity is less than 500 mg/L north of the Swan River and in areas near the Darling Scarp to the south east. The salinity exceeds 1,000 mg/L around the contact with the Kings Park Formation; in the eastern Swan Valley, the Kwinana Rockingham area, Serpentine, and in the Maddington area (where it is greater than 3,000 mg/L) (Davidson 2005).

The aquifer is unconfined at natural recharge locations where it directly underlies the superficial aquifer, but over short distances it becomes confined by discontinuous interbedding of siltstone and shale (Davidson 2005).

2.4 Yarragadee aquifer

The Yarragadee aquifer is a major confined aquifer, located below the Leederville aquifer and underlying the entire Perth Region and extending to the north and south within the Perth Basin. It is a multilayer aquifer, more than 2,000 m thick, consisting of interbedded sandstones, siltstones and shales of the Gage Formation, Parmelia Formation, Yarragadee Formation and Cattamarra Coal Measures. Over most of the area, the Yarragadee Formation is the major component of the aquifer, but in the northeastern and southern areas, the Parmelia Formation and the Cattamarra Coal Measures are, respectively, the major components. Only about the upper 500 m of the aquifer have been investigated by drilling (Davidson 2005).

Groundwater flow is from the north, with the addition of recharge in a comparatively small area in the north of the Gnangara Mound by leakage through the Wanneroo Member of the Leederville Formation. This recharge is low in salinity, less than 500 mg/L, and flows southwards to cross the coast between City Beach and Whitfords. Groundwater elsewhere in the aquifer is brackish, reaching over 3,000 mg/L in the Swan Valley.

3. PROJECT SITE: HYDRO-STRATIGRAPHIC SUMMARY

The results from drilling at a site near to the proposed northern reinjection location is described below and summarised in Table 1. It provides a good overview of the depths of the aquifers and geological layers.

Closest to the surface is the superficial aquifer, which is 46 m thick and consists of unconsolidated Bassendean Sand consisting of fine to coarse-grained quartz. Below this, the Mirrabooka aquifer occurs at a depth of 46 m and 108 m. It includes the Osbourne Formation and Henley Sandstone. The Osbourne Formation is comprised of two layers, an overlying sand layer comprised of fine to very coarse grained quartz and an underlying layer of sandstone that is weakly consolidated.

The Leederville Formation, which lies below the Mirrabooka aquifer, extends from 108 – 474 m and contains an upper siltstone and mudstone aquitard layer (a layer that separates aquifers and partially disconnects the flow of water) and lower sandstone and siltstone aquifer layer, both within the Wanneroo Member. Below these layers, there is approximately 30 m of siltstone and shale aquitard (in the Mariginiup Member).

The Leederville and Yarragadee Formations are separated by a 300 m thick siltstone and shale aquiclude (a layer that separates aquifers where there is zero flow) in the South Perth Shale. The Yarragadee Formation itself consists of a deep sandstone aquifer.

Groundwater salinity in the superficial and Mirrabooka aquifer in the vicinity of the drilling site is fresh and less than 500 mg/L TDS. Groundwater salinity gradually increases from about 250 mg/L at the top to about 800 mg/L TDS at the base of the Leederville aquifer.

Table 1. Hydro-Stratigraphic summary.

Average Depth (m)		Description	Stratigraphic Unit	Hydrogeology
From	To			
0	46	SAND: fine to coarse grained quartz	Bassendean Sand	Superficial
UNCOMFORMITY				
46	71	SAND: grey to pale green, fine to very course quartz with minor green staining (glauconite)	Osborne Formation	Mirrabooka Aquifer
71	81.5	SANDSTONE: greyish brown, fine to very course grained, poorly sorted, weakly consolidated		
81.5	108	SANDSTONE: grey very fine to very course grained with occasional granules, with minor clay	Henley Sandstone	
UNCOMFORMITY				
108	117	SILTSTONE: Dark grey, moderately to well consolidated, interbedded with fine to course grained sand	Leederville Formation	Wanneroo Member (Aquitard)
117	140	SILTSTONE, MUDSTONE: Dark grey to black, very well consolidate, interbedded with fine to medium grained quartz sandstone		
140	178	SANSTONE: Grey to dark grey, fine to coarse grain with some siltstone and clays.		Wanneroo Member (Aquifer)
178*	404*	SANDSTONE/SILTSTONE: fine to coarse grained quartz with some siltstone and shale beds.		
404*	474*	SILTSTONE AND SHALE		Mariginiup Member (Aquitard/Seal)
474*	776*	SILTSTONE AND SHALE	South Perth Shale	Aquiclude
>776*		SANDSTONE: light grey to grey, interbedded fine to medium grained well sorted quartz with fine to coarse grained poorly sorted beds. Few siltstone/shale beds. Garnet and heavy minerals occur throughout.	Yarragadee Formation	Yarragadee (Aquifer)

*Depths taken from PRAMS3.5 and interpretation from Beenyup lithology.

4. HYDROGEOLOGICAL MODELLING OF THE GWS

Hydrogeological modelling of the effects of GWR Stage 1 and Stage 2 which includes recharge and subsequent abstraction from new and existing assets for the Integrated Water Supply System (IWSS) was undertaken by Water Corporation in 2016. The assessment compares the net effect on the three main aquifers of the Gnangara groundwater system of recharge and abstraction of GWR Stage 1 and Stage 2 against the currently licenced IWSS Baseline abstraction plan. These effects were modelled over 30 years and Option 17 for GWR Stage 2 provides the preferred distribution of impacts relative to site specific environmental sensitivity and provides an operationally feasible option in terms of water quality, site access and IWSS capacity (see Water Corporation 2016).

The development of off-site recharge options has determined the balance of planned recharge between the Leederville and Yarragadee aquifers. This balance has evolved into the proposed recharge of 14 GL/year through a mix of two Leederville bores delivering 4 GL/year each and two Yarragadee bores delivering 3 GL/year each (Water Corporation 2016).

It is anticipated that an increase in pressure in the Leederville aquifer can help to reverse the historic de-pressurisation of the Leederville aquifer and decrease, or reverse, the existing downward vertical hydraulic gradient between the superficial and Leederville aquifers in some areas. Where the Leederville aquifer is unconfined, a significant change in vertical gradient can provide a mechanism to aid recovery of groundwater levels in the superficial aquifer. However, at the recharge sites in the Leederville aquifer some confinement of that aquifer is required to prevent the direct vertical movement of recharge water into the superficial aquifer where aquatic ecosystems might be impacted. Consequently Leederville recharge locations have been selected based on sites near where a confining layer (Wanneroo Member) pinches out to provide maximum pressure benefit but prevent direct vertical flux to the superficial aquifer (Water Corporation 2016).

5. OVERVIEW OF STYGOFAUNA AND PREFERRED HABITATS

5.1 Stygofauna

Stygofauna are animals that live in groundwater and arid Western Australia appears to be particularly rich in stygofauna. Nearly all stygofauna are invertebrates, mostly crustaceans, although stygofaunal fish have been found on around Exmouth Cape (e.g. Whitely 1945). Various terminologies have been applied to describe the relationship between stygofaunal species and groundwater. The most common scheme is that stygoxenes are surface species that use groundwater facultatively, stygophiles are species with most life stages completed in groundwater or some populations entirely dependent on groundwater, and stygobionts are obligate users of groundwater throughout their life cycle. In this document, however, all species using groundwater will be referred to as stygofauna. In general, stygofauna are characterised by the loss of eyes and skin pigmentation and the development of a vermiform body shape and more elongated appendages than surface relatives, although some species retain reduced eyes and not all have a vermiform shape.

The main concentrations of stygofauna in Western Australia appear to be in the Pilbara (Eberhard et al. 2005a, Halse et al. 2014) and the Yilgarn (Cooper et al. 2007) but they have also been found in the Kimberley (Hancock & Bennison 2005), Nullarbor and south-western Australia in lower abundance. Historically, intensive study of stygofauna in Western Australia began at Cape Range (Knott 1993) and then expanded to Barrow Island and the Pilbara before the Yilgarn was explored (see Humphreys

2001). There has been less survey effort in the South-West than in central and northern Western Australia.

A high proportion of stygofauna have restricted distributions (Gibert and Deharveng, 2002). According to Eberhard et al. (2009), about 70 % of Pilbara stygofauna species are likely to be short range endemics (SREs) as defined by Harvey (2002), with many of them having much smaller ranges than Harvey's criterion of 10,000 km^2. Species with restricted ranges are vulnerable to extinction following habitat destruction or environmental changes (Ponder and Colgan 2002; Fontaine et al. 2007).

5.1.1 Stygofauna of the Swan Coastal Plain

Knowledge of the subterranean fauna of the Swan Coastal Plain is relatively limited. An unpublished review of stygofauna occurrence in the Gnangara groundwater system suggested that the more frequently recorded groups are copepods, amphipods, syncarids, ostracods and oligochaetes (Bennelongia 2008).

More recently, Bennelongia has conducted monitoring in shallow bores at Kensington, with 59 samples collected from 12 bores over three years to 2015. Twenty-one species were collected and of these, at least 13 are true stygofauna including six copepods, three syncarids, three oligochaetes and one aphanoneuran species. The assemblage is typical of that found in alluvial/colluvial aquifers and is similar in higher-level taxonomic composition to the assemblages found in eastern Australian alluvial aquifers (Hancock and Boulton 2008). All of the species were collected at very low abundance.

The Western Australian Museum has undertaken ad-hoc stygofauna surveys of the subterranean fauna of the Swan Coastal Plain. Both unconfined (superficial) and confined (Leederville, Yarragadee) aquifers have been sampled. The surveys also revealed that stygofauna occur within the superficial aquifer but species richness is low. There were only 24 records of 11 species from a moderately extensive sampling program (Table 2) (Bennelongia 2008). The occurrence of stygofauna in the confined aquifers has not been confirmed.

Other sampling along the Swan Coastal Plain has been undertaken around the Yanchep area by Brenton Knott of the University of Western Australia, who has taken hundreds of samples to find only copepods, amphipods and a few ostracods (pers. comm. 2008). Results of other studies in the South-West are similar to those of the Museum and University, providing added confidence that the area does not support stygofauna communities as diverse as those in arid areas. Schmidt (2005) found relatively few species in groundwater associated with Marbling Brook on the eastern edge of the Darling Scarp in the Chittering catchment, 60 km north-east of Perth. The total yield from seven groundwater bores sampled 12 times was about 21 species, with most being copepods (Table 3). All animals collected were very small, with the exception of two species of amphipod, and only two of the 21 species were considered to be stygobionts. Other animals are either known, or likely to be, widespread. Another moderately diverse fauna was found on the eastern side of the Harvey Estuary, where 18 species were collected from 19 samples. All but four of the species were known to have a wider distribution than the study area (Bennelongia 2009).

With few stygobionts and extensive aquifers systems, few species on the Swan Coastal Plain would be expected to have highly restricted distributions. This has been confirmed when Swan Coastal Plain species have identified by morphological studies, with most stygobionts appearing to be wide-ranging. For example, the copepod *Kinnecaris eberhardi* has been recorded from both the Leeuwin-Naturaliste and Yanchep karsts (Tang and Knott, 2009). However, not all groups show this pattern, and regional endemism has been recorded in the worm fauna, with two congeneric species known only from Leeuwin-Naturaliste and Nambung north of Perth, respectively (Pinder *et al.* 2006). It should also be noted that taxonomic concepts are primarily based on morphology and no genetic studies have been carried out to test for cryptic speciation.

Table 2. Results of sampling in bores by the Western Australian Museum on the Swan Coastal Plain within the rectangle defined by 31° 30'S 115° 30'E and 32° 12'S 116° 00'E. Note that the number of stygobionts is uncertain but likely to be few. Data supplied by W.F. Humphreys

Taxon	No. records	Comments
Protozoa		
'Paramecium'	1	
Rotifera		
rotifer	1	few rotifers other than bdelloids are stygobionts
Oligochaeta		
Antarctodrilus WA3	1	
Enchytraeidae spp	1	usually widespread
Crustacea		
Ostracoda		
ostracod	5	prob. 2 species
Cyclopoida		
Paracyclops fimbriatus	7	=*P. chiltoni*, widespread surface species
cyclopoid	1	2nd species of cyclopoid
Harpacticoida		
harpacticoid	2	
Syncarida		
Bathynellidae	1	bathynellids usually stygobionts
Decapoda		
shrimp	1	atyid?
crustacea larvae	3	Order unknown but perhaps decapods

Table 3. Results of sampling seven groundwater bores 12 times for stygofauna at Marbling Brook (Schmidt, 2005)

Higher Taxon	No. bores present	Comments
Nematoda	6	
Oligochaeta	6	
Ostracoda	2	1+ species of candonid
Copepoda	5	4+ species of cyclopoid, 5+ of harpacticoid
Syncarida	2	2 secies, 1 bathynellid, 1 parabathynellid
Amphipoda	4	2+ species
Acariformes	6	5+ species, 4+ oribatids

5.2 Stygofauna Habitat

Stygofauna occur in an array of different groundwater habitats including porous, karstic and fractured-rock aquifers, springs and the hyporheos of streams (Eberhard *et al*. 2005). Calcrete and alluvium are typically considered to be productive habitats for stygofauna, although mafic volcanics support rich stygofauna communities compared with the moderate abundance of communities in banded iron formation (Halse *et al*. 2014). The groundwater habitats on the Swan Coastal Plain that are likely to support stygofauna includee porous alluvium and colluvium, limestone karst, springs and the hyporheos of rivers and streams.

In these habitats, both lateral and vertical connectivity of fissures and voids are important for the occurrence of stygofauna. Lateral connectivity enables animals to move about underground, while vertical connectivity through to the surface enables recharge of carbon and nutrients to the stygofauna community. There is a clear correlation between transmissivity of an aquifer and its suitability for stygofauna.

Stygofauna have mostly been recorded in fresh to brackish groundwater but may occur in salinities (expressed as conductivity) of up to 55,000 µS/cm (ca. 35,000 mg/L) (Watts and Humphreys 2006; Schulz *et al*. 2013). Apart from salinity, the physicochemical tolerance of stygofauna to different groundwater parameters, especially in the Pilbara, has been poorly defined (see Halse *et al.* 2014).

Irrespective of the prospectivity of the geology, few species and only low numbers of individuals are expected to occur where depth to the water table is much more than 30 m (Halse *et al.* 2014). Similarly few species will occur at large depths below the water table because of the attenuation of carbon and nutrient inputs with depth, so that productivity is reliant on chemosynthesis (Porter *et al*. 2009)

6. LIKELIHOOD OF IMPACT ON STYGOFAUNA

The geology within the Leederville and Yarragadee Aquifers is likely to be suitably transmissive for stygofauna and the water is fresh (<500 mg/L TDS), so that it might be considered to provide suitable habitat for stygofauna. Injection of recharge water is proposed to occur at depths of 140 m – 400 m and ~1350 m (Rockwater 2008), so that it is unlikely stygofauna will occur in the zone of recharge owing to the presence of confining layers and the attenuation of carbon and nutrient inputs with depth. Accordingly, there is unlikely to be any conservation impact on stygofauna as a direct consequence of recharge.

There might, theoretically, be an impact on stygofauna if recharge of the underlying Leederville and Yarragadee Aquifers led to upwards movement of recharged water into the superficial aquifer, where stygofauna are likely to be present. In this regard, it should be noted that recycled water is required to meet only drinking water guidelines (Water Corporation 2015), which are less stringent than ecological guidelines for parameters such as nitrogen (ANZEEC 2000). With that caveat and without detailed analysis of water flows, mixing and likely realised water quality after injection, it is considered unlikely that there will actually be an impact on stygofauna for four reasons:

- The salinity of groundwater in all aquifers and the recharge water has similar magnitude (approximately 250 – 500 mg/L in the superficial aquifer on the Gnangara Mound, 150 – 350 in the Mirrabooka aquifer, <500 in the Leederville aquifer, <500 in the Yarragadee aquifer and <600 in recharge) (Davidson 1995).
- The Leederville recharge locations have been selected such that they are where the Wanneroo Member pinches out to provide maximum pressure benefit but prevent direct vertical flux to the superficial aquifer.
- Aquatic invertebrate species in south-western Australia, including stygofauna species, have evolved in a relatively saline landscape and have relatively high salinity tolerances. The differences in salinity levels in the different aquifers and recharge water are unlikely to be ecologically meaningful below 600 mg/L (Pinder *et al*. 2005).
- Most species occurring in the superficial aquifer are likely to be relatively widespread at the scale of water management operations (about 13 km). It is likely that most stygofauna species with restricted distributions occur in association with landscape features, such as the Yanchep caves, approximately 20 km north of the scheme (Jasinska and Knott 2000), rather than in more hydrogeologically uniform parts of the Swan Coastal Plain. For example, Tang and Knott (2009) recorded 14 groundwater copepod species from the Gnangara Mound, of which only two species were restricted to the Mound: *Eucyclops edytea* which occurs in springs and caves, and *Paranitocrella bastiani* which occurs only in caves.

7. SUMMARY AND CONCLUSIONS

The Water Corporation is proposing to implement an expansion of the Groundwater Replenishment Scheme (Stage 2) including off-site recharge of the confined aquifers. Water is proposed to be reinjected to the Leederville or Yarragadee aquifers where the superficial aquifer is disconnected from the deeper aquifers, but close enough to where the deeper aquifers are unconfined and this report assesses the likelihood of stygofauna being present at, or immediately adjacent to, the proposed recharge locations.

Reinjection to the aquifer is proposed to occur at depths of 140 m – 400 m and ~1,350 m. The density of stygofauna is usually inversely proportional to depth because carbon and nutrient inputs decline with depth. In theory, there might be an impact on stygofauna if recharge of the underlying Leederville and Yarragadee aquifers leads to upwards movement of recycled water into the superficial aquifer where stygofauna are likely to occur. In practice, however, owing to mixing of recycled water with surrounding aquifer water after injection, it is considered unlikely that there will be any changes in water quality that are sufficient to impact on stygofauna in the superficial aquifer. Furthermore, most species in the Gnangara Mound, where the scheme will operate, appear to have ranges that extend beyond the Mound and any possible extent of water quality changes.

Given that stygofauna are unlikely to occur in the vicinity of reinjection points of recycled water because injection is occurring deep in confined parts of the Leederville and Yarragadee aquifers and that the likelihood of water quality changes in the superficial aquifer appears to very low, no impact on stygofauna conservation values would be expected from Stage 2 of the Groundwater Replenishment Scheme.

8. REFERENCES

ANZEEC (2000) Australian and New Zealand guidelines for fresh and marine water quality, volume 1: the guidelines. Australian and New Zealand Environment and Conservation Council, Canberra. https://www.environment.gov.au/system/files/resources/53cda9ea-7ec2-49d4-af29-d1dde09e96ef/files/nwqms-guidelines-4-vol1.pdf.

Bennelongia (2008) Literature review and monitoring program for stygofauna in the Gnangara groundwater system. Report 2008/24, Bennelongia Pty Ltd, Jolimont, 15 pp.

Bennelongia (2009) Subterranean fauna assessment at Point Grey. Report 2009/71, Bennelongia Pty Ltd, Jolimont, 15 pp.

Commander, P. (2003) Outline of the Hydrogeology of the Perth Region. *Australian Geomechanics* **30**, 33-42.

Cooper, S.J.B., Bradbury, J.H., Saint, K.M., Leys, R., Austin, A.D., and Humphreys, W.F. (2007) Subterranean archipelago in the Australian arid zone: mitochondrial DNA phylogeography of amphipods from central Western Australia. *Molecular Ecology* **16**, 1533-1544.

Davidson, W.A. (1995) Hydrogeology and Groundwater Resources of the Perth Region, Western Australia. *Western Australia Geological Survey Bulletin* **142**, 257.

Eberhard, S.M., Halse, S.A., Williams, M.R., Scanlon, M.D., Cocking, J., and Barron, H.J. (2009) Exploring the relationship between sampling efficiency and short-range endemism for groundwater fauna in the Pilbara region, Western Australia. *Freshwater Biology* **54**, 885–901.

Eberhard, S.M., Leys, R., and Adams, M. (2005) Conservation of subterranean biodiversity in Western Australia: using molecular genetics to define spatial and temporal relationships in two species of cave-dwelling Amphipoda. *Subterranean Biology* **3**, 13-27.

Folmer, O., Black, M., Hoeh, W., Lutz, R., and Vrijenoek, R. (1994). DNA primers for amplification of mitochondrial cytochrome c oxidase subunit 1 from diverse metazoan invertebrates. *Molecular Marine Biology and Biotechnology* **3**, 294–299.

Fontaine, B., Bouchet, P., Van Achterberg, K., Alonso-Zarazaga, M.A., et al. (2007) The European union's 2010 target: putting rare species in focus. *Biological Conservation* **139**, 167-185.

Gibert, J., and Deharveng, L. (2002) Subterranean ecosystems: a truncated functional biodiversity. . *BioScience* **52**, 473-481.

Halse, S.A. 1989. Wetlands of the Swan Coastal Plain - past and present. In Proceedings of the Swan Coastal Plain Groundwater Management Conference (ed. G. Lowe) pp. 105-112. Western Australian Water Resources Council, Perth.

Halse, S.A., Scanlon, M.D., Cocking, J.S., Barron, H.J., Richardson, J.B., and Eberhard, S.M. (2014) Pilbara stygofauna: deep groundwater of an arid landscape contains globally significant radiation of biodiversity. *Records of the Western Australian Museum Supplement* **78**, 443-483.

Hancock, P.J., and Boulton, A.J. (2008) Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics* **22**, 117-126.

Harvey, M.S. (2002) Short-range endemism amongst the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* **16**, 555-570.

Humphreys, W.F. (2001) Groundwater calcrete aquifers in the Australian arid zone: the context of an unfolding plethora of stygal biodiversity. *Records of the Western Australian Museum Supplement* **64**, 63-83.

Jasinska, E.J., and Knott, B., 2000. Root-driven faunas in caves. In: H Wilkens, DC Culver and WF Humphreys (Eds.), Subterranean Ecosystems. Ecosystems of the World. Elsevier, Amsterdam, pp. 287-307.

Knott, B. (1993) Stygofauna from Cape Range peninsula, Western Australia: Tethyan relicts. *Records of the Western Australian Museum Supplement* **45**, 109-127.

Pinder, A.M., Eberhard, S.M., and Humphreys, W.F. (2006) New phallodrilines (Annelida: Clitellata: Tubificidae) from Western Australian groundwater. *Zootaxa* **1304**, 31-48.

Pinder, A.M., Halse, S.A., McRae, J.M., and Shiel, R.J. (2005) Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity. *Hydrobiologia* **543**, 1-24.

Ponder, W.F., and Colgan, D.J. (2002) What makes a narrow-range taxon? Insights from Australian freshwater snails. *Invertebrate Systematics* **16**, 571-582.

Porter, M.L., Engel, A.S., Kane, T.C., and Kinkle, B.C. (2009) Productivity-diversity relationships from chemolithoautotrophically based sulfidic karst systems. *International Journal of Speleobiology* **38**, 27-40.

Rockwater (2008) Groundwater replenishment trial. Site evaluation report - aquifer assessment. Report for Water Corporation. Report No. 236.20.3/07/001i. 57.

Schmidt, S.I., 2005. Surface water/groundwater interactions and their association with sediment fauna in a Western Australian catchment., Tectum Verlag, Marlburg.

Schulz, C., Steward, A., and Prior, A. (2013) Stygofauna presence within fresh and highly saline aquifers of the border rivers region in Southern Queensland. *Proceedings of the Royal Society of Queensland* **118**, 27-35.

Tang, D., and Knott, B. (2009) Freshwater cyclopoids and harpacticoids (Crustacea: Copepoda) from the Gnangara Mound region of Western Australia. *Zootaxa* **2029**, 1-70.

Watts, C.H.S., and Humphreys, W.F. (2006) Twenty-six new Dytiscidae (Coleoptera) of the genera Limbodessus Guignot and Nirripirti Watts & Humphreys, from underground waters in Australia. *Transactions of the Royal Society of Australia* **130**, 123-185.

Water Corporation (2015) Drinking water quality: annual report 2014/15. Water Corporation, Leederville,https://www.watercorporation.com.au/-/media/files/about-us/our-performance/drinking-water-quality/annual-report-2015.pdf.

Water Corporation (2016) Perth Groundwater Replenishment Scheme Stage 2 Hydrogeological Report (modified) June 2016.

Whitely, P.G. (1945) New sharks and fishes from Western Australia. Part 2. *Australian Zoologist* **11**, 1-45.

HORIZON

HERITAGE MANAGEMENT

Preliminary Advice for the Water Corporation of an Aboriginal Heritage Survey with Whadjuk Representatives of the proposed Perth Groundwater Replenishment Project, October 2016.

OPEN INFORMATION

Disclaimer

The following information is being supplied to the Water Corporation so it can understand their requirements and responsibilities under the WA Aboriginal Heritage Act (1972) (AHA). Aboriginal sites are afforded protection under the AHA. Any impacts to Aboriginal sites without prior Section 18 consent from the Minister for Indigenous Affairs would be an offence under Section 17 of the AHA.

These preliminary results are being supplied to the Water Corporation for forward planning of any proposed development of the Perth Groundwater Replenishment (GWR) project to minimise risks to Aboriginal sites. Please note that the information contained in this Preliminary Advice would not suffice for Department of Aboriginal Affairs (DAA) regulatory approvals.

Project Background

The persistent drying climate has dwindled levels in our dams and groundwater areas. This has prompted the State Government to fast-track the groundwater replenishment expansion to bring even greater security to Perth's water supplies. On 14 July 2016, the Minister for Water announced the duplication (Stage 2) of the existing groundwater recycling plant at Beenyup to increase the capacity from 14 to 28 gigalitres per annum. As part of this duplication, additional recharge bores and a recharge pipeline connecting the Advanced Water Recycling Plant (AWRP) to the recharge bore sites will be required.

The project scope includes approximately 13km of recharge main to connect the Beenyup AWRP to the proposed recharge bores. The Water Corporation has identified a preferred pipeline route from the AWRP, along the east of Lake Joondalup to connect to the two recharge bore sites.

Whadjuk People

Horizon Heritage Management was engaged by the Water Corporation to undertake an Aboriginal Heritage Survey with Whadjuk People representatives nominated via a South West Indigenous Land Use Agreement (ILUA) and Noongar Standard Heritage Agreement (NSHA) with the South West Aboriginal Land and Sea Council (SWALSC) of the proposed Perth GWR project area in the northern suburbs of Perth, WA (see Figure 1).

Whadjuk Survey Representatives

- Nev Collard
- Cedric Jacobs
- Bella Bropho
- Kathy Penny
- Michael Blurton
- Alice Warrell
- Lalita Colbung
- Dennis Simmonds (accepted invitation but did not attend)

DAA Aboriginal Heritage Inquiry System (AHIS) Results

Horizon Heritage Management has identified only one (1) registered site within a close proximity to the proposed Perth GWR pipeline alignment.

Table 1: DAA Registered Site

DAA SITE ID	SITE TYPE	COORDINATE
3740 Lake Joondalup	Mythological, Camp, Hunting Place	384995mE 6486531mN Zone 50

Archaeological Survey

Horizon Heritage Management undertook the Archaeological survey the 8th and 9th October, 2016. The main survey objective was to physically inspect the land underlying the proposed Perth GWR project area for any cultural material, Aboriginal sites or heritage places. Horizon Heritage inspected and walked the majority of the proposed 13km long pipeline alignment. Some small areas of private property were inaccessible. No cultural material was identified during the survey and all previously identified Aboriginal Sites and Other Heritage Places are being avoided.

Ethnographic Survey / Project Consultation

Horizon Heritage Management undertook an ethnographic survey / project consultation on the 14th October, 2016. This was held at the Water Corporation's Balcatta office, where the Water Corporation made a power point presentation to the Whadjuk survey representatives of the proposed Perth GWR project. The project details were discussed and interactive satellite maps of the project area were examined. No heritage issues or concerns were raised with the project or the proposed alignment around DAA 3740 Lake Joondalup.

The Whadjuk survey representatives were supportive of the ground water aquifers being recharged with water. An invitation to physically visit the survey area was declined by all of the Whadjuk survey representatives as they felt that they knew the area in question well enough and the Water Corporation had chosen an alignment that would only impact on previously urbanised land while avoiding Lake Joondalup and thus minimising risks to Noongar heritage.

Preliminary Conclusions and Recommendations

Horizon Heritage Management makes the following preliminary conclusions and recommendations:

- No cultural material or new Aboriginal Sites or Other Heritage Places (archaeological or ethnographic) were identified during the Aboriginal heritage survey.
- The proposed Perth GWR will not impact on any Aboriginal Sites or Other Heritage Places.

Figure 1: Indicative Perth GWR Map

Jonathan Epps IACA
Consulting Arboriculturist

PO Box 1648
Fremantle WA 6959
p - 9314 5102
m - 040 222 1517
e - arboriculturist@iinet.net.au
w – www.iaca.org.au

Tanya McKenna
Environmental Consultant
Project Management
Water Corps
629 Newcastle St
LEEDERVILLE WA 6007

22 September 2016

Dear Tanya

Following a site meeting today, the following is the arboricultural advice required by your department area by area.

Area 1 – Poinciana Drive POS – Public Open Space

The entry and exit pits for the proposed HDD/microdrilling site is to be in open ground, clear of mature vegetation – see image next page, top right. The underground tunneling works will, however take place beneath an 'open woodland' type natural planting of mostly mature WA Flooded Gum – *Eucalyptus rudis,* typical of climax vegetation surrounding wetlands in the Perth metropolitan area – see image next page, top left. Other local species noted were WA Peppermint – *Agonis flexuosa* and local Wattle – *Acacia* sp.

Deep vertical roots arise from the main lateral roots, formed at the root crown area – part where the stem meets the rootplate. In such a location with an expected high natural water table on sand it is expected that such roots for the larger specimens may intrude 2m bgl. It is commonly known that 'tree roots' only extend 600mm-1m bgl. This is generally true for those roots extending out beyond the main root zone. Tree roots of most species do extend 'well out' beyond the dripline/edge of tree canopy.

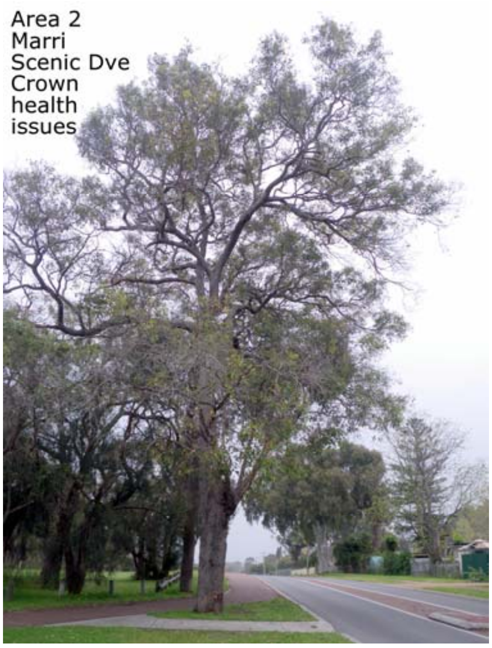
It is recommended that the proposed tunneling works be installed at least 2m bgl to top of bore in this area.

Area 2 – Corner Poinciana Drive & Scenic Drive

At this site the open trench will extend down the centre of Poinciana Drive, 2m from the edge of the kerb at Poinciana Drive. Near the corner of Scenic Drive are located three verge trees, all Marri – *Corymbia calophylla* – the dbh – diameter at breast height usually taken at 1.4m agl – of the largest tree to be impacted is 300mm dbh and 500mm, basal diameter. The calculation to determine the distance required is $(D \times 50)^{0.42} \times 0.64$ where D is the diameter of the lower stem taken just above the basal flare. This is the distance to protect the main structural roots – SRZ – Structural Root Zone – see (AS 4970 – Protection of Trees on Development Sites - 2009).

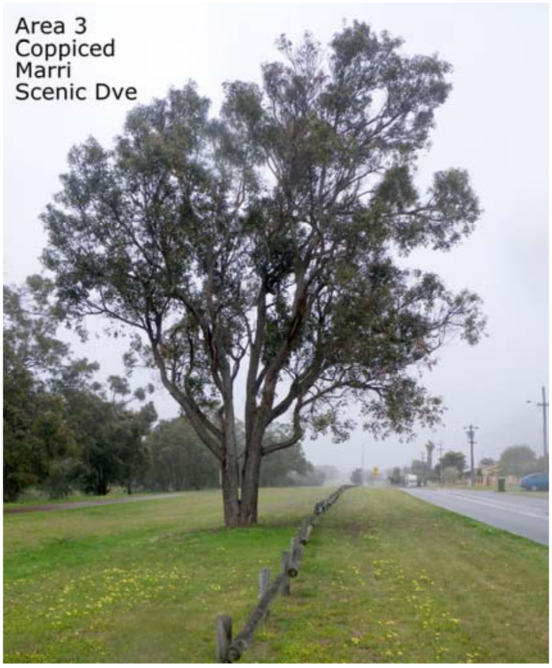
Therefore $(0.5 \times 50)^{0.42} \times 0.64 = 2.47$m. The proposed distance of the edge of the open trench will be 2m from the edge of the kerb. This distance plus the distance between the kerb and tree stems is considered to be enough to protect the structural roots of the three Marri verge trees.

At the corner of the above roads are located two more mature and older Marri specimens. The larger of the two has poor crown health – fungal canker not seen – see image below. The calculation to determine the distance is $(0.75 \times 50)^{0.42} \times 0.64 = 2.9$m. However, due to the fact that this specimen has reduced crown health it is recommeded that the horizontal distance be at least 4m.



Area 3 – Tree on Scenic Drive north of San Rosa Road

This is a single mature specimen of a Marri – see image below. This tree appears to be a re-grown coppice – multiple stems re-grown since the removal of the original single stem. The basal measurement for this tree is 1m. Therefore the horizontal distance required is $(1 \times 50)^{0.42} \times 0.64 = 3.3$m. From my professional experience, 4m would in this instance be preferable due to the fact that there appear to be some crown health issues with this paticular tree. Fungal canker, however was not seen. The small amount of Kino (red sap) noted at the bottom of the stem on the north west side appears to be from a mechanical injury, rather than exudation from canker activity.



Area 4 – Banksia Woodland

The entry and exit areas for the tunneling is again taking place in open ground – *cf* Area1. Banksia's by nature in my professional experience do not have an extensive root plate area, however Banksia are extremely vulnerable to 'Dieback'. This is a condition of contamination by fungal spores located in soil especially on machinery bought in from contaminated sites. The fungus is known as *Phytophora* sp and is common in the Perth area. It is extremely important that such machinery must be thoroughly steam cleaned and disinfected before arriving on site, and again once works have finished in this area to stop/prevent cross contamination. The recommended depth of the tunneling in this area is at least 2m bgl to top of bore.

Area 5 – Joondalup Drive Crossing into Bush Forever Site

The open trenching activity takes place alongside the southern side of Joondalup Drive. It crosses this road at 3841222.98m E – 6490260.65m S. It appears that at this location on the verge some specimens of Banksia will have to be removed. On crossing Joondalup Drive, the proposed tunneling will enter b/g a Banksia woodland which itself is already elevated 3+m above Joondalup Drive. It is still recommended that the top of the bore be 2m bgl under Joondalup Drive. The exit pit appears to take place in open ground. There appear to be no mature trees (other than Banksia) in the are of the proposed tunnel activity.

NB: In order to protect the tree crown area and complete root system under normal circumstances a calculation is made for the TPZ – Tree protection Zone – see (AS 4970 – Protection of Trees on Development Sites - 2009). This measurement is taken as 12 x dbh. In the case of Area 2 with the larger Marri, the dbh is approximately 500mm, therefore the TPZ is 12 x 0.5 = 6m. However as the proposed vertical intrusion may take place on one side of the tree only, in my professional experience 4m is the minimum horizontal distance that would be acceptable.

Please do not hesitate to contact me should you require further information and/or advice on the above.

Kind regards

Jonathan Epps

Jonathan Epps IACA
Consulting Arboriculturist
IACA Accredited Member – ACM0172003
ISA & AA Professional Member - No 1546 & 176110
Qualified Professional Tree Inspector UK 2008
Qualified Tree Risk Assessor ISA 2014

MEMBER OF
INSTITUTE OF AUSTRALIAN
IACA
CONSULTING ARBORICULTURISTS

Founding member since 2003®

Perth Groundwater Replenishment Scheme – Stage 2

Preliminary Risk Assessment Summary Report

Acknowledgement

The preparation of this document was undertaken by Debbie Reid and Vanessa Moscovis.

Appreciation is extended to Stacey Hamilton and contributors for the development of the Perth GWRS Stage 2 Treatment Process preliminary risk assessment report and Simon Higginson and contributors for the development of the Perth GWRS Stage 2 Aquifer preliminary risk assessment report.

Revision History

Version	Prepared by	Date Issued	Issued to	Comments Received
Final	V. Moscovis S. Hamilton S. Higginson	27 Sept 2016	IAWG DoW – John Connolly Susan Worley DoH - Richard Theobald Clemencia Rodriguez WC - Maria Russo	Clemencia Rodriguez Susan Worley
Rev 1	V. Moscovis S. Higginson	26 Oct 2016	IAWG and published	

Table of Contents

List of Tables

List of Figures

Acronym and Definitions

Advanced Water Recycling Plant (AWRP) means the multiple step treatment process consisting of ultrafiltration, reverse osmosis and ultraviolet disinfection required for groundwater replenishment which is designed to produce water that is as safe as drinking water.

ADWG means the Australian Drinking Water Guidelines.

AGWR Guidelines means the Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1) (2006), the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies (2008) and the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge (2009) published by the National Health and Medical Research Council.

ANZECC Guidelines means the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000a).

Beenyup facility means the Water Corporation's site in Craigie that houses the wastewater treatment and advanced water recycling plants.

Critical Control Points (CCPs) means an activity, procedure or process where control can be applied that is essential for operating the treatment process to ensure recycled water meets water quality guidelines.

Department of Environment Regulation (DER) are responsible for the protection of the environment (formerly known as the Department of Environment and Conservation).

Department of Health (DoH) are responsible for the protection of human health.

Department of Water (DoW) are responsible for the protection of water resources, including public drinking water sources.

Drinking Water means water intended primarily for human consumption, which also has other domestic uses.

Environmental Values (EVs) is the term applied to particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health.

Gigalitres (GL) one billion litres.

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

Groundwater Replenishment 1.5GL Scheme (1.5GL GWR Scheme) refers to the period the GWRT AWRP and recharge bore continued to operate after the conclusion of the GWRT.

Groundwater Replenishment Trial (GWRT) refers to the two-year operational trial completed in December 2012, which was located at the Beenyup facility and involved the design, construction, operation and monitoring of a 1.5GL Advanced Water Recycling Plant and replenishment of the confined Leederville aquifer. The Trial demonstrated that groundwater replenishment is a safe, viable and sustainable option to supplement Perth's groundwater.

Groundwater Replenishment Regulatory Framework (GWR Regulatory Framework) defines the approvals pathway required to develop, approve and provide ongoing regulation for a Groundwater Replenishment Scheme.

Groundwater Technical Reference Group (TRG) means the team of hydrogeological experts from CSIRO, Department of Water, Curtin University, Rockwater Pty Ltd and Water Corporation formed to assess the feasibility and potential hazards of GWR from available hydrogeological, water quality and geophysical data generated from the Trial and Leederville/Yarragadee investigation. This group will continue to assess Perth GWRS Stage 1 and 2 and define the required investigations/research to further inform and progress GWR.

Inherent Risk means the risk in the absence of mitigations.

Interagency Working Group (IAWG) means the group formed to apply the GWR Regulatory Framework for each GWR scheme proposed by the Water Corporation.

Limit of Reporting (LoR) The lowest limit at which the laboratory will report a quantitative result for a parameter: chemical, microbiological or radiological. Multiple LOR's may be applicable for analytes due to changes in methods.

Megalitres (ML) one million litres.

Perth Groundwater Replenishment Scheme (GWRS) refers to the Water Corporation's Groundwater Replenishment Scheme located at the Beenyup facility in Craigie.

Perth GWRS Stage 1 (Stage 1) refers to the first 14GL/yr AWRP at the Beenyup facility, recharging recycled water to three Leederville aquifer bores and one Yarragadee aquifer bore at the Beenyup facility.

Perth GWRS Stage 2 (Stage 2) refers to the second 14GL/yr AWRP at the Beenyup facility, recharging recycled water to the Leederville and the Yarragadee aquifers at two offsite recharge locations approximately 6.5km and 8.5km to the north of the Beenyup facility.

Perth Region Confined Aquifer Capacity (PRCAC) study refers to the Department of Water study investigating Perth's confined groundwater systems, with the aim to improve certainty on how much groundwater can be sustainably abstracted

Public Drinking Water Source Areas (PDWSA) are underground pollution control areas, water reserves and catchment areas that have been identified as current or future sources of drinking water.

Priority classifications are classification areas defined to manage the risk of pollution to the water source from catchment activities. Protection is mainly achieved though guided or regulated environmental risk management of land use activities.

Recharge Management Zone (RMZ) defines the minimum radial distance between the bores for recharge of recycled water and abstraction of groundwater for public drinking water supplies. Environmental values are always preserved and the recharged water becomes part of the environment beyond the RMZ boundary.

Recycled Water in the context of groundwater replenishment means water produced by the Advanced Water Recycling Plant and recharged to the confined aquifer.

Recycled Water Quality Indicators are chemicals or pathogens that best represent a larger group of chemical or microbiological hazards identified by the Recycled Water Quality Parameters.

Recycled Water Quality Parameters refer to the water quality parameters which define the requirements for recycled water to meet the drinking water quality standards, as defined by the Department of Health and set out in the WWS/GWR MoU 2014.

Residual Risk means the risk after mitigations have been applied.

Wastewater Catchment means the wastewater collection system that delivers inflows to wastewater treatment plants.

Wastewater Treatment Plant (WWTP) A treatment process which immediately precedes the Advanced Water Recycling Plant, providing secondary treatment to raw wastewater. In the context of GWRS it refers to the Beenyup WWTP, located in Craigie, Perth.

Water Quality Guidelines (WQG) has been set by the DoH in the WWS/GWR MoU 2014 or the DER licence and represents protection of human health and the Environmental Values.

WWS/GWR MoU 2014 means the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (Oct 2014).*

Executive Summary

The Water Corporation's Groundwater Replenishment Trial (GWRT) demonstrated that groundwater replenishment is a sustainable water source option for Perth. The three-year trial demonstrated the treatment process consistently and reliably produced recycled water that is compliant with water quality guidelines to protect the relevant environmental values, human health and the Department of Environment Regulation (DER) licence conditions. It also provided information to allow the regulators to assess groundwater replenishment and develop policy and regulation, and facilitated building community knowledge and support for any future groundwater replenishment schemes.

Based on the success of the GWRT, the Corporation is currently commissioning Stage 1 of the Perth Groundwater Replenishment Scheme (GWRS); a 14 gigalitres (GL) per year (yr) Advanced Water Recycling Plant (AWRP) recharging into the Yarragadee and Leederville aquifers onsite at the Beenyup facility. Recharge is expected to commence in December 2016.

In July 2016, the Minister for Water announced the expansion of the Perth GWRS, which will double the size of the scheme to approximately 28 GL/year. The Corporation is progressing planning for Stage 2 of the Perth GWRS (referred to hereafter as Stage 2), which will consist of a second, independently operated 14 GL/year AWRP co-located next to the Stage 1 AWRP and adjacent to the Beenyup Wastewater Treatment Plant (WWTP). The AWRP will have the same treatment process and will be operated by the same staff as Stage 1. Approximately 14 GL/yr of recycled water produced from Stage 2 will be recharged into the Yarragadee and Leederville aquifers at two recharge sites located north of the Beenyup facility. The recycled water will be conveyed via a 12.8 km pipeline to the recharge locations.

Following the same planning and approvals process completed for Stage 1, the Corporation will seek approval for Stage 2 in accordance with the GWR Regulatory Framework developed by the Interagency Working Group (IAWG) as an outcome of GWRT. The IAWG has defined the Environmental Values (EVs), water quality objectives and guidelines that the recycled water must meet at the point of recharge and at the boundary of the Recharge Management Zone (RMZ) relevant to Stage 2. The RMZ boundary for the Stage 2 recharge bores is a 250m radial distance from recharge, after which the recycled water becomes part of the environment.

Successful application of the GWR Regulatory Framework will ensure that there is no significant impact to the environment and human health is protected. This will be achieved by ensuring recycled water quality at the point of recharge and boundary of the RMZ meets the water quality guidelines defined to protect the EVs of the receiving environment (IAWG, 2016). The AWRP must also undergo an extensive, staged commissioning process, which requires DoH approval before recharge can commence.

The recharge and abstraction locations for Stage 2 determined collaboratively between the Department of Water (DoW) and the Corporation optimise recharge and abstraction rates and locations to maximise recovery of groundwater for public water supplies and enhanced management of the Perth groundwater system.

The Corporation utilised data from the GWRT and the operation of the 1.5GL GWR Scheme (including over 4,100 AWRP recycled water results, over 8000 operational results and 58,200 groundwater results), design of Stage 1, outcomes of additional aquifer investigations for Stage 1 and site specific aquifer investigations of the northern recharge site to inform this preliminary risk assessment of both the treatment process and aquifer response. However, it should be noted that the Stage 1 AWRP is still being commissioned and a full set of commissioning data and operational data is not yet available.

This report addresses the risks and mitigations associated with Stage 2. Two separate risk assessment workshops were undertaken on 7 September 2016:

- Treatment Process preliminary risk assessment, which included an assessment of the water quality against the water quality guidelines (hazard assessment) and potential failure modes of the treatment process (barrier assessment) across the wastewater catchment, Beenyup WWTP and AWRP to the point of recharge. It includes conveying recycled water through the pipeline to the point of recharge (via the two recharge locations).
- Aquifer preliminary risk assessment, which considered potential risks (hazards and mitigations) within Leederville and Yarragadee aquifers to the boundary of the RMZ and potential hazards to the overlying Superficial aquifer.

Both risk assessments employed the same processes and methodology used for the GWRT and Stage 1. The main difference between GWR Stage 1 and Stage 2 is that recharge of AWRP recycled water will occur at a different location (north of the Beenyup facility), thus requiring a recycled water pipeline to the two recharge sites.

The workshops were facilitated and attended by Water Corporation staff with design, construction, commissioning and operational expertise across the wastewater catchment, WWTP, AWRP, design and aquifer processes. The treatment process risk assessment was supported by an independent third party peer reviewer, while the aquifer risk assessment continues to be supported by the Groundwater Technical Reference Group (TRG), consisting of independent experts within regulation, research and industry.

Treatment Process Preliminary Risk Assessment

The Hazard risk assessment process considered 167 Recycled Water Quality Parameters that protect 123 guidelines set by the Department of Health (DoH) and defined in the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (Oct 2014)* (WWS/GWR MoU 2014).

An additional four water quality parameters were identified as part of the environment scan process and brought the number of hazards assessed to a total of 171.

The Hazard risk assessment considered 170 out of 171 inherent risks (i.e. mitigated by advanced water treatment processes) as Low. A Moderate residual risk was rated for Benzidine, which was a consequence of detection sensitivity issues and is being addressed via analytical method development.

The Barrier risk assessment considered 52 potential operational failures in the wastewater catchment, WWTP, AWRP and recycled water pipeline to the recharge bore. Two overarching project risks were identified regarding the perceived risks associated with trade waste entering the wastewater system and the risk of not meeting recycled water production targets. These were not formally assessed, as they can be effectively managed though existing robust trade waste management processes for existing and new customers and appropriate planning and operation of the WWTP and AWRP to produced target volumes.

The Barrier risk assessment resulted in 47 out of 52 residual (or mitigated) risks rated as Low, and five with residual risks rated as Moderate. The five Moderate residual risks were associated with Beenyup Ocean Outlet capacity and possible operational risks, which can be mitigated through design, commissioning, and application of the defined operational procedures. These risks will be further developed during the detailed design and commissioning phase. The risks and assumptions will be reassessed at future risk assessment review workshops.

Aquifer Preliminary Risk Assessment

The Corporation's project team and the independent experts within the Groundwater TRG and the AWRP has remained the same during GWRT, GWRS Stage 1 and GWRS Stage 2, ensuring continuity in knowledge and expertise gained in assessing risks.

The Aquifer risk assessment process was informed by extensive monitoring of the GWRT and 1.5GL GWR Scheme, aquifer characterisation at Beenyup (including mineralogy, lithology, geochemistry, microbiology, geophysics, sedimentology, and water quality analysis) and recent drilling at the northern recharge site.

The outcome of the risk assessment was that 32 out of 33 of the Leederville aquifer residual risks, 27 out of 29 of the Yarragadee aquifer residual risks and five out of five of the Superficial aquifer residual risks were rated as Low.

The remaining risk in the Leederville aquifer and two remaining risks in the Yarragadee aquifers cannot be ranked at this stage. Further characterisation of the aquifer will provide additional information to allow assessment of these three unranked risks. These risks relate to the uncertainty of the aquifer's response to high recharge rates, changes in pressure and the potential for dissolved gases to reduce bore permeability. However, the Corporation is confident that these risks will be mitigated by appropriately managing the recharge rates. The next review of risks will occur after site specific aquifer characterisation, drilling, construction and testing of the new recharge bores.

Summary

This preliminary risk assessment for the treatment process and receiving aquifer has demonstrated that there are no High or Extreme residual risks with the majority of risks mitigated to Low. The risk assessments have outlined the investigations and mitigation factors required to address six Moderate risks in the treatment process and three unranked risks in the aquifer through Stage 1 operation, design, commissioning, method development and further aquifer characterisation. The Corporation is confident that with appropriate mitigations in place:

- The treatment process will be effective at producing recycled water which meets water quality guidelines which will protect human health, the identified EVs and the licence limits set out in the 1.5GL GWR Scheme Department of Environment Regulation (DER) Licence.
- Construction of the recharge bores can be managed safely and in a way that maintains integrity of the aquifers.
- The recycled water quality at the boundary of the RMZ will meet the WQG or background groundwater quality.

The risk assessments are an iterative process with annual reviews, and more frequent reviews when required, to continually review risk mitigations to ensure all risks remain Low. The Corporation has extensive expertise and success in commissioning and operating water recycling plants such as the Kwinana Water Recycling Plant, Pilbara AWRP and the GWRT AWRP.

1 Introduction

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

GWR was trialled in Perth between November 2010 and December 2012 to assess technical feasibility, gain community support and allow the development of policy and regulation. The Groundwater Replenishment Trial (GWRT) demonstrated that advanced water treatment processes can successfully deliver a safe, reliable and sustainable water source option that adequately protects human health and environmental values (EVs).

Following completion of the GWRT, the Water Corporation continued to operate the 1.5GL Advanced Water Recycling Plant (AWRP), recharging recycled water to the Leederville aquifer.

The GWRT and 1.5GL GWR Scheme was licenced as a prescribed premise by the Department of Environment Regulation (DER) under the *Environmental Protection Act 1986,* with targets and limits set for recycled water. The Department of Health (DoH) has set performance requirements for the treatment process and water quality guidelines (WQG) for recycled water under the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (October 2014)* (WWS/GWR MoU 2014).

The 1.5GL GWR scheme ran until 2nd September 2014, at which time it was shut down to allow for construction of Stage 1. Extending the operation of the 1.5GL GWR Scheme allowed continued collection of data from the WWTP, AWRP and aquifer to inform design operation and risk assessments of future GWR schemes.

The Corporation is currently commissioning Stage 1 of the Perth Groundwater Replenishment Scheme (GWRS) (referred to hereafter as Stage 1), with recharge scheduled to commence in December 2016. Stage 1 consists of an AWRP, which will produce approximately 14 gigalitres (GL) per year (yr) of recycled water to be recharged to the Leederville and Yarragadee aquifers via recharge bores located within the Beenyup facility. Abstraction of groundwater relating to the Perth GWRS is licenced by the DoW under the *Rights in Water and Irrigation Act (1914).*

In July 2016, the Minister for Water announced the expansion of the Perth GWRS which will double the size of the scheme to approximately 28 GL/yr. The Corporation is progressing planning and approvals for Stage 2 of the Perth GWRS (referred to hereafter as Stage 2) which will consist of a second, independently operated 14 GL/yr AWRP co-located next to the Stage 1 AWRP and adjacent to the Beenyup Wastewater Treatment Plant (WWTP). The AWRP will have the same treatment process and will be operated by the same staff as Stage 1. Approximately 14 GL/yr of recycled water produced from Stage 2 will be recharged into the Yarragadee and Leederville aquifers at two recharge sites located north of the Beenyup facility. An increase to appropriately trained operational staff is expected to adequately manage and operate the Stage 1 and Stage 2 AWRPs.

Perth GWRS Stages 1 and 2 (Figure 1-1, Table 1-1,) will utilise the full current Beenyup wastewater flows and have been staged to allow flexibility to meet demand for public water supply.

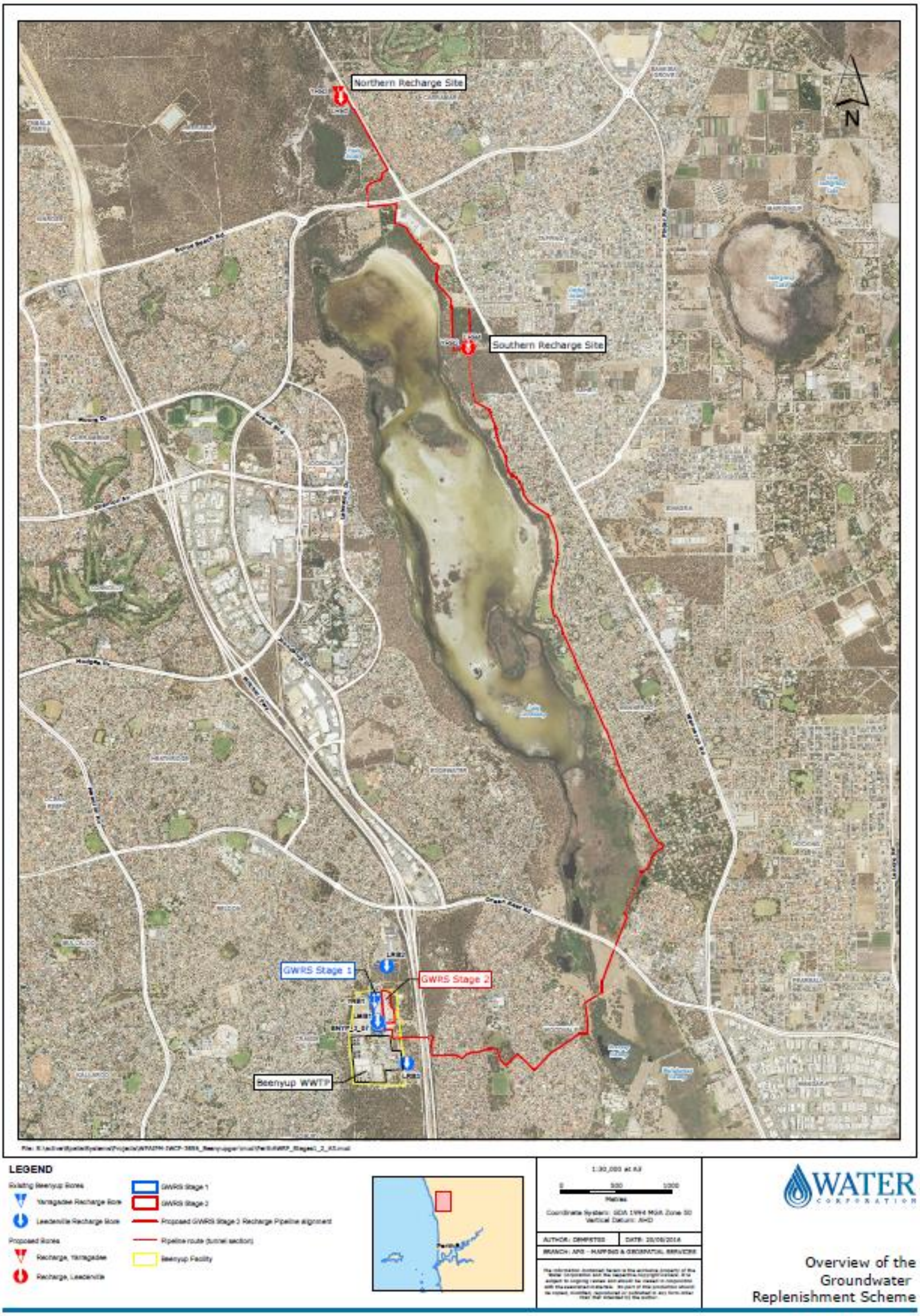
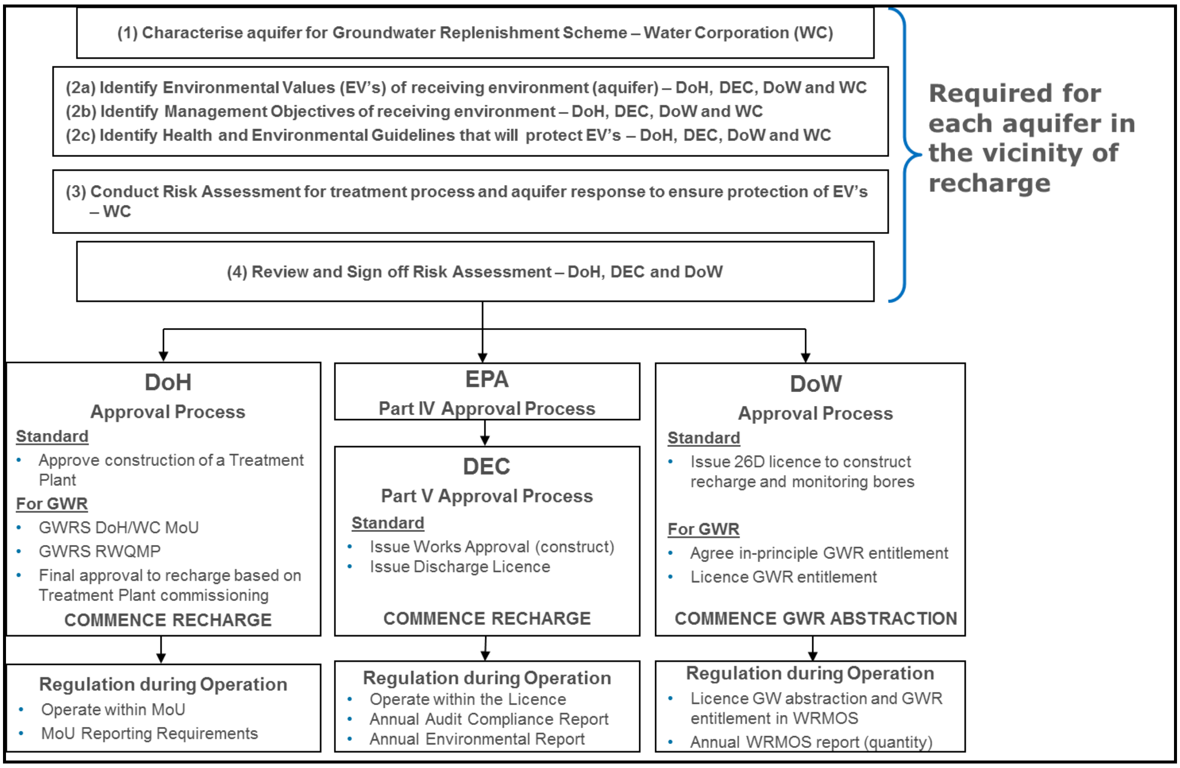


Figure 1-1: Perth GWRS Stage 1 and Stage 2

Table 1-1: Stages of the Perth GWRS

Perth GWRS	Date	Activity
Stage 1	Late 2016	Construct a 14GL/yr AWRP at the Beenyup facility. Recharge the Leederville and Yarragadee aquifers via recharge bores located at the Beenyup facility.
Stage 2	Late 2018	Construct an additional 14GL/yr AWRP at the Beenyup facility (to provide approximately 28GL of recycled water in total). Recharge the Leederville and the Yarragadee aquifers at two off-site recharge locations approximately 6.5km and 8.5km to the north of the Beenyup facility.

Following the same process as for Stage 1, the Corporation will obtain approvals for Stage 2 in accordance with the GWR Regulatory Framework (IAWG, 2012). This framework was developed in 2012 by the Interagency Working Group (IAWG) as an outcome of the GWRT and defines the approvals pathway required to develop, approve commencement of recharge and provide ongoing regulation for a groundwater replenishment scheme. An overview of the GWR Regulatory Framework (IAWG, 2012) is provided in Figure 1-2.



Note: This figure represents the version agreed in December 2012. The function performed by the DEC in 2012 is now performed by the DER.

Figure 1-2: Groundwater Replenishment Regulatory Framework

Application of the GWR Regulatory Framework requires collaboration between the Department of Health (DoH), Department of Water (DoW), Department of Environment Regulation (DER) (formerly Department of Environment and Conservation) and the Water Corporation to complete Step 2 (a-c) and Step 4. Since developing the GWR Regulatory Framework the DER has taken a different approach to assessing all projects within the applicable legislation and has chosen not to participate in this process. The DER will review the Perth GWRS Stage 2 proposal as part of the standard environmental approvals process. The IAWG has continued without the DER.

The Corporation utilised data from the GWRT, the operation of the 1.5GL GWR Scheme, investigations for Stage 1 and site specific investigations of the northern recharge site to characterise the Leederville and Yarragadee aquifers. The IAWG met on 22 August 2016 to review the aquifer characteristics and identify the relevant EVs (IAWG, 2016). Further information can be found in Section 4.

2 Purpose

The preliminary risk assessment for Stage 2 was conducted in two parts and is documented in the following reports:

- *Perth GWRS Stage 2 –Treatment Process Preliminary Risk Assessment Report*, (Water Corporation (2016d). This includes an assessment of the water quality against the WQG (Hazard risk assessment) and potential failure modes of the treatment process (Barrier risk assessment) across the wastewater catchment, Beenyup WWTP and AWRP to the point of recharge.
- *Perth GWRS Stage 2 –Aquifer Preliminary Risk Assessment Report* (Water Corporation (2016c). This considers potential hazards and mitigations within the Leederville and Yarragadee aquifers to the boundary of the Recharge Management Zone (RMZ) – a radial boundary 250m from the point of recharge – and potential hazards to the overlying Superficial aquifer.

The risk assessments identified and assessed potential risks associated with the AWRP producing up to 14 GL/yr, transferring the water to the northern and southern recharge sites and recharging to the Leederville and Yarragadee aquifers.

This report summarises the outcomes of the two risk assessments (as described in Figure 2-1) and completes Step 3 of the GWR Regulatory Framework. The risk assessment tables for the treatment process provided in Appendix 2 and for the aquifers in Appendix 3. Full preliminary risk assessment reports for the treatment process and aquifer are available on request.

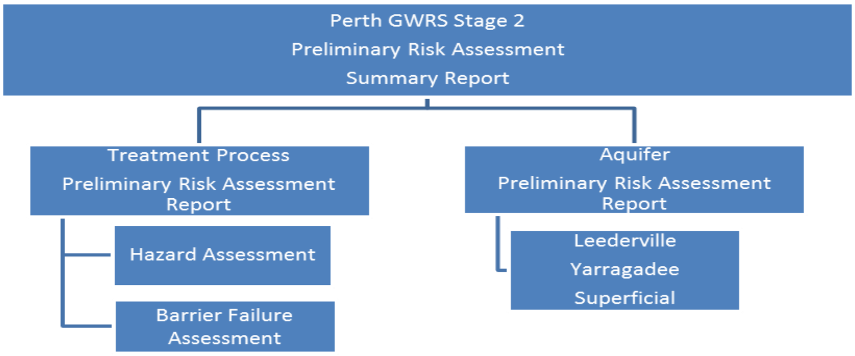


Figure 2-1: Perth GWRS Stage 2 risk assessment report structure

3 Risk Assessment Process

The Corporation ensures that the recycled water quality continuously meets water quality guidelines by applying the Wastewater Quality Framework, which adopts the risk management approach described in the *Australian Guidelines for Recycled Water: Managing Health and Environmental Risks (Phase 1)* (NRMMC-EPHC-AHMC, 2006).

Additional technical information was provided by the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies* (NRMMC-EPHC-NHRMC, 2008) and the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge* (NRMMC-EPHC- NHRMC, 2009).

The Corporation conducted the treatment process and aquifer response risk assessments separately to allow detailed discussion of the risks with the most appropriate expertise. The risk assessments followed the same process and applied Corporations' *Corporate Risk Assessment Criteria* to assess and assign risks. These criteria are provided in Appendix 1.

Each risk assessment sought to:

- assess all available information
- identify potential hazards and hazardous events
- assign an inherent risk based on the likelihood and the consequence of the hazard or hazardous event occurring
- identify mitigations to reduce the inherent risk to an acceptable level
- assign a residual risk rating
- if necessary, identify further investigation required to better assess the risk in the future.

These are the first risk assessments for Stage 2. They were prepared in accordance with the requirements of the GWR Regulatory Framework and employed the same methodology used for the GWRT and Stage 1. They will provide guidance to the Stage 2 project team, support the project referral to the Environmental Protection Authority and provide a basis for approvals from the DoH, DER and DoW as outlined in the GWR Regulatory Framework.

Both the Treatment Process and Aquifer risk assessment will be reviewed at key milestones in project development; after detailed design to validate the design, after commissioning to ensure the process performs as designed and risks remain at acceptable levels, and then regularly during the operational phase of the Scheme. There will be additional reviews if there is a change to the WQG.

Figure 3-1 illustrates the GWR risk assessment process and outlines how it is integral to the design, construction and operation of a GWR scheme.

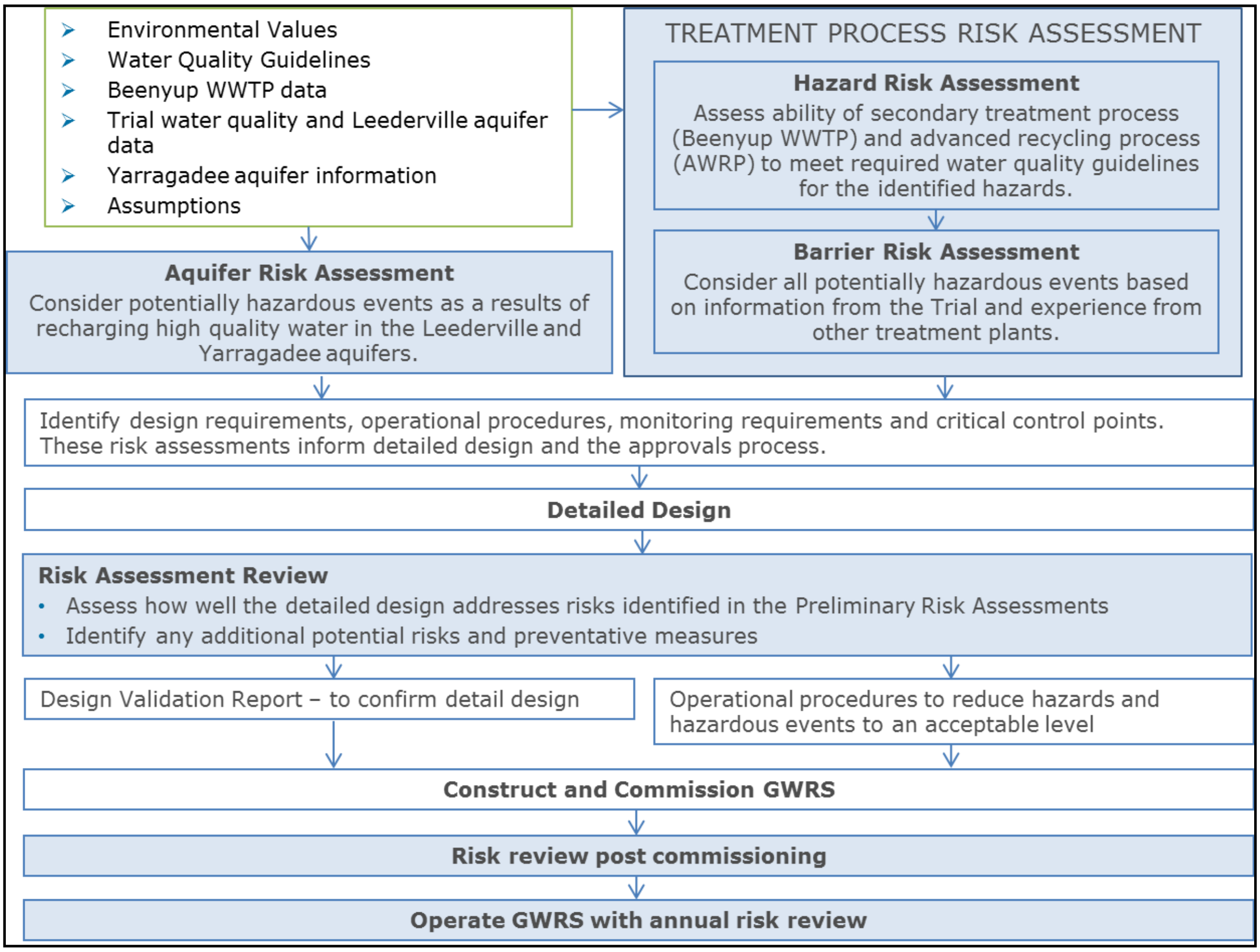


Figure 3-1: Risk Assessment Flow Chart

3.1 Treatment Process Risk Assessment Process

The Treatment Process risk assessment employed the same methodology and data as used in the Stage 1 post detailed design risk assessment (Water Corporation, 2016a).

Three planning workshops – one each for the wastewater catchment, WWTP and AWRP – were conducted prior to the main workshop to review existing hazards and identify potential new hazards. This approach allowed time for further information to be gathered prior to the main workshop.

The Treatment Process risk assessment was conducted in a half day morning workshop, facilitated by the Corporation on 7 September 2016 and attended by Water Corporation staff with design, construction, commissioning and operational expertise in industrial waste discharges, wastewater treatment, advanced water recycling treatment, as well as technical peer reviewers MWH Australia who provided technical expertise in wastewater and advanced water treatment processes.

Following the standard process, the Treatment Process risk Assessment was delivered in two parts:

- Hazard risk assessment.
- Barrier risk assessment.

3.1.1 Hazard Risk Assessment

The Hazard risk assessment assumes that the AWRP adequately treats water (mitigates hazards) to meet agreed WQG when operating under normal conditions, with trained operators following robust procedures. Hazards are considered low risk if the water that is recharged into the Leederville and/or Yarragadee aquifer meet the WQG, thus protecting human health, the identified EVs and the licence limits set out in the 1.5GL GWR Scheme DER Licence. Figure 3-2 outlines the process for undertaking a Hazard risk assessment.

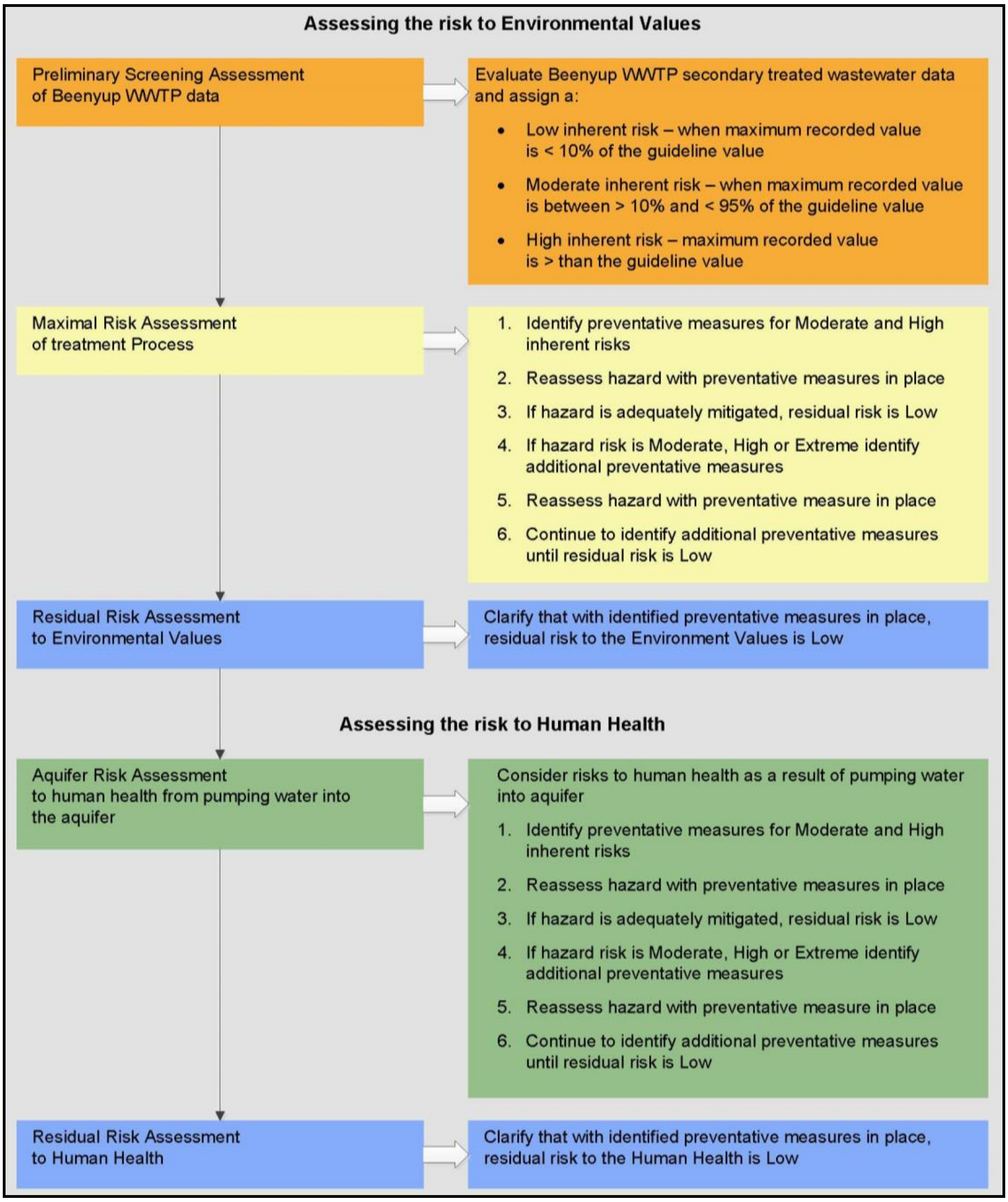


Figure 3-2: Hazard risk assessment process

Situations where the AWRP may operate outside of normal conditions were considered in the Barrier risk assessment, which is described in Section 3.1.2.

The Hazard risk assessment sought to:

- determine if the proposed AWRP design adequately mitigates the identified hazards.
- identify additional preventative measures (design or procedural) where required.
- identify where more information is needed.

It considered:

- the proposed design of the Stage 2 AWRP.
- data previously collected during the Stage 1 Treatment Process risk assessment.
- additional data gained from the GWRT, 1.5GL GWR Scheme and Beenyup WWTP since the Stage 1 risk assessment (following detailed design, held in January 2016).
- the WQG set by the DoH and defined in the WWS/GWR MoU 2014. Note these WQG have been revised from the GWRT. See Section 4.1 for details.
- additional parameters identified in the environment scan process since the Stage 1 risk assessment.
- the DER licence conditions set for the GWRT and 1.5GL GWR Scheme.

3.1.2 Barrier Risk Assessment

Barrier failures are failures in a treatment process or preventative measure (barrier) that impacts prevention or treatment of a hazard. The Barrier risk assessment identifies all potential failures (i.e. things that can go wrong) in the system from catchment to recharge – including industrial waste discharge, wastewater treatment, AWRP processes to the recharge bore, and then identifies preventative measures. Figure 3-3 describes the process used to assess barrier failures.

The Barrier risk assessment considered the detailed design of Stage 1 (assumed to be the same for Stage 2) and future operation of the AWRP and sought to:

- determine if the proposed AWRP design adequately mitigates the barrier failures identified in previous assessments.
- identify additional preventative measures (design or procedural) where required.
- identify areas where more information is needed.

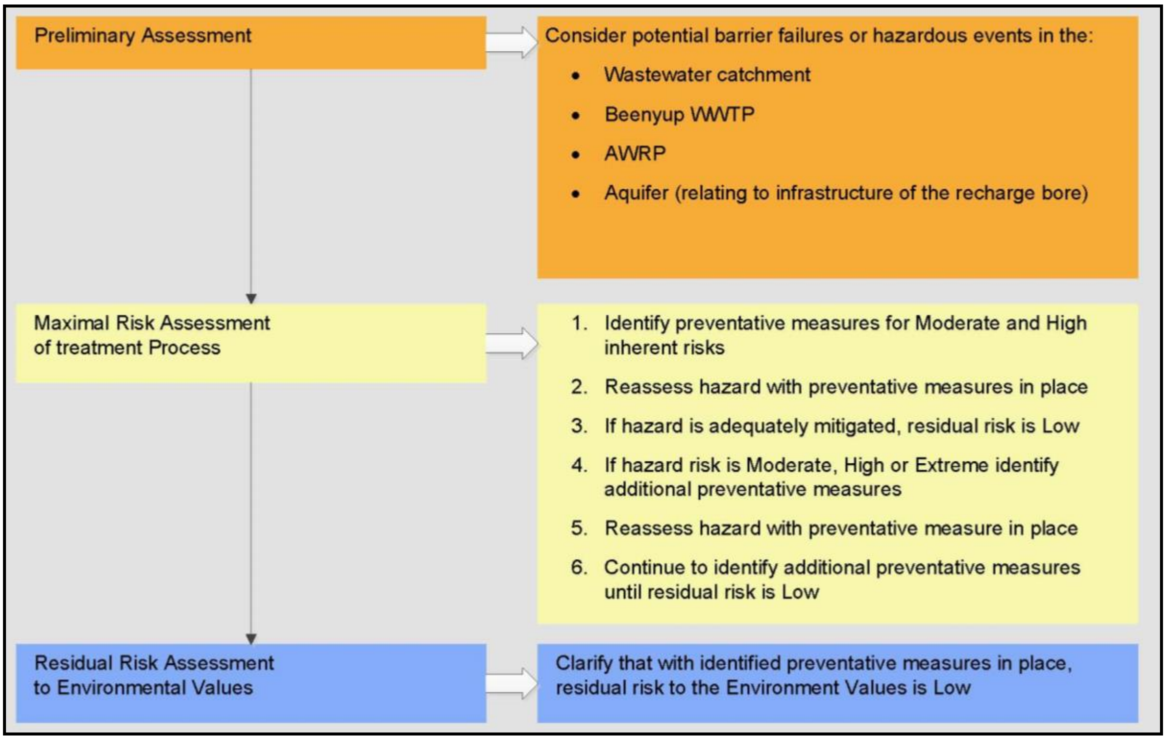


Figure 3-3: Barrier risk assessment process

3.1.3 Aquifer Risk Assessment

The Aquifer risk assessment considered any hazards that may occur as a result of recharging recycled water into the Leederville or Yarragadee aquifers, which may:

- cause an exceedance of the WQG at the boundary of the RMZ.
- affect recharge efficiency (operational consideration only, does not affect water quality).

The recharge volumes are planned to be equalised across the Leederville and Yarragadee aquifers and across the two sites (approx. 22ML/d, 7GL/yr per site). The final recharge volumes will be guided by information gathered from recharge achieved under Stage 1. However, to allow future operational flexibility, the process of identifying the EVs has taken a conservative approach by considering a maximum recharge volume of 14GL/yr to each aquifer at each site.

The process was similar to the Treatment Process risk assessment, involving two steps:

- assign an inherent risk of Low, Moderate, High or Extreme for the potential hazards based on the likelihood and consequence.
- assign a residual risk of Low, Moderate, High or Extreme for the potential hazards based on application of the mitigations identified for the:
    - Leederville aquifer based on data obtained from research and investigations, GWRT and the 1.5GL GWR Scheme.
    - Yarragadee aquifer based on research data and investigations.
    - Superficial aquifer based on modelling and DoW management of water resources.

The Aquifer risk assessment was conducted in a half day afternoon workshop, facilitated by the Corporation on 7 September 2016. Workshop participants included the Groundwater Technical Reference Group (TRG), which consists of technical specialists from the DoW, Water Corporation, CSIRO, Curtin University and hydrogeological consultants, Rockwater Pty Ltd. The Groundwater TRG has been involved with research of GWR since the start of the GWRT and has contributed extensively to the current understanding of GWR into the confined aquifers in Perth.

4 Inputs to the Risk Assessment

4.1 Environmental Values and Water Quality Guidelines

In August 2016, the IAWG identified the EVs, management objectives and WQG applicable to Stage 2. The EVs take into account the most conservative scenario (worst case) of recharging up to 14GL/year to each aquifer. This has been summarised in Table 4-1:

Table 4-1: The identified EVs, management objectives and WQG for Perth GWRS Stage 2

Environmental Value	Management Objective	Water Quality Guideline	
		Leederville aquifer	Yarragadee aquifer
Drinking Water	To maintain the water quality in the receiving aquifer to facilitate current and future use	• 17 Recycled Water Quality Indicators (RWQI) • 167 Recycled Water Quality Parameters[1] (RWQP) • 123 Water Quality Guidelines As defined in Binding Protocol 2 of the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (Oct 2014)*	
Primary Industries		• As per Drinking Water EV	
Industrial Water		• As per Drinking Water EV	
Cultural and Spiritual		• Consultation with Indigenous Community	

[1] 46 of the 167 RWQPs contribute to the calculation of "combined toxic equivalence" for Polycyclic Aromatic Hydrocarbons (PAHs) and Dioxins. Only a few of these RWQPs have relevant individual guideline values to report against.

The DoH regulates recycled water and is responsible for setting the WQG that protect the Drinking Water EVs and human health. These guidelines are also applied to the Primary Industries EV and Industrial Water EV on the assumption that human health/Drinking Water EV has the highest quality requirement, and the other two values would automatically be protected (IAWG, 2016).

The DoH set the WQG for the GWRT via the *Memorandum of Understanding between the Department of Health and Water Corporation for the Groundwater Replenishment Trial (2010)*. This original MoU had 18 Recycled Water Quality Indicators (RWQI) and 292 Recycled Water Quality Parameters (RWQPs) to be analysed to assess 254 WQG.

The AWRP was monitored extensively during the GWRT with at least six data points for each parameter collected to allow DoH to assess and refine the WQG following the GWRT. These are listed in the WWS/GWR MoU 2014 and summarised in Table 4-1.

These parameters are subject to ongoing review by the DoH, the Water Corporation, technical peer review experts and government agencies, and may be varied from time to time in accordance with strict change control processes. Changes to guidelines may be a result of, but are not limited to, amendment of the Australian Drinking Water Guidelines and Australian Guidelines for Recycled Water (from which the RWQP and RWQI are derived), assessment of emerging chemicals, perceived chemical of concern or new research, all of which are identified in the environment scan processes.

The DER licence the recharge of recycled water to the aquifer, i.e. the receiving environment under the *Environmental Protection Act (1986)*. The GWRT and 1.5GL GWR Scheme DER Licence set recycled water targets and limits for six parameters; turbidity, suspended solids, pH, total nitrogen, total phosphorus and total dissolved solids. These are intended to provide additional guidelines to the support the Primary Industry EV.

4.2 Groundwater Replenishment Trial and 1.5GL GWR Scheme

The GWRT AWRP operated between November 2010 and December 2012 under trial conditions. Following completion of the GWRT, the AWRP continued to operate as the 1.5GL GWR Scheme until September 2014. Both GWRT and the 1.5GL GWR Scheme operation provided data to assist in the evaluation of the potential risks of Stage 2. This included:

- over 4,100 recycled water quality results, providing a minimum of six data points for each of the 254 GWRT MoU parameters (hazards) used in the Hazard risk assessment.
- Critical Control Point (CCP) performance data and over 8,000 operational sampling results used in the Hazard and Barrier risk assessment.
- documentation of all technical issues that arose during design, construction and operation used in the Hazard, Barrier and Aquifer risk assessment.
- comprehensive research data from the Leederville aquifer, including over 58,200 water quality results. This data has been used in both the Leederville and Yarragadee aquifer risk assessments.
- modelling tools assessed or developed during the GRWT for use in predicting aquifer response were used in both the Leederville and Yarragadee aquifer risk assessments.

4.3 Perth GWRS Stage 1 Risk Assessment

Two Treatment Process risk assessments have been conducted for Stage 1:

- a preliminary risk assessment in 2014 to support approvals and provide direction to the incoming project team.
- a risk assessment was conducted in January 2016 following detailed design to demonstrate that the designed treatment process and operational procedures can reduce hazards to ensure recycled water meets guidelines and prevents barrier failure.

A third risk assessment is planned for early 2017 to follow the commissioning of the Stage 1, utilising commissioning data to further inform the risk assessment.

4.4 Leederville and Yarragadee Aquifer Investigations

Extensive research conducted in the Leederville aquifer as part of the GWRT provided a comprehensive understanding of aquifer processes and recharge conditions at the Beenyup facility. The information is considered to be transferable to other potential recharge locations and rates in the Leederville aquifer in the area and believed to be largely transferable to the Yarragadee aquifer.

Water Corporation and the Groundwater TRG conducted a preliminary risk assessment of the Yarragadee aquifer in August 2011 and Leederville aquifer in 2014 to define the characterisation programme required, providing additional information to allow for adequate assessment of the identified risks for the expansion to Stage 1.

This programme included:

- diamond coring of the Yarragadee and Leederville aquifers at Beenyup to assess the lithology, mineralogy, petrophysical, geochemical and reactivity characteristics.
- geophysical logging of all bores.
- site seismic surveys.
- water quality, flow, pressure and turbidity monitoring during intensive development of the recharge bores.
- step-rate and constant-rate pumping tests of each recharge bore.
- baseline water quality sampling.
- updates to analytical and numerical models.

These investigations informed the Stage 1 risk assessment, confirming that the recharge bore designs were adequate and bore construction, commissioning, operational procedures and monitoring plans would mitigate all risks to Low.

4.5 Risk Assessment Assumptions

A number of assumptions were made the Treatment Process risk assessment (see Table 4-2) and Aquifer risk assessment (Table 4-3).

Table 4-2: Treatment Process Risk Assessment Assumptions

No.	Assumption
1	The Recycled Water Quality Management Plan, WWS/GWR MoU 2014, and the Process Control Tables (including CCP locations) for the WWTP and AWRP will remain the same as Stage 1.
2	The treatment process for the AWRP will remain the same as the Stage 1 with UF, RO, degasser & UV disinfection (75 - 80% recovery for RO).
3	The same UF, RO and UV systems as the Stage 1.
4	Feed water into the AWRP will be continuous (to manage any negative impact of diurnal inflow and varying concentration loads from the WWTP).
5	The CCPs for Stage 2 are the same as Stage 1, but will operate separately to Stage 1 post the feed water compliance sampling point (SP 251). The final CCP will be located at the AWRP, with a PCP located at the recharge sites.
6	The Beenyup WWTP bypass inlet to the ocean outlet pipeline will be located downstream of the AWRP intake on the ocean outlet pipeline, with hydraulic separation between the two.
7	Beenyup WWTP will continue to have Citech control system, whereas the Stage 1 and 2 AWRP will have a SCADA control system.
8	All waste streams from the AWRP will be disposed of via the ocean outlet downstream of the inlet to the AWRP with hydraulic separation between the two, and not returned to Beenyup WWTP.
9	Water efficiency measures in the wastewater catchment may increase the nutrient load concentration of inflow into the WWTP but this should not have an impact on the treatment process of the WWTP or the AWRP.
10	The EVs and WQG will be the same as Stage 1.
11	The RMZ around the recharge bores is 250m.

Table 4-3: Aquifer Risk assessment assumptions

No.	Assumption
1	The new AWRP will have the same treatment process as the GWRT and Stage 1; therefore the same recycled water quality will be produced.
2	A final Critical Control Point will be located at the Beenyup facility – with a Process Control Point at the recharge sites.
3	Recharge will be up to an additional 14GL/yr via two Leederville sites and two Yarragadee sites.
4	Recharge rates will be incrementally stepped.
5	Monitoring bores will be screened over same interval as the recharge bores.
6	Monitoring bores will be located 50-100m from each recharge bore, representative of water quality at the boundary of the RMZ (250m).
7	The EVs and WQG will be the same as Stage 1.

5 Scheme Description

Figure 5-1 provides a conceptual overview of the Perth GWRS. Please note the schematic is not to scale, Stage 2 recharge will occur at two recharge locations to the north of the Beenyup facility.

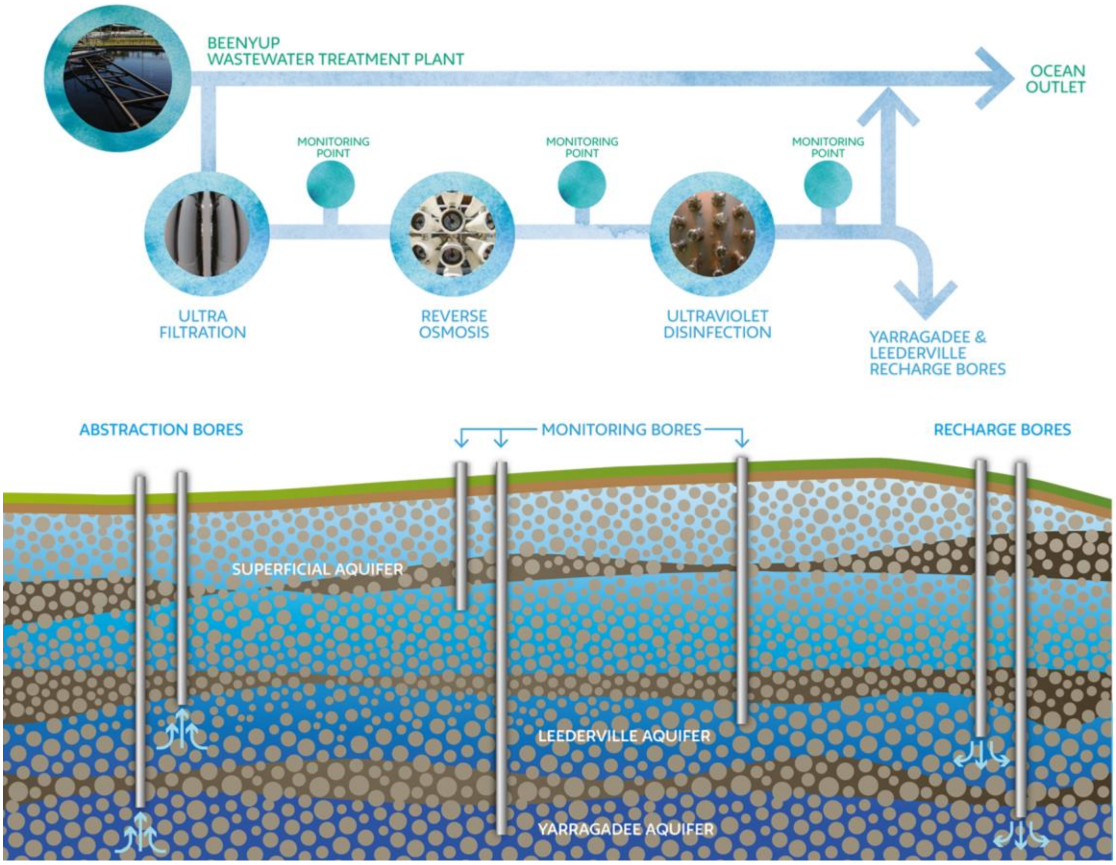


Figure 5-1: Conceptual Overview of Perth Groundwater Replenishment Scheme

The following section summarises the components of the scheme.

5.1 Source Water – Beenyup Wastewater Catchment

The majority of wastewater collected in the Beenyup wastewater catchment is sourced from households, with approximately 2% of the volume of wastewater entering Beenyup WWTP contributed by contributed by industrial and commercial businesses (defined as trade waste).

All trade waste discharges to the wastewater collection system must meet Corporation's trade waste acceptance criteria, which limit or prohibit substances that may compromise the wastewater collection and treatment infrastructure, treatment processes, reuse options, environmental discharges or health and safety of staff.

5.2 Beenyup Wastewater Treatment Plant (WWTP)

The Beenyup WWTP treats approximately 120 - 130 megalitres a day (ML/d) of wastewater to a secondary standard using an activated sludge treatment process. The main treatment process units include screens, grit removal, activated sludge aeration tanks, secondary sedimentation tanks, and sludge digestion.

5.3 Advanced Water Recycling Plant (AWRP)

The GWRT AWRP successfully demonstrated that the ultrafiltration, reverse osmosis and ultra violet disinfection treatment process sufficiently treats treated wastewater to produce recycled water that consistently meets the WQG. The same technology has been utilised in the Perth GWRS Stage 1 AWRP to produce approximately 14GL/yr (up to 44ML/day) of recycled water and will also be applied to Stage 2.

5.4 Leederville and Yarragadee Aquifers

The Leederville aquifer is a major regional aquifer composed of interbedded sandstone, siltstone and shale. The level of confinement varies regionally throughout the Swan Coastal Plain. Investigative drilling at the northern recharge site observed a low permeability hydraulic barrier consisting of predominantly dark grey siltstones and mudstones with minor very fine course grained quartz sands. The siltstone and mudstone horizons effectively confine the Leederville at this location. The Leederville aquifer recharge interval, consisting of mainly quartz sandstone, with thin siltstone and shale beds, is approximately 120-220m below ground level at Beenyup (Water Corporation, 2009), and is expected to be approximately 150-350m below ground level at the Stage 2 southern and northern recharge sites.

The Yarragadee aquifer occurs from the base of the South Perth Shale and comprises the Gage Formation and the Yarragadee Formation, consisting of alternating sandstones, siltstone and shales (Rockwater, 2013). The Yarragadee aquifer recharge interval is approximately 380-750m below ground level at Beenyup, and is expected to be approximately 1000-1200m below ground level at the Stage 2 southern and northern recharge sites.

The Department of Water led the Perth Region Confined Aquifer Capacity (PRCAC) study to improve the understanding of the Leederville and Yarragadee aquifer systems, and to ensure sustainable groundwater abstraction and recharge. The location of the Stage 2 recharge bores and abstraction bores was planned in collaboration with the DoW to provide a benefit to regional groundwater pressure, progress towards longer term environmental targets proposed by the PRCAC outcomes (DoW, 2016 in-prep), while maximising recharge and abstraction volumes for public water supply to minimise the identified impacts of abstraction. In addition, the recharge sites were chosen to meet the following criteria:

- Similar characteristics to the Beenyup site, where extensive characterisation and research has occurred.
- Available land access for the recycled water pipeline route and recharge sites (recharge bore, monitoring bore, storage tank, and pump housing).

Preliminary aquifer investigations were required at the northern recharge site to confirm the thickness of the confining layer between the Leederville and Superficial aquifers. This assessment confirmed the similarity of aquifer confinement of the proposed recharge locations to the Stage 1 recharge sites at the Beenyup facility. Drilling for core collection, petrophysical and geophysical analysis was completed in July – August 2016, allowing characterisation of the aquifer for the EV identification process (Water Corporation, 2016b).

The IAWG has identified that a RMZ for each recharge bore is a requirement of any GWR scheme. Recycled water must meet the WQG required for each EV at the point of recharge. There is potential for recycled water to have a physical or chemical reaction with the aquifer substrate or groundwater which may result in a change in water quality. A RMZ allows for these reactions to occur and the groundwater environment to return to equilibrium within the boundary of the RMZ.

Therefore, a RMZ defines the minimum distance between recharge of recycled water and abstraction of groundwater for public drinking water supplies. It also defines the boundary at which groundwater must meet the WQG required to protect the identified EVs (defined in Table 4 1). The EVs are always preserved and the recharged water becomes part of the environment beyond the RMZ boundary. Figure 5-2 provides a conceptual diagram of the RMZ.

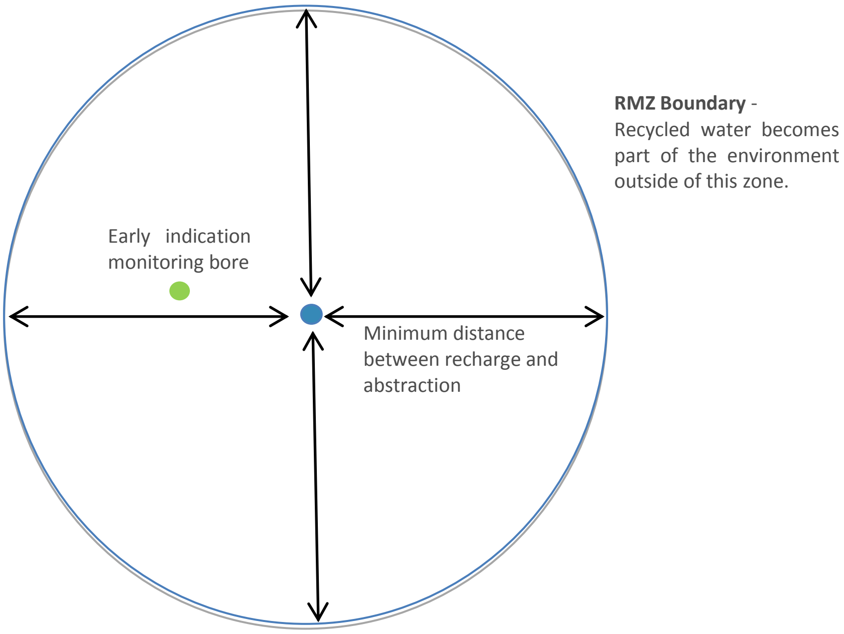


Figure 5-2: Conceptual Recharge Management Zone

The Groundwater TRG defined a RMZ for each Stage 2 recharge bore at a radial distance of 250m from the point of recharge, each with an early indication monitoring bore located between 50 to 100m from recharge (which is the same as Stage 1).

The recharge volumes are planned to be equalised across the Leederville and Yarragadee aquifers and across the two sites. However, to allow future operational flexibility the Aquifer risk assessment has taken a conservative approach and considered a maximum recharge volume of 14GL/yr to each aquifer at each site.

6 Treatment Process Risk Assessment

The following section summarises the Treatment Process risk assessment. The Hazard and Barrier risk assessment tables can be found in Appendix 2.

6.1 Hazard Risk Assessment Outcomes

The risk, that is likelihood and consequence, of all 167 RWQP (water chemical or microbiological parameters defined as hazards) exceeding the WQG (as defined in WWS/GWR MoU 2014) at the point of recharge was assessed using the process described in Section 3.1.1.

The 167 hazards were assessed within secondary treated wastewater produced by the Beenyup WWTP. Data available from the GWRT and the 1.5GL GWR Scheme allowed assessment of the WWTP's ability to reduce or remove these hazards. Preliminary screening resulted in 99 out of 167 hazards being assigned a Low risk. They were either not detected in the 1.5 GL AWRP feed water (secondary treated wastewater) or were consistently detected at less than 10% of the WQG.

An additional four parameters were identified through the Environment Scan process (methamphetamine, PFOS, PFOA and microplastics). There is no data currently available to allow assessment through the WWTP, therefore these hazards were automatically considered in the inherent risk assessment. This brought the total number of hazards assessed to 171.

The outcomes of the Preliminary screening are provided in Table 6-1.

Table 6-1: Outcomes of Hazard Assessment – Preliminary Screening

Number of Hazards	Assessment	Further action
99	Not detected or below 10% of the water quality guideline in the AWRP feedwater - assigned a Low risk rating	Not considered further
72 (68 + 4)	Above 10% of the water quality guideline in the AWRP feedwater - assigned a Moderate, High or Extreme inherent risk rating	Considered in inherent risk assessment

The remaining 72 hazards (inherent risks) were assessed to evaluate the effectiveness and efficiency of the AWRP treatment process to remove the hazard to less than the WQG (residual risk). The outcomes of the inherent and residual risk assessment for these hazards are provided in Table 6-2.

Table 6-2: Outcomes of Hazard Assessment – Inherent and Residual Risk Assessment

Stage of Assessment	Low Risk	Moderate Risk (between 10-100% of the guideline)	High Risk (> 100% of the guideline)	Extreme Risk (significantly higher than the guideline)
Inherent Risk Assessment	8 (+99)[1]	36	24	4
Residual Risk Assessment	170	1	0	0

1: Hazards which were not detected, or were below 10% of the WQG in the AWRP feedwater (as defined in Table 6-1)

An Extreme inherent risk rating was assigned to the four pathogen groups: virus, bacteria, protozoa and helminths, which are represented by the pathogen indicators; MS2 coliphage, somatic coliphage Thermotolerant coliforms (TTC) / *Escherichia coli* (*E.coli*) and *Clostridium perfringens* spores. This result is not surprising, as while some pathogen removal from the WWTP is expected (1 log), the degree of removal is not sufficient to reduce pathogens to below the WQG.

The GWRT and 1.5GL GWR Scheme has demonstrated by routine sampling of the ultrafiltration process and challenge testing of the reverse osmosis process that the AWRP is extremely effective in removing pathogens to below the water quality guidelines. The AWRP consistently met the treatment performance requirements for log reduction of pathogens resulting in a Low residual risk.

The risk assessment workshop categorised 68 inherent risks represented by existing WQG with a residual risk of Low. Water quality data for these 68 from the GWRT and the 1.5GL GWR Scheme demonstrated that the AWRP effectively removed the hazards to less than 10% of the guideline value.

There was one hazard, Benzidine that was assigned a residual risk of moderate. This assessment was due to the limitations of the Limit of Reporting (LoR) of the laboratory method, rather than confirmed presence in recycled water. The LoR for Benzidine during the GWRT and 1.5GL GWR Scheme was 1 microgram per litre (µg/L), which was three orders of magnitude higher than the DoH guideline level (0.2 ng/L). The LOR was reduced to 20 nanograms (ng/L) in October 2014 (still higher than the guideline level), and sampling at the secondary treated WWTP occurred in January/February 2015 and showed no detections at the lower LOR from six sampling events. Further method development is to be undertaken to meet the DoH guideline level. Nonetheless, the residual risk (after advanced water treatment) was assessed as Moderate, subject to review of the data at the lower LoR.

The residual risk of the four additional hazards were also assessed as Low. Methamphetamine was assigned a low risk after secondary treatment and the risk level post-AWRP treatment remained the same, as the expected removal by reverse osmosis of methamphetamine is 95%.

The other three hazards - perfluoroaoctane sulfonate (PFOS), perfluorooactanoic acid (PFOA) and microplastics were assigned a Moderate risk after secondary treatment and the risk level following AWRP treatment is reduced to Low. This is because the molecular weights of PFOS, PFOA and microplastics are higher than the molecular weight cut off of the reverse osmosis membranes and therefore, due to their size, will be rejected. Sampling of PFOS and PFOA will be conducted during six months of operation of Stage 1 to verify the removals demonstrated in a technical report provided by the Water Research Foundation (report # 4322). Sampling for microplastics will commence once an established method has been developed.

A Hazard risk assessment was also carried out against the recycled water quality targets and limits set out in the DER Licence for the GWRT and 1.5G GWR Scheme. The residual risk was assessed as Low for all parameters.

In summary, the GWRT and 1.5GL GWR Scheme have demonstrated that the AWRP consistently reduced the hazards to a Low residual risk, that is, well below the WQG defined in the WWS/GWR MoU 2014 and DER Licence, ensuring protection of human health, the identified EVs.

6.1.1 Ongoing Research and Development

The risk assessment is an iterative process, and ongoing sampling, continuous analytical method development and research occurring will re-validate the risk rating for eight of the hazards. These hazards have currently been categorised in the risk assessment based on potential impact to human health and the environment and include Benzidine, Pesticides (Flupropanate and Polihexanide), nanoparticles, methamphetamine, PFOS, PFOA and microplastics. Any new data from method development and ongoing monitoring and assessment of scientific evidence for these hazards will be evaluated at the next risk assessment review. Although data is still required to validate these hazards, expected removal efficiencies are based on initial results, scientific literature and the molecular weight of chemicals versus molecular weight performance cut off of the RO membranes. Therefore, the anticipated removal is based on robust scientific assumptions and these assumptions will be confirmed during ongoing sampling, method development and research analysis.

Microplastics sampling will commence once an established method has been developed. The Corporation is currently liaising with Water Research Australia to validate current investigations to verify the residual risk is low in collaboration with the DoH. Ongoing evaluation is occurring and microplastics will be assessed again at the next risk assessment review.

Five hazards (Tribromoacetonitrile, Tribromoacetic acid, Bromochloracetic acid, Dibromochloroacetic acid and 2-nitrophenol) are subject to method sensitivity issues, however the DoH accepts the LoR is sufficient to demonstrate safety and no further method development is required. The LoR will be reviewed annually.

6.2 Barrier Risk Assessment Outcomes

The Barrier risk assessment considered potential barrier failures within the treatment process, including the Beenyup wastewater catchment, WWTP and AWRP in addition to the delivery of AWRP recycled water via the pipeline to the recharge sites. The outcomes of the inherent and residual risk assessment are provided in Table 6-3.

Table 6-3: Outcomes of Barrier Risk Assessment

Barrier	Low Risk	Moderate Risk	High Risk	Extreme Risk
Inherent Risk Assessment				
Beenyup Catchment	6	1	0	0
WWTP	4	12	3	0
AWRP	1	2	4	0
Overarching event	2	4	3	0
Pipeline and recharge bore	9	1	0	0
Total	**22**	**20**	**10**	**0**
Residual Risk Assessment				
Beenyup Catchment	7	0	0	0
WWTP	18	1	0	0
AWRP	6	1	0	0
Overarching event	6	3	0	0
Pipeline and recharge bore	10	0	0	0
Total	**47**	**5**	**0**	**0**

Potential barrier failures included hazardous events such as:

- illegal dumping of substances into the wastewater catchment.
- events such as power loss and a reduction in the number of treatment tanks, which may compromise the effectiveness of the wastewater treatment process affecting AWRP feed water quality.
- failure of the ultrafiltration, reverse osmosis and ultra violet disinfection systems.
- integrity of the process control system.

There were 52 total risks identified during the Barrier risk assessment. Overall the inherent risk assessment identified zero Extreme risks, 10 High risks, 20 Moderate risks and 22 Low risks in total. These risks were investigated in detail with mitigation measures evaluated; they include but are not limited to:

- design
- processes and procedures (manuals)
- on-line monitoring
- automatic bypass
- automatic shutdown/divert and alarms
- trained operators
- supervision of processes and procedures
- internal and external audit
- constant review and ongoing evaluation and testing
- regulatory approval of processes and procedures
- maintenance schedules
- operating within Critical and Process Control Points
- cease recharge, emergency response plan

Through mitigation measures the residual risk evaluation resulted in 47 Low risks, five Moderate risks with zero High and Extreme risks. The five Moderate residual risks related to ocean outfall capacity, infrastructure, system integrity and operation of balance tanks. The risk assessment concluded the five Moderate residual risks would be mitigated through design, commissioning and operation, and will be continually assessed to ensure the solutions appropriately mitigate these risks.

As commissioning of the Stage 1 AWRP was in progress at the time of preparing this report, the Corporation is taking a conservative approach by maintaining a residual risk of Moderate for these five potential barrier failures. The Corporation will review this risk rating in future risk assessment reviews following monitoring and assessment of Stage 1 during a two year proving period.

7 Aquifer Risk Assessment

The following section summarises the preliminary Aquifer risk assessment. The risk assessment tables can be found in Appendix 3:.

33 potential hazards in the Leederville aquifer, and 29 potential hazards in the Yarragadee aquifer were identified and assessed. The hazards have been grouped as follows:

- risks from drilling and bore construction.
- casing/screen corrosion.
- aquifer response.
- operational (optimising bores).
- risks resulting in bore clogging or reduced aquifer permeability.
- risks to water quality guidelines at the RMZ boundary.
- risks of poor aquifer performance.
- impacts on other aquifer users.

These risks were investigated in detail with mechanisms to inform and mitigate risks including but not limited to:

- aquifer characterisation at the new recharge sites.
- natural aquifer processes within RMZ.
- ongoing verification and research monitoring and modelling.
- operational procedures.
- bore design, construction and extended development.
- clogging management.
- borefield commissioning.
- potential pH buffering of recycled water.
- Stage 1 operation and monitoring.
- consultation.

For both the Yarragadee and Leederville aquifer, there is uncertainty of the aquifer's response to high rate recharge and increase in pressures. An assessment of this risk will only be possible with operational experience; therefore the risk is identified but remains unranked in this preliminary risk assessment. Ultimately this does not pose a risk to the aquifer as the final mitigation will be to appropriately manage the recharge rates to all bores.

The risk assessment is an iterative process and it was concluded that new information and mitigation strategies were required to fully assess and mitigate the identified risks to Low. Additional geochemical modelling of the Yarragadee aquifer will be undertaken to assess if dissolved gases will reduce bore or aquifer permeability. Ongoing collation and synthesis of data will include:

- Operation of the Stage 1 to understand how the Leederville and Yarragadee aquifers will respond to recharging up to 15ML/d per bore.
- aquifer characterisation at the Stage 2 recharge sites including mineralogical, geophysical, geochemical petrophysical and hydraulic investigations, borefield commissioning and operation.

This data will be assessed by the Groundwater TRG at the next risk assessment review.

7.1 Leederville Aquifer Risk Assessment Outcome

The number of inherent and residual risks categorised by ranking for the Leederville aquifer are summarised in Table 7-1.

Table 7-1: Inherent and Residual Risk Assessment for the Leederville aquifer

Stage of Assessment	Low Risk	Moderate Risk	High Risk	Extreme Risk
Inherent Risk Assessment	19	9	5	0
Residual Risk Assessment	32	0	0	0
1 unranked residual risk – Aquifer response to high rate recharge and increase in pressures – managed and mitigated via additional information through Stage 1 GWR and aquifer characterisation				

With appropriate mitigations in place all residual risks, except one unranked risk, were assigned as Low. Details of the Moderate and High inherent risks are discussed below.

7.1.1 Risks from drilling and bore construction materials

There are a number of potential mechanisms for bore failure caused by poor construction practices resulting in a Moderate inherent risk being assigned. Mitigations such as appropriate bore design and engaging experienced and competent drilling companies can adequately manage these risks as demonstrated with previous Corporation bores. These mitigations will be applied to construction of all Corporation bores. Therefore, the residual risk was assessed as Low.

The recharge of low ionic strength recycled water could cause corrosion of the recharge bore casing and screens if inadequate materials are used in the construction. This issue resulted in a High inherent risk ranking. Well established mitigations are available, including the use of appropriate materials such as: fibre reinforced epoxy (FRP) or stainless steel casing and screens and pH adjustment of the recycled water. With these mitigations in place, the residual risk of bore corrosion is Low.

7.1.2 Risks from bore clogging or reduced aquifer permeability

Air bubbles entrained in recycled water caused by water cascading into the recharge bore may become trapped in the aquifer and plug the formation pores, resulting in reduced bore efficiency. This issue does not affect water quality, but does impact recharge efficiency as recharge must stop while the bore is being redeveloped. As a result, this potential risk was assigned an inherent risk of High. The GWRT demonstrated air-entrainment can be readily mitigated through appropriate design of the recharge bore infrastructure. Therefore, by maintaining current or a similar design and operational procedures of the Leederville recharge bores, this risk is mitigated to Low.

Microbiological clogging can occur when bacteria introduced during drilling, during bore maintenance, or indigenous bacteria, undergo increased growth due to change in conditions. Again this issue does not affect water quality, but impacts on recharge efficiency resulting in a reduction in the recharge capacity. As a result it was assigned an inherent risk of Moderate. Managing nutrient concentrations in the recycled water and applying good hygiene practices and disinfection during maintenance and drilling will reduce this risk to Low. Recharge bores will require redevelopment during the operation of the GWR Scheme, which will aim to recover any reduction in bores permeability.

With the given mitigations the workshop assessed the residual risks as Low.

7.1.3 Risks to Water Quality Guidelines at the RMZ boundary

All 58,200 groundwater quality results collected from the 22 monitoring bores (20 located within the Leederville aquifer) during the GWRT and 1.5GL GWR Scheme met WQG, indicating that the of not meeting the WQG at the boundary is Low. Aquifer characterisation to assess the mineralogy and geochemistry, with similar groundwater monitoring will occur for GWR Stage 2 bores to verify water quality issues remain Low risk.

The mobilisation of phosphorus and/or fluoride as a result of the dissolution of the naturally occurring mineral, crandallite may occur in the Leederville aquifer due to chemical reactions between the recycled water and aquifer material. This was observed during the GWRT, although phosphorus and fluoride concentrations remained below WQG[1]. GWRT data also demonstrated that phosphorus and fluoride concentrations decreased after an initial peak following breakthrough. Therefore the risk of mobilisation of phosphorus and fluoride was assigned a Moderate inherent risk due to the 'possible' likelihood of the event occurring, but given that the concentrations remained below WQG and are expected to continue to decrease after an initial peak, the residual risk was Low.

7.1.4 Risks of poor aquifer response, operation and impact to other users

There are a number of situations in which an undesired aquifer response may occur. This can include subsurface barriers (i.e. faults) or low permeability intervals, which may restrict the rate at which recycled water may be recharged. Investigations (e.g. seismic, geophysical, pumping tests) will occur through 2017 and during the construction of the new bores to determine optimal volumes that can be sustainably recharged while to protecting the aquifer, overlying confining layer and to prevent leakage of recycled water into the overlying Superficial aquifer.

Water Corporation scientists with extensive understanding of the GWR Scheme will closely monitor and optimise recharge strategies for both the Stage 1 and Stage 2 GWR to ensure the identified risks do not eventuate. Data will be presented to the Groundwater TRG at regular intervals for expert review and refinement of recharge and monitoring plans. Stage 1 GWR will commence recharge slowly during commissioning and operational strategies will be refined for Stage 2 based on operational experience from Stage 1.

With ongoing monitoring, review and refinement of recharge, including learning from Stage 1 by Water Corporation hydrogeologists, and new data from hydrogeological and geophysical investigations at the new recharge sites, and with support from the Groundwater TRG, the risks can be mitigated risk to Low.

[1] Phosphorus is not a Perth GWRS Scheme water quality guideline, however it was included on the 1.5GL AWRP DEC discharge licence. Therefore a conservative approach was taken and the risk of phosphorus not meeting the existing guideline at the RMZ boundary was considered.

7.2 Yarragadee Aquifer Risk Assessment Outcome

The number of inherent and residual risks categorised by ranking for the Yarragadee aquifer are summarised in Table 7-2.

Table 7-2: Inherent and Residual Risk Assessment for the Yarragadee aquifer

Stage of Assessment	Low Risk	Moderate Risk	High Risk	Extreme Risk
Inherent Risk Assessment	18	8	3	0
Residual Risk Assessment	27	0	0	0
2 unranked residual risks - • Aquifer response to high rate recharge and increase in pressures – managed and mitigated via additional information through Stage 1 and aquifer characterisation; • Dissolved gases reducing permeability - Modelling required to assess				

With appropriate mitigations in place all residual risks, except two unranked risk, were assigned as Low. Details of the Moderate and High inherent risks are discussed below.

7.2.1 Risks from drilling and bore construction

There are a number of potential mechanisms for bore failure caused by poor construction practices resulting in assigning a Moderate inherent risk, particularly as the Yarragadee aquifer bores will be drilled much deeper at the new recharge sites (~1200m). Mitigations such as appropriate bore design, mud and cementing programmes and engaging experienced and competent drilling companies can adequately manage these risks as demonstrated with previous deep water bore drilling. These mitigations will be applied to construction of all Water Corporation bores. Therefore the residual risk was assessed as Low.

Similar to the Leederville aquifer (see section 7.1.1), recharging low ionic strength recycled water could cause corrosion of the recharge bore screen if inadequate materials are used in construction. This has resulted in assigning an inherent risk of High. Use of appropriate construction materials and pH adjustment of the recycled water, if required, will reduce the residual risk to Low.

7.2.2 Risks resulting in bore clogging or reduced aquifer permeability

The Yarragadee aquifer has similar aquifer mineralogy to the Leederville aquifer, in particular kaolinite that can break down and release fine particles which clog up the aquifer pore spaces. This clogging does not compromise water quality, but can adversely affect recharge efficiency; consequently a moderate inherent risk was assigned. Preliminary investigations of cored material of the Yarragadee aquifer at Beenyup (for Stage 1) observed that recharge of low ionic strength recycled water can increase the potential occurrence of clogging. Mitigations that are available to reduce the risk of aquifer clogging include appropriate design of recharge bore (longer screens, large diameter to reduce exit velocities), stepped flow recharge rates, redevelopment if clogging of the recharge bore were to occur and pH adjustment of recycled water. With appropriate mitigations in place, the residual risk was assigned as Low.

Similar to the Leederville aquifer, the risk of air-entrainment during recharge caused by cascading water plugging the pores in the aquifer was identified in the Yarragadee aquifer (see section 7.1.2) and was also assigned a Moderate inherent risk due to the consequence of extended down time to redevelop the bore. This risk can be adequately mitigated by using the same design as the Leederville recharge bore, reducing the residual risk to Low.

7.2.3 Risks to Water Quality Guidelines at the RMZ boundary

Results from the Yarragadee core collected at the Beenyup site indicate similar mineralogy to the Leederville aquifer. Therefore, a similar or less reactive geochemical response to the recharge of recycled water compared to the Leederville aquifer is expected (Patterson et al., 2014).

The risk of geochemical reactions causing a change in which groundwater pH will exceed the WQG (6.0 – 8.5) was assigned a Moderate inherent risk. Reactive transport modelling for pH in the Leederville aquifer suggests that the pH will not drop below 6.2 at Beenyup. Given that the Yarragadee appears to be less reactive than the Leederville it has been assumed that a significant decrease in pH is also unlikely. Monitoring will occur in the Yarragadee aquifer to verify the water quality remains within guidelines during operation of Stage 1 and Stage 2 GWR. If any adverse water quality changes were to occur during recharge, then amending the buffering capacity (increasing alkalinity) of the recycled water will adequately mitigate the risk. Therefore, the residual risk assigned is Low.

The inherent risk of chemical mobilisation in the Yarragadee aquifer primarily due to a decrease in pH was assessed as Moderate. Geochemical experiments on the Yarragadee aquifer core indicated that the primary reactions once recycled water is recharged included oxidation of organic matter and pyrite oxidation. However, overall, the aquifer material was less reactive than the Leederville aquifer. Therefore the risk of chemical or metal mobilisation is less than the Leederville aquifer. Aquifer characterisation will occur at the new recharge sites to confirm similar mineralogy to the Beenyup facility. Natural buffering processes within the recycled water and aquifer are expected to maintain water quality within guidelines. Monitoring will occur in the Yarragadee aquifer to verify the water quality remains within guidelines during operation of Stage 1 and Stage 2 GWR. If any adverse water quality changes were to occur during recharge, then amending the buffering capacity (increasing alkalinity) of the recycled water will adequately mitigate the risk. Therefore, the residual risk assigned is Low.

7.2.4 Risks of poor aquifer response, operation and impact to other users

There are a number of situations in which an undesired aquifer response may occur. This can include subsurface barriers (i.e. faults) or low permeability intervals, which may restrict the rate at which recycled water may be recharged. Investigations (e.g. seismic, geophysical, pumping tests) will occur through 2017 and during the construction of the new bores to determine optimal volumes that can be sustainably recharged while to protecting the Yarragadeee aquifer.

Water Corporation scientists with extensive understanding of the GWR Scheme will closely monitor and optimise recharge strategies for both the Stage 1 and Stage 2 GWR to ensure the identified risks do not eventuate. Data will be presented to the Groundwater TRG at regular intervals for expert review and refinement of recharge and monitoring plans. Stage 1 GWR will commence recharge slowly during commissioning and operational strategies will be refined for Stage 2 based on operational experience from Stage 1.

With ongoing monitoring, review and refinement of recharge, including learning from Stage 1 by Water Corporation hydrogeologists, and new data from hydrogeological and geophysical investigations at the new recharge sites, and with support from the Groundwater TRG, the risks can be mitigated risk to Low.

7.3 Superficial Aquifer Risk Assessment Outcome

The Corporation has included risks on water level increases and the risk of leakage of recycled water into the Superficial aquifer through the 30m of low permeability siltstones and mudstones overlying the Leederville aquifer at the northern recharge site. Table 7-3 highlights that five risks were assessed with an inherent and mitigated risk of Low.

Table 7-3: Inherent and Residual Risk Assessment for the Superficial aquifer

Stage of Assessment	Low Risk	Moderate Risk	High Risk	Extreme Risk
Inherent Risk Assessment	5	0	0	0
Residual Risk Assessment	5	0	0	0

All five inherent risks were rated Low as hydraulically it is extremely unlikely that recycled water will move upward into the Superficial aquifer from the Leederville aquifer. This assertion is made considering the results of an investigation hole drilled at the proposed northern recharge site. That bore confirmed the presence of thick (30m) low permeability sediments between the Superficial and Leederville aquifers. Further detailed aquifer characterisation, pumping tests and modelling will occur to confirm this assertion. The DoW, as the water resource manager, will work with the Corporation on the optimisation of recharge and abstraction strategies for the overall benefit of the Perth Groundwater System.

In summary, the outcome of the Aquifer risk assessment has determined that the risks to the Leederville, Yarragadee and Superficial aquifers as a result of recharging recycled water to the confined aquifer with appropriate mitigations is Low. Further work is being undertaken to characterise and inform on all risks, including the three unranked risks.

7.4 Additional Research and Aquifer Characterisation

Additional research and aquifer characterisation will be completed during drilling at the recharge sites north of the Beenyup facility as shown in Table 7-4. This work is to confirm as the subsurface conditions are similar to at Beenyup and that the water quality monitoring programme is appropriate to demonstrate that guidelines will be met and the EVs protected.

Table 7-4: Proposed Aquifer Characterisation

Risk	Characterisation at new sites
Impact on aquatic ecosystems	• Assessment of the thickness of the confining layer to further assess vertical travel times (down hole geophysics, lithological logging, pumping test). • Surface seismic lines to assess how far until the confining layer is not present between the Leederville and Superficial aquifers.
Adverse water quality changes	• Drilling at new sites to assess mineralogical and geochemical properties to assess the risk of pH change or metal mobilisation, and similarity to Beenyup.
Increase aquifer pressures • Damage to the aquifer or confining layer	• Assessment of the thickness and permeability of the confining layer to determine the maximum tolerance to ensure recharge will not impact layer integrity. • Geophysical, petrophysical, aquifer and formation testing to assess maximum pressures the aquifer can accept.
Hydrogeological barriers • Local low permeabilities • Regional barriers	• Down hole geophysics to assess permeabilities. • Surface seismic to assess the presence/absence of faults. • Pumping tests with appropriate monitoring. • Modelling.
Drilling and construction of bores	• Appropriate drilling techniques with experienced contractors. • Detailed pre-planning and bore design. • Appropriate mud, cementing and gravel packing programme.
Reductions in permeability	• Operation of Stage 1 GWR will inform on the effectiveness of the current mitigations.

The aquifer characterisation investigations will inform site specific data interpretation and the operation of Stage 1 will further inform the risks and mitigations strategies. The next review of risks via the Groundwater TRG will occur after drilling, construction and testing at the proposed Stage 2 recharge sites.

8 Conclusion

The Corporation has commenced the approvals process for the Perth GWRS Stage 2 in accordance with the GWR Regulatory Framework.

A detailed risk assessment has been conducted for the GWR Scheme including; the wastewater catchment, WWTP, AWRP, recharge pipeline and Leederville, Yarragadee and Superficial aquifers.

The outcome of the Treatment Process preliminary risk assessment is that 171 out of 172 inherent risks (Hazard risk assessment) were rated as Low. One Moderate residual risk was rated for Benzidine as a consequence of detection sensitivity issues and is being addressed via analytical method development.

The Barrier risk assessment resulted in 47 out of 52 inherent risks rated as Low with five rated as Moderate. The five Moderate risks were associated with Beenyup Ocean Outlet capacity and operational potential risks, which will be mitigated via design solutions and commissioning, and operational procedures that will be further developed during the detailed design and commissioning phase.

The outcome of Aquifer preliminary risk assessment is that 32 out of 33 Leederville aquifer, 27 out of 29 Yarragadee aquifer and 5 out of 5 Superficial aquifer inherent risks were mitigated to Low. One unranked risk in the Leederville aquifer and two unranked risks in the Yarragadee aquifers were identified; the uncertainty of the aquifer's response to high recharge rates, including changes in pressure and bore performance and the potential for dissolved gases to reduce bore permeability.

The residual risk of all known aquifer risks was Low. Further characterisation of the aquifer will provide additional information to allow further assessment of all risks, including the three unranked risks; however, the ultimate mitigation will be to appropriately manage the recharge rates to all bores.

Therefore the location of recharge, quality of recycled water and thickness of the confining layer between the Leederville and Superficial aquifers will ensure that there is NO significant impact to the existing or future EVS, other users, the Superficial aquifer or any surface feature from activities associated with Stage 2.

The outcomes of the Treatment Process risk assessment and the Aquifer risk assessment will be used to inform further investigations, design, operation and method development to reduce all risks to Low

The next review of risks will occur after drilling, construction and testing of the new recharge sites and during detailed design, commissioning and ongoing operation.

9 References

Department of Health and Water Corporation, (2010). *Memorandum of Understanding between the Department of Health and Water Corporation for the Groundwater Replenishment Trial*. July 2010.

Department of Health and Water Corporation, (2014). *Memorandum of understanding for wastewater services and groundwater replenishment between the Department of Health and Water Corporation*. October 2014.

Department of Water, (2016 in-prep). *Perth region Leederville and Yarragadee aquifer re-interpretation report*, Hydrogeological Records serires HR363, Department of Water, Perth.

Groundwater TRG. (2012). *GWR Management Zone and Monitoring Requirements.*

InterAgency Working Group. (2012). *Groundwater Replenishment Regulatory Framework.* Perth.

InterAgency Working Group. (2013). *Perth Groundwater Replenishment Scheme - Environmental Values for the Leederville Aquifer and the Yarragadee Aquifer at the Beenyup Site.*

InterAgency Working Group. (2016). *Perth Groundwater Replenishment Scheme – Stage 2 - Environmental Values for the Leederville Aquifer and the Yarragadee Aquifer.*

NRMMC-EPHC- NHRMC. (2009). *Australian Guidelines for Water Recycling: Managed Aquifer Recharge (Phase 2)*. Natural Resources Ministerial Management Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra.

NRMMC-EPHC-AHMC. (2006). *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)*. Natural Resources Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers' Conference, Canberra.

NRMMC-EPHC-NHRMC. (2008). *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies (Phase 2)*. Natural Resources Ministerial Management Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra.

Patterson, B.M., Prommer, H., Donn, M., Torkzaban, S., Harris, B., Wendling, L., Ginige, M., (2014). *Characterisation and quantification of water quality evolution during recharge of recycled water into the Yarragadee aquifer*. October 2014, Report to the Water Corporation of Western Australia.

Rockwater. (2013). *Beenyup Groundwater Replenishment Scheme. BNYP YMB 1/12 Yarragadee monitoring bore completion report.*

Water Corporation. (2009). *Site Characterisation Report - Groundwater Replenishment Trial.*

Water Corporation. (2010). *Recycled Water Quality Management Plan Groundwater Replenishment Trial*. Western Australia.

Water Corporation. (2011). *Yarragadee Aquifer Preliminary Risk Assessment.*

Water Corporation, (2016a). *Health and Environmental Risk Assessment Report – Preliminary Assessment for Groundwater Replenishment 14 GL Plant – Stage 1.* January 2016. (Post detailed design)

Water Corporation, (2016b). *Perth Groundwater Replenishment Scheme – Stage 2 – GWR_SMB1_16 Bore Completion Report*.

Water Corporation, (2016c). *Perth Groundwater Replenishment Scheme – Stage 2 – Preliminary Aquifer Risk Assessment Report*. September 2016.

Water Corporation, (2016d). *Perth Groundwater Replenishment Scheme – Stage 2 – Preliminary Treatment Process Risk Assessment*. September 2016.

Appendix 1: Risk Assessment Criteria Tables

Consequence Rating

Rank	Financial	People & Public	Environmental	Service Interruption / Customer Impact	Reputation	Compliance	Descriptor
1	Less than $1M	Injuries or illness not requiring medical attention, or Minor first aid Injury	No lasting effect on the environment or social amenity, and/or Recovery– less than 1 week, and/or Cosmetic remediation	Brief loss of local services, and No measurable operational impact.	Low public awareness, no media coverage, possible localised impact on trust and credibility, and/or Inconsequential complaints from the community, and/or No government/ministerial involvement.	Licence or regulatory limit exceedance, informal approach with no formal action or no Regulator involvement.	**Insignificant**
2	$1M - $10M	Injury requiring medical treatment(no alternative duties), or Localised illnesses requiring medical attention	Short term or low-level long-term impact on the environment or social amenity, and/or Recovery – 1 week to several months, and/or Easy remediation	Localised operations or service interruption, and Temporary, short term service cessation (<6 hours)	Limited local media coverage, localised impact on trust and credibility with Minor Stakeholders, and/or Random substantiated complaints from the community, and/or Local member of parliament enquiry.	Non-compliance or breach of regulation – Formal direction by a Regulator or administrative / Statutory body with administrative or minor operational impacts	**Minor**
3	$10M - $100M	Middle to long term injury (able to return to work), or Long term condition, or Localised illnesses requiring hospitalisation	Long term impact on the environment or social amenity, and/or Recovery – several months to several years, and/or Challenging remediation	Wide-spread customer impacts – entire regional centre or country scheme, multiple metropolitan suburbs, and Temporary loss of operations and services (<24 hours)	Local and state-wide media coverage, impacts on trust and credibility with Minor and Major Stakeholder, and/or Coordinated communication of community concerns and complaints, and/or Parliamentary question / Ministerial directive.	Non-compliance or breach of regulation – Formal direction by a Regulator or administrative / Statutory body with threat of prosecution or localised public undertakings Loss of accreditations (e.g. Environmental, OH&S)	**Moderate**
4	$100M - $500M	Permanent disabling injuries, or Widespread illness requiring hospitalisation, or Single death	Extensive, long term impact on the environment or social amenity, and/or Recovery – several years to several decades, and/or Uncertain reversibility of remediation	Widespread degradation of operations or services, and Sustained service cessation (>24 hours)	State-wide and National media coverage, impacts on trust and credibility with Significant and Major Stakeholders, and/or Sustained community outrage, and/or Government Department Investigation.	Non-compliance or breach of regulation – Formal direction a Regulator or administrative / Statutory body with significant operational constraints/restriction and/or public undertaking Criminal / quasi-criminal charges for Water Corporation and/or personnel Loss of multiple/significant abstraction licence	**Major**
5	Greater than $500M	Multiple deaths	Significant extensive impact on the environment or social amenity, and/or Impacts are irreversible and/or permanent.	Significant widespread degradation of operations or services, and Long, sustained, loss of operations or services	Extensive National and/or some International media coverage, and/or Impacts on trust and credibility with all Corporate stakeholder categories, and/or Sustained community outrage.	Non-compliance resulting in cancellation or loss of operating licence. Loss of significant or major licence	**Catastrophic**

Likelihood Rating

Rank	Descriptor	Frequency	Description
A	Almost Certain	Will occur more than once a year Multiple times in a year	The event is expected or known to occur often
B	Likely	Once per year Once in a year or so	Known to re-occur approximately annually
C	Possible	Will occur once every 5 years Once in 5 years or multiple times over 10 years	The event should occur at some time Is sporadic, but not uncommon
D	Unlikely	Will occur once in 10 years Could occur once in 10 years or multiple times over 20 years	The event could occur at some time, usually requires combination of circumstances to occur
E	Rare	Will occur once every 30 years Once in 30 years or less frequent	The event may occur in exceptional circumstances Not likely to occur, but it's not impossible

Likelihood

Control Effectiveness Rating

Rank	Descriptor	Description
O	Optimal	The control is designed and operating effectively and consistently Improvements to the control are not feasible or are unnecessary
A	Adequate	Control is designed to be effective The control is operating effectively Errors in control application can result in isolated cases of inconsistencies Improvements should be made if feasible
I	Improvement Required	The control is not designed and/or operating effectively Improvements are required

Risk Matrix

CONSEQUENCES	LEVEL OF RISK				
5 Catastrophic	H	H	E	E	E
4 Major	M	H	H	E	E
3 Moderate	L	M	H	H	H
2 Minor	L	L	M	H	H
1 Insignificant	L	L	L	M	M
	E Rare	**D** Unlikely	**C** Possible	**B** Likely	**A** Almost Certain
	LIKELIHOOD				

Appendix 2: Treatment Process Preliminary Risk Assessment Tables

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	**Hazard/Compound**	**Description (including nature of impact on the business)**	**Consequence**	**Existing Barriers**	**Consequence**	**Likelihood**	**Risk Level**	**AWRP Barriers**	**Comments re Barrier Effectiveness**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Post Additional Mitigations**	**Consequence**	**Likelihood**	**Risk Level**
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix** - **Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
	METALS	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
1	Aluminium (Al) (Filtered)	**DoH GL = 0.2 mg/L** Feed Max = 0.039 mg/L (>10% of GL) Feed Ave = 0.022 mg/L (>10% of GL) LOR = 0.005 mg/L = <10% of GL n = 10	- neurotoxicity Drinking water contributes <2% of average daily intake	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment (Chloramination, Ultrafiltration (UF), Reverse Osmosis (RO), UV irradiation (UV), Stabilisation (Degas, NaOH)) Process & Control Point monitoring Maintain operational protocols	Max = <0.005 mg/L LOR = 0.005 mg/L = <10% of GL n = 19	O	1	E	Low		1	E	Low
2	Antimony	**DoH GL = 3 µg/L** Feed Max = 0.4 µg/L (>10% of GL) Feed Ave = 0.3 µg/L (10% of GL) LOR = 0.1 µg/L = <10% of GL n = 10	- Increase in blood cholestrol - Decreased blood sugar	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <0.1 µg/L LOR = 0.1 µg/L = <10% of GL n = 19	O	1	E	Low		1	E	Low
3	Arsenic	**DoH GL = 10 µg/L** Feed Max = <1 µg/L (<10% of GL) LOR = 1 µg/L = 10% of GL n = 10	- Skin damage - Effect on circulatory system - Potential increase of cancer risk	Secondary Treatment - Primary - Activated Sludge - Clarification	2	D	Low	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <1 µg/L LOR = 1 µg/L = 10% of GL n = 19	O	2	E	Low		2	D	Low
4	Barium (Ba)	**DoH GL = 2 mg/L** Feed Max = 190 µg/L (<10% of GL) Feed Ave = 115 µg/L (<10% of GL) LOR = 2 µg/L = <10% of GL n = 92	- Increased blood pressure - Increased risk of cardiovascular disease	Secondary Treatment - Primary - Activated Sludge - Clarification	2	D	Low	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <7 µg/L (<10% of GL) LOR = 2 µg/L = <10% of GL n = 102 Note: Only once incident of detect (i.e. <7 µg/L). Otherwise, all data (n = 101): <LOR of 2 µg/L (<10% of GL).	O	1	E	Low		1	E	Low
5	Cobalt	**DoH GL = 0.001 mg/L** Feed Max = 0.0004 mg/L (>10% of GL) Feed Ave = 0.0002 mg/L (>10% of GL) LOR = 0.0001 mg/L = 10% of GL n = 10	- Liver or kidney damage	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <0.0001 mg/L LOR = 0.0001 mg/L = 10% of GL n = 19	O	1	E	Low		1	E	Low
6	Iron (Fe)	**DoH GL (iron, unfiltered) = 0.3 mg/L** Feed Max (Filtered) = 0.075 mg/L (>10% of GL) Feed Ave (Filtered) = 0.04 mg/L (>10% of GL) LOR (Filtered) = 0.005 mg/L = <10% of GL n (Filtered) = 92 Feed Max (Unfiltered) = 0.14 mg/L (>10% of GL) Feed Ave (Unfiltered) = 0.04 mg/L (>10% of GL) LOR (Unfiltered) = 0.01 mg/L = <10% of GL n (Unfiltered) = 92	GL set for taste threshold, GW does often exceed GL and GWTP can easily remove	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max (Unfiltered) = 0.01 mg/L LOR (Unfiltered) = 0.01 mg/L = <10% of GL n (Unfiltered) = 102	O	1	E	Low		1	E	Low
7	Lead (Pb)	**DoH GL = 0.01 mg/L** Feed Max (Filtered) = 0.0011 mg/L (>10% of GL) Feed Ave (Filtered) = 0.0007 mg/L (<10% of GL) LOR (Filtered) = 0.0001 mg/L = <10% of GL n (Filtered) = 10 Feed Max (Unfiltered) = 0.0016 mg/L (>10% of GL) Feed Ave (Unfiltered) = 0.0009 mg/L (<10% of GL) LOR (Unfiltered) = 0.0005 mg/L = <10% of GL n (Unfiltered) = 8	- Impact on physical and mental development (children) - Impacy kidney function - Increased blood pressure	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max (Filtered) = <0.0001 mg/L LOR(Filtered) = 0.0001 mg/L = <10% of GL n (Filtered) = 19 Max (Unfiltered) = 0.002 mg/L >10% of GL LOR (Unfiltered) = 0.0005 mg/L = <10% of GL n (Unfiltered) = 17	O	2	E	Low	Metals for the Product Water Post Tank samples in MoU review are to be measured as filtered as per brieing note # 9790557.	1	E	Low
8	Nickel (Ni)	**DoH GL = 20 µg/L** Feed Max = 3 µg/L (>10% of GL) Feed Ave = 1.5 µg/L (<10% of GL) LOR = 1 µg/L = <10% of GL n = 10	- kidney & blood disorders at high concentrations	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <1 µg/L LOR = 1 µg/L = <10% of GL n = 19	O	1	E	Low		1	E	Low
	PESTICIDES	**Based on Max conc. In 2ndry WW**							**Based on Max In Treated Water**								
9	Simazine	**DoH GL = 20 µg/L** Commissioning Feed Max = 110 µg/L (>DoH GL) Max During Recharge = 6.5 µg/L (>10% of GL) Feed Median = 0.1 µg/L (<10% of GL) LOR (n = 7) = 1 µg/L = <10% of GL; LOR (n = 35) = 0.1 µg/L = <10% of GL n (total) = 42 Note: Only 2 incidents of detect over DoH GL (i.e. 110 µg/L & 47 µg/L) - both during Commissioning. Otherwise, majority of data (n = 28): <LOR of 1 or 0.1 µg/L (<10% of GL).	- Problems with blood - Possible carcinogen - potential increased risk of ovarian cancer	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 201 Max = <0.1 µg/L LOR = 0.1 µg/L = <10% of GL n = 35	O	1	E	Low	Action: Maintain catchment review for simazine	1	E	Low
10	Flupropanate	**DoH GL = 9 µg/L** NO METHOD AVAILABLE	Low acute oral and dermal toxicity. Affects kidney & liver function in rats and mice. Not readily biodegraded Slow-acting herbicide	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 168 No method available	U	2	E	Low	Method development required (Aqua # 8205705).			Low
11	Polihexanide	**DoH GL = 700 µg/L** NO METHOD AVAILABLE	Poorly absorbed by the body. Low acute oral & dermal toxicity. Not carcinogenic. Affects liver function and irriates skins at very high doses.	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 433 No method available	O	1	E	Low	Method development required (Aqua # 8205705).			Low
	DISINFECTION BYPRODUCTS	**Based on Max conc. In 2ndry WW & UF filtrate**							**Based on Max In Product Water**								
12	Bromodichloromethane	**DoH GL = 6 µg/L** (WHO GL = 60 µg/L) Feed Max = <1 µg/L (>10% of GL) LOR = 1 µg/L = >10% of GL n = 47 Commissioning UF Filtrate Max = 3.3 µg/L (>10% of GL); UF Filtrate Max During Recharge = <1 µg/L (>10% of GL), n = 9 n (UF Filtrate, total) = 17 Note: Only 3 incidents (during Commissioning) of detect in UF Filtrate (range between 1.2 - 3.3 µg/L) over LOR. Otherwise, all UF Filtrate data (n = 14): <LOR of 1 µg/L (>10% of GL).	Possibly carcinogenic At high doses - fetal toxicity, carcinogenic in animals	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring - Maintain operational protocols	MW = 163.8 Max = <1 µg/L (>10% of GL) LOR = 1 µg/L = >10% of GL n = 53	O	1	E	Low		2	E	Low

Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use,
Risk assignment determined using the Water Corporation Risk Matrix - Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.
ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,
DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines
WHO = World Health Organisation Guidelines for drinking MW = Molecular weight
 # = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met
Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	Hazard/Compound	Description (including nature of impact on the business)	Consequence	Existing Barriers	Consequence	Likelihood	Risk Level	AWRP Barriers	Comments re Barrier Effectiveness	Control Effectiveness Rating	Consequence	Likelihood	Risk Level	Post Additional Mitigations	Consequence	Likelihood	Risk Level
13	Bromochloroacetic acid #	**DoH GL = 0.7 µg/L** Feed Max = <2 µg/L (>DoH GL) LOR = 2 µg/L = >DoH GL n = 29 UF Filtrate Max = 29 µg/L (>DoH GL); n = 9 Note: 7 incidents of detects in UF Filtrate (range between 2.7 - 29 µg/L) over DoH GL/LOR (sampled 16/02/2011 - 21/11/2012). Note: DoH Satisfied that LOR is sufficiently low to demonstrate safety.		Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring - Maintain operational protocols	MW = 173 Max = <2 µg/L (>DoH GL) LOR = 2 µg/L = >DoH GL n = 29	A	2	D	Low	DoH is satisfied with a LOR of 2 µg/L (AQUA #8205705).	1	E	Low
14	Dibromochloroacetic acid #	**DoH GL = 0.7 µg/L** Feed Max = <5 µg/L (>DoH GL), n = 21; <2 µg/L (>DoH GL), n = 8 LOR (n = 21) = 5 µg/L = >DoH GL; LOR (n = 8) = 2 µg/L = >DoH GL n (total) = 29 UF Filtrate Max = <5 µg/L (>DoH GL), n = 3; <2 µg/L (>DoH GL), n = 7 n (UF Filtrate, total) =9 Note: DoH satisfied that LOR is sufficiently low to demonstrate safety.	Reduced fertility, reproductive effects Potentially mutagenic	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring - Maintain operational protocols	MW = 252 Max= <5 µg/L (>DoH GL), n = 21; <2 µg/L (>DoH GL), n = 8 LOR (n = 21) = 5 µg/L = >DoH GL; LOR (n = 8) = 2 µg/L = >DoH GL n (total) = 29	A	2	D	Low	DoH is satisfied with a LOR of 2 µg/L (AQUA #8205705).	1	E	Low
15	Tribromoacetic acid #	**DoH GL = 0.7 µg/L** Feed Max = <10 µg/L (>DoH GL), n = 2; <1 µg/L (>DoH GL), n = 8 LOR (n = 2) = 10 µg/L = >DoH GL; LOR (n = 8) = 1 µg/L = >DoH GL n (total) = 10 UF Filtrate Max = <10 µg/L (>DoH GL), n = 2; <1 µg/L (>DoH GL), n = 6 n (UF Filtrate, total) = 8 Note: DoH satisfied with new LOR of 1 µg/L.		Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring - Maintain operational protocols	MW = 297 Max = <10 µg/L (>DoH GL), n = 2; <1 µg/L (>DoH GL), n = 8 LOR (n = 2) = 10 µg/L = >DoH GL; LOR (n = 8) = 1 µg/L = >DoH GL n (total) = 10	A	2	D	Low	DoH is satisfied with a LOR of 2 µg/L (AQUA #8205705).	1	E	Low
16	Chlorate	**DoH GL = 700 µg/L (0.7 mg/L)** Feed Max = 30 µg/L (<10% of GL) LOR = 10 µg/L = <10% of GL n = 33 UF Filtrate Max = 320 µg/L (>10% of GL); n = 8 Note: 6 incidents of detect in UF Filtrate (range between 80 - 320 µg/L, i.e. >10% of GL) over LOR of 10 µg/L (sampled between 16/02/2011 - 15/08/2012). Note: Was observed in NeWater plants associated with excessive time of storage of hypochlorite (dosed in chloramination)	Oxidative damage to red blood cells at high doses	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = 20 µg/L (<10% of GL) Median = <10 µg/L LOR = 10 µg/L = <10% of GL n = 35	O	2	E	Low	Operational protocols: store hypochlorite for minimum time Design is such that no large volumes will be stored on site.	2	E	Low
17	Dichloroacetic acid	**DoH GL = 100 µg/L** Feed Max = <3 µg/L (<10% of GL), n = 21; <2 µg/L (<10% of GL), n = 8 LOR (n = 21) = 3 µg/L = <10% of GL; LOR (n = 8) = 2 µg/L = <10% of GL n (total) = 29 UF Filtrate Max = 45 µg/L (>10% of GL); n = 9 Note: Detection in UF Filtrated ranged from 7.3 - 45 µg/L (sampled between 17/11/2010 - 21/11/2012; n = 9).			2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 129 Max = <3 µg/L (<10% of GL), n = 20; <2 µg/L (<10% of GL), n = 9 LOR (n = 20) = 3 µg/L = <10% of GL; LOR (n = 9) = 2 µg/L = <10% of GL n (total) = 29	O	2	E	Low		2	E	Low
18	Tribromoacetonitrile	**DoH GL = 0.70 µg/L** NO METHOD AVAILABLE	DNA damage, developmental toxicity	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 277 No method available	O	1	E	Low	Method development required (Aqua # 8205705).			Low
	NITROSAMINES	**Based on Max conc. Data post chloramination.**							**Based on Max In Product Water**								
19	N-nitrosodimethylamine (NDMA)	**DoH GL = 100ng/L** Feed Max = 28 ng/L (>10% of GL) Feed Median = 5.1 ng/L (<10% of GL) LOR (n = 18) = 10 ng/L = 10% of Post Trial GL; LOR (n = 35) = 2 ng/L = <10% of GL; LOR (n = 79) = 1 ng/L = <10% of GL n (total) = 134 UF Filtrate Max = 35 ng/L (>10% of GL) UF Filtrate Median = 5.9 ng/L (<10% of GL) n (UF Filtrate, total) = 99 Note: NDMA & Precursors exist in secondary treated wastewater. Chloramination may elevate levels above guidelines	"probable human carcinogen" Cancer?: 5.8 in a million	Secondary Treatment (Source Control) - Primary - Activated Sludge - Clarification	3	D	Moderate	Advanced Treatment (Chloramination, Ultrafiltration (UF), Reverse Osmosis (RO), UV irradiation (UV), Stabilisation (Degas, NaOH)) **Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps** Process & Control Point monitoring Maintain operational protocols Adopted Protocol for diversion: WHO guideline criteria 100 ng/L as upper limit	MW = 74 Commissioning Max = 17 ng/L (<10% of GL) Max During Recharge = 7.3 ng/L (<10% of GL) Median = 2.3 ng/L LOR (n = 18) = 10 ng/L = 10% of I GL; LOR (n = 37) = 2 ng/L = <10% of GL; LOR (n = 94) = 1 ng/L = <10% of GL n (total) = 149 Note: Shown significant removal across degasser & UV. UV degrades NDMA, however depending on presence of organic precursors, reformation can occur.	A	2	D	Low		3	E	Low

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	**Hazard/Compound**	**Description (including nature of impact on the business)**	**Consequence**	**Existing Barriers**	**Consequence**	**Likelihood**	**Risk Level**	**AWRP Barriers**	**Comments re Barrier Effectiveness**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Post Additional Mitigations**	**Consequence**	**Likelihood**	**Risk Level**
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix** **- Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
20	N-nitrosodiethylamine (NDEA)	**DoH GL = 10 ng/L** Feed Max = 24 ng/L (> DoH GL) Feed Median = 2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = DoH GL; LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (>10% of GL); n = 11 Note: Only one incident of detect in Feedwater (i.e. 24 ng/L) over DoH GL. Otherwise, majority of Feedwater data (n = 50) were <LOR of 10 ng/L (=DoH GL) or 2 ng/L (>10% of GL).	- Cancer risk 2X10-6	Secondary Treatment - Primary - Activated Sludge - Clarification	4	C	**High**	Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 102 Commissioning Max = <10 ng/L (DoH GL), n = 18 Max During Recharge = 2.5 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
21	N-nitrosomorpholine (NMOR)	**DoH GL = 5 ng/L** Feed Max = 39 ng/L (>DoH GL) Feed Median = 4.1 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 Commissioning UF Filtrate Max = 8.7 ng/L (>DoH GL) UF Filtrate Max During Recharge = 5.5 ng/L (>DoH GL) UF Filtrate Median = 3.6 ng/L (>10% of GL) n (UF Filtrate, total) = 11 Note: Only 5 incidents of detect in Feedwater (range between 5.2 - 39 ng/L) over DoH GL, and only 3 incidents of detect in UF Filtrate (range between 5.1 - 8.7 ng/L) over DoH GL.	Carcinogenic NMOR can be created outside or within the human body from morpholine - present in some packaging, waxes, toiletries, rubber babies pacifiers/bottles	Secondary Treatment - Primary - Activated Sludge - Clarification	4	C	**High**	Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 116 Commissioning Max = <10 ng/L (>DoH GL), n = 18 Max During Recharge = 3.1 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
22	N-nitrosodi-n-butylamine (NDBA)	**DoH GL = 6 ng/L** Commissioning Feed Max = <10 ng/L (>DoH GL) Feed Max During Recharge = 4.5 ng/L (>10% of GL) Feed Median = 2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (>10% of GL); n = 11		Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	**Moderate**	CCPs on WWTP to minimise pre-cursor availability Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 158 Commissioning Max = <10 ng/L (>DoH GL) Max During Recharge = 3.2 ng/L (>10% of GL) Median = 2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
23	N-nitrosodi-n-propylamine (NDPA)	**DoH GL = 5 ng/L** Commissioning Feed Max = <10 ng/L (>DoH GL) Feed Max During Recharge = 4.4 ng/L (>10% of GL) Feed Median = 2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (>10% of GL); n = 11	Probable human carcinogen – increased tumour incidence at multiple sites in two rodent species and in monkeys. Produces benign and malignant tumours of the liver, kidney, oesophagus and respiratory tract. Inadequate evidence available for humans	Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	**Moderate**	CCPs on WWTP to minimise pre-cursor availability Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 130 Commissioning Max = <10 ng/L (>DoH GL) Max During Recharge = <2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
24	N-nitrosoethylmethylamine (NEMA)	**DoH GL = 2 ng/L** Commissioning Feed Max = <10 ng/L (>DoH GL) Feed Max During Recharge = <2 ng/L (=DoH GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (>10% of GL); n = 11	Probable human carcinogen – increased incidences of tumours of the liver and other sites in two rat strains. Inadequate evidence for humans.	Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	**Moderate**	CCPs on WWTP to minimise pre-cursor availability Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 88 Commissioning Max = <10 ng/L (>DoH GL) Max During Recharge = <2 ng/L (=DoH GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
25	N-nitrosopiperidine (NPIP)	**DoH GL = 4 ng/L** Commissioning Feed Max = <10 ng/L (>DoH GL) Feed Max During Recharge = <2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL LOR (n = 35) = 2 ng/L = >10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (>10% of GL); n = 11	Probable human carcinogen – carcinogenic in mice, rats, hamsters and monkeys and produces benign and malignant tumours. Carcinogenic in mice and hamsters after single dose administration. No data available for humans.	Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	**Moderate**	CCPs on WWTP to minimise pre-cursor availability Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 114 Commissioning Max = <10 ng/L (>DoH GL) Max During Recharge = <2 ng/L (>10% of GL) LOR (n = 18) = 10 ng/L = >DoH GL; LOR (n = 38) = 2 ng/L = >10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
26	N-nitroso-pyrrolidine (NPYR)	**DoH GL = 20 ng/L** Commissioning Feed Max = <10 ng/L (>10% of GL) Feed Max During Recharge = <2 ng/L (=10% of GL) LOR (n = 18) = 10 ng/L = >10% of GL; LOR (n = 35) = 2 ng/L = <10% of GL n (total) = 53 UF Filtrate Max = <2 ng/L (<10% of GL); n = 11	Sufficient evidence of a carcinogenic effect in humans. Produces hepatocellular carcinoma in rats and increases the incidence of lung adenomas in mice following oral administration. No data available for humans.	Secondary Treatment - Primary - Activated Sludge - Clarification	2	D	**Low**	CCPs on WWTP to minimise pre-cursor availability Advanced Treatment Designed to minimise chloramine contact time & finely controlled chloramine dosing pumps Process & Control Point monitoring Maintain operational protocols	MW = 100 Commissioning Max = <10 ng/L (>10% of GL) Max During Recharge = S2 ng/L (=DoH GL) LOR (n = 18) = 10 ng/L = >10% of GL; LOR (n = 38) = 2 ng/L = <10% of GL n (total) = 56	A	2	D	**Low**	Method development completed - Lower LOR achieved, with new LOR of 2 ng/L (AQUA #8205705).	3	E	**Low**
	VOCs - Volatile	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
27	Dichloromethane (methylene chloride)	**DoH GL = 4 µg/L** Feed Max = 4.1 µg/L (>DoH GL) Feed Median = 1 µg/L (>10% of GL) LOR = 1 µg/L = >10% of GL n = 18	Least toxic of the chlorohydrocarbons Volatile - most toxicity studies on inhalation effects - very slightly carcinogenic Metabolised by the body to carbon monoxide	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring - Maintain operational protocols	MW = 85 Commissioning max = 12 µg/L (>10% of GL) Max During recharge = 2.8 µg/L (>10% of GL) Median = 1 µg/L LOR = 1 µg/L = >10% of GL n (total) = 30	A	2	C	**Low**	Ubiquitous in laboratory as a solvent. Samples analysed <5 days (AQUA # 6522923)	3	E	**Low**
28	Chlorophene	**DoH GL = 0.35 µg/L** Max = <0.05 µg/L LOR = 0.05 µg/L = >10% of GL n = 7 Method available from December 2013 (LOR = 0.05 µg/L, >10% of GL)	Chlorophene is used as a germicide in formulating disinfectant and sanitizer products. End applications include soaps, anionic detergents, cosmetics and aerosol spray products.	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Chloramination Microfiltration (UF) Reverse Osmosis (RO) Ultra Violet (UV) Stabilisation (Degas, NaOH)	MW = 219 Max = <0.05 µg/L LOR = 0.05 µg/L = >10% of GL n = 7 Method available from December 2013 (LOR = 0.05 µg/L, >10% of GL)	A	2	D	**Low**		1	E	**Low**
	HORMONES	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK				RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource		
Ref	**Hazard/Compound**	**Description (including nature of impact on the business)**	**Consequence**	**Existing Barriers**	**Consequence**	**Likelihood**	**Risk Level**	**AWRP Barriers**	**Comments re Barrier Effectiveness**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Post Additional Mitigations**	**Consequence**	**Likelihood**	**Risk Level**
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix** **- Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
29	Ethinyl estradiol	**DoH GL = 1.5 ng/L** Feed Max = 2.2 ng/L (>DoH GL) Feed Median = <1 ng/L (>10% of GL) LOR = 1 ng/L = >10% of GL n = 35	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 296 Max = <1 ng/L LOR = 1 ng/L = >10% of GL n = 35	A	2	D	**Low**	Lower LOD & Additional monitoring Complete. Health Hazard Assesment Report (AQUA # 5766597)	3	E	**Low**
30	Estrone	**DoH GL = 30 ng/L** Feed Max = 16 ng/L (>10% of GL) Feed Median = 2.5 ng/L (<10% of GL) LOR = 1 ng/L = <10% of GL n = 35	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 270 Max = <1 ng/L LOR = 1 ng/L = <10% of GL n = 35	O	2	E	**Low**	Review source control options Ongoing. (AQUA # 7089625)	2	E	**Low**
31	Equilin	**DoH GL = 30 ng/L** Feed Max = 4.6 ng/L (>10% of GL) Feed Median = <2 ng/L (<10% of GL) LOR = 2 ng/L = <10% of GL n = 36	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 268 Max = <2 ng/L LOR = 2 ng/L = <10% of GL n = 30	O	2	E	**Low**		1	E	**Low**
32	Mestranol	**DoH GL = 2.5 ng/L** Feed Max = <2 ng/L LOR = 2 ng/L = >10% of GL n = 36	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 310 Max = <2 ng/L LOR = 2 ng/L = >10% of GL n = 29	O	2	E	**Low**		1	E	**Low**
33	Norethindrone	**DoH GL = 250 ng/L** Feed Max = <100 ng/L LOR = 100 ng/L = >10% of GL n = 36	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 298 Max = <100 ng/L LOR = 100 ng/L = >10% of GL n = 29	O	2	E	**Low**		1	E	**Low**
34	Progesterone	**DoH GL = 105 ng/L** Feed Max = <100 ng/L LOR = 100 ng/L = >10% of GL n = 36	Impacts Endocrine system	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 314.5 Max = <100 ng/L LOR = 100 ng/L = >10% of GL n = 29	O	2	E	**Low**		1	E	**Low**
	PHARMACEUTICALS	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
35	Diclofenac	**DoH GL = 1.8 µg/L** Feed Max = 0.93 µg/L (>10% of GL) Median = 0.3 µg/L (>10% of GL) LOR (n = 26) = 0.1 µg/L = <10% of GL; LOR (n = 96) = 0.05 µg/L = <10% of GL n = 122	Non-steroidal anti-inflammatory, some damage to kidney at high doses	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 296 Max = <0.1 µg/L (<10% of GL), n = 26; <0.05 µg/L (<10% of GL), n = 94 LOR (n = 26) = 0.1 µg/L = <10% of GL; LOR (n = 94) = 0.05 µg/L = <10% of GL n (total) = 120	O	2	E	**Low**		2	E	**Low**
	CHELATING AGENTS	Based on Max conc. In 2ndry WW							**Based on Max In Product Water**								
36	Ethylenediamine Tetraacetic Acid (EDTA)	**DoH GL = 250 µg/L** Feed Max = 630 µg/L (>DoH GL) Feed Median = 200 µg/L (>10% of GL) LOR (n = 94) = 10 µg/L = <10% of GL; LOR (n = 12) = 1 µg/L = <10% of GL n (total) = 106 UF Filtrate Max = 530 µg/L (>DoH GL) UF Filtrate Median = 190 µg/L (>10% of GL) n (UF Filtrate, total) = 78	- chelating agent, does not accumulate in the body - can mobilise heavy metals in environment (metal complexing agent) - prevents Zinc adsorption in gastrointestinal tract	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment (Chloramination, Ultrafiltration (UF), Reverse Osmosis (RO), UV irradiation (UV), Stabilisation (Degas, NaOH)) Process & Control Point monitoring Operational protocols	MW = 292 Max = <10 µg/L (<10% of GL), n = 100; <1 µg/L (<10% of GL), n = 11 LOR (n = 100) = 10 µg/L = <10% of GL; LOR (n = 11) = 1 µg/L = <10% of GL n (total) = 111	O	1	E	**Low**		1	E	**Low**
37	Diethylenetrinitrilopentaacetic acid (DTPA)	**DoH GL = 20 µg/L** Feed Max = 24 µg/L (>DoH GL) Feed Median = 2 µg/L (10% of GL) LOR = 1 µg/L = <10% of GL n = 11 Note: Only one incident of detect (i.e. 24 µg/L) in Feedwater over DoH GL.	- chelating agent - used to clean poisons (including radioactive contamination) from the body May cause nausea, vomitting, diarrhea	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 393 Max = <2 µg/L (10% of GL), n = 3; <1 µg/L (<10% of GL), n = 7 LOR = 1 µg/L = <10% of GL n = 10 Note: Only 3 incidents where LOR was increased to 2 µg/L (=10% of GL) during recharge.	O	2	D	**Low**	Increased LOR from 1 µg/L (<10% of GL) to 10 µg/L (>10% of GL). DoH endorsed (GWRT HAC, Item 4. Aqua # 10051490).	2	E	**Low**
	PHENOLS	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
38	4-cumylphenol	**DoH GL = 0.35 µg/L** Feed Max = <10 µg/L (> DoH GL), n = 18; 0.06 µg/L (>10% of GL), n = 6 LOR (n = 18) = 10 µg/L = >DoH GL; LOR (n = 6) = 0.05 µg/L = >10% of GL n = 24 Note: All samples prior to Oct 2013 have LOR of 10 µg/L, future samples will have LOR of 0.05 µg/L. Note: Laboratory was notified to use LOR of 10 µg/L from Jan 2014 for sample group OrganoChemical-07.	no acute toxicity data is available	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW= 212 Max = <10 µg/L (>DoH GL), n = 19; <0.05 µg/L (>10% of GL), n = 6 LOR (n = 19) = 10 µg/L = >DoH GL; LOR (n = 6) = 0.05 µg/L = 10% of GL n (total) = 25 Note: Laboratory was notified to use LOR of 10 µg/L from Jan 2014 for sample group OrganoChemical-07.	A	2	D	**Low**	(10/2013) Method development completed - Lower LOR achieved (to below DoH GL), with new LOR of 0.05 µg/L (AQUA #8205705).	1	E	**Low**
39	2-nitrophenol	**DoH GL = 0.7 µg/L** Feed Max = <1 µg/L (>DoH GL) LOR = 1 µg/L = >DoH GL n = 10 Note: DoH satisfied that LOR is sufficiently low to demonstrate safety, no further method development required.	moderate toxicity potential	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 139 Max = <1 µg/L LOR = 1 µg/L = >DoH GL n = 10 Note: DoH satisfied that LOR is sufficiently low to demonstrate safety, no further method development required.	U	2	D	**Low**	Lower LOD & Additional monitoring Complete. (AQUA # 7812194). (10/2013) DoH satisfied that LOR is sufficiently low to demonstrate safety, no further method development required (AQUA #8205705).	1	E	**Low**

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	Hazard/Compound	Description (including nature of impact on the business)	Consequence	Existing Barriers	Consequence	Likelihood	Risk Level	AWRP Barriers	Comments re Barrier Effectiveness	Control Effectiveness Rating	Consequence	Likelihood	Risk Level	Post Additional Mitigations	Consequence	Likelihood	Risk Level
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix** - **Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
40	4-tert-Octylphenol	**DoH GL = 50 µg/L** Feed Max = <10 µg/L LOR = 10 µg/L = >10% of GL n = 18	Safe Work Australia - irritant, risk and dangerous to the environment	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 206 Max = <10 µg/L LOR = 10 µg/L = >10% of GL n = 19	A	2	D	Low		1	E	Low
41	2,6-Dichlorophenol	**DoH GL = 10 µg/L** Feed Max = <5 µg/L (>10% of GL), n = 3; Note: LOR raised due to matrix interference for 3 samples LOR = 1 µg/L (n = 16) = 10% of GL n (Feedwater, total) = 19	Data on the toxicity of 2,4-dichlorophenol are limited. Therefore, no health-based guideline value has been derived.	Secondary Treatment - Primary - Activated Sludge - Clarification	2	D	Low	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 163 Max = <5 µg/L (>10% of GL), n = 2; Note: LOR raised due to matrix interference for 2 samples LOR = 1 µg/L (n = 17) = 10% of GL n (total) = 19	A	2	D	Low		1	E	Low
42	2,6-di-tert-butylphenol	**DoH GL = 2 µg/L** Feed Max = <10 µg/L (>DoH GL), n = 16; 0.15 µg/L (<10% of GL) LOR (n = 16) = 10 µg/L = >DoH GL; LOR (n = 6) = 0.05 µg/L = <10% of GL n (total) = 22 Note: new LOR available (0.05 ug/L) in DEC 2013 Note: Laboratory was notified to use LOR of 10 µg/L from Jan 2014 for sample group OrganoChemical-07.	May cause liver damage. Causes gastrointestinal tract irritation	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 206 Max = <10 µg/L (>DoH GL), n = 17; <0.05 µg/L (<10% of GL), n = 6 LOR (n = 17) = 10 µg/L = >DoH GL; LOR (n = 6) = 0.05 µg/L = <10% of GL n (total) = 23 Note: New LOR available in Dec 2013 (0.05 ug/L, > 10% DoH GL). Note: Laboratory was notified to use LOR of 10 µg/L from Jan 2014 for sample group OrganoChemical-07.	U	2	D	Low	New LOR available from December 2013 (Aqua # 8205705). DoH GL (2 µg/L) clarified (Aqua #9150373).	1	E	Low
	POLYCYCLIC AROMATIC COMPOUNDS	**Based on Max conc. Data**							**Based on Max In Product Water**								
43	PAHs (total TEQ)	**DoH GL = 0.01 µg/L** (TEQ = 0.002 µg/L for 2014, n = 2) TEQ from 17 parameters. All <LOR LORs lowered Nov 2013 to allow TEQ calculation to occur LOR = 0.01 µg/L = DoH GL; LOR = 0.001 µg/L = <10% of GL	- Mutagenic, highly carcinogenic - Primary exposure through smoke, burnt food	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	MWs = 128 - 278 All <LOR, TEQ < 0.01 ug/L No change to TEQ, individual parameters with GLs are low risk, apart from Benzo (a) pyrene (noted below). LOR = 0.01 µg/L = DoH GL; LOR = 0.001 µg/L = <10% of GL	A	2	D	Low	Refer to briefing note (dated 4/2/2013), AQUA #8584946, for calculations of toxic equivalence (TEQs) for PAHs, PCBs and Dioxins. New LORs (as listed in GWRT Uberlist, AQUA #9555311, v46).	1	E	Low
44	Benzo (a) pyrene	**DoH GL = 0.01 µg/L** Feed Max = <0.1 µg/L (>DoH GL), n = 7; <0.01 µg/L (>10% of GL), n = 22; <0.001 µg/L (=10% of GL), n = 2 LOR (n = 7) = 0.1 µg/L = >DoH GL; LOR (n = 25) = 0.01 µg/L = >10% of GL; LOR (n = 2) = 0.001 µg/L = 10% of GL n (total) = 34	- Mutagenic, highly carcinogenic - Primary exposure through smoke, burnt food	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 252 Max = <0.1 µg/L (>DoH GL), n = 7; <0.01 µg/L (>10% of GL), n = 22; <0.001 µg/L (=10% of GL), n = 2 LOR (n = 7) = 0.1 µg/L = >DoH GL; LOR (n = 22) = 0.01 µg/L = >10% of GL; LOR (n = 2) = 0.001 µg/L = 10% of GL n (total) = 31	A	2	D	Low	Refer to briefing note (dated 4/2/2013), AQUA #8584946, for calculations of toxic equivalence (TEQs) for PAHs, PCBs and Dioxins. New LOR of 0.001 µg/L (as listed in GWRT Uberlist, AQUA #9555311, v46).	2	E	Low
	OTHER ORGANIC CHEMICALS	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
45	Dioxins & PCBs	**DoH GL = 16 pg/L (TEQ for total dioxins and PCBs)** Max TEQ = 3.29 pg/L TEQ for Feedwater During Recharge = 2.85 - 3.33 pg/L n = 10 (All <LORs; LORs range from 1 to 100 pg/L) TEQ from 29 parameters	- Reproductive difficulties - Increased risk of cancer	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max TEQ = 3.49 pg/L TEQ During Recharge = 3.29-3.49 pg/L n = 11 (All <LORs; LORs range from 1 to 100 pg/L)	A	2	D	Low	Refer to briefing note (dated 4/2/2013), AQUA #8584946, for calculations of toxic equivalence (TEQs) for PAHs, PCBs and Dioxins. New LORs (as listed in GWRT Uberlist, AQUA #9555311, v46).	2	E	Low
46	Benzidine #	**DoH GL = 0.2 ng/L** Feed Max = <1 µg/L (>DoH GL) LOR (n=10) = 1 µg/L = (>DoH GL) LOR (n = 6) = 20 ng/L (> DoH GL) Note: Further method development required to lower LOR. Reviewed annually.	carcinogenic. Used in production of dyes & in test for cyanide & previously blood. Largely withdrawn from use. Biodegradable in soil at low concentrations, also adsorbs particularly at low pH	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 184 Max = <1 µg/L (>DoH GL) LOR = 1 µg/L = >DoH GL n = 10 Note: New LOR of 20 ng/L (>DoH GL) (Oct 2014)	U	2	C	Moderate	Lower LOR and/or additional source risk assessment. (10/2013) Required to review the method development annually to lower LOR to below DoH GL (AQUA #8205705). DOH satisified for LOR of 20 ng/L (AQUA # 11815656).	1	E	Low
47	Tolyltriazole	**DoH GL = 20 µg/L** Feed Max = 4.9 µg/L (>10% of GL) Feed Median = 3.1 µg/L (>10% of GL) LOR = 1 µg/L = <10% of GL n = 9	corrosion inhibitor for copper and brass Detailed information about the effects of overexposure is unavailable	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	MW = 133 Max = <1 µg/L LOR = 1 µg/L = <10% of GL n = 9	A	2	E	Low	(10/2013) Method development completed - Lower LOR achieved (to below DoH GL), with new LOR of 1 µg/L (AQUA #8205705).	1	E	Low
48	Benzotriazole	Parameter identified by TOC characterisation post-RO at GWRT by Curtin Uni **DoH GL = 20 µg/L** Feed Max = 4.3 µg/L (>10% of GL) LOR = 1 µg/L = <10% of GL n = 9	corrosion inhibitor for copper and brass Detailed information about the effects of overexposure is unavailable	Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	Moderate	Advanced Treatment Process & Control Point monitoring Operational protocols	Post-RO: 750-1300 ng/L over 4 days in Jan 2012, n = 4 Post-UV: 375-550 ng/L over 4 days in Jan 2012 <10% of GL, therefore adequate removal (84% from WW) MW = 119 Max = <1 µg/L LOR = 1 µg/L = <10% of GL n = 9	A	3	E	Low				Low

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	Hazard/Compound	Description (including nature of impact on the business)	Consequence	Existing Barriers	Consequence	Likelihood	Risk Level	AWRP Barriers	Comments re Barrier Effectiveness	Control Effectiveness Rating	Consequence	Likelihood	Risk Level	Post Additional Mitigations	Consequence	Likelihood	Risk Level
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix - Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
49	Nanoparticles	Chemicals with a particle size generally 1-100nm as defined by the US EPA (2007), Currently water is an unlikely exposure route. Most exposure through sunscreens & cosmetics. Do not forsee there being large sources of nano-particles in the wastewater catchment, however if these were present it is anticipated that RO would be effective at removing them.		Secondary Treatment - Primary - Activated Sludge - Clarification	3	E	Low	RO	particle size: 1 - 100 nm. RO excludes particles>~0.6nm Only chemicals with a molecular width under about 0.6nm can pass through the RO membrane (Bellona et al. 2004). Most newly engineered nano-materials potentially used in medical, electronics and other engineering areas (e.g. Buckminster fullerene) have very large molecular weights and molecular widths such that they cannot pass through RO.	A	3	E	Low	Aqua Doc#5404431 Aqua Doc#7878518 Aqua Doc# 10006095 Method development of surrogate required. Ongoing discussions with Chem Centre. Approval for continuation of GWR 1.5 stated that once a method for nanoparticles was found, sampling of the secondary treated wastewater and after RO was to be conducted (AQUA # 9042337).			Low
	NUTRIENTS & OTHER	**Based on Max conc. In 2ndry WW**							**Based on Max In Product Water**								
50	Nitrate	**DoH GL = 11 mg/L as N** Feed Max = 21 mg/L (>DoH GL) Feed Median = 13 mg/L (>DoH GL) LOR = 0.01 mg/L = <10% of GL n = 95 UF Filtrate Max = 20 mg/L (>DoH GL) UF Filtrate Median = 12 mg/L n (UF Filtrate) = 62	- Blue baby syndrome (infants <6months)	Secondary Treatment - Primary - Activated Sludge - Clarification	4	C	High	Advanced Treatment (Chloramination, Ultrafiltration (UF), Reverse Osmosis (RO), UV irradiation (UV), Stabilisation (Degas, NaOH)) Process & Control Point monitoring Maintain operational protocols	Max = 3.6 mg/L (>10% of GL) Ave = 1.7 mg/L (>10% of GL) LOR = 0.01 mg/L = <10% of GL n = 100	A	1	D	Low		1	D	Low
51	Nitrite	**DoH GL = 1 mg/L as N** Feed Max = 0.39 mg/L (>10% of GL) Feed Median = 0.09 mg/L (<10% of GL) LOR = 0.01 mg/L = <10% of GL n = 95 UF Filtrate Max = 0.03 (<10% of GL); n = 62	- Blue baby syndrome (infants <6months)	Secondary Treatment - Primary - Activated Sludge - Clarification	3	D	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = 0.05 mg/L (<10% of GL) LOR = 0.01 mg/L = <10% of GL n = 98	A	1	D	Low		1	D	Low
52	Ammonia	**DoH GL = 0.5 mg/L (Aesthetic GL)** Feed Max = 6 mg/L (>DoH GL) Feed Median = 0.14 mg/L (>10% of GL) LOR = 0.01 mg/L = <10% of GL n = 95	Metabolism effects above 1000mg/L ammonium chloride Attacks copper pipes & fittings above 0.5mg/L	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols Ammonia CCP at feedwater is now diverted at 4 mg/L (July 2013) - previously 7 mg/L	Commissioning Max = 0.49 mg/L (approx. DoH GL) Max During Recharge = 0.44 mg/L (>10% of GL) Median = 0.28 mg/L (>10% of GL) LOR = 0.01 mg/L = <10% of GL n = 100	A	2	D	Low	Note: Feedwater ammonia target range: 0.0 - 3.0 mg/L; alert and violation limits are set at 3.0 mg/L and 4.0 mg/L, respectively (as specified in GWR 1.5 GL Scheme PCT: Aqua # 7637201) Ammonia GL at recharge is 0.5 mg/L. The feedwater ammonia concentration has to allow removal of ammonia through the system to achieve GL without any additional treatment processes.	2	D	Low
53	Sodium	**DoH GL = 180 mg/L** Feed Max = 220 mg/L (>DoH GL) Feed Ave = 166 mg/L (>10% of GL) LOR = 0.1 mg/L = <10% of GL n = 62	- can aggravate conditions of hypertentsion and congestive heart failure - water provides small contribution to dietary intake	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	HIgh	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = 15.4 mg/L (<10% of GL) Ave = 9.3 mg/L (<10% of GL) LOR = 0.1 mg/L = <10% of GL n = 72	O	1	E	Low		1	E	Low
54	Chloride	**DoH GL = 250 mg/L** Feed Max = 270 mg/L (>DoH GL) Feed Ave = 210 mg/L (>10% of GL) LOR = 1 mg/L = <10% of GL n = 61	Not harmful unless there is insufficient fresh water available. Food is major source of chloride.	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = 12 mg/L (<10% of GL) LOR = 1 mg/L = <10% of GL n = 71	O	1	E	Low		1	E	Low
55	TDS (Total dissolved solids)	**DoH GL = 500 mg/L** **Aesthetic GL = 1000 mg/L** Feed Max = 760 mg/L (>DoH GL) Feed Ave = 650 mg/L (>DoH GL) LOR = 10 mg/L = <10% of GL n = 82 UF Filtrate Max = 750 mg/L (>DoH GL) UF Filtrate Median = 660 mg/L (>DoH GL) n = 14	None	Secondary Treatment - Primary - Activated Sludge - Clarification	2	A	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	GWRT: Max = 66 mg/L (>10% of GL) Median = 30 mg/L (<10% of GL) LOR = 10 mg/L = <10% of GL n = 99	O	1	E	Low		1	E	Low
56	Turbidity & suspended solids	**DoH GL = 5 NTU** Feed Max = 6.6 NTU (>DoH GL) Feed Median = 1.7 NTU (>10% of GL) LOR = 0.5 NTU = 10% of GL n = 80 UF Filtrate Max = <0.5 NTU (<10% of GL); n = 14	Can affect efficiency of disinfection, can harbour contaminants	Secondary Treatment - Primary - Activated Sludge - Clarification	3	B	High	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <0.5 NTU (=10% of GL) LOR = 0.5 NTU = 10% of GL n = 98	O	1	E	Low		1	E	Low
57	Chloramine	**ADWG GL =3 mg/L** Secondary WW Feed Range = 0 - <1 mg/L Secondary WW Feed Median = 0.025 mg/L Disinfection target above 1.5 mg/L PCT: Max UF filtrate <3 mg/L	Possibly carcinogenic	Secondary Treatment - Primary - Activated Sludge - Clarification	2	E	Low	Advanced Treatment Process & Control Point monitoring Maintain operational protocols RO stop operating at RO feed concentrations >3mg/L Required for AWRP operation - disinfectant	Max = 1.9 mg/L	A	2	D	Low		2	E	Low
58	Iodide	**DoH GL = 0.1 mg/L** Feed Max = <0.02 mg/L LOR = 0.02 mg/L = >10% of GL n = 60	Iodism - similar to sinus cold. Affects thyroid at >2mg/day. Not carcinogenic. Main exposure: food, pharmaceuticals, drinking water	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <0.02 mg/L LOR = 0.02 mg/L = >10% of GL n = 68	A	2	D	Low		2	E	Low

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	**Hazard/Compound**	**Description (including nature of impact on the business)**	**Consequence**	**Existing Barriers**	**Consequence**	**Likelihood**	**Risk Level**	**AWRP Barriers**	**Comments re Barrier Effectiveness**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Post Additional Mitigations**	**Consequence**	**Likelihood**	**Risk Level**
Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use, **Risk assignment determined using the Water Corporation Risk Matrix - Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.** **ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,** **DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines** **WHO = World Health Organisation Guidelines for drinking MW = Molecular weight** **# = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met** **Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.**																	
59	Fluoride	**DoH GL = 1.5 mg/L** Feed Max = 1 mg/L (>10% of GL) Feed Ave = 0.84 mg/L (>10% of GL) LOR = 0.05 mg/L = <10% of GL n = 61 Note: below concentration added for health benefits to drinking water	Skeletal & Dental fluorosis with excessive long term intake. Acute symptoms of overdose include: vomiting, diarrhoea, skin rash, lethal at 14mg/kg body weight. Not carcinogenic. Fluoridated water is major source of daily intake	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Commissioning Max = 0.87 mg/L (>10% of GL) Max During Recharge = 0.39 (>10% of GL) Median = 0.1 mg/L (<10% of GL) LOR = 0.05 mg/L = <10% of GL n = 71	A	2	D	**Low**		2	E	**Low**
60	Cyanide	**DoH GL = 0.08 mg/L** Feed Max = <0.01 mg/L LOR = 0.01 mg/L = >10% of GL n = 28	Low Dose: loss of consciousness, general weakness, giddiness, headaches, vertigo, perceived difficulty in breathing. High dose: coma with seizures, apnea and cardiac arrest	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = <0.01 mg/L LOR = 0.01 mg/L = >10% of GL n = 29	A	2	E	**Low**	Lower LOD & Additional monitoring Not required	2	E	**Low**
61	Sulfate	**DoH GL = 500 mg/L** Commissioning Feed Max = 84.3 mg/L (>10% of GL) Feed Ave = 66.6 mg/L (>10% of GL) LOR = 0.1 mg/L = <10% of GL n = 74 RO Feed #1 Max (i.e. post-sulphuric acid dosing) = 158 mg/L (>10% of GL) RO Feed #1 Median = 124mg/L (>10% of GL) n (RO Feed #1) = 114		Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	**Moderate**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Max = 0.5 mg/L (<10% of GL) LOR = 0.1 mg/L = <10% of GL n = 71	O	3	E	**Low**		2	E	**Low**
62	Perchlorate	**DoH GL = 6 µg/L** Max = <20 µg/L (>DoH GL) LOR (n = 29) = 20 µg/L = >DoH GL; LOR (n = 4) = 0.5 µg/L = <10% of GL n (total) = 33	Thyroid effects through inhibition of iodide uptake - takes months to cause adverse effects. Lethal dose is 250mg/kg body weight. Intake is primarily through food & beverages.	Secondary Treatment - Primary - Activated Sludge - Clarification	3	C	**High**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	MW = 99 Max = <20 µg/L (>DoH GL), n = 30; <0.5 µg/L (<10% of GL), n = 5 LOR (n = 30) = 20 µg/L = >DoH GL; LOR (n = 5) = 0.5 µg/L = <10% of GL n (total) = 35	U	2	D	**Low**	Lower LOD & Additional monitoring . (10/2013) Method development completed - Lower LOR achieved (to below DoH GL), with new LOR of 0.5 µg/L (AQUA #8205705).	2	E	**Low**
	MICROBIOLOGICAL	**See GWR Treatment Validation Report - Feb 2010**															
63	Bacteria	Unsuitable for drinking: 6 log/L Treatment must achieve **8.5** log removal	- Gastroenteritis	Secondary Treatment - Primary - Activated Sludge - Clarification	4	A	**Extreme**	Advanced Treatment (Chloramination, Ultrafiltration (UF), Reverse Osmosis (RO), UV irradiation (UV), Stabilisation (Degas, NaOH)) Process & Control Point monitoring Maintain operational protocols	Removal Credited 1 log secondary 3 log UF 3 log RO 4 log UV **11 log TOTAL**	O	3	E	**Low**		3	E	**Low**
64	Virus - Adenovirus	Unsuitable for drinking: 3 log/L Treatment must achieve **9.5** log removal	- Respiratory and intestinal infections	Secondary Treatment - Primary - Activated Sludge - Clarification	4	A	**Extreme**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols -	Removal Credited 1 log secondary 3 log UF 3 log RO 4 log UV **11 log TOTAL**	O	3	E	**Low**	Additional monitoring & validation of removal through RO treatment and WWTP - Ongoing	3	E	**Low**
65	Virus - Other	Unsuitable for drinking: 3 log/L Treatment must achieve **9.5** log removal	- Gastroenteritis	Secondary Treatment - Primary - Activated Sludge - Clarification	4	A	**Extreme**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Removal Credited 1 log secondary 3 log UF 3 log RO 4 log UV **11 log TOTAL**	O	3	E	**Low**		3	E	**Low**
66	Protozoa	Unsuitable for drinking: 3 log/L Treatment must achieve **8** log removal	- Gastroenteritis	Secondary Treatment - Primary - Activated Sludge - Clarification	4	A	**Extreme**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	Removal Credited 0.5 log secondary 3 log UF 3 log RO 4 log UV **10.5 log TOTAL**	O	3	E	**Low**		3	E	**Low**
67	Helminth	Unsuitable for drinking: 4 log/L Not an endemic hazard in SW Australia	- Gastroenteritis	Secondary Treatment - Primary - Activated Sludge - Clarification	4	D	**High**	Advanced Treatment Process & Control Point monitoring Maintain operational protocols	As per Protozoa	O	3	E	**Low**		3	E	**Low**
	RADIATION	**Based on Max conc. In 2ndry WW**							**Based on Max In Treated Water**								
68	Radionuclides	**Gross alpha particle activity** **DoH GL = 0.5 Bq/L** Commissioning Feed Max = 0.08 Bq/L (>10% of GL) Feed Max During Recharge = 0.046 Bq/L (<10% of GL) LOR = 0.02 Bq/L = <10% of GL n = 19 **Gross beta particle activity minus K40 contribution** **DoH GL = 0.5 Bq/L** Feed Max = 0.25 Bq/L (>10% of GL) Feed Median = 0.07 Bq/L (>10% of GL) LOR = 0.01 Bq/L = <10% of GL n = 20	Associated with risk of cancer		3	E	**Low**		Gross alpha particle activity DoH GL = 0.5 Bq/L Commissioning Max = <0.04 Bq/L (<10% of GL) Max During Recharge = 0.027 Bq/L (<10% of GL) LOR = 0.01 Bq/L = <10% of GL n = 19 Gross beta particle activity minus K40 contribution DoH GL = 0.5 Bq/L Commissioning Max = <0.09 Bq/L (>10% of GL), n = 2 Max During Recharge = <0.08 Bq/L (>10% of GL) LOR = 0.01 Bq/L = <10% of GL n = 19	O	3	E	**Low**		3	E	**Low**
	OTHERS from Environment Scan and Research	**If parameter has been assessed and will be removed from further risk assessments - it must be registered in Audit Trail Document (AQUA # 14170562)**															

Hazard Assessment of Environmental Value: Endpoint 1: Drinking Water, Endpoint 2: Industrial Use,
Risk assignment determined using the Water Corporation Risk Matrix - Data Used for this RA is from 1/1/2010 - 31/12/2015. Commissioning of GWRT was prior to recharge commencement (10/11/2010). GWR 1.5 shutdown 4/9/2014. n = number of data points during this period.
ACRONYMS: LOR = Limit of Reporting, LOD = Limit of detection GL = Guideline, AGWR = Australian Guidelines for Water Recycling Phase 2: Augmentation of Drinking Water Supplies,
DoH = Department of Health WWS & GWR Memorandum of Understanding, Oct 2014 ADWG= Australian Drinking Water Guidelines
WHO = World Health Organisation Guidelines for drinking MW = Molecular weight
 # = Parameter as marked in DoH MoU indicating GWRT LOR is insufficiently low to demonstrate GL is met
Note: If a parameter has >1 method, the oldest information and oldest LOR values are presented first, followed by more current data. Otherwise, all information presented are determined using current methods.

HUMAN HEALTH HAZARD ASSESSMENT					INHERENT RISK Post 2ndry Treated Wastewater Screening			Recycled Water Treatment Process			Post AWRP Treatment SCREENING RISK			RESIDUAL RISK to Groundwater EVs to protect Drinking Water Resource			
Ref	Hazard/Compound	Description (including nature of impact on the business)	Consequence	Existing Barriers	Consequence	Likelihood	Risk Level	AWRP Barriers	Comments re Barrier Effectiveness	Control Effectiveness Rating	Consequence	Likelihood	Risk Level	Post Additional Mitigations	Consequence	Likelihood	Risk Level
69	Methamphetamine	Illicit drug		Secondary Treatment - Primary - Activated Sludge - Clarification	3	E	Low	RO (removal is expected to be approx. 95%)	MW = 149 " Due to both low concentrations levels in WW influent and high removal during treatment, amphetamine and methamphetamine were not detected in effluent samples".	O	3	E	Low	Journal articles AQUA#13564774, #13564765. Fact sheet: AQUA # 14796167	3	E	Low
70	Perfluorooctane sulfonate (PFOS)	PFOS has been used in industrial processes and consumer products. Used in firefighting foams and coatings for food packaging (Scotchgard, Teflon).	Chemical has bene identified as a persistant organic pollutant and does not break down easily.	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	RO (removal is expected to be approx. 95%) - Water Research Foundation Report (Web Report #4322)Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances	MW = 500 g/mol. ADWG: 5 µg/L (LOR: 0.01 µg/L) Background Technical Information for Poly- and Perfluoroalkyl Substances (PFASs or PFCs) by Alice Fulmer, Water Research Foundation (May 2016) stated "The most effective treatment technologies appear to be nanofiltration (NF) and reverse osmosis (RO), which worked even for the smallest PFASs studied"	A	2	D	Low	Fact sheet: AQUA # 14794835 www.health.gov.au/internet/ministers/publishing.nsf/Content/0C493E60E6CEEE7ECA25800500 0E59FD/$File/SL045.pdf	2	D	Low
71	Perfluorooctanoic acid (PFOA)	PFOA has been used in industrial processes and consumer products. Used in firefighting foams and coatings for food packaging (Scotchgard, Teflon).	Chemical has been identified as a persistant organic pollutant and does not break down easily.	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	RO (removal is expected to be approx. 95%) - Water Research Foundation Report (Web Report #4322)Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances	MW = 414 g/mol. ADWG: 0.5 µg/L (LOR: 0.01 µg/L) Background Technical Information for Poly- and Perfluoroalkyl Substances (PFASs or PFCs) by Alice Fulmer, Water Research Foundation (May 2016) stated "The most effective treatment technologies appear to be nanofiltration (NF) and reverse osmosis (RO), which worked even for the smallest PFASs studied"	A	2	D	Low	Fact sheet: AQUA # 14794835 www.health.gov.au/internet/ministers/publishing.nsf/Content/0C493E60E6CEEE7ECA25800500 0E59FD/$File/SL045.pdf	2	D	Low
72	Microplastics	Particles (or fibres) with a size range of 50 µm to 5mm.	Soprtion of contaminants to microplastics (PAHs, PCBs etc) Transfer to aquatic systems via organic matter Microplastics are found in: cosmetics, synthetic fibres, tyre abrasion and industry/agriculture Risk is for aquatic life (ocean outfall)	Secondary Treatment - Primary - Activated Sludge - Clarification	2	C	Moderate	Advanced treatment - UF/RO/UV Coarse screens/fine screens	Lack of established, uniform method for measuring and reporting microplastics. Water RA Node presentation by CWQRC showed 80-97% removal at a WWTP (AQUA # 15224096)	A	2	D	Low	Presentation from CWQRC can be found at: http://www.waterra.com.au/events/events/2016-06-16/western-australia-node-meeting/ Nanoplastics recent article: http://dx.doi.org/10.1016/j.scitotenv.2016.05.041	2	D	Low

General Risk Classification:

Risk	Description
Low	If max. value ≤ 10% of DoH GL
Moderate	If max. value >10% and/or <95% of DoH GL or LOR
High	If max. value or LOR > DoH GL
Extreme	Exposure directly impacts human health (e.g. microbiological)

Note: If DoH is satisfied with the LOR (even if it > GL), the risk is considered "Low".
Note: If LOR is > GL, but the parameter is a VOC, the risk is considered "Low" as VOCs will not be present in the AWRP
Note: If more than one LOR has been used for the parameter, the risk is based on the new LOR (if >6 data points have been obtained)

Legend:

Colour	Description
(black)	Previous to 2016
(blue)	Post 2016

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK			Drinking Water consumption RESIDUAL RISK			
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
	Risk highlighted in workshop but not considered as part of health & environment risk assessment																	
1	Reputational risk associated with legal discharge from Trade Waste (TW) or non-TW customers who are perceived to have discharges that will contaminate a drinking water source	Anything: Organic chemicals microbiological	Reputational Human Health	Serious reputational risks if WC doesn't understand the types of businesses discharging to BYP catchment	Possible	4	C	**High**	Capture in Corporate Risk Assessment Implement "environment scan" procedure for appropriate Water Corp staff and Project partners: C&IS Technical Assessment implemented & ongoing Including NICNAS reviews, GWRT validation outcomes ID'ed customers of concern: hospitals, catchment review Technical assessments, discussed at CWQC Governance Meetings Chemical assesment framework being developed by C&IS to provide information on impact of chemicals in trade waste discharges to sewer. Fact sheet for hospital waste has been developed. CCPs reviewed post Trial	Need to have a technical assessment for all discharges that may be 'a concern' Need to be able to communicate on how hospital wastes are handled (details as well - Radiation, pharmaceuticals, infectious pathogens, blood) Update fact sheet on Hospital wastes and distribution to appropriate spokes people. Facts sheets are used - not widely distributed				**Not Asessed**				**NA**
2	WWTP capital upgrades & planned shutdowns	water allocation	Reputational Human Health Plants	Can not meet water quality production targets Project Risk - get a failure/shutdown of AWRP Delays, reputation	biggest issue during daily peak flow	4	C	**High**	Ensure capital upgrades occur at Beenyup Design of AWRP to ensure 28 GL can be produced	Project risk needs to be raised				**Not Asessed**				**#N/A**
	Barrier assessment for trade waste in wastewater catchment **Risk assignment determined using the Water Corporation Risk Matrix**																	
3	Illegal toxic dumping to sewer access chambers results in contamination in recycled water	Potentially dumped: Metals (unlikely) Organics Pesticides Small organics (unlikely) Radioactivity (unlikely)	Soils Human Health	Contamination of product water due to: Increased contaminant load to AWRP, could overload RO. OR dumped chemical not well removed by RO	Unlikely - big catchment thus dilution Volume of Parameters more likely to be dumped are less likely to pass through treatment Need to analyse Feed & UF filtrate TOC to understand frequency of occurrence One elevated TOC event occurred Xmas 2010, possibly from this type of event? Corrective actions occured (for data see Doc#4364847). One elevated feed Simazine event occurred in Apr 2010 (~100ug/L but was removed by RO) most likely due to a "dumping" event (Review Doc #5468002 & 5306236). Sensitivity of the UF filtrate TOC would be unlikely to detect this change in concentration (i.e. 100ug/L change in ~8000ug/L TOC background).	3	D	**Moderate**	DER controlled waste tracking program Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Diversion - on violation for RO permeate TOC reading. TOC in UF filtrate used for an event monitoring tool. Developed ongoing communication with trade waste customers who potentially store CoCs (fact sheet). Periodic surveillance occurs of commercial precincts in catchment.	online TOC - post UF - investigative purposes CCP - online TOC - RO permeate	Adequate	2	D	**Low**		2	E	**Low**
4	Illegal toxic dumping to sewer access chambers results in failure of secondary treatment process	Potentially dumped: Metals Organics Pesticides Microbiological	Human Health	Contamination of product water due to reduced efficiency 'Failure' of activated sludge process (loss of nitrification) resulting in inadequately treated feed water - chemicals, pathogens, suspended solids	Rare - big catchment thus dilution Volume of parameters more likely to be dumped are less likely to pass through treatment or affect the WWTP operation	3	E	Low	DER controlled waste tracking program Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Diversion - on violation for RO permeate TOC reading Develop & implement AWRP procedures for response to failure of WWTP - using same procedure for GWR 28 as GWRT/GWR 14 When WWTP process under-performing, alarms visible & actioned at plant. Clarify CCP/PCP philosophy between Beenyup and GWR plants. Periodic surveillance occurs of commerical precincts in catchment.	WWTP CCP - online DO - (alarmed at AWRP - as a PCP) AWRP inlet CCP - turbidity and ammonia Online TOC - post UF - used for investigative purposes CCP - online TOC - RO permeate	Adequate	2	D	**Low**		2	E	**Low**
5	Illegal discharge from fixed connections results in contamination of recycled water (unidentified TW customers)	Potentially dumped: Metals Organics Pesticides	Human Health	Contamination of product water	Rare - big catchment thus dilution Volume of parameters more likely to be dumped are less likely to pass through treatment	3	E	**Low**	Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Diversion - post RO on excessive TOC reading - complete post-RO Ensure don't install uncontrolled influent access spots, such as unsecured camlock dump points outside pump stations. In-sewer monitoring program using portable monitors being developed, will occur when operating. Periodic surveillance occurs of commercial precincts in catchment.	online TOC - post UF CCP - online TOC - post-RO	Adequate	2	E	**Low**		2	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK				Drinking Water consumption RESIDUAL RISK		
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
6	Illegal discharge from fixed connections results in failure of secondary treatment process - (unidentified TW customers)	Potentially dumped: Metals Organics Pesticides	Human Health	Contamination of product water Reduced efficiency "failure" of activated sludge process resulting in contamination	Rare - big catchment thus dilution Affects digestors (for a couple of months, e.g. toluene), once in 20+ yrs	3	E	**Low**	Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Diversion - post RO on excessive TOC reading - Complete for post RO Develop & implement AWRP procedures for response to failure of WWTP - complete When WWTP process under-performing, alarms visible & actioned at plant - complete Response and communication protocols for AWRP and Beenyup should be implemented and there should be training - to be implemented once operational Periodic surveillance occurs of commercial precincts in catchment.	WWTP CCP - online DO - alarmed at AWRP AWRP inlet - online Turbidity and ammonia online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate	Adequate	2	E	**Low**	Embed Aroona/AWRP procedure for catchment surveillance at Beenyup	2	E	**Low**
7	Major industries (managed customers) discharging in excess of TW acceptance criteria impacting product water quality	Potentially discharged: BOD Metals Organics	Human Health	Increased BOD, Contamination	Rare: Few large industries in Beenyup catchment, with well-characterised WW & well-defined licencing process Unlikely under enhanced surveillance	2	E	**Low**	Diversion - pre recharge on CCP out of spec Industrial waste licencing criteria met Revise and embed basic response plans for relevant managed customers - COMPLETE Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Site audits carried out at all managed customers and revised permits, specifying allowable loadings and reporting requirements during process or pretreatment failed being rolled out where required. Managed customers are subject to ongoing compliance monitoring programs.	online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate	Adequate	2	E	**Low**		2	E	**Low**
8	Major industries (managed customers) discharging in excess of TW acceptance criteria resulting in WWTP process inefficiency (e.g. process issue in Brownes WWTP)	Potentially discharged: BOD (only current) Possible future: Metals Organics	Human Health	Reduced efficiency of activated sludge process resulting in contamination Increased ammonia levels resulting from higher BOD	Rare: Dependent on operation/efficiency of Industry treatment However Brownes treatment is relatively inneffective anyway so any failure will not excessively increase load on the WWTP Unlikely under enhanced surveillance	2	E	**Low**	Diversion - pre recharge on CCP out of spec Industrial waste licencing criteria met Revise and embed basic response plans for relevant managed customers - COMPLETE Response to unusual discharges – formal procedure developed for responding to unusual discharges and recording outcomes of investigations. Implemented with PRA for events in collection system, partially implemented with Aroona for events at WWTPs (but not yet at Beenyup). Site audits carried out at all managed customers and revised permits, specifying allowable loadings and reporting requirements during process or pretreatment failed being rolled out where required. Managed customers are subject to ongoing compliance monitoring programs.	WWTP CCP - online DO - (alarmed at AWRP as a PCP) AWRP inlet CCP - turbidity and ammonia online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate	Adequate	2	E	**Low**		2	E	**Low**
9	Major industries (managed customers) discharging within TW acceptance criteria but discharging an excess of contaminants not covered by criteria impacting product water quality	Organics Pharmaceuticals Hormones	Human Health	Managed customers discharge unduly adds load to treatment processes for removal of hazards Reputational risks if WC don't understand the wastewater characteristics of businesses discharging to BYP catchment e.g. hospitals	Unlikely as indicated by catchment review Few large industries in Beenyup catchment, with well-characterised WW & well-defined licencing process Only one large hospital within catchment	2	D	**Low**	Treatment process (WWTP & AWRP) adequately reduces all hazards to below guideline value. Managed customers' wastewater quality profiles reviewed as part of site audits Review waste produced by hospital (C&IS) - COMPLETE Reinforcement of correct disposals of Schedule 8 pharmaceuticals - directed by DoH - COMPLETE Site audits carried out at all managed customer to identify chemicals used. Limits on chemicals not currently included in acceptance criteria will be developed and included in trade waste permits where required. Assessment/framework for new chemicals - database within the Corporation to be implemented	online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate Standard Comms for Big customers - Comms complete and on-going	Optimal	2	E	**Low**		2	E	**Low**
	Barrier assessment for Beenyup WWTP **Risk assignment determined using the Water Corporation Risk Matrix**																	
10	Failure of plant screening resulting in 'rags' from TWW entering AWRP	solids (rags)	Infrastructure	Blockage reduced inflow quality - "rags"	Power backup, alarms Screens actually need to be removed to fail, or flow bypass: at inlet or at individual screens Rare for all 5 to be off simultaneously	2	E	**Low**	Screening prior to membranes Communication when/if screens removed or bypassed to allow more frequent backwashing of AWRP incoming screens Primary treatment can assist in settling and removing rags	Screens at inlet of AWRP Feed turbidity as CCP & Pressure differential over screens monitoring Look at the effect strainers are having on instruments during commissioning	Adequate	2	E	**Low**		2	E	**Low**
11	Bypass options 1&2: Partial bypass of PST or failure of PST to Aeration Tanks OR Bypass options 3, 4 & 5: Partial bypass of aeration tanks affecting secondary wastewater quality (see Bypass Options flow chart, AQUA doc #1776113)	solids (rags) chemicals	Infrastructure Human Health	Poor secondary WW quality	More likely in winter, 30mins possible during high flow period wet weather AND during construction works No secondary bypass in previous years (2011/12 and 2012/13 and 2013/14 and 2014/15 and 2015/16)	3	C	**High**	Monitoring requirements of WWTP in Beenyup WWTP Process Control Table. Complete Monitoring requirements in AWRP Process Control Table. Complete Comms link between AWRP & WWTP during Bypass - VERBAL communication and action log Calibrate level indicator in primary effluent channel - Complete Locate offtake for AWRP upstream of secondary process bypass (mitigates full bypass only) Alarms for bypass high level at channel Bypass located downstream feedwater intake	CCPs for WWTP identified in WWTP & AWRP PCTs: CCP: DO at WWTP; PCP: suspended solids; AWRP influent CCP: turbidity and ammonia CCP of >1 WWTP secondary sedimentation tank and aeration tank offline at any one time in one module, or shut down AWRP	Optimal	1	E	**Low**		1	E	**Low**
									AWRP treatment	Feedwater CCP - ~~turbidity~~, ammonia	Adequate	2	E	**Low**		2	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK				Drinking Water consumption RESIDUAL RISK		
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
12	Loss of nitrification for long enough periods in activated sludge process	Ammonium	Plants Human Health	Toxicity (45 mg/L, upper band limit) (This is the upper limit for raw WW) Increased biofouling with in AWRP (i.e.membranes)	Major cause is loss of power or blowers and loss of nitrifing bacteria population Power outage occurred twice in 2013 Power surges 2016 lasting for a couple of hours (after hours) If blowers lose power it takes approx. 1.5 - 2 hours to get back to performance required.	3	D	**Moderate**	Understand ammonia trends out of WWTP by installation of on-line analyser at AWRP inlet (doesn't control aeration at WWTP) - COMPLETE Monitoring CCPs in WWTP in Beenyup WWTP Process Control Table Monitoring CCPs in AWRP Process Control Table Automated Diversion - pre AWRP on low DO as well as high ammonia Comms link & protocol between AWRP & WWTP Defined basis of product water quality requirement: continuous NOT average Response procedures for after hours alarms - implemented	CCPs for WWTP identified in WWTP & GWR PCTs CCP: DO at Beenyup WWTP; PCP: suspended solids; AWRP influent CCP: turbidity, ammonia RO working as defined by: CCP - online conductivity, TOC	Optimal	1	E	**Low**	AWRP CCPs are continuous - it is preferable that the CCPs at Beenyup become continuous rather than composite	1	E	**Low**
13	Loss of healthy microbiological community (aeration) in activated sludge process	pharmaceuticals & trace organics microbiological	Human Health	Contamination - higher feed concs into AWRP (Nitrification/denitrificati on process provides a bio-monitor on feed water quality - marker for source control issues)	Rare - similar to Risk #3 on toxic dumping to sewer From experience: 'wash out" doesn't happen (ie.e. reduced treatment due to high rainfall flows, but no reduction in treatment following the high flows).	3	E	Low	Monitoring CCPs in WWTP in Beenyup WWTP Process Control Table Monitoring CCPs in AWRP Process Control Table Diversion - pre-AWRP on alarms as above TOC online monitoring Asset replacement program for diffusers in place. Need to watch capacity issues and ensure upgrades occur in sufficient time - design capacity not exceeded, operating at capacity. AWRP water treatment if WWTP CCPs don't mitigate risk Diffusers lifespan 10-12 yrs, but are replaced every 8 yrs Annual confirmation on capacity to be reviewed annually in Risk Assessment	DO the CCP for WWTP, alarmed to WWTP/ AWRP and auto diversion CCP - on-line ammonia - AWRP inlet RO working as defined by: CCP - online conductivity, TOC on permeate	Optimal	1	E	**Low**		1	E	**Low**
14	Overloading of treatment tanks (Aeration and/or Secondary SSTs) during maintenance	pharmaceuticals & trace organics microbiological	Human Health	Contamination through insufficient treatment	Unlikely - as above	3	D	**Moderate**	Consider efficiency of treatment during maintenance events - with respect to log credit removal of virus. - PCT specifies CCP of <=1 WWTP tank offline at any one time, or shut down AWRP Comms protocol between WWTP & AWRP - Effective (1x weekly as WWTP CCP by Aroona central laboratory) combined effluent ammonia, plus on-line AWRP feed ammonia analyser Beenyup PCT and AWRP PCT updated after upgrades to reflect 10 aeration tanks in service	CCP - online Turbidity - AWRP inlet CCP - online Ammonia - AWRP inlet online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate CCP: on-line DO measurement in aeration tanks and notified of diversion	Adequate	1	E	**Low**				**Low**
15	Unplanned Power failure impact on activated sludge treatment - no backup power	Phosphorus	(Human Health) Environment Infrastructure	Loss of nitrification/ denitrification Significant P release that can cause membrane scaling - primarily an Infrastructure risk	8hrs blackout max to date, Rare usually short <10mins, 3-4x per year No major power failures in past yr - Need to consider power maintenance as well Currently blackouts occuring approx. once a month (<10 mins)	3	D	**Moderate**	AWRP will be shutdown anyway during power failure, ID lag time required for AWRP re-start after power comes back on, based on failure time Ensure AWRP re-start has lag time On re-start: Pump to dump and monitor (AWRP Turbidity + ammonia & WWTP DO) initially following power failure Still want time specified for >6hrs failures, as DO returns within spec quickly - time should be based on hydraulics of the system WI (for AWRP) in place which indicates follow-up procedure following a power failure. Specific to time (i.e. >8hrs). Also use TOC in AWRP to confirm if have started too early. Diversion due to ammonia will occur before DO Low pH and anti-scalant at RO membranes avoids phosphorus precipitation Review DO time limits as per CCP review (AQUA # 13938591)	CCP - online DO on WWTP aeration tanks online TOC - pre UF - investigative purposes CCP - online TOC - post-RO Time (monitoring & control process to be defined - manual or automatic) CCP - feedwater ammonia	Adequate	3	E	**Low**		3	E	**Low**
16	Unplanned Power failure impact on activated sludge treatment - no backup power	Ammonia Solids	(Human Health) Environment Infrastructure	Loss of nitrification/ denitrification	8hrs blackout max to date, Rare usually short <10mins, 3-4x per year No major power failures in past yr - Need to consider power maintenance as well Currently blackouts occuring approx. once a month (<10 mins)	3	D	**Moderate**	AWRP will be shutdown anyway during power failure, On re-start: Pump to dump and monitor (AWRP Turbidity + ammonia & WWTP DO) initially following power failure Still want time specified for >6hrs failures, as DO returns within spec quickly - time should be based on hydraulics of the system WI (for AWRP) in place which indicates follow-up procedure following a power failure. Specific to time (i.e. >8hrs). Also use TOC in AWRP to confirm if have started too early. Diversion due to ammonia will occur before DO Low pH and anti-scalant at RO membranes avoids phosphorus precipitation Review DO time limits as per CCP review (AQUA # 13938591)	CCP - online DO on WWTP aeration tanks online TOC - pre UF - investigative purposes CCP - online TOC - post-RO Time (monitoring & control process to be defined - manual or automatic) CCP - feedwater ammonia	Adequate	3	E	**Low**		3	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK			Drinking Water consumption RESIDUAL RISK			
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
17	Solids carried over from secondary sedimentation tanks (Clarifiers upset)	solids chemicals microbiological	Infrastructure Human Health	Contamination - solids carry over Solids carry over causing membrane fouling or fine screen blockage resulting in reduced productivity	Clarifier upset: 2 - 3 day turbidity increase in inflow, at least 15x per year = 12% of time Reduced frequency for 2009/10 ~ 6x per year this last year Reduced frequency and duration for 2010/11 (2-6hrs) Reduced frequency 2012/13 (8-10 per year) Issues in 2012/13 were not due to clarifier upsets due to solids, but due to power outages. Good settleability occurs. Occurred in 2014 - Blockages in the foam harvester and skimmer for scum allowed solid carryover (March). There were also issues with the mixers and recycle pumps in the secondary treatment area (April), the chlorination system at Beenyup WWTP and the mixed liquors (June) which resulted in solids carryover to the AWRP. Heavy rainfall events occured in 2014/2015 resulting in solid carry over. Shutdowns for AWRP in 15/16 occured	2	A	**High**	Operate WWTP in accordance with WWTP PCT Continuous turbidity & ammonia monitoring of AWRP influent (E&H reliable, changed once per year) CCP resulting in auto AWRP bypass Ensure well calibrated Turbidity meter Investigate all spikes from on-line data to determine cause - Complete, Process defined: report is created and sent to AWRP PTO by WWTP PTO Investigation of turbidity vs inflow to Beenyup particularly on days/events of rainfall to be commenced.	SVI & Solids loading weekly on Secondary WWTP PCT CCP - online Turbidity and ammonia - AWRP inlet online TOC - pre UF - investigative purposes CCP - online TOC - RO permeate SDI automated - frequency to be determined during commissioning	Optimal	1	D	**Low**		1	D	**Low**
18	Poor quality centrate from centrifuges and/or DAF tanks causing organics overload	Polymer Nutrients Solids Struvite	Human Health	Contamination of feed water to AWRP	Occurs very infrequently Fines removed in secondary treatment Polymer/struvite can cause nutrient overload	2	C	**Moderate**	Monitor quality of centrate and DAFT underflow on a scheduled basis WWTP PCT controls secondary treatment Published WWTP sludge handling PCT which does not need to be in AWRP PCT as the DO CCP for WWTP is satisfactory.	WWTP CCP - online DO measurements CCP - online Turbidity and ammonia - AWRP inlet online TOC - post UF - investigative purposes CCP - online TOC - RO permeate CCP online ammonia in AWRP feed would indicate overload of AWRP - need to monitor appropriately daily & set target	Optimal	1	E	**Low**		1	E	**Low**
19	Poor quality reject from other treatments (minor solids treatment required from other trains)	Solids	Human Health	Contamination of AWRP feedwater	Unlikely Major tank drainage goes to the head of the process	2	D	**Low**	Design of AWRP sufficient WWTP PCT controls secondary treatment	WWTP CCP - online DO measurements CCP - online Turbidity and ammonia - AWRP inlet online TOC - post UF - investigative purposes CCP - online TOC - RO permeate CCP online ammonia in AWRP feed would indicate overload of AWRP - need to monitor appropriately daily & set target	Optimal	2	E	**Low**		1	E	**Low**
20	Skimmings carried over from PSTs and passed through secondary treatment process	Oil and Grease	Infrastructure	Damage to UF	Unlikely Bulk oil & grease will be removed by PSTs and inlet screens, remainder will be well treated by secondary treatment process Skimming scraper breakdown, inadequate removal of new SSTs (no scrapers) Foam harvester at secondary treatment on channels AWRP has a feedwater boundary limit of 5 mg/L for O&G - no O&G detected at AWRP	2	D	**Low**	Design of AWRP sufficient, Oil & grease removed in PSTs & not taken up by AWRP influent pumps Submerged pump in AWRP wet well (oil & grease float) Grease use for lubrication/maintenance has a WI for disposal or leak/spill management	Not required	Optimal	2	E	**Low**		2	E	**Low**
21	Skimmings/biolofical fouling carried over from feedwater pump station	Biological	Infrastructure	Damage to UF	Likely - biological scum has been observed in feedwater pump station in 2016. That is scum overflowing from secondary tanks and is being collected in the feedwater pump station. When pump station lelve is low, scum can be drawn into the feed pumps in a "batch". Skimming scraper breakdown, inadequate removal of new SSTs (no scrapers) Foam harvester at secondary treatment on channels	2	C	**Moderate**	Design of AWRP sufficient - screens/UF/RO/UV Fouling has been observed post feedwater turbidity - will be sent to in-line balance tank as per proposed design Submerged pump in AWRP wet well	UF filtrate turbidity CCP Turbidity PCP downstream of feed tank	Optimal	2	E	**Low**		2	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK			Drinking Water consumption RESIDUAL RISK			
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
22	Contamination of WWTP influent by AWRP reject - including backflush water, RO concentrate, water treatment byproducts, purge water & bypass at Feed	solids chemicals organics	WWTP	Microbiological treatment processes - digestion, activated sludge, settleability of solids Hydraulic load (particularly of bypass) overloads WWTP	Designed to be unlikely, assess through Reject water monitoring Experience indicates no issues over last 3 years Biocide used in 2013 - quantity of biocide returning to head of plant is insignificant Weir design for Feedwater pump station	2	C	Moderate	Designed no storage of reject so no shock load to WWTP. Checked against Industrial waste acceptance criteria Ensure reject water meets IW acceptance criteria - monitoring Design is the mitigation, waste from the AWRP will goo to the OO not the head of the WWTP. To be comfirmed during commissioning. Design of Stage 2 to consider balancing tanks and PSTs and screens for return of screening reject into Burns Beach Sewer	Assessed likely reject water quality against C&IS criteria normal process to provide 'permit' for Trial/Stage 1 plant waste stream	Optimal	2	E	**Low**		2	E	**Low**
23	WWTP capital upgrades & planned shutdowns	solids chemicals organics	Infrastructure Human Health Plants	Non compliant feedwater Project Risk - get a failure/shutdown of AWRP Delays, reputation	biggest potential impact is during daily peak flow Proposed upgrade schedule for Beenyup to occur whilst Stage 2 is operating	2	C	Moderate	Regular communication between AWRP Ops and Beenyup Ops team during Operation. AWRP Ops, WWTP Ops liaison meetings - informally - co-located now ONGOING: Ensure any large maintenance items picked up in Comms between AWRP Ops & WWTP Ops Pre-start meeting at AWRP every day discusses Beenyup WWTP Maintenance meetings weekly Proposed upgrade schedule for Beenyup to occur whilst Stage 2 is operating Monitoring of CCPs in AWRP	CCPs - AWRP	Adequate	2	D	**Low**		2	E	**Low**
24	Refurbishment of old/aging assets in WWTP	solids chemicals organics	Infrastructure	Non compliant feedwater Project Risk - get a failure/shutdown of AWRP Delays, reputation	Likely - need to plan for it Proposed upgrade schedule for Beenyup to occur whilst Stage 2 is operating	2	C	Moderate	Regular communication between AWRP Ops and Beenyup Ops team during Operation. AWRP Ops, WWTP Ops liaison meetings - informally - co-located now ONGOING: Ensure any large maintenance items picked up in Comms between AWRP Ops & WWTP Ops Pre-start meeting at AWRP every day discusses Beenyup WWTP Maintenance meetings weekly Proposed upgrade schedule for Beenyup to occur whilst Stage 2 is operating	Not applicable	Adequate	2	D	**Low**		2	E	**Low**
25	Ocean outfall operational capacity	solids chemicals organics	Reputational Infrastructure Human Health Plants	Operational capacity of ocean outfall - could lead to back up in flow in weir /WWTP Corrosing/biofouling	Corrosion or biofouling of outfall from seawater instrusion If outfall "blocked" under high flow, potential for downstream leveles to rise and weir fails to control backflow and influent ammonia CCP fails	3	C	**High**	Prevention of salt water intrusion Clogging of ports by marine life Design required to prevent/minimise seawater intrusion into outfall Weir arrangement (AQUA # 14928556) replaced the duck bill valve to prevent backflow Weir set up at RL8.3 m AHD for 28 GL/year flows High level instrument and high level alarms required downstream of weir	Nil CCPs AWRP - turbidity	Adequate if appropriate design implemented, otherwise inadequate	3	D	Moderate	Moderate risk should be reduced to low following detailed design processes and will be reassessed at detailed design RA.	2	E	**Low**
26	Capacity of WWTP to meet feed water quality requirements sufficiently	water allocation	Reputational	Can not meet water production targets Project Risk - get a failure/shutdown of AWRP Delays, reputation	Designed to be unlikely - assess through monitoring	2	C	Moderate	Ensure WWTP can meet production targets Design of AWRP to ensure 28 GL can be produced		Optimal	2	E	**Low**		2	E	**Low**
27	WWTP not being able to adequately meet water quality requirements for AWRP from power outages/shutdowns	solids chemicals organics	Human Health	Microbiological treatment processes - digestion, activated sludge, settleability of solids Hydraulic load (particularly of bypass) overloads WWTP	Designed to be unlikely - assess through monitoring	2	C	Moderate	Regular communication between AWRP Ops and Beenyup Ops team during Operation. AWRP Ops, WWTP Ops liaison meetings - informally - co-located now ONGOING: Ensure any large maintenance items picked up in Comms between AWRP Ops & WWTP Ops Pre-start meeting at AWRP every day discusses Beenyup WWTP Maintenance meetings weekly Proposed upgrade schedule for Beenyup to occur whilst Stage 2 is operating	CCPs AWRP	Optimal	2	E	**Low**		2	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK			Drinking Water consumption RESIDUAL RISK			
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
28	Misalignment of WWTP upgrade/maintenance & secondary treatment operations		Infrastructure	Non compliant feedwater Project Risk - get a failure/shutdown of AWRP Delays, reputation	biggest issue during daily peak flow	2	C	**Moderate**	Regular communication between AWRP Ops and Beenyup Ops team during Operation. AWRP Ops, WWTP Ops liaison meetings - informally - co-located now ONGOING: Ensure any large maintenance items picked up in Comms between AWRP Ops & WWTP Ops Pre-start meeting at AWRP every day discusses Beenyup WWTP Maintenance meetings weekly	Not applicable	Adequate	2	D	**Low**		2	E	**Low**
	Barrier assessment for GWR AWRP **Risk assignment determined using the Water Corporation Risk Matrix**																	
29	Ineffective chloramination	Microbiological (fouling)	Infrastructure	biological fouling of membranes chloramination not designed for pathogen removal Biofouling of membranes observed - but only long term (days) loss of chloramination causes irreversible fouling	(dosing failure) Yes occurs, but interlock to shutdown Raw water pumping New GWRS design incorporates preformed monochloramine dosing.	2	C	**Moderate**	Design allows for finely controlled dosing pumps chloramine online analysers - with frequent maintenance & lab verification Stop raw water pumping if lose monochloramine dosing. Maintenance servicing of dosing system to be confirmed Duty-standby on dosing system (I.e. redundancy) Top up point for monochloramine dosing prior to RO Current trends (Feb-June 2016) ammonia concentration is variable. Commissioning of AWRP Stage 1 still to occur.	Interlock on monochloramine dosing system Adequate chloramine analyser on UF and RO feed	Optimal	2	D	**Low**		2	D	**Low**
30	Contamination of AWRP feedwater with AWRP Reject Water via BOO	Pathogens Chemicals	Human Health	Contamination of AWRP feedwater resulting in process upset	Designed to be unlikely, assess through monitoring	2	A	**High**	Weir arrangement (AQUA # 14928556) replaced the duck bill valve Weir set up at RL8.3 m AHD for 28 GL/year flows High level instrument and high level alarms required downstream of weir	Interlocks CCPs present at AWRP inlet	Adequate	2	D	**Low**	To be confirmed at commissioning for Stage 1 Recommended CCP for Stage 2			
31	In-line operation of balance tank causing excessive microbiological growth in the balancce tank impacting AWRP operation	Microbiological (fouling) Temperature	Human Health Infrastructure	Increased microbial loading onto membranes Process upset with vairable feedwater	New process design - to be assessed during commissioning	2	C	**Moderate**	New design to be assesed during commissioning and operation for Stage 2 Tanks are designed to operate at full working volume for all times Design for Stage 2 is for full flow operation	CCPs - turbidity UF feed turbidity - PCP	Adequate subject to suitable design	2	C	Moderate	To be confirmed at commissioning for Stage 2. Risk is deemed to be low, but operational performance and detailed design is required to reassess the risk.			
32	Membrane degradation (UF) Damage or loss of membrane integrity (fibres or seals broken)	solids Organic chems Microbiological	Human Health	Contamination (loss of LRV for pathogens)	Due to: -Process malfunction - PDT process failure (blowers, air process) -chemical attack (all membranes at once) - CIP/MW strength -wear and tear (lifetime) -defects Choice of new UF membrane supplier could reduce this risk in the future	4	C	**High**	On-line analysers: Filtrate turbidity Instrument calibration - high priority with Maintenance supplier & Ops Pressure decay testing (PDT daily) System inspection & audit Monitor delta pressure, & flow across membranes (incl alarms) CIP, Maintenance washes daily, back-washes. CIP backwash procedures optimised SDI tests done weekly on RO feed - also confirms suitable UF operation Look for and recognise slippy fibre (& other defects) early GWR 14 Design: Bubble tubes for PDTs, individual membrane isolation Test rigs available for integrity investigations QA/QC protocols on installation verification FAT/SAT of manufacturing process Protect UFs from contamination (with suitable specification of pipework flushing - e.g. high pressure flushing pipework) Storage requirements to be followed MS2 testing to confirm LRV	On-line analysers: interlocks CCP: turbidity (individual filtrate turbidity, combined filtrate turbidity) Instrument calibration Pressure decay testing (PDT daily) & system inspection Monitor delta pressure across membranes (alarms with action)	Optimal	2	E	**Low**		2	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK				Drinking Water consumption RESIDUAL RISK		
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
33	Membrane degradation (RO) Damage or loss of membrane integrity (membrane or seals damaged)	Organic chemicals Microbiological	Human Health	Contamination Loss of micro LRV	Due to: - Back pressure surge (happened in commissioning) - oxidative attack, - irreversible fouling (chemical or biological) - instrument malfunction - wear & tear - CIP chemicals (e.g. caustic)	4	C	**High**	Online meters & alarms identifying adequate treatment: conductivity, TOC, Online salt passage (for Info) Instruments protecting RO (feed): pH, ORP (RO feed automated on alarm to prevent Cl2 oxn), monoCl, filtrate turbidity, Instrument calibration. Antiscalant dosing Manual SDI check (weekly) of RO feed water. Automated - to be confirmed during commissioning CIP. High press safegards inplace (normal operation & CIPs); CIP discharge pump press; RO cartridge filt DP; bursting discs; CIP valve sequencing; DP across stages/trains (alarmed). Commissioning - ensure sufficient procedures (Hydranautics) for QA/QC & membrane mapping. Use vessel probing/profiling to trouble shoot membrane integrity issues. Automated profiling - GWR Design Use pH and ORP to investigate whether UF CIP solution is passing onto RO - extra UF flush now prevents this. Instrument calibration & Antiscalant dosing Rhodamine challenge testing (2011 - 2014) > 3LRV - 6 monthly Sulfate testing > 3 LRV (2012 - 2014) - weekly Ongoing for GWR 14 - Research to continue Test rig available for integrity investigations 3 way valve design on Stage 1 - potential to dead head RO membranes. Not installed for Stage 2. Lesson learned for Stage 2 - update BDC to ensure good valve design.	Online meters & alarms: CCPs: conductivity, TOC, (autodivert if outside criteria) Feed interlocks (auto-diverts): pH, ORP, monochloramine, Turbidity Monitor delta pressure across stage 1 & 2 membranes (alarms & interlocks) Conductivity and temperature alerts	Optimal	2	E	**Low**	Ensure valve design for RO's do not allow the potential to dead head RO	2	E	**Low**
34	UV effectiveness reduced	chemicals	Human Health	Loss of barrier (Loss of virus LRV)	Effectiveness reduced due to: film build up lamp failure Divert to waste if UV Intensity does not achieve intensity setpoint % Transmittance - normal water quality at a higher trasmittance than required (97% vs 94%).	4	D	**High**	Use Corporate Design standard Maintenance; reg cleaning program in place with stds recommended by manufacturer + sensor cleaning. Chloramine, UF, RO operation. Continuous monitoring of UV Intensity, Power, transmissivity & flow with alarms. on-line UV intensity indicates film or scaling	CCP continuous monitoring of UV intensity, flow, dose (RED)	Optimal	2	C	**Low**		2	D	**Low**
35	Process By-pass through AWRP	chemicals pathogens	Human Health	Cross connections	Designed to be unlikely, assess through monitoring Cross connections have occurred during construction of Treatment Plants	2	D	**Low**	Installation and commissioning of the AWRP Stage 1 Balance tank for Stage 2 is in-line Ensure instruments have corect piping and flushing operation (to avoid potable water contamination as well) N.B. Need to confirm that no possibility of backflow through the reject collection system from Stage 1 to Stage 2 (and vice versa).	Online instrumentation CCPs	Adequate	2	D	**Low**	To be confirmed at commissioning for Stage 1	2	E	**Low**
	Over-arching Hazardous Events **Risk assignment determined using the Water Corporation Risk Matrix**																	
36	Monitoring system integrity failure due to: - Inadequate calibration program of monitoring devices	TOC, conductivity, turbidity, pH	Infrastructure Human Health Plants	destroy membranes recharging non-compliant water	Likely, need to plan for it - i.e. a robust maintenance & calibration program required for all instruments e.g. TOC instrument	3	B	**High**	Design for shutdown for appropriate failures Appropriate instrument selection and calibration program - Monitored by Ops/Plant Manager Calibration program reviewed for pH, conductivity & TOC (included all instruments) Instrument verification/management required ongoing (look for partial failures) Audit procedures - in house Appropriate maintenance program, Spares Redundancy - consider for critical control points - to be confirmed WWTP DO probe calibration process includes regular 2 weekly cleans Approval of PCT Effective change management required for GWR 14 Access requirements - CCP set points locked. Change management process required for changes. Ensure AS4020 compliance for all instruments post RO permeate	Shutdown on CCP instrument or Communications failures Calibration and verification of instruments Management System QA/QC Process	Optimal	3	D	**Moderate**	GWR system proving required (2-3 years) before inherent risk can be reduced. Risk is deemed to be low, but operation of Stage 1 will confirm risk rating to be lowered.	3	E	**Low**
37	Monitoring system integrity failure due to: PLC issues / FCD coding errors	TOC, conductivity, turbidity, pH	Infrastructure Human Health Plants	destroy membranes recharging non-compliant water Uncertainty causing major inconvenience, regulatory risk (causing shutdown)	Likely, need to plan for it - i.e. a robust maintenance & calibration program required	3	B	**High**	Design for shutdown for appropriate failures Verification/management required ongoing (look for partial failures) Effective use and management of PLC programme version control, (Backup prior to any modification & regularly: Reviewed by Ops) Audit procedures - in house Effective change management required for GWR 14 Access requirements - CCP set points locked. Change management process required for changes. FAT and SAT testing of the PLC and control system will be undertaken to detect any issues with programming	Management System	Optimal	3	D	**Moderate**	GWR system proving required (2-3 years) before inherent risk can be reduced. Risk is deemed to be low, but operation of Stage 1 will confirm risk rating to be lowered.	3	E	**Low**

Barrier Failure Assessment						Risk to AWRP INHERENT RISK					Post Mitigation INHERENT RISK				Drinking Water consumption RESIDUAL RISK		
Ref	Description (Failure mode or process upset)	Hazard/Compound	End Point	Consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigation	Critical Control point	Control Effectiveness Rating	Consequence	Likelihood	Risk Level	Environmental Barrier	Consequence	Likelihood	Risk Level
38	Insufficient commissioning of AWRP treatment processes and control systems	TOC, conductivity, turbidity, pH	Infrastructure Human Health Plants	destroy membranes recharging non-compliant water Uncertainty causing major inconvenience, regulatory risk (causing shutdown)	Likely, need to plan for it - i.e. ensure construction is complete prior to commissioning	3	B	High	Design for shutdown for appropriate failures Verification/management required ongoing (look for partial failures) Audit procedures - in house Effective change management required for GWR 28 Access requirements - CCP set points locked. Change management process required for changes. FAT and SAT testing of the AWRP processes Ensure appropriate hold points for commissioning program are adhered to (WC accountability)	Management System	Adequate	3	D	Moderate	GWR system proving required (2-3 years) before inherent risk can be reduced. Risk is deemed to be low, but operation of Stage 1 will confirm risk rating to be lowered.	3	E	Low
39	Re-introduction of solids post-RO causing clogging of recharge bore	Clogging of bore-aquifer interface due to solids introduction post-RO	Physical clogging of recharge bore	Clogging of bore aquifer interface	Unlikely: only treatments post-RO are: UV disinfection, degassing, and NaOH dosing Intrusive maintenance work instructions Storage/transfer tank to be used prior to sending water to recharge bores	2	D	Low	Limited opportunity for solids introduction in treatment process post-RO. Strainer on NaOH dosing line Manual daily turbidity sampling of product water at headworks Degasser filters checked for integrity Storage/transfer tank to be used prior to sending water to recharge bores	Strainers of NaOH dosing line Operations Protocol: manual sampling post-tank pre-recharge bore - on commencement of recharge	Optimal	2	E	Low		2	E	Low
40	Reintroduction of any contamination prior to final CCP	Microbiological Chemical Turbidity	Human health	Non compliance	Unlikely: not seen in GWRT	3	D	Moderate	Maintenance and operational procedures to ensure lines are flushed Approved chemical suppliers. Procurement/ contract process ensures quality suppliers (Same as for Drinking Water). GWR 14 Design: Divert at the pump station downstream from product tank prior to recharge Security around recharge bores AS4020 compliance post RO permeate		Optimal	2	E	Low		2	E	Low
41	Reintroduction of any contamination post final CCP prior to recharge	Microbiological Chemical Turbidity	Human health	Non compliance	Unlikely	3	D	Moderate	Maintenance and operational procedures to ensure lines are flushed Approved chemical suppliers. Procurement/ contract process ensures quality suppliers (Same as for Drinking Water). GWR 14 Design: Divert at the pump station downstream from product tank prior to recharge Security around recharge bores AS4020 compliance post RO permeate		Optimal	2	E	Low		2	E	Low
42	Reintroduction of any contamination after final CCP prior to recharge (i.e. transfer pump at AWRP to storage tank)	Microbiological Chemical Turbidity	Human health	Borefield contamination	Unlikely	3	D	Moderate	Maintenance and operational procedures to ensure lines are flushed Approved chemical suppliers. Procurement/ contract process ensures quality suppliers (Same as for Drinking Water). GWR 28 Design: Divert prior to recharge Security around recharge bores Recharge bore headworks are designed to prevent cross-contamination from external sources (to WC drinking water production bore standards) Appropriate pipeline material AS4020 compliance post RO permeate		Optimal	2	E	Low	Final CCP for Stage 2 is at Beenyup (AQUA # 15402254)	2	E	Low
43	Cross contamination between wastewater plant and AWRP and recharge bore - maintenance - sampling	microbiological	Human Health	Sample contamination giving false positive results Confusion & uncertainty, Loss of credibility	Use of common tools Insufficient QA on sampling Recharge bores are located off-site Considered a higher risk with off-site locations	2	C	Moderate	Operator training, culture, adequate procedures including: Maintenance protocols - WI exists: includes disinfecting tools. Only disposable items are changed, boots washed and tools disinfected. QA/QC for sampling including change of gloves, sampling order (clean to dirty) AWRP Stores within old GWRT plant/maintenance shed. Dedicated team for AWRP for GWR 14. Recharge bores are located off-site Procedure required for maintenance work required on abstraction bore vs recharge bore	Management System QA/QC Process, Work Instructions Maintenance Plan	Adequate	2	E	Low		2	E	Low
44	Cross connections between potable water on site with process water	microbiological	Human Health	Sample contamination giving false positive results Confusion & uncertainty, Loss of credibility	Designed to be unlikely, assess through monitoring Cross connections have occurred during construction of Treatment Plants	2	D	Low	Installation and commissioning of the AWRP for Stage 1/Stage 2 Monitor construction of Stage 2 pipework to avoid cross contamination with Stage1	CCPs Management System QA/QC Process, Work Instructions Maintenance Plan	Adequate	2	E	Low		2	E	Low
	Barrier Assessment for New Off-site Pipeline and bore compound **Risk assignment determined using the Water Corporation Risk Matrix**																	
45	New Pipeline from AWRP to borefield - material selection for pipework/construction activities	Microbiological Chemical	Infrastructure Human Health	Non compliant product water	New process design Design using HDPE/GRP to avoid pipeline contaminating product water	2	D	Low	management requirement for flushing - PRA WI CCPs/PCPs required to monitor water quality up to recharge bores Ensure AS4020 compliance for any material post RO permeate Consutrction FAT/SAT testing	pH, temperture, conductivity at recharge bores monitoring program for borefield		2	E	Low	Bringing a supply main back on-line (AQUA # 367317) http://aqua/link/Link.aspx?doc=459300 Precommissioning form for flushing mains (AQUA # 14174884)	2	E	Low

Barrier Failure Assessment						Risk to AWRP INHERENT RISK						Post Mitigation INHERENT RISK				Drinking Water consumption RESIDUAL RISK		
Ref	**Description (Failure mode or process upset)**	**Hazard/Compound**	**End Point**	**Consequence**	**Likelihood**	**Consequence**	**Likelihood**	**Risk Level**	**Mitigation**	**Critical Control point**	**Control Effectiveness Rating**	**Consequence**	**Likelihood**	**Risk Level**	**Environmental Barrier**	**Consequence**	**Likelihood**	**Risk Level**
46	New Pipeline from AWRP to borefield - pipework compromised (e.g maintenance activities)	Microbiological Chemical	Reputation Compliance Infrastructure Human Health	Integrity of pipework compromised/security breaches e.g. via Valves/scour points/air valves	New process design	3	E	Low	management requirement for flushing - PRA WI recharge bores are in a secure location and can not be tampered with Standards required for pipework - recycled water (e.g. purple pipe) / drinking water / transfer main	monitoring program for borefield		2	E	Low	Bringing a supply main back on-line (AQUA # 367317) http://aqua/link/Link.aspx?doc=459300 Security breach: AQUA # 554554 Internal discussions required about nomenclature of water post final CCP - this will influence the standards required for the pipework	2	E	Low
47	New Pipeline from AWRP to borefield - illegal connections	Microbiological Chemical	Infrastructure Human Health	Contamination of pipework by Illegal connections	New process design	3	E	Low	management requirement for flushing - PRA WI CCPs/PCPs required to monitor water quality up to recharge bores sizing of transfer pipework - highly unlikley customers will be able to connect (pipework also undergound)	monitoring program for borefield		2	E	Low	Bringing a supply main back on-line (AQUA # 367317) http://aqua/link/Link.aspx?doc=459300 Securtiy breach: AQUA # 554554	2	E	Low
48	New Pipeline from AWRP to borefield - non compliance in water quality	Microbiological Chemical	Infrastructure	Non compliant product water Maintenance of the pipework not carried out Bore efficiency	New process design Design using HDPE/GRP to avoid pipeline contaminating product water	2	D	Low	management requirement for flushing - PRA WI maintenance plans/inspections for pipework	monitoring program for borefield		2	E	Low	Precommissioning form for flushing mains (AQUA # 14174884)	2	E	Low
49	Impact of perceived incompatible activities within recharge management zone	Microbiological Chemical	Reputational Human Health	Land management for Rechage Management Zone > 250 m	New process design	2	D	Low	Approved bore construction materials and processes to protect confined aquifer bore from contamination from surface or superificial aquifer activities Stage 1 monitoring occuring Communication response plan developed for perceived impact	monitoring program for borefield		2	E	Low		2	E	Low
50	Security breach at bore compound	Microbiological Chemical	Infrastructure Human Health	Integrity of bore compound compromised/security breaches	New process design	3	E	Low	management requirement for flushing - PRA WI recharge bores are in a secure location and can not be tampered with Reporting protocol for security breaches to DoH - sampling possibly required	monitoring program for borefield / AWRP		2	E	Low	Security breach: AQUA # 554554 Internal discussions required about nomenclature of water post final CCP - this will influence the standards required for the pipework/reporting requirements after security breach	2	E	Low
51	Off spec water at recharge bore (PCPs have triggered but all CCPs are within specification)	Microbiological Chemical	Infrastructure Human Health	Integrity of pipework / instruments	New process design	3	D	Moderate	management requirement for PCP and CCP operation for recharge site recharge bores are in a secure location and can not be tampered with Reporting protocol to to DoH - sampling possibly required	monitoring program for borefield / AWRP		2	E	Low		2	E	Low
52	Non compliance in water quality at bore compound	Microbiological Chemical	Infrastructure Human Health	Non compliant product water Bore efficiency	New process design	2	D	Low	management requirement for flushing - PRA WI maintenance plans/inspections for pipework	monitoring program for borefield		2	E	Low	Precommissioning form for flushing mains (AQUA # 14174884)	2	E	Low
53	Bore clogging requires redevelopment of bores	Microbiological Chemical	Environment Human Health	Disposal / environmental approvals	New process design	2	D	Low	management requirement for flushing - PRA WI	monitoring program for borefield		2	E	Low	Discussion with DER on environmental approvals required for bore redevelopment	2	E	Low
54	Microbiological clogging of bores caused by indigenous or introduced microbiological communities	Microbiological	Environment Human Health Aquifer	Recycled water provides a food source for native biological communities	Service interruption Unlikely - no detectable microbial clogging observed during GWRT	2	D	Low	AWRP designed to remove micro-organisms Maintain low concentrations of nutrients in recycled water to limit biomass growth Disinfection residul - monochloramine dosing in AWRP Disinfect down hole valve equipment after maintenance prior to returning to service	monitoring program for borefield	Adequate	2	D	Low	Discussion with DER on environmental approvals required for bore redevelopment	2	E	Low

Legend for Colours:

Previous to 2016

Post 2016 RA

Appendix 3: Aquifer Preliminary Risk Assessment Tables

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
Leederville Aquifer Risk Assessment													
Risks from Drilling and Bore Construction													
1	**Bore failure** caused by geological conditions	Bore Infrastructure	Cavernous limestone causing loss of drilling fluids.	**Insignificant [Financial]:** Increased construction times and costs.	**Almost Certain**	1	A	Moderate	Current practices mitigate this risk, i.e.: (1) Approved drilling techniques (2) Appropriately set pre-collars (3) Drilling pre-collar holes using approved technique (such as dual rotary, mud rotary advance casing). If mud used, driller prepared for significant or total mud loss (4) Hydrogeologist availability	Adequate	1	E	Low
2	**Bore failure** caused by geological conditions	Bore Infrastructure	Swelling of clays resulting in loss of drilling equipment.	**Minor [Financial]:** Increased construction times and costs.	**Unlikely**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and drilling mud, ensuring muds do not contaminate samples or aquifer. (2) Appropriate mud programme developed with advice from "Mud Engineer" (3) Appropriate supervision including real time monitoring (4) Contractor planning - minimise the time the hole is open	Adequate	2	D	Low
3	**Bore failure** caused by geological conditions	Bore Infrastructure	Encountering hard rock resulting in slow penetration through the aquifer	**Insignificant [Financial]:** Increased construction times and costs.	**Possible**	1	C	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and equipment (2) Appropriate contractor planning, maintenance and spares	Adequate	1	C	Low
4	**Bore failure** caused by bore construction technique	Bore Infrastructure	Loss or collapse of casing string.	**Minor [Financial]:** Increased construction times and costs. Required to redesign and drill new a bore.	**Possible**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and equipment and process control. (2) Utilise "quick connectors" in bore casing/screen assembly	Adequate	2	D	Low
5	**Bore failure** caused by bore construction technique	Bore Infrastructure	Failure during cement grouting of casing resulting in cement setting in screens.	**Minor [Financial]:** Increased construction times and costs. Change in bore design.	**Possible**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques. (2) Appropriate bore construction. (3) Appropriate cementing methodology with controls (possible stage cementing)	Optimal	2	E	Low
6	**Bore failure** caused by bore construction technique	Bore Infrastructure	Bore screens are not set in selected geological unit.	**Insignificant [Reputational]:** Water quality results do not reflect geological units as expected.	**Unlikely**	1	D	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques (2) Lithological and Geophysical logging (3) QA/QC during receive/storage/transport/construction - casing tally, numbering/barcoding Thick sandstone beds are present in Leederville aquifer which will make it easier to set screens in required geological unit.	Adequate	1	D	Low
7	**Bore failure** caused by poor installation gravel pack OR incorrect gravel size or slot size for application	Bore Infrastructure	Has potential for collapse of aquifer formation around the bore during development which will result in reduced permeability of recharge zone near bore interface	**Minor [Financial]:** Reduced recharge capacity Required to redesign and drill new a bore.	**Possible** **Is an issue with deep bores due to unconsolidated parts of the formation**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor, methodology and equipment and process control.	Adequate	2	D	Low
8	**Recharge of non-target layers** caused by poor sealing of bore annulus	Aquifer - wrong layers recharged	Poor sealing allows unintended transfer of the recharged water into other layers of the aquifer	**Minor [Reputational]:** Bore no longer reliable, potentially resulting in: * inefficient recharge * upward leakage into overlying aquifer * flow into Superficial aquifer	**Unlikely**	2	D	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques (2) Engage a cementing contractor/specialist, ensuring appropriate cementing controls, pressure monitoring (3) Possible staged cementing completion (4) Geophysical logging	Adequate	2	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
9	**Ingress of non-target groundwater into bore samples** caused by poor sealing of bore annulus	Aquifer - wrong layer sampled	Poor sealing allows ingress of groundwater from overlying and underlying strata resulting in incorrect sampling.	**Insignificant [Compliance]:** Bore no longer reliable and could result in sampling layers other than that intended, therefore water quality results do not reflect geological units as expected.	**Unlikely**	1	D	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques (2) Engage a cementing contractor/specialist, ensuring appropriate cementing controls, pressure monitoring (3) Possible staged cementing completion (4) Geophysical logging	Adequate	1	D	Low
10	**Casing/Screens corrosion**	Bore Infrastructure	Low ionic strength recycled water may cause corrosion to the casing/screens, potentially causing damage to recharge bore infrastructure	**Minor [Service Interruption]:** Bore infrastructure failure caused by corrosion	**Likely -** Minimal buffering capacity of recycled water, corrosion will occur if inadequate materials are used for construction	2	B	High	**Design:** Use appropriate materials in bore construction that are approved for use in water bores (i.e. FRP casing, SS screens) **Operation:** pH adjustment to target 7.5 (NaOH dosing) will assist in ongoing mitigation of risk **Monitoring:** Inspection of GWRT recharge bore (LRB1) after ~4yrs recharge, by camera log Oct-2014 indicated screens in very good condition (limited corrosion of welds) Implement bore condition monitoring programme	Optimal	2	D	Low
11	**Risk of deteriorating recharge bore integrity**	Operator and Visitor safety	Infrastructure damage caused by recharge pressure. Damage to headworks and bore, releases water under pressure at surface injuring a by-stander Lost recharge production	**Minor [People]:** Upward leakage caused by inadequately sealed bore casing Injured by-stander **Minor [Service Reduction]:** Reduced recharge capacity	**Rare**	2	E	Low	**Design:** Utilise appropriate bore design, drilling and construction techniques Design criteria and WI in place to ensure appropriate materials/fittings used Design limit for headworks is 150m (TBC once final design) head above ground level, maximum operating pressure will be below this, controlled with setpoints with automatic shutdown if exceeded **Monitoring:** Pressure monitoring and control setpoints of recharge system Recharge pump monitoring and improvement with appropriate maintenance	Optimal	2	E	Low
12	**Poor site layout resulting in reduced drilling, redevelopment options**	Operation	Multiple Leederville and Yarragadee monitoring and recharge bores will be installed on the same site. Site to be structured to enable optimal drilling and construction plus redevelopment and sampling options once all site infrastructure installed.	**Minor [Service Reduction]:** Site layout does not allow for safe efficient redevelopment and sampling options, increase time and cost	**Rare** If proper planning is implemented	2	E	Low	**Planning:** Ensure drilling project engages surface project to design optimal site layouts.	Optimal	2	E	Low
Bore Clogging and Reduced Aquifer Permeability													
13	**Clogging of recharge bore - aquifer interface** caused by solids in recycled (recharged) water	Bore Infrastructure	Clogging of bore-aquifer interface due to solids introduction after reverse osmosis	**Minor [Service Interruption, Financial]:** Physical clogging of the recharge bore resulting in reduced efficiency - potentially to the extent that recharge cannot occur.	**Unlikely -** with current level of treatment (i.e. low risk of introduction of solids after reverse osmosis)	2	D	Low	GWRT AWRP design mitigated this potential hazard as there are limited opportunities for solids to be introduced in treatment process. **Design and operational mitigations include:** Strainers installed on the NaOH dosing line Daily turbidity sampling of recycled water Work instructions describing cleaning and flushing of pipes and fittings after maintenance Ability to flush headworks and recharge mains Operational bore development (i.e. backwash/airlift) If alkalinity buffering is considered necessary in the future, to mitigate other risks, then the risk of physical clogging will need to be reviewed. **Characterisation:** Camera log and short term step test and constant rate test of GWRT recharge bore determined no loss in bore efficiency after ~4yrs recharge. Will be reassess once operational data available. Review risk over time.	Optimal	1	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
14	**Clogging of aquifer pore spaces** caused by mobilisation of colloids	Aquifer	Components of the aquifer material such as kaolinte have the potential to mobilise or breakdown releasing colloids which may clog aquifer pore spaces and reduced the in permeability in formation at distance from recharge bore	**Minor [Service Interruption, Financial]:** Reduced permeability of the aquifer potentially requiring new recharge bores off the Beenyup site Service interruption as full volume produced by the AWRP may not be recharged	**Unlikely -** Successive depletion of colloids as source exhausted as recycled water flushes through. Expect peak of colloids around time of initial breakthrough, with subsequent decline.	2	D	Low	Confirmed as low risk during operation of the GWRT at a recharge rate of 5ML/d - to be further assessed during Stage 1 at higher rates **Design:** Appropriate commissioning of recharge bores Design of recharge bore (appropriate screens length/intervals) Operational strategy for all recharge bores developed Potentially amend (increase salinity of recycled water at AWRP. Further investigation would be required to determine correct dosing requirements and design. **Monitoring:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response Water quality monitoring (including total Al) to determine if colloids are mobilised **Characterisation:** Site characterisation to assess likelihood of reductions in permeability however unlikely to cause significant reductions in permeability over the whole recharge interval	Adequate	2	D	Low
15	**Clogging of aquifer pore spaces** caused by mobilisation of fines	Aquifer	Components of the aquifer have potential to mobilise induced by high velocities due to recharge releasing fine particles which may clog aquifer pore spaces.	**Moderate [Service Interruption, Financial]:** Reduced permeability of the aquifer potentially requiring new recharge bores off the Beenyup site Service interruption as full volume produced by the AWRP may not be recharged	**Likely -** Fines present, almost certain that fines will be mobilised, it is likely that they will clog the screens/aquifer at increased recharge rates as previously occurred at the M345 ASR trial	3	B	High	Confirmed as low risk during operation of the GWRT at a recharge rate of 5ML/d to be further assessed during operation of Stage 1 **Design:** Appropriate commissioning of recharge bores Step flow recharge rates Operational strategy for all recharge bores developed Operational bore development (i.e. backwash/airlift) **Monitoring:** Pressure monitoring to determine if clogging is occurring and triggers to initiate management response **Characterisation:** Site characterisation required to confirm the likelihood Flow log of new recharge bores Intensive recharge bore development Additional development prior to recharge to remove any fines that have settled in the bore	Adequate	2	D	Low
16	**Air-entrainment in recycled water** caused by recycled water cascading into recharge bore	Aquifer	Clogging of recharge bore due to entrained air (cascading water)	**Minor [Service Interruption, Financial]:** Reduced recharge bore efficiency	**Possible -**	2	A	High	**Design:** Design and commission appropriate recharge infrastructure Down hole valve utilised in all bores with a minimum recharge head of 15m above ground design for Stage 1 Air and vacuum relief valves installed in recharge main and bore headworks **Operational:** Control setpoints will shutdown recharge if recharge pressure too low	Optimal	2	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
17	**Microbiological clogging**	Aquifer	Recycled water provides a food source (nutrients or organic carbon) for native microbiological communities, causing excessive growth, or micro-organisms introduced via recycled water or drilling, resulting in clogging.	**Minor [Service Interruption, Financial]:** Clogging of aquifer due to microbial population growth	**Possible -** No significant microbiological clogging observed during Trial, however microbiological monitoring has confirmed populations increase after recharge commenced Surface area for potential clogging increases as recycled water moves through aquifer, reducing likelihood of aquifer clogging	2	C	Moderate	**Operational:** No sign of this during the Trial (mitigation considered effective): AWRP designed to remove micro-organisms. Maintain low concentrations of nutrients in recycled water to limit biomass growth Disinfect down hole equipment after maintenance prior to returning to service If detected, undertake bore remediation - i.e. backwash/airlift. **Monitoring:** Pressure monitoring to determine clogging and trigger corrective action Potential responses may include camera log of recharge bore and water quality monitoring to determine cause/extent and remedial actions Determine a microbiological (including Fe bacteria) monitoring programme **Design:** Design recharge bore to allow disinfection/backwash/airlift Disinfect at the end of construction	Adequate	2	D	Low
18	**Geochemical Clogging** caused by reactions between recycled water and groundwater or aquifer matrix	Aquifer	Reactions between recycled (recharged) water, groundwater or aquifer matrix, may result in precipitating of minerals. Have not seen this in the Leederville aquifer after ~4 years of recharge.	**Minor [Service Interruption, Financial]:** Reduced permeability of the aquifer, reduced recharge efficiency, **new recharge bore**	**Unlikely -** GWRT demonstrated that precipitation of chemicals in Leederville concentrations in high enough to cause clogging is unlikely.	2	D	Low	**Monitoring:** Pressure monitoring to determine clogging and trigger corrective action. Corrective action may include constructing a new recharge bore on site **Characterisation:** Site characterisation to confirm if mineralogy is similar to Beenyup	Optimal	2	D	Low
19	**Clogging of Bore- Aquifer interface** caused by scaling	Bore Infrastructure	Clogging of bore-aquifer interface due to geochemical reactions with recycled water	**Minor [Service Interruption, Financial]:** Bio-geo chemical reaction causes 'scale' clogging May affect rate of recharge and require downtime during maintenance.	**Unlikely -** If recycled water is similar to GWRT	2	D	Low	**Design:** Allow for possible in-situ redevelopment options of recharge bores AWRP to produce recycled water with very low ionic strength with limited capacity to precipitate Reducing exit velocities (longer/larger diameter screens) **Monitoring:** Online monitoring of pressure and bore performance If detected, determine cause and where possible limit source in AWRP Conduct regular bore maintenance. **Characterisation:** Assess recycled water quality data during AWRP commissioning to further assess the risk	Optimal	2	E	Low
Risks to Human and Environmental Health													
Mobilisation of Chemicals													
20	**pH change**	Human Health	Geochemical reactions resulting from the addition of recycled water causes a change in pH outside health guidelines DoH GL - 6.0 - 8.5	**Minor [Compliance]:** Non-compliance to health guidelines	**Possible -** This risk has been assessed at the monitoring bore as opposed to the boundary of the RMZ, a pH decline may occur due to a reduction in buffering capacity in the aquifer and recycled water, resulting in non-compliance and creating the potential for metal mobilisation.	2	C	Moderate	Corrective action is to amend the recycled water at AWRP if required Aquifer buffering reactions and oxygen consumption are predicted to keep pH within guidelines within RMZ, more will be learnt through Stage 1 **Monitoring:** Verification sampling at compliance bore, if pH change occurred management response triggered which may include additional monitoring, research or triggering recycled water amendment **Characterisation:** Mineralogical and geochemical analysis at northern recharge site to compare similarity to Beenyup Additional GWR reactive transport modelling to be conducted to validate RMZ during Stage 1	Adequate	2	E	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
21	**Metal mobilisation**	Human Health	The aquifer material contains naturally occurring metals and minerals bound up in the geological units. Addition of recycled water may cause reactions which may result in mobilisation of metals and mineral dissolution. (i.e. As, Co, Fe, Mn, Pb)	**Minor [Compliance]:** Non-compliance to health guidelines	**Unlikely -** Groundwater maximum at Beenyup: As - 0.004mg/L, Co - 0.0006mg/L, Mn - 0.14mg/L, Pb - 0.0059mg/L Mobilisation studies max: As - <LOD Natural buffering capacity of aquifer likely sufficient to reduce risk of mobilisation Modelling indicates Co to be release to a maximum of 0.0006mg/L, <GL Fe - Baseline concentrations greater than maximum mobilised concentrations observed during GWR1.5	2	D	**Low**	Native groundwater already exceeds some water quality guidelines. Transient increases in metals on breakthrough, at different times in different layers, aquifer concentration (weighted average) will be less than a discrete layer concentration **Monitoring:** pH/ORP/HCO_3 (possible trigger values) at compliance bore Initiate a management response if monitoring indicates a metal is approaching set level (lower than GLV) and moving to further monitoring bores Corrective action may include buffering the recycled water GWTP's designed for iron and manganese removal Discussion of WQ results with regulators **Characterisation:** Mineralogical and geochemical analysis at northern recharge site to compare similarity to Beenyup Additional GWR reactive transport modelling to be conducted to validate RMZ during Stage 1, which will be applicable to Stage 2 sites Background groundwater analysis (at least 6 data points)	Adequate	2	E	**Low**
22	**Mobilisation of chemicals** Fluoride	Human Health	Geochemical reactions resulting from the recharge of low ionic strength recycled water causes mobilisation of fluoride (potential release from crandallite **and/or francolite**) DoH guideline = 1.5mg/L	**Minor [Compliance]:** Non-compliance to health guidelines	**Possible -** Transient increases following breakthrough of the recycled water	2	C	**Moderate**	Transient increases in fluoride on breakthrough, at different times in different layers, aquifer concentration (weighted average) will be less than a discrete layer concentration. Discrete layer concentrations will successively decrease after an initial peak with time after breakthrough. Natural levels of fluoride in some production bores can exceed guideline concentrations Fluoridation of DW occurs in WA (pop >3000, range of 0.7-1.0mg/L with target of 0.9mg/L) Discussion of WQ results with regulators if required **Monitoring:** Verification sampling at compliance bore **Characterisation:** Mineralogical and geochemical analysis at northern recharge site to compare similarity to Beenyup Additional GWR reactive transport modelling to be conducted to validate RMZ during Stage 1 Further research will be conducted regarding the mechanisms and fate of fluoride	Adequate	2	D	**Low**

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
23	**Mobilisation of chemicals** Total Phosphorus	Environmental Health	Geochemical reactions resulting from the recharge of low ionic strength recycled water causes mobilisation of phosphorus (potential release from crandallite **and/or francolite,** as indicated by Total P) GWRT Environmental target - 2.1mg/L GWRT Environmental limit - 2.3mg/L	**Minor [Compliance]:** Non-compliance to environment guidelines	**Possible -** Transient increases following breakthrough of the recycled water	2	C	Moderate	Transient increases of phosphorus on breakthrough, at different times in different layers, aquifer concentration (weighted average) will be less than a discrete layer concentration. Discrete layer concentrations will successively decrease after an initial peak with time after breakthrough. Discussion of WQ results with regulators if required **Monitoring:** Verification sampling at compliance bore **Characterisation:** Mineralogical and geochemical analysis at northern recharge site to compare similarity to Beenyup Additional GWR reactive transport modelling to be conducted to validate RMZ during Stage 1 Further research will be conducted regarding the mechanisms and fate of phosphorus	Adequate	2	D	Low
24	**Increase in nitrite**	Human Health	Due to the recharge of nitrate at ~2.5mg/L and denitrifying conditions in the aquifer, nitrate is reduced to nitrite, which may exceed the DoH guideline of 1mg/L	**Minor [Compliance]:** Non-compliance to health guidelines	**Unlikely -** Managed by AWRP, RWQMP and MoU	2	D	Low	**Design:** The GWRT AWRP design limited the concentration of nitrate to below guidelines in the recycled water to an observed maximum of 3.6mg/L. The new AWRP to have the same design as the Trial. If NO_3 is limited, the TRG are confident that the NO_2 guideline will not be exceeded	Adequate	2	E	Low
Recycled Water Quality													
25	**Recycled water quality** Organics/chemicals in recycled water recharged	Human Health	Low levels of NDMA (max detected 1.5ng/L, GL = 100ng/L) Low levels of metals (Boron average 0.09mg/L, GL = 4mg/L)	**Minor [Compliance]:** Non-compliance to health guidelines	**Unlikely -** GWRT demonstrated that recycled water is well below guideline limits Managed by AWRP, RWQMP and MoU	2	D	Low	Stage 2 GWR AWRP will have the same treatment processes as the GWRT and Stage 1 (UF, RO, UV) Effectively managed via AWRP, Process Control Tables, Recycled Water Quality Management Plan and MoU with DoH and Recharge Management Zone	Optimal	2	E	Low
Risks of Poor Aquifer Response													
26	**Hydrogeological barrier** preventing or reducing efficiency of recharge	Bore Infrastructure	Possible hydrogeological barriers (Kings Park Formation, Badaminna Fault, Joondalup Fault, aquifer cementing, dipping beds, lower transmissivities)	**Minor - [service interruption]:** * Reduced recharge capacity * Increased head build-up * Drilling into cemented material resulting in no recharge * Bore needs to be abandoned and new bore drilled	**Unlikely -**	2	D	Low	Pumping tests of Beenyup recharge bores indicated a hydrogeological barrier appropriate investigations and monitoring are required to determine if barriers are present/absent the new sites and how impacts to recharge management. Appropriate pumping tests with regional monitoring in collaboration with the DoW to further assess barriers Regional seismic surveys planned with Curtin University Leak off tests during drilling to assess in-situ permeabilities Down hole geophysical such as NMR can assist in determine permeabilities	Optimal	2	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
27	**Integrity of the confining layer**	Aquifer	Local confining layer damage due to over pressuring the Leederville aquifer	**Minor - [Service Interruption]:** Upward leakage of recycled water	**Rare -** Pressure applied will be likely be too low and thickness of confining layer is too great for this to occur	2	E	Low	**Characterisation:** Confirmed confining layer sufficient at new sites via coring at the northern sites and interpretation from lithological descriptions, geophysical characterisation Aquifer pumping tests and leak off tests will help further assist the assessment of maximum pressure **Operational:** Appropriate commissioning of recharge borefield to ensure pressure are not too great Close assessment of operational recharge data If pressures are too great - construct additional recharge bores offsite Mitigated by design and operation (setpoints) of recharge pump station Recharge over a greater area (longer screens, more bores) **Monitoring:** Pressure monitoring of Superficial monitoring bore at northern site, and review DoW regional pressure data Consider in-situ monitoring pressure, temperature or conductivity in recharge bores	Optimal	2	E	Low
28	**Leakage of recycled water to the overlying aquifer**	Aquifer	Vertical movement of recycled water through the confining layer into the Superficial aquifer	**Minor - [Compliance]:** Upward leakage of recycled water recharged the identification of the current EVs did assumed that there was no upward flow to the superficial aquifer.	**Rare -** Vertical flow model >2000yrs to travel through confining layer @ 14GL/yr at northern site >45,000yrs at likely maximum planned rate of 12ML/d (~4.5GL/yr)	2	E	Low	Confirmed extremely low at GWRT recharge bore (LRB1) **Monitoring:** Pressure monitoring of Superficial monitoring bore at northern site to assess potential of vertical movement **Characterisation:** Confirmed confining layer sufficient at new sites via coring at the northern sites and interpretation from lithological descriptions, geophysical characterisation Aquifer pumping tests and leak off tests will help further assist the assessment of maximum pressure Preferential flow horizontal rather than vertical Confining layer reduction in permeability if recycled water were to move upwards If pressures are too great - construct additional recharge bores offsite	n/a	2	E	Low
29	**Aquifer dissolution** due to pH change (high or low)	Aquifer	Recycled water reacts with aquifer minerals and native groundwater; resulting in dissolution of the aquifer	**Insignificant [Environmental]:** Increased permeability caused by dissolution of the aquifer, consequence in a predominantly sandstone aquifer insignificant	**Rare -** Aquifer characterisation indicates low carbonates therefore unlikely to occur pH is unlikely to increase to levels that may cause silica dissolution	1	E	Low	**Monitoring:** Aquifer and recharge bore pressures and flow Water quality as indicators of dissolution Check filter pack on recharge bore and replace if required **Characterisation:** Confirm mineralogy at northern recharge site	Optimal	1	E	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
30	**Artesian flowing conditions** Increased pressurisation resulting in nearby bores becoming flowing artesian	Reputational	Increased pressurisation - resulting in nearby well becoming flowing artesian	**Minor - [Reputational]:** Leakage of recycled water and groundwater at surface	**Likely -** Modelling indicated zone at Beenyup will become flowing artesian	2	B	High	Bores appropriately sealed **Model:** Model artesian zone to determine if other users are impacted (potentially AM bores) Run PRAMS to assess regional risk of artesian conditions **Monitor:** Pressures in nearby AM bores to confirm groundwater does not flow to surface and headworks modified if required Engage other Leederville aquifer users that may be impacted (Water Corporation, DoW, Private) Monitor Stage 1 - time to amend for Stage 2.	Optimal	2	E	Low
31	**Operation** Poor balancing of recharge rates/pressures adversely impact aquifer	Aquifer	Poor balancing of recharge rates/pressures adversely impact aquifer/bores	**Moderate [Financial, Reputation, Service Interruption, Environmental, Compliance]**	**Possible -** Excessive recharge pressures to the Leederville aquifer may lead to damage to aquifer, confining layer, bore damage, upward leakage, clogging and artesian conditions	3	C	High	Ensure operational recharge strategy designed to ensure recharge capacities and pressures do not increase the risk of damage to the Leederville aquifer, recharge bores, and confining layer Close monitoring of recharge by Water Corporation hydrogeologists and TRG members at commencement of recharge, and during ongoing operation If pressures are too great - construct additional recharge bores offsite	Adequate	3	E	Low
32	**Operation** Uncertainty of response by increase pressure particularly past pre-abstraction conditions	**Aquifer**	High rate recharge has not been tested in the Leederville aquifer, there is some uncertainty on how the increase in pressure will impact the formation and overlying formations	**Uncertain [Financial, Reputation, Service Interruption, Environmental, Compliance]**	**Uncertain**				**Uncertain - further information required** Monitoring and Operation: Assessment of Stage 1 GWR Obtain more data from new sites, review calliper logs, conduct step rate (leak) test Ensure appropriate monitoring by AWRP Operations, Hydrogeologist and TRG	Uncertain			
Risks of impact to other users													
33	**Impact to other Leederville aquifer users** temperature/pressure	People	Note: this has been assessed as a social and reputational risk. Changes in pressure extending through aquifer, impacting abstraction on other users. Lesser risk in temperature, RMZ manages WQ	**Minor - [Reputation and Financial]**	**Unlikely -** Water Corporation predominate user Assessment required on new Neerabup production bore	2	D	Low	**Design:** Longer screens to distribute the recycled water over greater interval **Modelling:** To assess temperature and pressure impact regionally **Engagement:** Engagement with impacted users to discuss the risks	Adequate	2	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
Yarragadee Aquifer Risk Assessment													
Risks from Drilling and Bore Construction													
34	**Bore failure** caused by geological conditions	Bore Infrastructure	Cavernous limestone causing loss of drilling fluids.	**Insignificant [Financial]:** Increased construction times and costs.	**Almost Certain**	1	A	Moderate	Current practices mitigate this risk, i.e.: (1) Approved drilling techniques (2) Appropriately set pre-collars (3) Drilling pre-collar holes using approved technique (such as dual rotary, mud rotary advance casing). If mud used, driller prepared for significant or total mud loss (4) Hydrogeologist availability	Optimal	1	E	Low
35	**Bore failure** caused by geological conditions	Bore Infrastructure	Swelling of clays resulting in loss of drilling equipment.	**Minor [Financial]:** Increased construction times and costs.	**Likely**	2	B	High	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and drilling mud, ensuring muds do not contaminate samples or aquifer. (2) Appropriate mud programme developed with advice from "Mud Engineer" (3) Appropriate supervision including real time monitoring (4) Contractor planning - minimise the time the hole is open	Optimal	2	D	Low
36	**Bore failure** caused by geological conditions	Bore Infrastructure	Encountering hark rock resulting in slow penetration of water through the aquifer	**Insignificant [Financial]:** Increased construction times and costs.	**Possible**	1	C	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and equipment (2) Appropriate contractor planning, maintenance and spares	Adequate	1	C	Low
37	**Bore failure** caused by bore construction technique	Bore Infrastructure	Loss or collapse of casing string.	**Minor [Financial]:** Increased construction times and costs. Required to redesign and drill new a bore.	**Possible**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and equipment and process control. (2) Utilise "quick connectors" in bore casing/screen assembly	Adequate	2	D	Low
38	**Bore failure** caused by bore construction technique	Bore Infrastructure	Failure during cement grouting of casing resulting in cement setting in screens.	**Minor [Financial]:** Increased construction times and costs. Change in bore design.	**Possible**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques should engineer this out (2) Appropriate bore construction. (3) Appropriate cementing methodology with controls (possible stage cementing)	Optimal	2	E	Low
39	**Bore failure** caused by bore construction technique	Bore Infrastructure	Bore screens are not set in selected geological unit.	**Insignificant [Reputational]:** Water quality results do not reflect geological units as expected.	**Unlikely**	1	D	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate bore design, drilling and construction techniques (2) Use longer screens (3) Lithological and geophysical logging (4) QA/QC during receive/storage/transport/construction - casing tally, numbering/barcoding In addition, thicker sandstone beds are present in Yarragadee aquifer which will make it easier to set screens in required geological unit.	Adequate	1	D	Low
40	**Bore failure** caused by use of incorrect installation gravel pack OR incorrect gravel size or slot size for application	Bore Infrastructure	Has potential for collapse of aquifer formation around the bore during development which will result in reduced permeability of recharge zone near bore interface	**Minor [Financial]:** Reduced recharge capacity Required to redesign and drill new a bore.	**Possible** **Less of an issue than Leederville due to the consolidation of parts of the formation**	2	D	Low	Current practices mitigate this risk, i.e.: (1) Utilise appropriate drilling contractor and equipment and process control. (2) consider the need to gravel pack.	Adequate	2	D	Low
41	**Recharge of non-target layers** caused by poor sealing of bore annulus during cementing	Aquifer - layer recharged	Poor sealing allows unintended transfer of the recharged water into other layers of the aquifer Formation damage during cement grouting resulting in inadequate isolation	**Minor [Reputational, Financial]:** Bore no longer reliable, potentially resulting in: (1) inefficient recharge (2) upward leakage into overlying aquifer (3) flow into Leederville or Superficial aquifer (4) Resulting in bore abandonment and replacement	**Possible**	2	C	Moderate	Current practices mitigate this risk, i.e.: (1) Utilise adequate bore design and drilling techniques (2) Cementing with appropriate equipment/methods with cementing contractor/specialist (3) Two stage cementing programme with appropriate control - pressure monitoring (4) Appropriate mud programme design by "mud engineer"	Adequate	2	D	Low
42	**Ingress of non-target groundwater into bore samples** caused by poor sealing of bore annulus	Aquifer - layer sampled	Poor sealing allows ingress of groundwater from overlying and underlying strata resulting in incorrect sampling.	**Insignificant [Compliance, Financial]:** Bore no longer reliable and could result in sampling layers other than that intended, therefore water quality results do not reflect geological units as expected. Bore replacement would be required	**Possible**	1	C	Low	Current practices mitigate this risk, i.e.: (1) Utilise adequate bore design and drilling techniques (2) Cementing with appropriate equipment/methods with cementing contractor/specialist (3) Two stage cementing programme with appropriate control - pressure monitoring (4) Appropriate mud programme design by "mud engineer"	Adequate	1	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
43	**Casing/Screens corrosion**	Bore Infrastructure	Low ionic strength recycled water may cause corrosion to the casing/screens, potentially causing damage to recharge bore infrastructure	**Minor [Service Interruption]:** Bore infrastructure failure caused by corrosion	**Likely -** Minimal buffering capacity of recycled water, corrosion will occur if inadequate materials are used for construction	2	B	High	**Design:** Use appropriate materials in bore construction that are approved for use in water bores (i.e. FRP, SS) **Operation:** pH adjustment to target 7.5 (NaOH dosing) will assist in ongoing mitigation of risk **Monitoring:** Inspection of GWRT recharge bore (LRB1) after ~4yrs recharge, by camera log Oct-2014 indicated screens in very good condition (limited corrosion of welds) Implement bore condition monitoring programme	Optimal	2	D	Low
44	**Risk of deteriorating recharge bore integrity**	Operator and Visitor safety	Infrastructure damage caused by recharge pressure. Damage to headworks and bore, releases water under pressure at surface injuring a by-stander Lost recharge production	**Minor [People]:** Upward leakage caused by inadequately sealed bore casing Injured by-stander **Minor [Service Reduction]:** Reduced recharge capacity	**Rare**	2	E	Low	**Design:** Utilise appropriate bore design, drilling and construction techniques Design criteria and WI in place to ensure appropriate materials/fittings used Design limit for headworks is 150m (TBC once final design) head above ground level, maximum operating pressure will be below this, controlled with setpoints with automatic shutdown if exceeded. Investigate feasibility of installing two smaller recharge bores instead of one to decrease flows and recharge pressures **Monitoring:** Pressure monitoring and control setpoints of recharge system Recharge pump monitoring and improvement with appropriate maintenance	Optimal	2	E	Low
Bore Clogging and Reduced Aquifer Permeability													
45	**Clogging of Recharge bore - Aquifer interface** caused by solids in recycled (recharged) water	Bore Infrastructure	Clogging of bore-aquifer interface due to solids introduction post-RO	**Minor - [Service Interruption]** Physical clogging of recharge bore , resulting in reduced efficiency - potentially to the extent that recharge cannot occur.	**Unlikely** with current level of treatment (i.e. no introduction of solids after RO)	2	D	Low	**Design and Operational:** The Stage 1 AWRP design mitigates this potential hazard as there are limited opportunities for solids to be introduced or made in treatment process. Strainers installed on the NaOH dosing line Daily turbidity sampling of recycled water Work instructions describing cleaning and flushing of pipes and fittings after maintenance Ability to flush headworks and recharge mains If alkalinity buffering is considered necessary in the future, to mitigate other risks, then the risk of physical clogging will need to be reviewed. **Characterisation:** Camera log and short term step test and constant rate test of GWRT recharge bore determined no loss in bore efficiency after ~4yrs recharge. Will be reassess once operational data available.	Optimal	1	D	Low
46	**Clogging of aquifer pore spaces** caused by mobilisation of colloids	Aquifer	Components of the aquifer material such as kaolinte have the potential to mobilise or breakdown releasing colloids which may clog aquifer pore spaces and reduced the in permeability in formation at distance from recharge bore	**Insignificant [Financial]:** Reduced permeability of the aquifer potentially requiring new recharge bores off the Beenyup site Service interruption as full volume produced by the AWRP may not be recharged	**Unlikely -** Successive depletion of colloids as source exhausted as recycled water flushes through. Expect peak of colloids around time of initial breakthrough, with subsequent decline observed in the GWRT.	**2**	D	Low	Assessed as low risk for the GWRT to the Leederville aquifer, Stage 1 recharge will further inform on this risk. **Design:** Appropriate commissioning of recharge bores Design of recharge bore (appropriate screens lengths/diameters) Operational strategy for recharge bore developed Potentially amend (increase salinity recycled (recharged) water at AWRP. Further investigation would be required to determine correct dosing requirements and design. **Monitoring:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response Water quality monitoring (including total Al) to determine if colloids are mobilised **Characterisation:** Site characterisation to further assess likelihood, however TRG assess as unlikely to cause significant reductions in permeability over the whole recharge interval	Adequate	1	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
47	**Clogging of aquifer pore spaces** caused by mobilisation of fines	Aquifer	**Mobilisation of fines in the aquifer is likely due to occur due to high exit velocities causing agitation of fines and has the potential to clog aquifer pore spaces**	**Minor - [service interruption]** Reduced permeability of the aquifer.	**Possible -** fines present, almost certain that fines will be mobilised, but it is only possible that they will clog the aquifer Preliminary dispersion tests - at low flow small particles are mobilised at an almost continuous rate - at higher rates mobilised as a pulse	2	C	Moderate	**Design:** Investigate the potential for multiple bores to reduced exit velocities Appropriately sized screens (length/diameter) to reduce exit velocities Appropriate stepped commissioning of recharge bores Step flow recharge rates Operational strategy for recharge borefield developed Bore development (i.e. backwash/airlift) **Monitoring:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response **Characterisation:** Site characterisation required to confirm the likelihood Flow log of new recharge bores Intensive recharge bore development	Optimal	2	D	Low
48	**Air-entrainment in recycled water** caused by recycled (recharged) water cascading into recharge bore	Aquifer	Clogging of recharge bore due to entrained air (cascading water)	**Minor - [Service Interruption]** Reduced recharge bore efficiency	**Possible -** Current design of GWRT recharge bore infrastructure (positive recharge head and installed below resting water level) mitigates this potential hazard.	2	C	Moderate	**Design:** Design and commission appropriate recharge infrastructure Down hole valve utilised in all bores with a minimum recharge head of 15m above ground designed for Stage 1 Air and vacuum relief valves installed in recharge main and bore headworks **Operational:** Control setpoints will shutdown recharge if recharge pressure too low	Optimal	2	D	Low
49	**Microbiological clogging** caused by indigenous or introduced microbiological communities to increasing their growth rate creating biofilm/biomat.	Aquifer	Recycled water provides a food source (nutrients or organic carbon) for native microbiological communities, causing excessive growth, or micro-organisms introduced via recycled water or drilling, resulting in clogging.	**Minor - [Service Interruption]** Clogging of aquifer due to microbial population growth	**Unlikely -** Different but diverse population of bacteria in Yarragadee compared to the Leederville aquifer at Beenyup No detectable microbiological clogging observed during the GWRT Surface area for potential clogging increases as recycled water moves through aquifer, reducing likelihood of aquifer clogging	2	D	Low	**Operational:** AWRP designed to remove micro-organisms Maintain low concentrations of nutrients in recycled water to limit biomass growth Disinfect down hole equipment after maintenance prior to returning to service If detected, undertake bore remediation **Monitoring:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response Potential responses may include camera log of recharge bore and water quality monitoring to determine cause/extent and remedial actions Determine a microbiological (including Fe bacteria) monitoring programme **Design:** Design recharge bore to allow disinfection/backwash/airlift Disinfect at the end of construction	Adequate	2	D	Low
50	**Geochemical Clogging** caused by reactions between recycled water and groundwater or aquifer matrix	Aquifer	Reactions between recycled (recharged) water, groundwater or aquifer matrix, may result in precipitating of minerals. Have not seen this risk in the Leederville aquifer after **~4** years of recharge.	**Minor - [Service Interruption]** Reduced permeability of the aquifer.	**Unlikely -** GWRT demonstrated that precipitation of chemicals in Leederville concentrations in high enough to cause clogging is unlikely. Differing water quality and mineralogy in Yarragadee to Leederville, with Yarragadee generally better quality (e.g. lower concentrations of iron) and generally less reactive	2	D	Low	**Monitor:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response **Characterisation:** Site characterisation to confirm if mineralogy is similar to Beenyup Corrective action may include constructing a new recharge bore if geochemical clogging is significant	Optimal	2	D	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
51	**Clogging of Bore-Aquifer interface** caused by scaling	Bore Infrastructure	Clogging of bore-aquifer interface due to geochemical reactions with recycled water	**Minor - [Service Interruption]** Bio-geo chemical reaction causes 'scale' clogging May affect rate of recharge and require downtime during maintenance.	**Unlikely -** Not seen during ~4 years recharge during GWRT.	2	D	**Low**	**Design:** Allow for backwashing/airlifting of recharge bore AWRP to produce recycled water with very low ionic strength with limited capacity to precipitate Reducing exit velocities (longer/larger diameter screens/multiple recharge bores) **Monitoring:** Aquifer, bore and pump pressure monitoring to determine if clogging is occurring and triggers to initiate management response If detected, determine cause and where possible limit source in AWRP Conduct regular bore maintenance. **Characterisation:** Assess recycled water quality data during AWRP commissioning to further assess the risk	Optimal	1	E	**Low**
52	**Release of dissolved gases** - reducing permeability	Aquifer	Higher temperature conditions within the Yarragadee aquifer may potentially result in the release of dissolved gases from the recharge water, subsequently causing clogging in the aquifer as pore spaces become blocked by air bubbles.	**Minor - [Service Interruption]** Reduced permeability of the aquifer, reduced recharge efficiency	**Rare -** Due to higher pressure in Yarragadee aquifer. Higher temperatures may allow release of gases, however high pressure should compensate for this.	2	E	**Low**	Assess via PHREEQC modelling as per Stage 1	Uncertain			
Risks to Human and Environmental Health													
Mobilisation of Chemicals													
53	**pH change**	Human Health	Geochemical reactions resulting from the addition of recycled water causes a change in pH outside health guidelines DoH GL - 6-8.5	**Minor [Compliance]** Non-compliance to health guidelines	**Possible - Buffering capacity of the Yarragadee is less than the Leederville, however there is also less potential for acidity to be created.**	2	C	**Moderate**	Corrective action is to amend the recycled water at AWRP if required Aquifer buffering reactions is predicted to keep pH within guidelines, and could be effectively managed within RMZ **Monitoring:** Verification sampling at compliance bore, if pH change occurred management response triggered which may include additional monitoring or triggering recycled water amendment **Characterisation:** Mineralogical and geochemical analysis confirmed the Yarragadee is similar to Leederville, similar reactions likely to occur at Beenyup Characterisation required for Stage 2 to further assess this risk	Optimal (with pH and alkalinity buffering)	2	D	**Low**
54	**Chemical mobilisation**	Human Health	The aquifer material contains naturally occurring metals and minerals bound up in the geological units. Addition of recycled water may cause reactions which may result in mobilisation of these metals and mineral dissolution. (Co, Cd, Cu, Ni, Zn)	**Minor [Compliance]** Non-compliance to health and environmental guidelines	**Possible -** Yarragadee aquifer could potentially release Cd, Co, Cu, Ni, Zn. Acid digestion tests showed release of Co, Cu, Ni, Mn. Co present in screened intervals, which in the Leederville aquifer was more prone to mobilisation with decreasing pH. Mineralogy similar to the Leederville aquifer Predominantly silica with substantial kaolinite and feldspar minerals Trace pyrite, siderite and almandine garnet detected	2	C	**Moderate**	Transient increases in metals on breakthrough, at different times in different layers, aquifer concentration (weighted average) will be less than a discrete layer concentration Corrective action is to amend the recycled water at AWRP if required **Monitoring:** Verification sampling at compliance bore, Initiate a management response if monitoring indicates a metal is approaching set level (lower than GLV), which may trigger recycled water amendment Baseline groundwater monitoring - minimum of 6 data points to ensure representative of native conditions **Characterisation:** Mineralogical and geochemical analysis confirmed the Yarragadee is similar to Leederville, similar reactions likely to occur at Beenyup Characterisation required for Stage 2 to further assess this risk	Optimal (with pH and alkalinity buffering)	2	D	**Low**

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
Recycled Water Quality													
55	**Recycled water quality** Organics/chemicals in recycled water recharged	Human Health	Low levels of NDMA (max detected 1.5ng/L) GL = 10ng/L to be changed to 100ng/L Low levels of metals (Boron average 0.09mg/L, GL = 4mg/L	**Minor [Compliance]** Non-compliance to health guidelines	**Unlikely -** GWRT demonstrated that recycled water is well below guideline limits	2	D	Low	Stage 1 GWR AWRP will have the same treatment processes as the GWRT (UF, RO, UV). Additional information will be available after the commissioning of Stage 1. Stage 2 AWRP will not commence recharge until DoH approval received Effectively managed via AWRP, Process Control Tables, Recycled Water Quality Management Plan and MoU with DoH	Optimal	2	E	Low
Risks of Poor Aquifer Response													
56	**Possible hydrogeological barrier preventing or reducing efficiency of recharge**	Bore Infrastructure	Possible hydrogeological barrier (fault, aquifer cementing, dipping beds)	**Minor - [service interruption]** * Reduced recharge capacity * Increased head build-up * Drilling into cemented material resulting in no recharge * Bore needs to be abandoned and new bore drilled	**Unlikely -** Almost certain within Yarragadee - low at Beenyup site	2	D	Low	**Characterisation:** Common new seismic activities to further assess this risk. Developed appropriate aquifer pumping tests at each recharge bore and monitoring programme to further assess **Monitoring:** Develop an appropriate local and regional monitoring programme in collaboration with TRG and Dow to further assess this risk after recharge has commenced	Optimal	2	D	Low
57	**Integrity of the confining layer**	Aquifer	Local confining layer (South Perth Shale) damage due to over pressuring Yarragadee aquifer	**Minor - [Service Interruption]** Upward leakage of recycled water	**Rare -** Pressure applied is too low for the thickness of confining layer	2	E	Low	**Formation:** Thickness of South Perth Shale **Design/Operation:** Maximum recharge rate will be ~15ML/d **Characterisation:** Appropriate testing; leak off, geophysical and pumping tests to further assess this risk	Optimal	2	E	Low
58	**Risks of aquifer dissolution**	Aquifer	Change in pH causing dissolution of the aquifer	**Minor - [Service Interruption]** Increased permeability caused by dissolution of the aquifer, consequence in highly sandy aquifer insignificant	**Rare -** Aquifer characterisation indicates low carbonates therefore unlikely to occur pH is unlikely to increase to levels that may cause silica dissolution	1	E	Low	**Monitoring:** Aquifer, bore and pump pressure monitoring to assist assessment if dissolution is occurring and triggers to initiate management response Water quality as indicators of dissolution **Characterisation:** Confirm mineralogy - predominantly silica sandstone aquifer	Optimal	1	E	Low
59	**Risk of leakage to the overlying aquifer**	Aquifer	Vertical movement of recycled water through the South Perth Shale into the Leederville, through the confining layer into the Superficial aquifer	**Minor -** Upward leakage of recycled water recharged	**Rare**	2	E	Low	**Characterisation:** Assess connection between Yarragadee and Leederville once bores constructed and tested. **Design/Operation:** Good bore construction **Monitoring:** Pressure monitoring during recharge	Optimal	2	E	Low
60	**Operation Poor operation of recharge rates/pressures adversely impact aquifer**	**Aquifer**	**Poor balancing of recharge rates/pressures adversely impact aquifer/bores**	**Moderate [Financial, Reputation, Service Interruption, Environmental, Compliance]**	**Possible - Excessive recharge pressures to the Yarragadee aquifer may lead to damage to aquifer, confining layer, bore damage, upward leakage, clogging and artesian conditions**	**3**	**C**	**High**	Ensure operational recharge strategy designed to ensure recharge capacities and pressures do not increase the risk of damage to the Yarragadee aquifer, recharge bores, and confining layer Close monitoring of recharge by Water Corporation hydrogeologists and TRG members at commencement of recharge, and during ongoing operation If pressures are too great - construct additional recharge bores offsite	Adequate	3	E	Low

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
61	**Operation** Uncertainty of response by increase pressure particularly past pre-abstraction conditions	**Aquifer**	High rate recharge has not been tested in the Yarragadee aquifer, there is some uncertainty on how the increase in pressure will impact the overlying formations, and the Yarragadee formation, including possible reactivation of faults hydraulically or seismically)	**Moderate [Financial, Reputation, Service Interruption, Environmental, Compliance]** Formation damage	**Rare -** Long bore screening interval, recharge at much lower pressures much higher permeability than where reference study was conducted	**3**	**E**	**Low**	**Uncertain - further information required** Monitoring and Operation: Assessment of Stage 1 GWR Obtain more data from new sites, review calliper logs, conduct step rate (leak) test Ensure appropriate monitoring by AWRP Operations, Hydrogeologist and TRG	Uncertain			
Risks of impact to other users													
62	**Impact to other Yarragadee users** temperature/pressure	People	Note: this has been assessed as a social and reputational risk. Decrease in temperature extending through aquifer, impacting abstraction on other users. Increased pressure impacting other users	**Minor - [Reputation and Financial]**	**Unlikely -** ~10km between recharge bore and closest private bore Assessment required on new Neerabup production bore	2	D	**Low**	**Design:** Longer screens to distribute the recycled water over greater interval **Modelling:** To assess temperature and pressure impact **Engagement:** Engagement with impacted users to discuss the risks	Optimal	1	E	**Low**

GWR - Stage 2 - Aquifers Inherent Risk Identification and Assessment						Inherent Risk			GWR - Stage 2 - Aquifer - Risk Mitigation and Assessment		Mitigated Risk		
Ref	Risk	Inherent Risk	Description (Risk cause & background information)	Risk consequence	Likelihood	Consequence	Likelihood	Risk Level	Mitigations (Tasks and Actions)	Control Effectiveness Rating	Consequence	Likelihood	Risk Level
Superficial Aquifer Risk Assessment													
63	**Increase in water levels resulting in acid sulphate soils**	**Aquifer/Users**	Through the selected recharge and abstraction locations for the expansion of Stage 2 GWR which were determined collaboratively between the DoW and Water Corporation, may result in the maintenance or limited increase in water levels in the Superficial aquifer, which may lead to an increase in ASS risks	**Moderate -** Decrease in pH and subsequent water quality changes may impact other users	**Rare -** extremely unlikely to identify the specific impact of GWR from other impacts (climate, urbanisation, private supply) An increase in water levels is more likely to reduced atmospheric oxygen penetration and decrease the potential for acid release from ASS	3	E	**Low**	Managed by the DoW on optimising recharge and abstraction regimes, including private users for the overall benefit of the Perth Groundwater System	Optimal	3	E	**Low**
64	**Increase in water levels resulting mobilisation of existing contaminated sites to existing aquifer users**	**Aquifer/Users**	Through the selected recharge and abstraction locations for the expansion of Stage 2 GWR which were determined collaboratively between the DoW and Water Corporation, may result in the maintenance or limited increase in water levels in the Superficial aquifer, may mobilise existing contaminated site to the detriment of other users	**Minor -** Poor water quality for other Superficial aquifer users, increase in contaminant plumes.	**Rare -** extremely unlikely to identify the specific impact of GWR from other impacts (climate, private supply)	2	E	**Low**	Managed by the DoW on optimising recharge and abstraction regimes, including private users for the overall benefit of the Perth Groundwater System	Optimal	2	E	**Low**
65	**Upward movement of recycled water and movement into wetlands**	**Groundwater Dependant Ecosystems**	Recycled water eventually rises out of the Leederville aquifer, into the Superficial aquifer eventually entering wetland	**Minor -** Native groundwater is pushed upwards into the overlying aquifer into a wetland, followed by recycled water that has changed geochemically through the long travel distance/times	**Rare -** hydraulically very unlikely	2	E	**Low**	Hydraulically extremely unlikely, WQ is protect via a RMZ	Optimal	2	E	**Low**
66	**Upward movement of recycled water and impact on stygofauna**	**Groundwater Dependant Ecosystems**	Recycled water eventually rises out of the Leederville aquifer, into the Superficial aquifer	**Minor -** Native groundwater is pushed upwards into the overlying aquifer, followed by recycled water that has changed geochemically through the long travel distance/times	**Rare -** hydraulically very unlikely extremely unlikely to identify the specific impact of GWR from other impacts (climate, private supply)	2	E	**Low**	Hydraulically extremely unlikely, to enter the Superficial, WQ is protect via a RMZ Pre-abstraction conditions - there was potential for native Leederville groundwater to move into the Superficial	Optimal	2	E	**Low**
Other Risks													
67	**Intrusion of Salt Water Interface**	**Aquifer, Users**	Intrusion of SWI caused by additional abstraction to the west of recharge	**Minor [Environmental]** Increased salinity levels impacting other users	**Unlikely** PRCAC modelled long term impacts	2	D	**Low**	Managed by the DoW on optimising recharge and abstraction regimes, including private users for the overall benefit of the Perth Groundwater System	Adequate	2	E	**Low**
68													

Perth Groundwater Replenishment Scheme

Stage 2

Environmental Values for the Leederville Aquifer and the Yarragadee Aquifer

August 2016

Prepared by:

Government of Western Australia Department of Health

Government of Western Australia Department of Water

WATER CORPORATION

Blank page

Revision History

Version	Prepared By	Date Issued	Issued to	Comments Received from
Workshop outcomes - draft	V. Moscovis	23/8/2016	IAWG and workshop attendees: DoW – Matthew Awang Ben Drew Susan Worley DoH - Richard Theobald Clemencia Rodriguez WC - Nick Turner Simon Higginson Daniel Rossi Kevin Guppy Stacey Hamilton Tanya McKenna (environmental consultant)	Clemencia Rodriguez Matthew Awang Ben Drew Stacey Hamilton
Workshop outcomes - final	V. Moscovis	29/8/2016	As per above	
EV Report - First draft	V. Moscovis S. Higginson	13/9/2016	IAWG and workshop attendees: DoW – Matthew Awang Ben Drew Susan Worley DoH - Richard Theobald Clemencia Rodriguez WC - Nick Turner Daniel Rossi Kevin Guppy Stacey Hamilton Deanne McDonald Maria Russo Andrew Jones Tanya McKenna (environmental consultant)	Deanne McDonald Maria Russo Tanya McKenna Andrew Jones Clemencia Rodriguez Matthew Awang Susan Worley
EV Report Final	V. Moscovis S. Higginson	27/9/2016		

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 Water**, of 168 St Georges Terrace, Perth, Western Australia

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

In endorsing this document, the Department of Health, Department of Water and the Water Corporation agree on the Environmental Values relevant to Stage 2 of the Perth Groundwater Replenishment Scheme.

Signed for
Department of Health

Mr Richard Theobald
Manager Water Unit

27/09/16.
Date

Signed for
Department of Water

M. Awang

Mr Matthew Awang
A/Director of Regulation

23/09/16
Date

Signed for
Water Corporation

Maria R.

Ms Maria Russo
A/Branch Manager
Asset Investment Planning - Metro

23/09/16
Date

Table of Contents

List of Figures

List of Tables

List of Appendices

Definitions and Acronyms

Advanced Water Recycling Plant (AWRP) means the multiple step treatment process consisting of ultrafiltration, reverse osmosis and ultraviolet disinfection required for groundwater replenishment which is designed to produce water that is as safe as drinking water.

ADWG means the Australian Drinking Water Guidelines (2011).

AGWR Guidelines means the Australian Guidelines for Water Recycling: Managing Health and Environmental Risk (Phase 1) (2006), the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies (2008) and the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge (2009) published by the National Health and Medical Research Council.

ANZECC Guidelines means the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000a)

Beenyup facility means the Water Corporation's site in Craigie that houses the wastewater treatment and advanced water recycling plants.

Department of Environment Regulation (DER) are responsible for the protection of the environment (formerly known as the DEC, Department of Environment and Conservation.

Department of Health (DoH) are responsible for the protection of human health.

Department of Water (DoW) are responsible for the protection of water resources, including public drinking water sources.

Drinking Water means water intended primarily for human consumption, which also has other domestic uses.

Environmental Values (EVs) is the term applied to particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health.

Gigalitres (GL) one billion litres.

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

Groundwater Replenishment Trial (GWRT) refers to the two-year operational trial completed in December 2012, which was located at the Beenyup facility and involved the design, construction, operation and monitoring of a 1.5GL Advanced Water Recycling Plant and replenishment of the confined Leederville aquifer. The Trial demonstrated that groundwater replenishment is a safe, viable and sustainable option to supplement Perth's groundwater.

Groundwater Replenishment Regulatory Framework (GWR Regulatory Framework) defines the approvals pathway required to develop, approve and provide ongoing regulation for a Groundwater Replenishment Scheme.

Groundwater Technical Reference Group (TRG) means the team of hydrogeological experts from CSIRO, Department of Water, Curtin University, Rockwater Pty Ltd and Water Corporation formed to assess the feasibility and potential hazards of GWR from available hydrogeological, water quality and geophysical data generated from the Trial and Leederville/Yarragadee investigation. This group will continue to assess Perth GWRS Stage 1 and 2 and define the required investigations/research to further inform and progress GWR.

Interagency Working Group (IAWG) means the group formed to apply the GWR Regulatory Framework for each GWR scheme proposed by the Water Corporation.

Megalitres (ML) one million litres.

Perth Groundwater Replenishment Scheme (GWRS) refers to the Water Corporation's Groundwater Replenishment Scheme located at the Beenyup facility in Craigie.

Perth GWRS Stage 1 (Stage 1) refers to the first 14GL/yr AWRP at the Beenyup facility, recharging recycled water to three Leederville aquifer bores and one Yarragadee aquifer bore at the Beenyup facility.

Perth GWRS Stage 2 (Stage 2) refers to the second 14GL/yr AWRP at the Beenyup facility, recharging recycled water to the Leederville and the Yarragadee aquifers at two offsite recharge locations approximately 6.5km and 8.5km to the north of the Beenyup facility.

Public Drinking Water Source Areas (PDWSA) are underground pollution control areas, water reserves and catchment areas that have been identified as current or future sources of drinking water.

Priority classifications are classification areas defined to manage the risk of pollution to the water source from catchment activities. Protection is mainly achieved though guided or regulated environmental risk management of land use activities.

Recharge Management Zone (RMZ) defines the minimum radial distance between the bores for recharge of recycled water and abstraction of groundwater for public drinking water supplies. Environmental values are always preserved and the recharged water becomes part of the environment beyond the RMZ boundary.

Recycled Water in the context of groundwater replenishment means water produced by the Advanced Water Recycling Plant and recharged to the confined aquifer.

Recycled Water Quality Indicators are chemicals or pathogens that best represent a larger group of chemical or microbiological hazards identified by the Recycled Water Quality Parameters.

Recycled Water Quality Parameters refer to the water quality parameters which define the requirements for recycled water to meet the drinking water quality standards, as defined by the Department of Health and set out in the WWS/GWR MoU 2014.

Wastewater Catchment means the wastewater collection system that delivers inflows to wastewater treatment plants.

WWS/GWR MoU 2014 means the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (Oct 2014).*

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 Stage 2 of the Perth Groundwater Replenishment Scheme (GWRS), which will double the size of the scheme, and will result in a total recharge volume of approximately 28 gigalitres (GL) per year to the confined Leederville and Yarragadee aquifers across three recharge locations; Beenyup site, northern recharge site, southern recharge site.

Perth GWRS Stages 1 and 2 utilise the full current capacity of the Beenyup wastewater flows and have been staged as described in Table ES-1 to allow flexibility to meet demand for public water supply.

Table ES-1: Current stages of the Perth GWRS

Perth GWRS	Activity
Stage 1	Construct a 14GL/yr Advanced Water Recycling Plant (AWRP) at the Beenyup facility. Recharge the Leederville and the Yarragadee aquifers onsite at the Beenyup facility.
Stage 2	Construct an additional 14GL/yr AWRP at the Beenyup facility (to provide approximately 28GL of recycled water). Recharge the Leederville and the Yarragadee aquifers at two off-site recharge locations approximately 6.5km and 8.5km to the north of the Beenyup facility.

Determining the Environmental Values

The Water Corporation will seek approvals for the Perth GWRS Stage 2 in accordance with the GWR Regulatory Framework (IAWG, 2012). This regulatory framework was developed in 2012 by the Interagency Working Group (IAWG) as an outcome of the Groundwater Replenishment Trial (GWRT) and defines the approvals pathway required to develop, approve commencement of recharge and provide ongoing regulation for a groundwater replenishment scheme.

Application of the GWR Regulatory Framework requires collaboration between the Department of Health (DoH), Department of Water (DoW), Department of Environment Regulation (DER, formerly Department of Environment and Conservation) and the Water Corporation to identify the Environmental Values (EVs) relevant to the recharge locations as well as identify the management objective and water quality guidelines required to protect these EVs.

In order to progress approvals for Stage 2 of the Perth GWRS, the Corporation requested the DoH, DER and DoW to reform the IAWG and apply the GWR Regulatory Framework. Since developing the GWR Regulatory Framework the DER has taken a different approach to assessment requirements within the applicable legislation and has chosen not to participate in the GWR Regulatory Framework process for Perth GWRS Stage 2. The IAWG will continue without the DER, who will review the proposal as part of the standard environmental approvals process.

Step 2a-c of the GWR Regulatory Framework requires the IAWG to identify the relevant EVs for the receiving environment, i.e. the Leederville and Yarragadee aquifers. The EVs of the Superficial aquifer will also be considered if upward flow of groundwater into the Superficial aquifer was significant. The six environmental values to be considered are: to support aquatic ecosystems and cultural and spiritual values or to provide water for public water supply, primary industry, industrial use and recreation and aesthetics.

The IAWG met on 22 August 2016 to review the aquifer characteristics and identify the relevant EVs (see Appendix 1). This report:

- Provides details of the aquifer characteristics required by the IAWG to identify the relevant EVs (Step 1);
- Identifies EVs of the Leederville aquifer and the Yarragadee aquifer relevant to a GWR scheme at off-site recharge locations (Step 2a);
- Identifies the management objectives for the EVs (Step 2b); and
- Identifies the water quality guidelines required to protect the EVs (Step 2c).

Aquifer assessment

The location of recharge bores and abstraction of the GWR equivalent recharge volumes was planned collaboratively between the DoW and Water Corporation to optimise recharge and abstraction rates and locations to maximise recovery of groundwater for public water supplies and enhanced management of the Perth groundwater system.

The Groundwater Technical Reference Group (TRG) has set the Recharge Management Zones (RMZ) for each recharge bore at 250m radially from the point of recharge (see Appendix 2). These are the same conditions required for Perth GWRS Stage 1. Early indication monitoring for each recharge bore will occur between 50 and 100m from the point of recharge.

Investigative drilling, core collection and analysis of the northern recharge site verified that the aquifer characteristics at the proposed Perth GWRS Stage 2 recharge sites were similar to the characteristics at the Perth GWRS Stage 1 sites. This similarity enables the Water Corporation to utilise and build on the vast amount of information gathered as part of GWRT and Perth GWRS Stage 1.

The investigation identified the presence of an extensive confining layer between the Leederville and the Superficial aquifers. Using an analytical model based on data from GWRT and Stage 1, and refined using data obtained from the northern recharge site, the Groundwater Technical Reference Group (TRG) assessed the likelihood of vertical flow to the Superficial aquifer. A number of recharge rates to the Leederville aquifer were considered. The outcomes of the modelling are provided in Table ES-2.

Table ES-2: Stage 2 recharge sites - estimated travel times to the Superficial aquifer

Recharge rates to the Leederville aquifer		Travel time to the base of the Superficial aquifer	
GL/yr	ML/day	Recharge bore (years)	Boundary of the RMZ (years)
3.5	9.6	1,500,000	n/a
4.4	12	45,000	n/a
7	19.2	11,500	1,500,000
10	27.4	6,200	26,800
14	38.4	3,800	11,500
20	54.8	2,400	6,200

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 overlying aquitard in the Wanneroo member, formerly referred to as the Pinjar Member, which forms an effective seal between the Superficial aquifer and the recharge interval within the Leederville Formation.

In considering upward flow from the Yarragadee aquifer into the Superficial aquifer, the Groundwater TRG noted 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, were assessed to be in the order of tens of thousands of years.

Based on this information, the IAWG confirmed that the water quality and EVs in the Superficial aquifer are not impacted by Perth GWRS Stage 2 recharge, and therefore is not considered for the Perth GWRS Stage 2. This is consistent with the EVs applied to Stage 1.

The likelihood of freshwater ecosystems surviving in the Leederville and Yarragadee aquifers in the vicinity of recharge has been determined. Bennelongia Environmental Consultants assessed the likely presence of stygofauna in the Leederville and Yarragadee aquifers in the vicinity of recharge, and conclude: (full report provided as Appendix 3).

> *The geology within the Leederville and Yarragadee aquifers is transmissive and the water is fresh (<500mg/L); thus both aquifers may provide suitable habitat for stygofauna where they are unconfined. However stygofauna are unlikely to occur naturally at the actual point of injection of recycled water, which will be at depths of 140 – 400 m (Leederville) or ~ 1350 m (Yarragadee) and about because levels of carbon and nutrients will be very low.*

As a result, the Aquatic Ecosystem EV was determined not to apply to the Leederville and Yarragadee aquifers for Perth GWRS Stage 2.

Groundwater from the Leederville aquifer is currently used by the Corporation for public water supply, by local government for irrigation of parks and gardens and by private suppliers for horticultural and industrial purposes. Groundwater from the Yarragadee aquifer is also used by the Corporation for public water supply, and to a lesser extent by local government for heating public swimming pools and private suppliers for industrial purposes. 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, Primary Industry and Industrial Use EVs are applicable the Leederville and Yarragadee aquifer. The Cultural and Spiritual EV is also required to be maintained.

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

In summary, the IAWG have identified the EVs, management objective and water quality guidelines for the Leederville and Yarragadee aquifers relevant to Perth GWRS Stage 2. They are consistent with the EVs applied to Stage 1 and are provided in Table ES-3.

Table ES-3: Water Quality Guidelines for the identified EVs

Environmental Value	Management Objective	Water Quality Guideline	
		Leederville aquifer	Yarragadee aquifer
Drinking Water	To maintain the water quality in the receiving aquifer to facilitate current and future use	• Recycled Water Quality Indicators • Recycled Water Quality Parameters As defined by the WWS/GWR MoU 2014	
Primary Industries		• As per Drinking Water EV	
Industrial Water		• As per Drinking Water EV	
Cultural and Spiritual		• Consultation with Indigenous Community	

The water quality guidelines for drinking water are based on health guidelines provided in the Australian Drinking Water Guidelines (ADWG) (ADWG, 2011), Australian Guidelines for Water Recycling (AGWR) Phase 2 (NRMMC-EPHC- NHRMC, 2009) and results from the Premiers Collaborative Research Project (DoH et al, 2009) and the Groundwater Replenishment Trial (Corporation, 2013). These water quality guidelines are tailored to the Beenyup wastewater catchment.

Groundwater monitoring will occur within the 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 the EVs remain protected. A monitoring plan will be developed from the risk assessment and revised annually as part of the risk review.

Identification of the relevant EVs, management objectives and water quality guidelines concludes the activities required to complete all of the parts of Step 2 of the GWR Regulatory Framework.

The Water Corporation will now proceed with Step 3 “Conduct a risk assessment for treatment processes and aquifer response to ensure protection of EVs.

Following completion of this step, the IAWG will reconvene to review the risk assessment and approve as appropriate.

1 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. Groundwater replenishment has been identified by the Water Corporation as a safe sustainable water source option for the Integrated Water Supply Scheme (IWSS).

The Groundwater Replenishment Regulatory Framework (IAWG, 2012) (the GWR Regulatory Framework) describes the legislation, statutory and approvals processes applicable to GWR and the role and responsibility of the DoW, DoH and DER in regulating a GWR scheme.

The GWR Regulatory Framework was developed in 2012 by the Groundwater Replenishment Trial Interagency Working Group (IAWG) which consisted of the Department of Health (DoH), the Department of Environment and Conservation [now the Department of Parks and Wildlife (DPaW) and the Department of Environment Regulation (DER)], the Department of Water (DoW) and the Water Corporation.

The GWR Regulatory Framework defines the approvals pathway required to develop, approve commencement of recharge and provide ongoing regulation for a Groundwater Replenishment Scheme. It uses existing statutory processes wherever possible and follows national guidelines to assess aspects that are unique to groundwater replenishment.

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

The DoW is the State's water resources manager and is responsible for managing the Gnangara groundwater system for economic, social and environmental benefit. The management framework for all Gnangara aquifers including the Leederville and Yarragadee aquifers is documented in the *"Gnangara groundwater areas allocation* plan" (DoW, 2009). As part of its role within the IAWG, the DoW is working with the Water Corporation to ensure that the GWR scheme is compatible with current and future directions for groundwater management.

The Water Corporation is progressing planning for Stage 2 of the Perth Groundwater Replenishment Scheme (GWRS) (hereafter referred to as Stage 2) which will double the size of the scheme, approximately 28 gigalitres (GL) per year recharged to the Leederville aquifer and the Yarragadee aquifer at three locations. Those locations include Beenyup and two sites located north of the Beenyup facility.

The Water Corporation will undertake approvals for the Perth GWRS Stage 2 in accordance with the GWR Regulatory Framework. In order to progress these approvals, the Water Corporation has requested that the DoH, DER and DoW reform the IAWG and apply the GWR Regulatory Framework. Since developing the GWR Regulatory Framework the DER has advised that it is taking a different approach to assessment requirements within the applicable legislation and will not participate in the IAWG to assess Stage 2. The IAWG will continue without the DER, who will review the Stage 2 proposal as part of the approvals process within both Section IV and Section V of the *Environmental Protection Act (1986)*.

2 Report Purpose

The GWR Regulatory Framework requires the IAWG to identify the Environmental Values (EVs) applicable to the proposed GWR Scheme.

The IAWG met on 22 August 2016 to review the aquifer characteristics and identify the relevant EVs (see Appendix 1). This report:

- Provides details of the aquifer characteristics required by the IAWG to identify the relevant EVs;
- Identifies EVs of the Leederville and the Yarragadee aquifers relevant to a GWR Scheme recharging approximately 14 GL/yr at the off-site recharge locations;
- Identifies the management objectives for the EVs; and
- Identifies the water quality guidelines required to protect the EVs.

3 GWR Regulatory Framework Process

A summary of the GWR Regulatory Framework is provided in Figure 2-1 and a detailed description of the first four steps has been reproduced below with an adjustment to recognise the absence of DER from this process.

Two of the first four steps of the GWR Regulatory Framework involve collaboration between the DoH, DoW and Water Corporation.

Step One: Aquifer Characterisation

This step requires the Water Corporation to characterise the receiving groundwater environment such that appropriate EVs can be defined. An understanding of how water flows within the aquifer that is being recharged (horizontal or lateral flow) as well as if it will flow from the aquifer that is recharged to adjacent aquifers (vertical or upward flow) is required to adequately identify the EVs.

Information used to characterise the aquifer can be derived from, but is not limited to, existing knowledge of groundwater systems and models that can predict pressure, fate and solute transport. Site investigations may also be carried out to inform this step. The extent of the investigations will depend on the amount of background knowledge that is available to the receiving groundwater environment at the vicinity of recharge.

Previous experience with the GWRT, subsequent schemes and Table 4.2 in chapter 4 of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge (NRMMC-EPHC- NHRMC, 2009) have been referenced to define the key issues to consider at this stage of project development.

Step Two: Environmental Values, Management Objectives and Water Quality Guidelines

This step involves:

1. Defining the EVs for the receiving groundwater environment in the vicinity of recharge.
2. Establishing a set of broad management objectives for the relevant EVs.
3. Determining appropriate water quality guidelines or criteria.

Environmental Values

'Environmental values' is the term applied to particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) (ANZECC Guidelines) recognise six environmental values:

1. Drinking water resource
2. Primary industries (irrigation and general water uses, stock drinking water, aquaculture and human consumers of aquatic foods)
3. Industrial water
4. Cultural and spiritual value
5. Aquatic ecosystems
6. Recreation and aesthetics

The IAWG has identified the EVs relevant to the receiving groundwater environment for Perth GWRS Stage 2 in this report.

Environmental Management Objectives

The environmental management objectives reflect the desired state for EVs identified as relevant to the receiving groundwater environment, such as "maintain for current and future use".

The IAWG has identified the EVs relevant to the receiving groundwater environment for Perth GWRS Stage 2 in this report.

Water Quality Guidelines

Associated with each EV are 'guidelines' or 'trigger values' for substances that might potentially impair water quality (e.g. pesticides, metals or nutrients). If these values are exceeded, they may be used to trigger an investigation or initiate a management response. Where two or more agreed EVs apply to a water body the more conservative or stringent of the associated guidelines should be selected as the applicable water quality guideline.

Determining the EVs and associated water quality guidelines provides a clear pathway for assigning Agency responsibilities where multiple agencies can regulate a GWR scheme. The GWR Regulatory Framework defines the water quality guidelines provided in Table 2 -1 appropriate for the protection of the EVs.

Table 2-1: Water Quality Guidelines appropriate for the protection of EVs

Environmental Value	Water Quality Guideline that will protect the Environmental Value
Aquatic Ecosystems	DER to establish water quality criteria[1] which will be applied with assistance from DoW and DoH.
Primary Industries	Given the unrestricted access to potable (drinking) water for the purpose of primary industry, the Drinking Water Resource EV water quality guidelines will be applied.
Recreation and Aesthetics	DoH to establish water quality criteria with assistance from DoW.
Drinking Water Resource	*Recycled Water Quality Parameters* and *Recycled Water Quality Indicators* identified by the DoH and defined in the current version of the *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (October 2014)* and *Binding Protocol 2 - Demonstrating Recycled Water Quality for Groundwater Replenishment* (part of the MoU).
Industrial Water	Given the unrestricted access to potable (drinking) water for the use in industrial processes, the Drinking Water Resource EV water quality guidelines will be applied.
Cultural and spiritual values	No water quality guidelines are provided for this environmental value. Water Corporation to continue to engage with Indigenous stakeholders.

Representatives from the IAWG will convene to identify the water quality guidelines required to protect the relevant EVs.

Step Three: Risk Assessment

The Water Corporation will undertake a risk assessment covering the wastewater catchment to the boundary of the RMZ by applying the process described in the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk* (AGWR Guidelines) to evaluate how the GWR scheme will protect the EVs.

The risk assessment will consider whether the:

1. Management approaches in wastewater catchments are adequate to mitigate risks to feed water quality for the treatment process.
2. Recycled water produced by the treatment process meets the required water quality guidelines at the point of recharge.
3. Potential aquifer risks can be adequately managed to ensure that water quality continues to meet the water quality guidelines at the boundary of the RMZ (see Section 4).

Step Four: Agency Evaluation

The Water Corporation will present the risk assessment to the IAWG, including risk mitigation strategies.

The IAWG will evaluate and provide written advice regarding the acceptability of the risk assessment process and resultant risks.

The Water Corporation will also provide a copy of the risk assessment report to the DER at this stage.

[1] Water quality criteria may use existing Guidelines or guidelines may need to be developed.

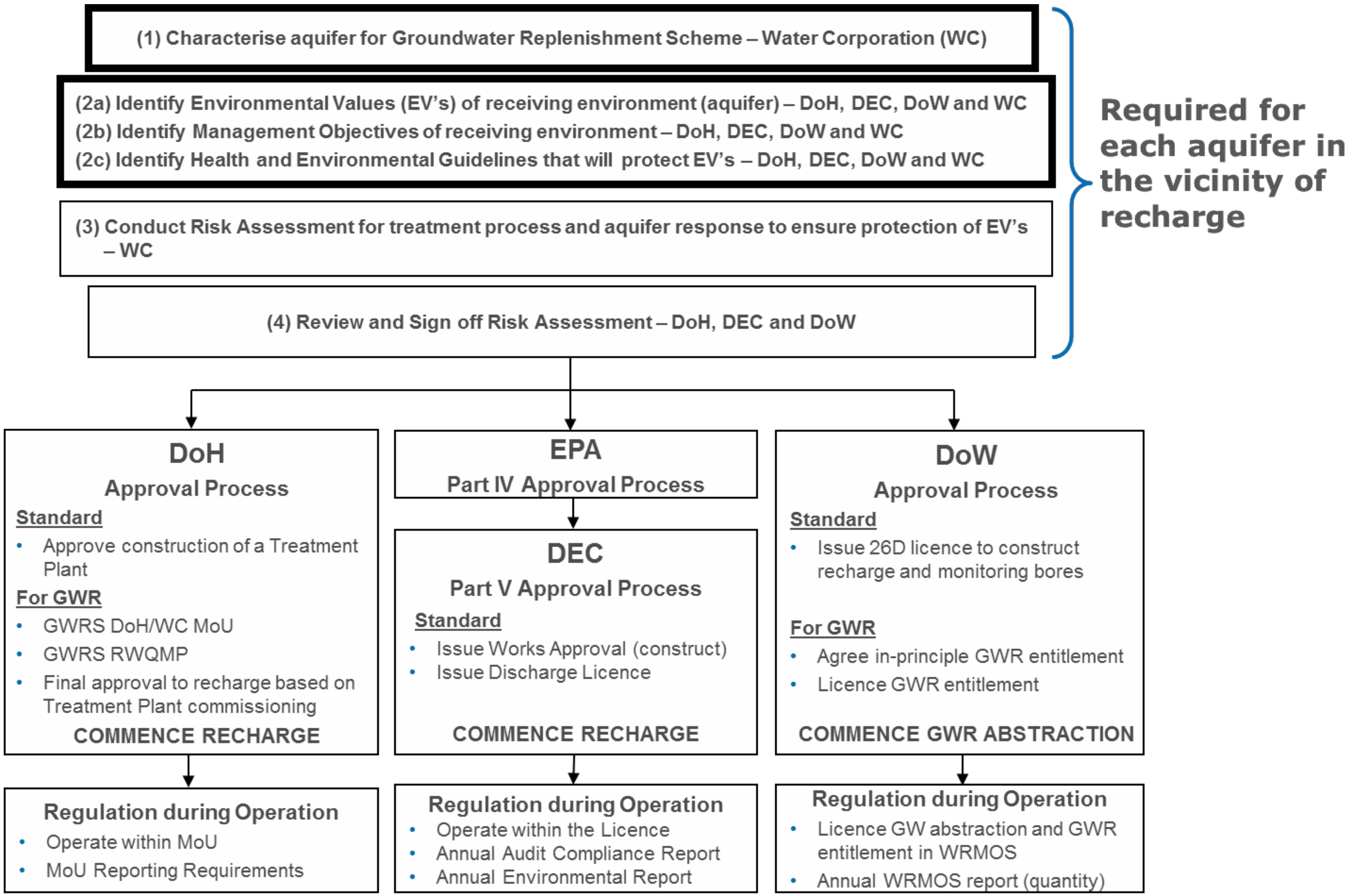


Figure 2-1: Groundwater Replenishment Regulatory Framework

Note: This figure represents the version agreed in December 2012. The function performed by the DEC in 2012 is now performed by the DER.

The DER has elected not to be included in this process for the assessment of Perth GWRS Stage 2

4 Recharge Management Zones

The IAWG has identified that a RMZ for each recharge bore is a requirement of any GWR scheme.

Recycled water must meet the water quality guidelines required for each EV at the point of recharge. There is potential for recycled water to have a physical or chemical reaction with the aquifer substrate or groundwater which may result in a change in water quality. A RMZ allows for these reactions to occur and the groundwater environment to return to equilibrium within the boundary of the RMZ.

Therefore, a RMZ defines the minimum distance between recharge of recycled water and abstraction of groundwater for public drinking water supplies. It also defines the boundary at which groundwater must meet the water quality guidelines required to protect the identified EVs. The EVs are always preserved and the recharged water becomes part of the environment beyond the RMZ boundary. Figure 2-2 provides a conceptual diagram of the RMZ.

A RMZ has a radial boundary and an early indication monitoring bore located between 50- 100 m from the point of recharge. The monitoring bore is designed to monitor any potential changes to water quality. A series of management actions can be executed, if an unacceptable change is detected, including but not limited to additional monitoring, additional research, additional or altered treatment.

This early indication monitoring bore can also be used for compliance purposes. If unacceptable changes are detected at this bore, the Corporation will discuss the management response and compliances requirements with the relevant regulating agency.

The Groundwater TRG (consisting of hydrogeological experts from CSIRO, Department of Water, Curtin University, Rockwater Pty Ltd and Water Corporation) have determined that the RMZ boundary of 250m from each recharge bore is appropriate for Perth GWRS Stage 1 and Stage 2 (see Appendix 2). The RMZ will be validated during recharge from Perth GWRS Stage 1, and assessed through the iterative risk assessment process.

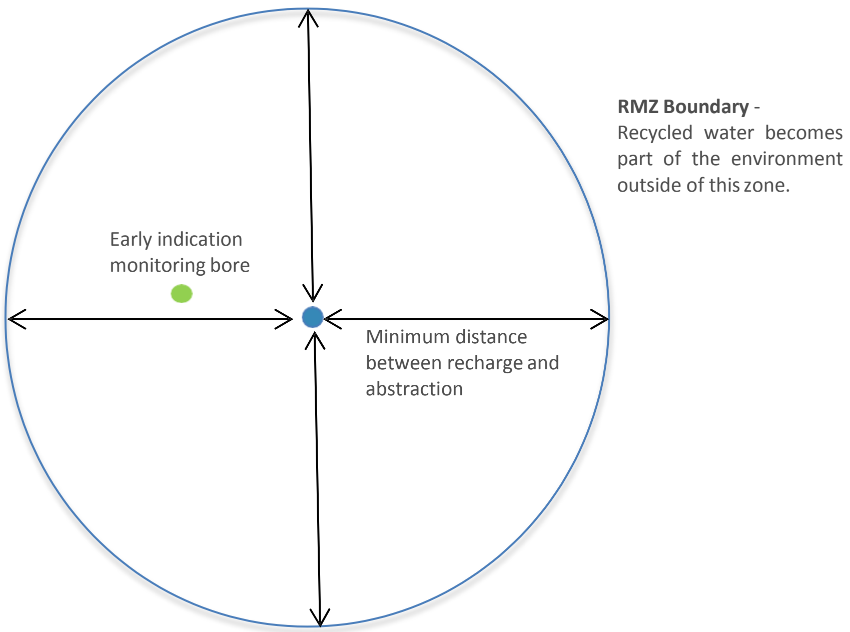


Figure 2-2: Conceptual Recharge Management Zone

5 Perth Groundwater Replenishment Scheme

The Water Corporation is progressing development of the Perth GWRS at the Beenyup site in Craigie, in Perth's northern suburbs.

The scheme is being planned in stages, allowing a flexible approach to meet demand requirements of the Integrated Water Supply Scheme (IWSS).

Based on current wastewater volumes and the advanced water treatment process the scheme can deliver approximately 28 GL/y).

Delivery of the current Perth GWRS is planned in two stages, described in Table 5-1 and illustrated in Figure 5-1.

Table 5-1: Current Stages of the Perth GWRS

Stage	Due to commence recharge	Activity
Stage 1	Late 2016	Construct a 14GL/yr Advanced Water Recycling Plant (AWRP) at the Beenyup facility. Recharge the Leederville and the Yarragadee aquifers at the Beenyup facility.
Stage 2	Late 2018	Construct an additional 14GL/yr AWRP at the Beenyup facility (to provide approximately 28GL of recycled water). Recharge the Leederville and the Yarragadee aquifers at two off-site recharge locations approximately 6.5km and 8.5km to the north of the Beenyup facility.

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.

Figure 5-1: Perth GWRS Stage 1 and Stage 2

5.1 Perth GWRS Stage 1

The Perth GWRS Stage 1 (hereafter referred to as Stage 1) was announced by the State Government as Perth's next water source in mid - 2013. Recharge is scheduled to commence in December 2016.

Located at the Beenyup facility, it consists of an AWRP which can produce approximately 14 GL/year and recharge onsite via three Leederville aquifer recharge bores and one Yarragadee aquifer recharge bore.

The Stage 1 recharge bores are located within a Priority 3 classification area Public Drinking Water Supply Areas (PDWSA). PDWSA's are underground pollution control areas, water reserves and catchment area that have been identified as current or future sources of drinking water. The IAWG have determined that the potential risks presented by undertaking groundwater replenishment in a P3 can be adequately managed, as the recycled water must meet drinking water guidelines (as defined by the WWS/GWR MoU 2014) at the point of recharge.

The Groundwater TRG defined a RMZ for each recharge bore at a radial distance of 250m from the point of recharge, each with an early indication monitoring bore located between 50m to 100m from recharge screened over the same interval as the recharge bore (Figure 5-2). A groundwater monitoring plan to demonstrate protection of the environmental values of the receiving groundwater environment was derived from the groundwater risk assessment.

The environmental values, management objectives and water quality guidelines applicable to Stage 1 are described in the table below.

Table 5-2: GWRS Stage 1 EVs, Management Objectives and Water Quality Guidelines

Environmental Value	Management Objective	Water Quality Guideline	
		Leederville aquifer	Yarragadee aquifer
Drinking Water	To maintain for current and future use	• Recycled Water Quality Indicators • Recycled Water Quality Parameters As defined by the WWS/GWR MoU 2014	
Primary Industries		• As per Drinking Water EV	
Industrial Water		• As per Drinking Water EV	
Cultural and Spiritual		• Consultation with Indigenous Community	