Government of **Western Australia**
Department of **Jobs, Tourism, Science and Innovation**

Report to National Water Infrastructure Development Fund

Western Trade Coast Managed Aquifer Recharge of Treated Wastewater for Industrial Water Supply

Feasibility Study

April 2019

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

Executive summary

Background

The Western Trade Coast (WTC) is a critical industrial region of Western Australia that anticipates increased water demand, in the face of limited groundwater supply and continued growth in the cost of scheme water supply.

Prefeasibility studies have shown that a managed aquifer recharge (MAR) scheme could be technically and financially viable to support the WTC's water demand into the future, while also being potentially environmentally beneficial.

This report documents the Feasibility Study of the two most prospective MAR scheme sites, and is a synthesis of a number of work packages:

- An engineering design and costing study (GHD, 2018),
- Local groundwater and solute transport modelling,
- A Stage 2 risk assessment under Phase 2 of the *Australian guidelines for water recycling: Managing health and environmental risks (MAR)* (Donn, et al., 2019),
- A commercial feasibility assessment (Synergies, 2018), and
- A regulatory and licensing requirements assessment and workshop.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the report.

Site 1 scheme overview

Site 1 (7.4 ha) is located near the mid to northern part of the WTC within the Thompsons groundwater subarea. The site is proposed to receive treated waste water (TWW) from Water Corporation's Woodman Point Waste Water Treatment Plant (WWTP) via the Sepia Depression Ocean Outlet Landline (SDOOL), at an offtake ~200 m west of the site.

TWW will be processed through MAR pre-treatment facilities, which will be upgraded in 2030 to accommodate water quality changes when brine from the future Advanced Water Recycled Plant (AWRP) at Woodman Point is connected to the SDOOL. The pre-treatment facility will consist of denitrifying filters initially; and reverse osmosis added in the future stage.

Recharge of the recycled water will be achieved using two (duty/resting) 10,000 m^2 infiltration basins, at a design recharge rate of 10 ML/d, and the residuals pumped back to the SDOOL.

The site is constrained by existing utilities and the planned Fremantle Rockingham Controlled Access Highway (FRCAH) and associated road/rail works. It has been assumed that the SDOOL offtake and supply main to Site 1 will be constructed prior to development of the FRCAH, and that any future modifications required as a consequence of the FRCAH (e.g. relocation of offtake and supply main) would be completed at that time.

Site 2 scheme overview

Site 2 (6.0 ha) is located in the southern part of the WTC within the Wellard groundwater subarea, and is approximately 1.5 km east of the SDOOL, and 3 km north east of Water Corporation's East Rockingham WWTP.

It is proposed that TWW will be sourced from the East Rockingham WWTP and pumped to a pre-treatment facility near the WWTP for removal of solids and nitrogen via denitrifying filters. Recycled water will then be pumped to the recharge site via several major asset crossings (i.e. proposed FRCAH, existing and proposed rail corridors, Mandurah Road and the Dampier to Bunbury Natural Gas Pipeline). The recharge method will be via three buried infiltration galleries at a recharge rate of 10 ML/d, and the residuals pumped back to the SDOOL.

Environmental considerations

The Stage 2 risk assessment identified the majority of hazards for both sites to have low risk ratings after proposed mitigation measures are introduced. However a number of key aspects require further investigation prior to scheme development. In particular:

- The potential impact of nitrogen and organic chemicals on receiving environments (nearby wetlands and Cockburn Sound) is likely low, but remains uncertain given a lack of data.
- There is limited information on the Geomorphic Wetlands nearby the recharge sites, and while the risk of any impact is likely low, analysis of the wetlands is required to confirm this.
- There are known and suspected contaminated sites within or adjacent to both sites.
- Additional ground-truthing of the groundwater model is required to validate the areas of inundation currently predicted near Site 1.

Furthermore, Site 2 is situated within a 'Bush Forever' reserve. This designation creates a key constraint that increases the challenge of obtaining a clearing permit approval from the Department of Water and Environmental Regulation and planning approval from the Western Australian Planning Commission.

Financial viability

Capital and operating cost estimates (accuracy ±25%) for Sites 1 and 2 are summarised below.

Site 1 and 2 cost summary

Site		CAPEX (2018 $M)	OPEX (2018 $M/year)		Unit cost (100% utilisation) ($/kL)
			Annual cost	Periodic gallery costs (notionally every 10 yrs)	
Site 1	Stage 1	21.5	**0.95**	N/A	**0.95**
	Stage 2	6.6	**1.62**	N/A	**1.13**
	Total	**28.1**	N/A	N/A	N/A
Site 2	Total	**17.3**	**0.85**	**0.83**	**0.60**

A financial analysis of Site 1 has not been undertaken given that it is more costly, will supply less area and is expected to receive significantly less demand.

A MAR scheme at Site 2 appears financially viable and could deliver large financial returns (Financial Net Present Value ~$30 million) if projected growth scenarios are realised. The project could be almost riskless if identified user demand events eventuate (i.e. several major users switching from scheme water to MAR, and several proceeding with expansion plans), but it faces considerable risk without them.

Service models

The following service models for structuring a MAR scheme have been assessed, with varying pros and cons applicable to each:

- The Water Corporation or a private, independent water utility, owns and operates the scheme and establishes supply contracts with licensed MAR customers in the WTC.
- A joint venture (JV) of major water users in the WTC develops, owns and operates the MAR scheme and grants the members of the JV rights to water under that scheme.

Next steps

A number of key knowledge gaps are still to be addressed, including confirmation of the timing and arrangements of the future FRCAH, confirmation of design standards and water quality and access arrangements to the SDOOL/East Rockingham WWTP with Water Corporation, and consultation to confirm land acquisition at the proposed sites and pipeline routes, as well as confirmation of the environmental considerations outlined earlier.

Upon addressing these knowledge gaps and developing a detailed design for the preferred site, the relevant approvals for the two schemes should be addressed, the process of which is detailed herein (refer Section 9.4). Should Site 1 be considered a preferable alternative to Site 2, the financial viability of Site 1 should be assessed in similar detail to that of Site 2.

It is expected that a project proponent would likely build its business case around the prospective users who have been identified as willing to switch to MAR water to secure foundation contracts. The proponent may then build some capacity in addition to the level required to meet the foundation demand as a calculated risk that there will be reasonably strong underlying demand growth, from which the proponent could earn additional returns.

Table of contents

Executive summary i

1. Introduction 1
   1.1 Background 1
   1.2 Report structure 3
   1.3 Purpose of this report 3
   1.4 Limitations 3

2. Current supply and demand situation 5
   2.1 Water sources 5
   2.2 Demand projections 6
   2.3 What would business as usual look like? 8

3. The Western Trade Coast managed aquifer recharge proposal 9
   3.1 Scheme overview 9
   3.2 Superficial aquifer 10
   3.3 Site 1 setting 10
   3.4 Site 2 setting 11
   3.5 Treated wastewater sources 13

4. Engineering design 17
   4.1 Approach 17
   4.2 Site 1 18
   4.3 Site 2 21
   4.4 Groundwater monitoring 26

5. Cost estimates 27
   5.1 CAPEX 27
   5.2 OPEX 28
   5.3 Unit cost of MAR water 29

6. Stage 2 risk assessment 30
   6.1 Approach 30
   6.2 Groundwater understanding 30
   6.3 Receiving environments/receptors 31
   6.4 Hazard identification 33
   6.5 Maximal and pre-commissioning residual risk assessment 46

7. Financial, economic and commercial analysis 56
   7.1 Approach 56
   7.2 Financial and economic analysis 56
   7.3 Commercial analysis 63

8. Conclusions 67
   8.1 Environmental considerations 67
   8.2 Engineering considerations 68

8.3 Financial viability 69
8.4 Commercial considerations and service models 69
9. Next steps 71
9.1 Knowledge gaps and further investigations 71
9.2 Design development 74
9.3 Stage 3 risk assessment 74
9.4 Approvals 74
9.5 Government involvement 77
9.6 Commercial considerations 77
9.7 Service models 78
10. References 79

Table index

Table 2-1 Groundwater allocations for the Superficial aquifer (DWER, 2018) 5
Table 2-2 Future supply constraints 8
Table 3-1 Comparison of forecast median TWW quality in 2030 14
Table 3-2 Comparison of forecast median TWW quality in 2050 15
Table 3-3 Target recycled water quality 15
Table 4-1 Site 1 pre-treatment facility overview 19
Table 4-2 Site 2 pre-treatment facility 26
Table 4-3 Example groundwater quality sampling suite 26
Table 5-1 CAPEX estimate summary 27
Table 5-2 CAPEX estimate exclusions 27
Table 5-3 OPEX estimate summary 28
Table 5-4 OPEX estimate exclusions 29
Table 5-5 Levelised unit cost of MAR water (Synergies, 2018) 29
Table 6-1 Life cycle GHG emissions (Donn, et al., 2019) 46
Table 6-2 Risk assessment method adapted from Phase 1 Australian Guidelines for Water Recycling (Donn, et al., 2019) 47
Table 6-3 Maximal risk assessment for Site 1 (Donn, et al., 2019) 48
Table 6-4 Maximal risk assessment for Site 2, where different to Site 1 (Table 6-3) (Donn, et al., 2019) 54
Table 7-1 Water pricing assumptions 57
Table 7-2 Summary of sensitivity analyses (Synergies, 2018) 61
Table 7-3 Risk summary (Synergies, 2018) 63
Table 7-4 Overview of service provision options (Synergies, 2018) 65
Table 9-1 Site 1 terms of reference summary 71

Table 9-2 Site 2 terms of reference summary....72

Figure index

Figure 1-1 WTC study area and location of proposed MAR sites (DPLH, 2018)....2
Figure 2-1 Heavy industry water demand (central) forecasts for Valley and Wellard subareas (Synergies, 2018)....7
Figure 3-1 Prospective MAR sites identified in prefeasibility studies, eleven initial sites (left) and six final locations (right) (McFarlane, DJ (ed), 2015, p. 152)....9
Figure 3-2 Locality plan – Site 1....11
Figure 3-3 Locality plan – Site 2....12
Figure 3-4 Bush Forever and wetlands near Site 2....13
Figure 3-5 Schematic illustration of SDOOL assets and connections....14
Figure 3-6 SDOOL flow projections (Synergies, 2018)....16
Figure 3-7 East Rockingham WWTP flow projections (Synergies, 2018)....16
Figure 4-1 Engineering Design and Costing Study work packages....17
Figure 4-2 Site 1 MAR scheme general arrangement (from Engineering Drawing 61-35557-C004) (GHD, 2018)....18
Figure 4-3 Site 1 MAR scheme – Process flow diagram....20
Figure 4-4 Site 2 general arrangement (from Engineering Drawing 61-35557-C003) (GHD, 2018)....21
Figure 4-5 East Rockingham WWTP temporary final effluent pump station....22
Figure 4-6 Site 2 infiltration gallery (from Engineering Drawing 61-35557-C006) (GHD, 2018)....23
Figure 4-7 Images of DS Agency's Flatbed Leach Drain System....23
Figure 4-8 Site 2 MAR scheme – Process flow diagram....24
Figure 6-1 Receiving environments (Donn, et al., 2019)....32
Figure 6-2 Modelled travel time for TWW infiltrated at Site 1 (a and b) and Site 2 (c and d). Both long term and short term travel times are depicted (Donn, et al., 2019)....35
Figure 6-3 Heavy metal/metalloid concentrations in TWW, trigger values as per footnote (Donn, et al., 2019)....37
Figure 6-4 Salinity of TWW sources, groundwater and important wetlands (Thomson's Lake and The Spectacles Swamp) (Donn, et al., 2019)....38
Figure 6-5 Total phosphorus concentrations in TWW sources (Donn, et al., 2019)....39
Figure 6-6 Concentration of nitrogen species in TWW sources (Donn, et al., 2019)....40
Figure 6-7 TSS concentration in TWW sources (Donn, et al., 2019)....41
Figure 6-8 Median inundation extent across all models for Site 1 (a and b) and Site 2 (c and d) for the no MAR scenario (a and c) and the MAR no recovery scenario (b

and d) under the DWER dry climate scenario (2030). End of model (2045) results shown. (Donn, et al., 2019) 43

Figure 6-9 Median maximum mound height across all models at Site 1 (a and b) and Site 2 (c and d) both with (left) and without (right) 10 ML/d of additional groundwater abstraction down gradient of the sites (Donn, et al., 2019) 44

Figure 6-10 TWW pH 45

Figure 7-1 Marginal revenue relative to existing sources (Synergies, 2018) 57

Figure 7-2 MAR marginal revenue (real), 2017 to 2080 (Synergies, 2018) 58

Figure 7-3 MAR demand relative to other supply sources (Synergies, 2018) 58

Figure 7-4 Site 2: optimal MAR scheme start years (Synergies, 2018) 60

Figure 7-5 Site 2: average NPV by optimal commencement year, 2019 to 2038 (Synergies, 2018) 60

Figure 9-1 Approvals flow diagram (DJTSI, 2018) 76

Appendices

Appendix A – Engineering Design and Costing Study

Appendix B – Stage 2 Risk Assessment

Appendix C – Commercial Feasibility Assessment

Appendix D – Approval requirements

Acknowledgements

This feasibility study is supported by funding from the Australian Government's National Water Infrastructure Development Fund, an initiative of the Northern Australia and Agricultural Competitiveness white paper.

This feasibility study is also supported by contributions from the Kwinana Industries Council and the CSIRO.

The Department of Jobs, Tourism, Science and Innovation thanks members of the Working Group and Steering Committee established to oversee the feasibility study including the CSIRO, Department of Health, Department of Water and Environment Regulation, Kwinana Industries Council and LandCorp. The Department also acknowledges the expertise contributed by GHD and Synergies Economic Consulting to the feasibility study.

GHD, Synergies Economic Consulting and CSIRO would like to thank Marzia Zamir and Ella Herbert from the Department of Jobs, Tourism, Science and Innovation for their management and peer review of this study. Furthermore, the study team acknowledges Amy Cowdell from the Department of Water and Environmental Regulation and Helen McGettigan from the Water Corporation for their support and guidance throughout the study.

Acronyms

AGWR	Australian Guidelines for Water Recycling
AHD	Australian height datum
AWRP	Advanced Water Recycling Plant
BOD	Biological oxygen demand
Capex	Capital expenditure
DBNGP	Dampier Bunbury Natural Gas Pipeline
DJTSI	Department of Jobs, Tourism, Science and Innovation
DoEE	Department of the Environment and Energy
DoH	Department of Health
DoW	Department of Water (former department)
DPLH	Department of Planning Lands and Heritage
DWER	Department Water and Environmental Regulation
EPA	Environmental Protection Authority
ERA	Economic Regulation Authority
FEPS	Final Effluent Pump Station
FRCAH	Fremantle Rockingham controlled access highway
GHG	Greenhouse Gas
GWR	Groundwater replenishment
JDAP	Joint Development Assessment Panel
KIC	Kwinana Industries Council
KWRP	Kwinana Water Reclamation Plant
MAR	Managed aquifer recharge
MRWA	Main Roads Western Australia
NBN	National Broadband Network
NGER	National Greenhouse and Energy Reporting
NWIDF	National Water Infrastructure Development Fund
Opex	Operating expenditure
P&ID	Piping and instrumentation diagram
PFD	Process flow diagram
RIZ	Rockingham Industrial Zone
RO	Reverse osmosis
RWQMP	Recycled water quality management plan
SDOOL	Sepia Depression Ocean Outlet Landline
SEA	Strategic Environmental Assessment
SPP	State Planning Policy
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
TWW	Treated wastewater
WAPC	Western Australian Planning Commission
WTC	Western Trade Coast
WWTP	Wastewater treatment plant

1. Introduction

1.1 Background

The Western Trade Coast (WTC) is a primary industrial region of Western Australia (WA) that is critical to WA's economy and a major source of employment. The WTC encompasses the Kwinana Industrial Area, Latitude 32 Industry Zone, Rockingham Industry Zone and Australian Marine Complex, and is located approximately 30 km south of Perth, as shown in Figure 1-1. The WTC is a significant contributor to the WA economy with direct sales in excess of $14 billion per annum and employment of over 11,000 people [1].

The Department of Jobs, Tourism, Science and Innovation (DJTSI) is the Western Australian Government's Lead Agency for the Western Trade Coast and the Project Proponent for this feasibility study which is supported by the National Water Infrastructure Development Fund (NWIDF). The Kwinana Industries Council (KIC) and the CSIRO are co-contributors and project partners to the Feasibility Study, and the Department of Water and Environment Regulation (DWER), Water Corporation, LandCorp and Department of Health (DoH) have assisted with advice and review throughout.

Earmarked for continued development, the significant water demand of the heavy industry in the WTC is expected to increase by up to 25 GL by 2031 (REU, 2014). The Superficial Aquifer and confined aquifers within the region are already fully allocated, and additional allocations are unlikely to be granted given reduced recharge rates associated with the region's drying climate. Water supply is expected to become more expensive as self-supply groundwater sources are depleted and costs to access and treat the water increase.

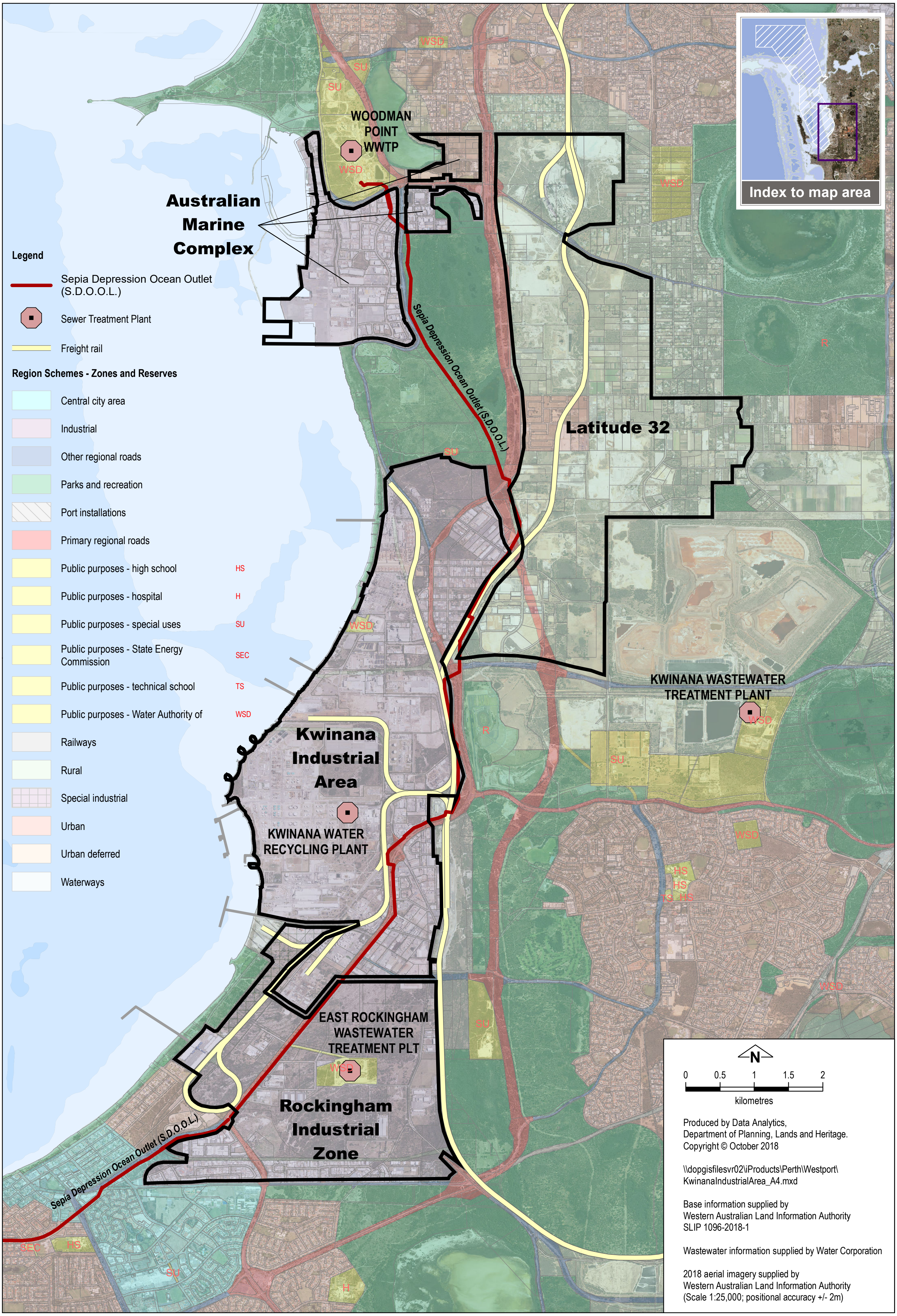
Pre-feasibility studies led by CSIRO (McFarlane, DJ (ed), 2015), and a subsequent local water supply strategy (DoW, 2016) have identified that a managed aquifer recharge (MAR) scheme could be technically and financially viable to support the WTC's water demand into the future, while also being environmentally beneficial.

A number of work packages have since been undertaken for the two most prospective MAR schemes, including:

- Engineering and cost estimates (GHD, 2018),
- A Stage 2 risk assessment under Phase 2 of the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (MAR)* (Donn, et al., 2019),
- Local groundwater and solute modelling (results are incorporated in the above risk assessment),
- A commercial feasibility assessment (Synergies, 2018), and
- Assessment of regulatory and licensing requirements (DJTSI, 2018).

This report documents the overall findings from the above work packages to form the Feasibility Study for the MAR schemes.

[1] https://www.landcorp.com.au/Documents/Projects/Industrial/Western%20Trade%20Coast/Western-Trade-Coast-Integrated-Assessment.pdf



Western Trade Coast

1.2 Report structure

This report is structured as follows:

- Section 2 identifies existing water supply and demand conditions in the WTC, and describes options to maintain security of supply into the future (including the base case scenario).
- Section 3 provides an overview of the two MAR schemes, the treated wastewater sources, and the geological and hydrogeological setting of the region.
- Section 4 outlines the engineering design for the two schemes.
- Section 5 outlines the associated costs for the two schemes.
- Section 6 details the Stage 2 risk assessment incorporating outcomes of the hydrogeological modelling and investigations.
- Section 7 establishes an understanding of the financial, economic and commercial viability of the MAR schemes.
- Section 8 summarises the outcomes and conclusions of the above sections.
- Section 9 identifies the additional work required to bring the project to a status ready for investment.

1.3 Purpose of this report

This report is a synthesis of the studies undertaken as separate components of the overall Feasibility Study, as described in Section 1.1. This report therefore represents the Feasibility Study for the WTC MAR scheme, and outlines the additional work required to advance the project to acquire sufficient planning, approvals, design and service models to ready the project for financial commitment.

1.4 Limitations

This report has been prepared by GHD for LandCorp and the Department of Jobs, Tourism, Science and Innovation (DJTSI) and may only be used and relied on by LandCorp and DJTSI for the purpose agreed between GHD, LandCorp and DJTSI as set out in Section 1.3 of this report.

Without limiting any other qualification or limitation under this Section 1.4 and supplementary to GHD's qualification as to unverified information, whilst GHD has in accordance with the agreed scope of work selected, extracted and referenced in this report information contained in the third party reports annexed to this report (Synergies, 2018; Donn, et al., 2019) ("Third Party Content"), GHD accepts no responsibility for and does not endorse, guarantee or make any recommendation as to the accuracy, reliability or currency of the Third Party Content or the extent to or manner in which GHD has selected, extracted or referenced the Third Party Content in this report. GHD disclaims all liability from any views that may be occasioned directly or indirectly through the use of, or reliance on the Third Party Content. This report is not in substitution for full reference to the sources of the Third Party Content and does not diminish or otherwise prejudice any qualifications and limitations particular to the Third Party Content as may be expressed in those sources. The Third Party Content in this report also remains subject to any such qualifications and limitations.

GHD otherwise disclaims responsibility to any person other than LandCorp and DJTSI arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by DJTSI, Synergies, CSIRO, and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary cost estimate/prices set out in Section 5 of this report ("Cost Estimate") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD.

The Cost Estimate has been prepared for the purpose of informing potential proponents of the approximate costs of the MAR schemes, and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the proposed MAR Scheme(s) can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

2. Current supply and demand situation

2.1 Water sources

The heavy industry in the WTC is estimated to source 16 GL of its water annually from groundwater, 5 GL from the Kwinana Water Reclamation Plant (KWRP), 4 GL from potable scheme water, and the remainder from stormwater reuse, making up ~28.5 GL per year (DoW, 2016).

2.1.1 Groundwater

The WTC boundary lies approximately within the Cockburn Groundwater Area (CGA), of which the Valley and Wellard groundwater subareas are of most relevance to this study. Table 2-1 outlines the allocation limits and licensed allocations for these groundwater areas.

Of note, a significant portion of the Valley and Wellard licensed entitlements remain unused (DoW, 2016). However, the Department of Water and Environmental Regulation (DWER) has determined that these groundwater subareas are over-allocated by a total of 2.8 GL, indicating that future use could exceed sustainable quantities.

Recognising this issue, DWER intend to recoup long-term unused water entitlements to meet revised allocation limits set in the Cockburn Groundwater Allocation Plan, shown in Table 2-1 (DWER, 2018). Based on the five-year period up to 2016, the average unused water entitlements make up 1.84 GL, and it is expected that a similar volume will be recouped going forward, as discussed further in Section 7.2.2.

The majority of groundwater demand in the WTC is associated with a very small portion of licensed users. In particular, Synergies (2018) found that eight groundwater licences located within the Wellard groundwater subarea make up more than 90% of the allocated water from the Perth Superficial Swan groundwater resource.

While future availability may be limited, groundwater is generally a low-cost water source given that pumping and on-site treatment (site-specific) are the only applicable costs. Many users generally apply on-site reverse osmosis to treat groundwater to suit their particular industrial purpose (the exception being water used for cooling) (Synergies, 2018).

Table 2-1 Groundwater allocations for the Superficial aquifer (DWER, 2018)

Groundwater allocation area	General allocation limit (2018)	Current (2018) licensed entitlements (GL)
Valley subarea	5.5	8.7
Wellard subarea	5.38	6.6

2.1.2 Kwinana Water Reclamation Plant

Owned and operated by Water Corporation, the KWRP is an advanced water recycling plant that treats ‘raw water’, sourced from the Sepia Depression Ocean Outlet Landline (SDOOL), which is primarily treated wastewater (TWW) from the Woodman Point Wastewater Treatment Plant (WWTP). The plant has a design (output) capacity of 6 GL per year (16.7 ML/d), and currently supplies ~5 GL per year (14 ML/d) of recycled water to five or six industrial customers in proximity to Kwinana, at a price below that of scheme water. There is potential to expand the plant by an additional 3.6 GL (9.9 ML/d) with further investment.

There is currently scope for the plant to supply additional users in proximity to Kwinana, however providing for other areas of the WTC would require establishment of an expensive pipe network.

Recycled water from the KWRP is of a sufficient quality that several customers do not treat the water further, while others ‘shandy’ the recycled water with groundwater to ensure the water quality meets their requirements (Synergies, 2018).

2.1.3 Potable scheme water supply

Water Corporation’s Integrated Water Supply Scheme (IWSS) ensures potable scheme water is available to all industrial properties in the WTC. Water Corporation has confirmed that all industrial customers in the WTC, including those from future greenfield sites, could be supplied via the IWSS if required.

However, customers would be required to pay for any distribution scheme upgrades or mains extensions required to supply their site, on top of the standard infrastructure contribution fee. The water quality of scheme water is also generally of a higher quality than required for most industrial uses.

Scheme water is therefore a reliable backup water source that can meet growing industrial demand in the WTC, however it is likely to be less cost efficient than other sources.

2.2 Demand projections

Three sets of water demand forecasts to 2031 were developed by Resource Economics Unit (REU) to inform the *WTC heavy industry local water supply strategy* (DoW, 2016). The forecasts are based on an economic input-output model that considers macro-economic variables and an analysis of international trends for export products (REU, 2014). The model projections predict water demand will increase with the following economic indicators:

- Total output projections (upper bound demand),
- Value added projections (medium demand), and
- Employment projections (lower bound demand).

A single economic growth scenario is assumed, however the three projections adopt differing relationships between economic growth and water demand growth.

Synergies extended the forecasts to 2040, and further disaggregated the projections into the four groundwater subareas of the CGA with consideration to the industries, land availability and planning arrangements of each subarea (Synergies, 2018).

Figure 2-1 displays the medium demand forecasts for the Valley and Wellard groundwater subareas. The predictions suggest faster growth in the Wellard subarea compared to the Valley subarea, with demand projected to increase to ~15 GL per year and 4 GL per year by 2040, respectively.

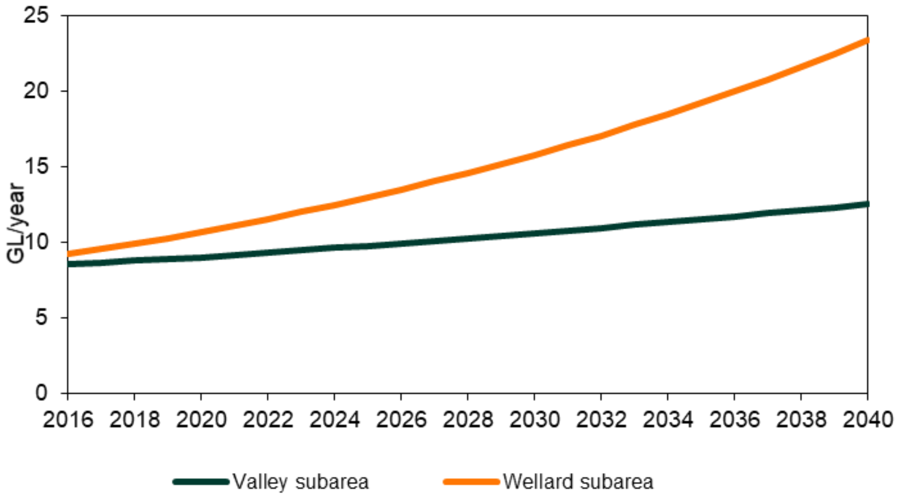


Figure 2-1 Heavy industry water demand (central) forecasts for Valley and Wellard subareas (Synergies, 2018)

It is noted that actual growth would likely occur in step changes rather than as smooth growth, as existing industries expand or new industries develop. Furthermore, given future economic growth rate uncertainties and the nature of future changes in economic structure, it is also considered plausible that water demand will not grow at all (Synergies, 2018).

Interviews with ten of the WTC's largest users of groundwater were undertaken to explore the validity of the projections, and found that there is an expected demand increase of at least 2.7 GL by 2020, which is roughly consistent with the forecasts (Synergies, 2018).

The interviews also discerned that four large users are looking at alternative sources to replace their scheme water usage. Other users are also considering selling or trading their groundwater allocations. Trades and transfers of water licence entitlements are approved by DWER in accordance with DWER's *Operational policy 5.13 Water entitlement transactions for Western Australia 2010* and *Cockburn Groundwater Allocation Plan for public comment 2018*.

Demands from proposed developments on greenfield sites were unable to be quantified, however the following planned developments are noted (Synergies, 2018):

- Lithium carbonate and/or hydroxide refinery (Covalent Lithium),
- Lithium hydroxide processing facility (under construction) (Tianqi Lithium Australia), and
- Outer harbour development, freight logistics and intermodal facilities (Latitude 32 / Westport).

2.3 What would business as usual look like?

Under a business as usual scenario (herein referred to as the “Base Case” scenario), it is assumed that future demand can be met from some combination of groundwater, TWW from KWRP, or scheme water [2]. This Base Case scenario is considered a reference against the MAR scheme.

The precise combination for each business will depend on their access to the supply sources, cost and suitability of use, as summarised in Table 2-2. Groundwater makes the most economic sense, but is constrained in quantity and quality, while recycled water from the KWRP is more costly and is constrained by location and quantity. Scheme water however, is effectively unconstrained but would be the most costly. Nonetheless, the cost of water for typical businesses in the WTC currently comprises only ~0.2% of their total production value, and as such businesses will likely be willing to pay for scheme water if needed (Synergies, 2018).

Table 2-2 Future supply constraints

Source	Predicted cost ($/kL)	Availability
Surplus groundwater	Up to ~0.50 [3]	~1.84 GL of allocated water currently unused (refer Section 2.1.1)
Recycled water from KWRP	1.5 [4]	~1 GL for areas near KWRP Additional ~3.6 GL if expanded (refer Section 2.1.2)
Scheme water	2.4 [5]	Effectively unconstrained

[2] A consortia could find an alternative source, such as development of an on-site desalination plant, if that was more cost-effective than purchasing scheme water. However, for the purpose of Synergies’ analysis, scheme water from the IWSS is considered the backup water source. To the extent that desalination is less expensive than scheme water, this would reduce the financial competitiveness of MAR (as it would then compete with desalination, not scheme water).

[3] Pricing data for water trades in WTC is not available, though some evidence suggests prices rarely exceed $0.50/kL.

[4] Estimated by Synergies (Synergies, 2018), though value has not been verified as Water Corporation pricing information is commercial in confidence.

[5] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105.

3. The Western Trade Coast managed aquifer recharge proposal

3.1 Scheme overview

The MAR scheme aims to produce additional water through recycling of TWW, recharging the Superficial aquifer and development of an additional groundwater allocation component associated with a MAR Management Zone based on the rates of recharge.

Prefeasibility studies identified prospective sites for recharge works, as depicted in Figure 3-1. An aquifer recharge rate of 10 ML/d was determined to be the maximum rate which should be targeted for the MAR scheme (McFarlane, DJ (ed), 2015). This was based on twice the rate of infiltration observed at Water Corporation's Kwinana WWTP.

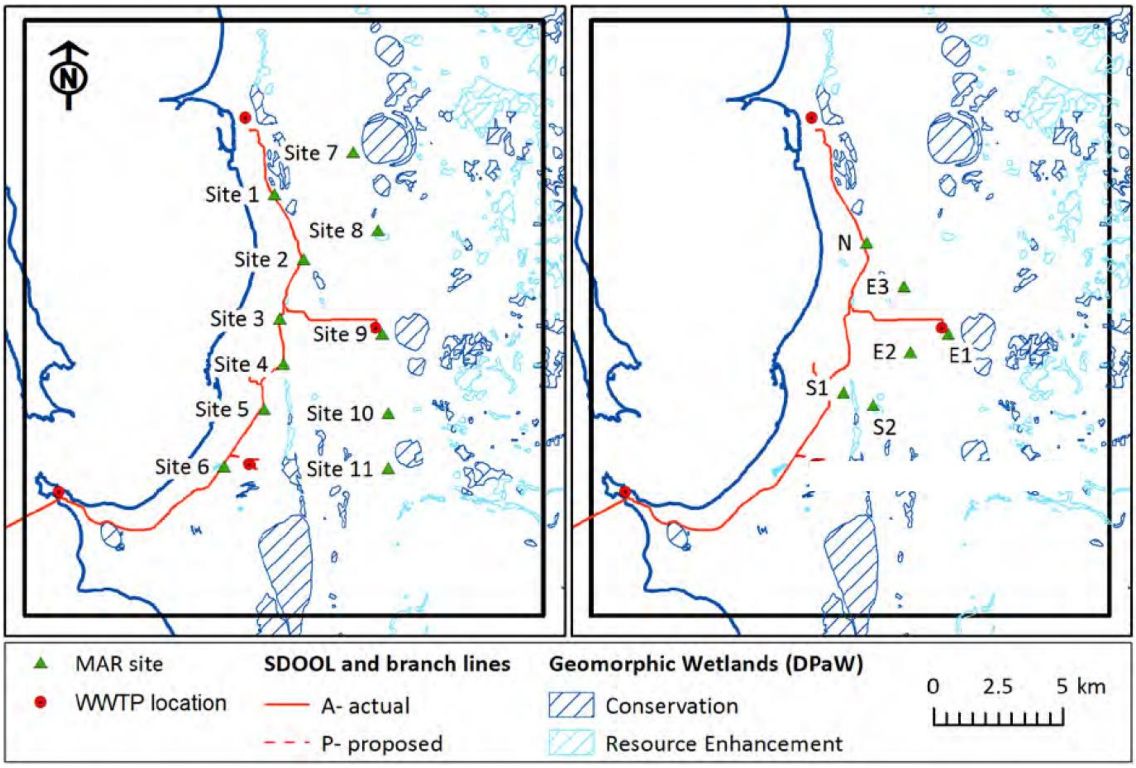


Figure 3-1 Prospective MAR sites identified in prefeasibility studies, eleven initial sites (left) and six final locations (right) (McFarlane, DJ (ed), 2015, p. 152)

The two sites that are the focus of the current study, being the two most prospective sites of those identified in the prefeasibility studies, are in close proximity to locations N and S2 shown in Figure 3-1 (on the right), and involve the following:

- Site 1 – Recycling and infiltration facility tailored to further treatment of TWW from the SDOOL, and
- Site 2 - Recycling and infiltration facility tailored to further treatment of TWW from the East Rockingham WWTP.

The design aquifer recharge rate is 10 ML/d. This is the maximum rate of the two rates considered by CSIRO in prefeasibility studies and associated predictive groundwater modelling (McFarlane, DJ (ed), 2015).

3.2 Superficial aquifer

The Superficial aquifer is an unconfined, multi-layered aquifer system extending throughout the Swan Coastal Plain between the Darling Scarp and the Indian Ocean. Quaternary and Tertiary Sediments in this aquifer range from clayey (Guildford Clay) in the east, through a sandy succession in the central plain (Bassendean Sand, Gnangara Sand, to sand and limestone in the coastal fringe (Safety Bay Sand, Becher Sand and Tamala Limestone) (Castilla, et al., 2018).

The two proposed sites are situated on the Tamala Limestone formation to the east of the Safety Bay Sand occurrence. The Tamala Limestone is a highly transmissive calcareous eolianite with variable proportions of quartz sand, fine- to medium-grained shell fragments and minor clay lenses (Davidson & Yu, 2008). It is approximately 30 m thick at Site 1 and approximately 25 m thick at Site 2 (Donn, et al., 2019).

Further detail on the regional geology and Superficial aquifer properties can be found in Castilla et al. (2017).

3.3 Site 1 setting

Site 1 is located near the northern end of the City of Kwinana, and lies on the western side of the Kwinana freight railway line, and east to north-east of the Naval Base industrial area (refer Figure 3-2). The northern end of the site is approximately 600 m east of Rockingham Road and 200 m east of Water Corporation’s SDOOL. The total area of the site is approximately 7.4 ha.

3.3.1 Ownership

This site is owned by LandCorp and is currently leased to WA Limestone who are mining sand and limestone from the area.

3.3.2 Topography

Ground surface levels across the site range from ~3 m AHD to 18 m AHD, with the majority of the site varying between 5 and 15 m AHD. Of note, quarrying operations at this site are ongoing, and WA Limestone has advised that the “approved” final ground level across the site is 4.0 m AHD.

3.3.3 Constraint considerations

Major road and rail works in the vicinity of Site 1 are in planning, as depicted in Figure 3-2. As these road works are confirmed and completed, Site 1 will be bounded by the existing freight railway line (to the east/south), the Fremantle Rockingham Controlled Access Highway (FRCAH, to the west) and Rowley Road as well as a future freight railway line (to the north).

Planning for transport corridors in the vicinity of Site 1 is also affected by considerations for an Outer Harbour in Cockburn Sound. This is subject to on-going strategic planning by Westport, and hence the detailed impacts on Site 1 are not entirely known at this point. The DJTSI is involved in Westport and will consider the potential impacts of this strategic planning on this MAR project.

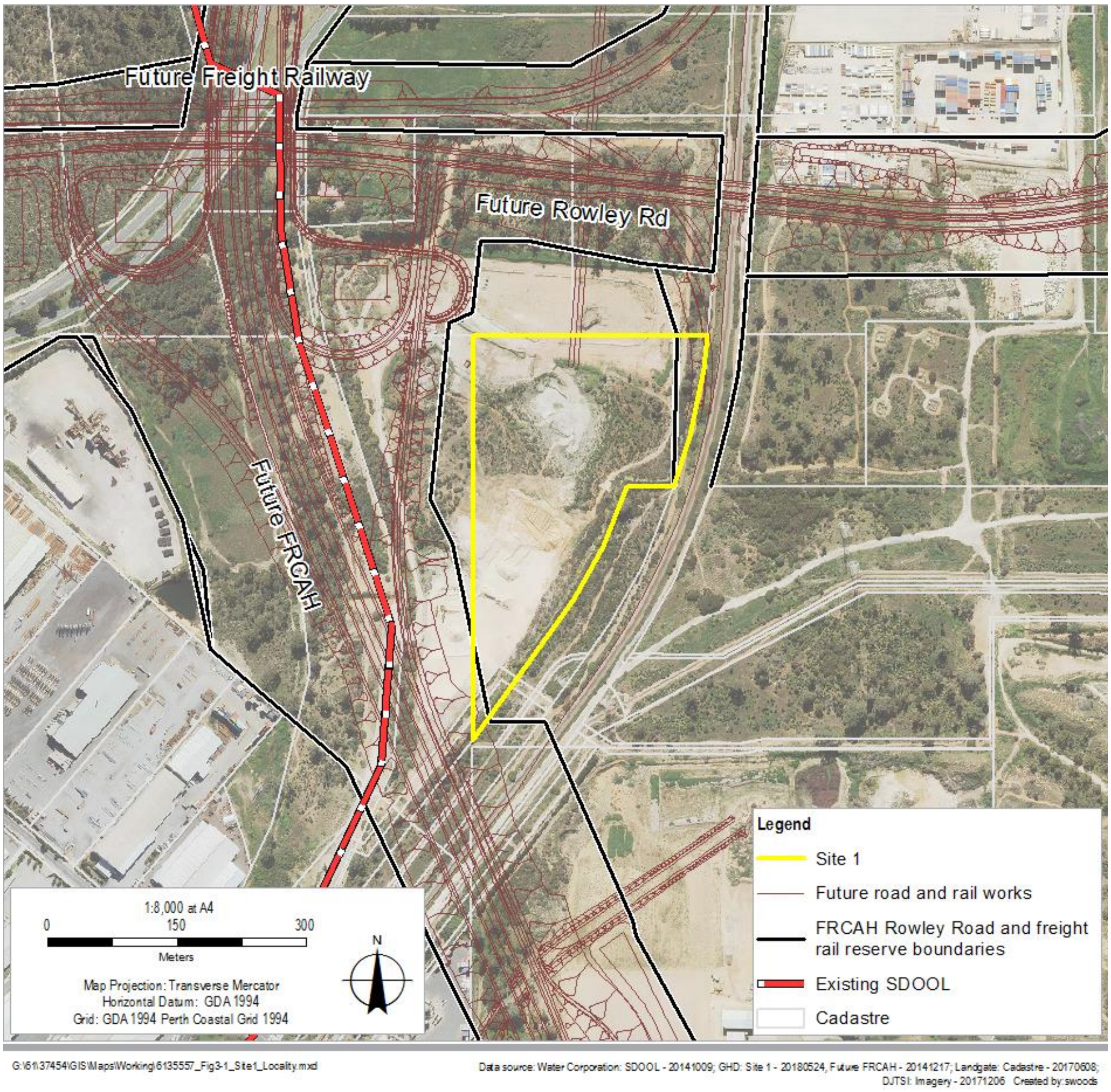


Figure 3-2 Locality plan – Site 1

3.4 Site 2 setting

Site 2, also within the City of Kwinana, is located west of the Kwinana Golf Course and adjacent to Gentle Road (refer to Figure 3-3). The site is approximately 1.5 km east of the SDOOL, and 3 km north east of the Water Corporation's East Rockingham WWTP. The boundary assumed for Site 1 in this report includes Crown Reserve P157953, and portion of Reserve R25309 (encompassing a portion of the Kwinana Golf Course). It has a total area of ~6.0 ha.

3.4.1 Ownership

The majority of the site is within Reserve R25309 which is vested with the City of Kwinana.

3.4.2 Topography

Ground surface levels across Site 2 vary from ~4 m AHD in the north-east corner of the site to ~31 m AHD in the south-west corner of the site. A significant portion of the site has a slope of 10% (1V:10H) or greater.

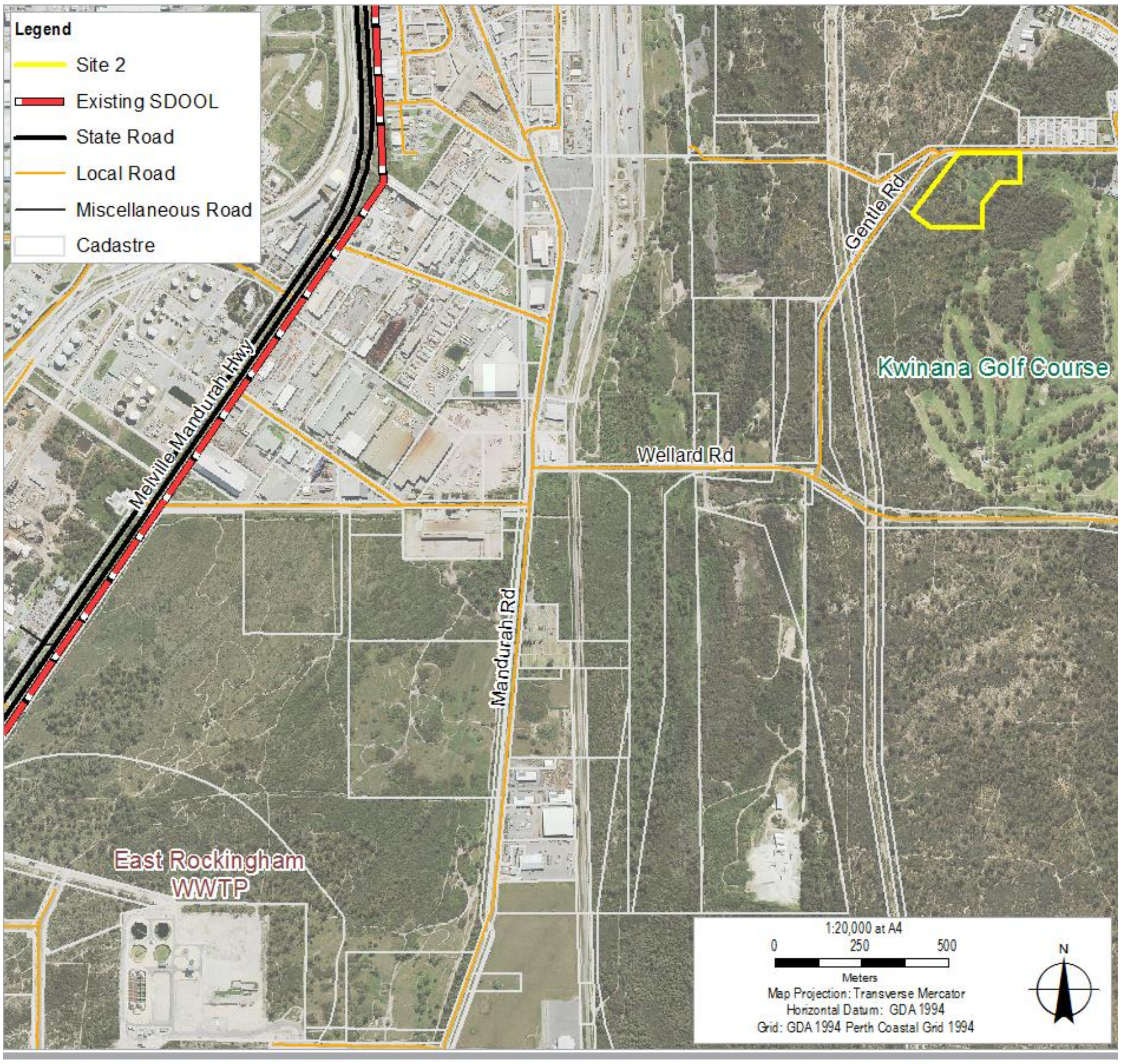


Figure 3-3 Locality plan – Site 2

3.4.3 Constraint considerations

Site 2 is close to a number of resource enhancement category sumplands and one conservation category sumpland. It is also within reserves that have 'Bush Forever' status (refer Figure 3-4). Clearing to construct infrastructure in Bush Forever areas is likely to require approval from the Western Australian Planning Commission (WAPC) on the advice of the Department of Planning Lands and Heritage (DPLH) and a clearing permit from DWER.

The crown reserve adjacent to Gentle Road on the western side of the site is an area listed on the City of Kwinana's municipal heritage list (place number 16043 [6]), by virtue of it being the site of a former army camp. DJTSI was advised by the City of Kwinana that there are no structures remaining on the site. As a category C site, it is a place of some cultural heritage significance to the City of Kwinana, and is to be retained and conserved if possible.

[6] http://inherit.stateheritage.wa.gov.au/Public/Search/PlaceNoSearch?placeNo=16043

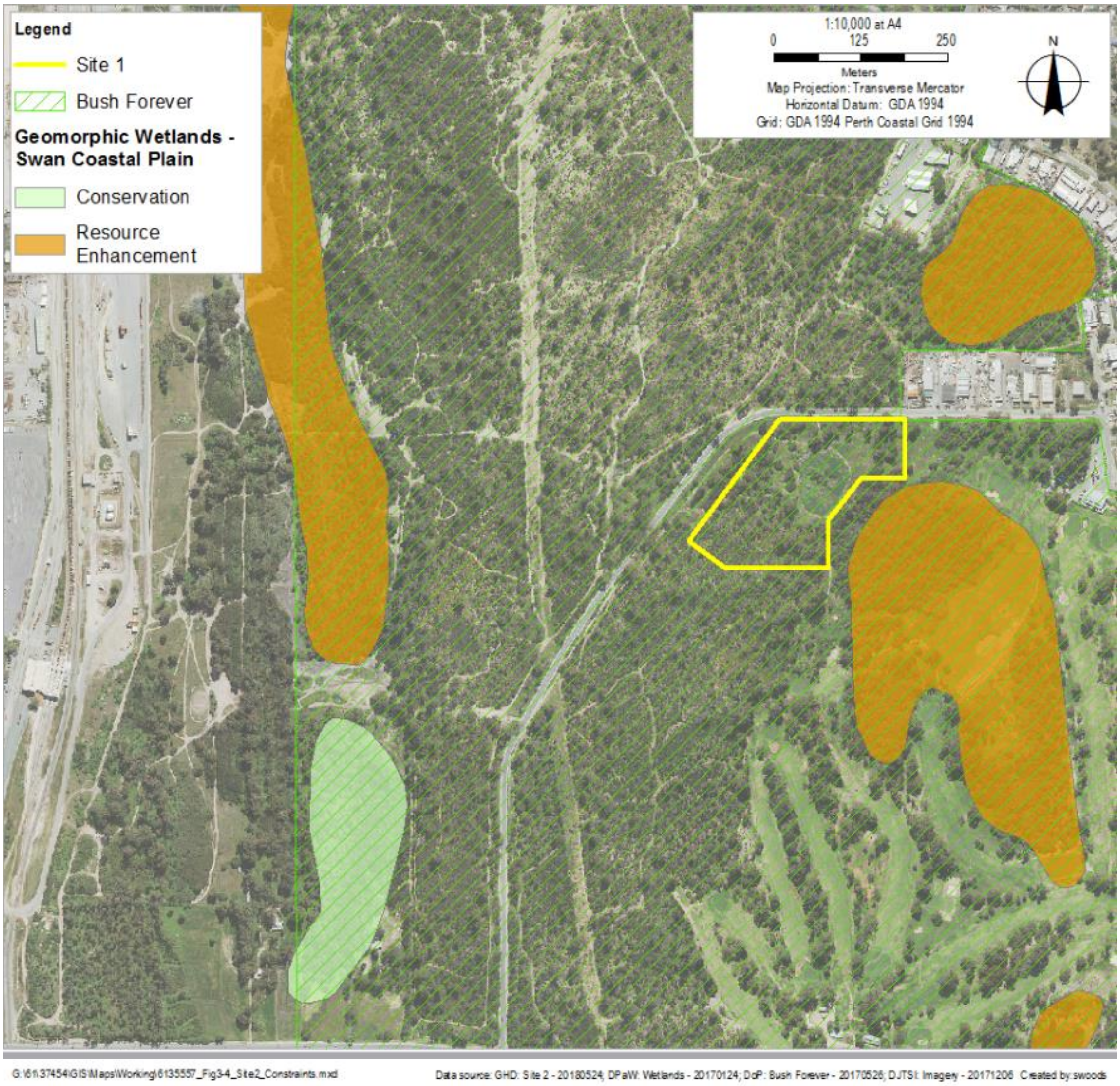


Figure 3-4 Bush Forever and wetlands near Site 2

3.5 Treated wastewater sources

The SDOOL and East Rockingham WWTP are the preferable sources for TWW supply to Site 1 and Site 2, respectively, as determined by their proximity to the sites, TWW quantity and quality (GHD, 2018) [7]. Figure 3-5 depicts the proposed MAR configurations as a simple schematic, along with all other assets connected to the SDOOL. The figure also shows Water Corporation's future advanced water recycled plant (AWRP) at Woodman Point for drinking water groundwater replenishment (GWR).

The Water Corporation advised that it would be possible to source TWW direct from the SDOOL via pipework connected into the SDOOL bypass pipework [8]; subject to a number of specific requirements being met, as described in the Engineering Design report (GHD, 2018).

---

[7] A review of sourcing TWW from the East Rockingham WWTP was also undertaken for both sites. Of note, the East Rockingham WWTP may be the lower cost option for Site 1 if desalination of TWW from the SDOOL is required, however the pipeline route required could prove non-viable due to the numerous major crossings involved. Additional work is warranted in the next stage to further investigate this possibility.

[8] Connecting into ("hot-tapping") the main pipeline itself would not be acceptable.

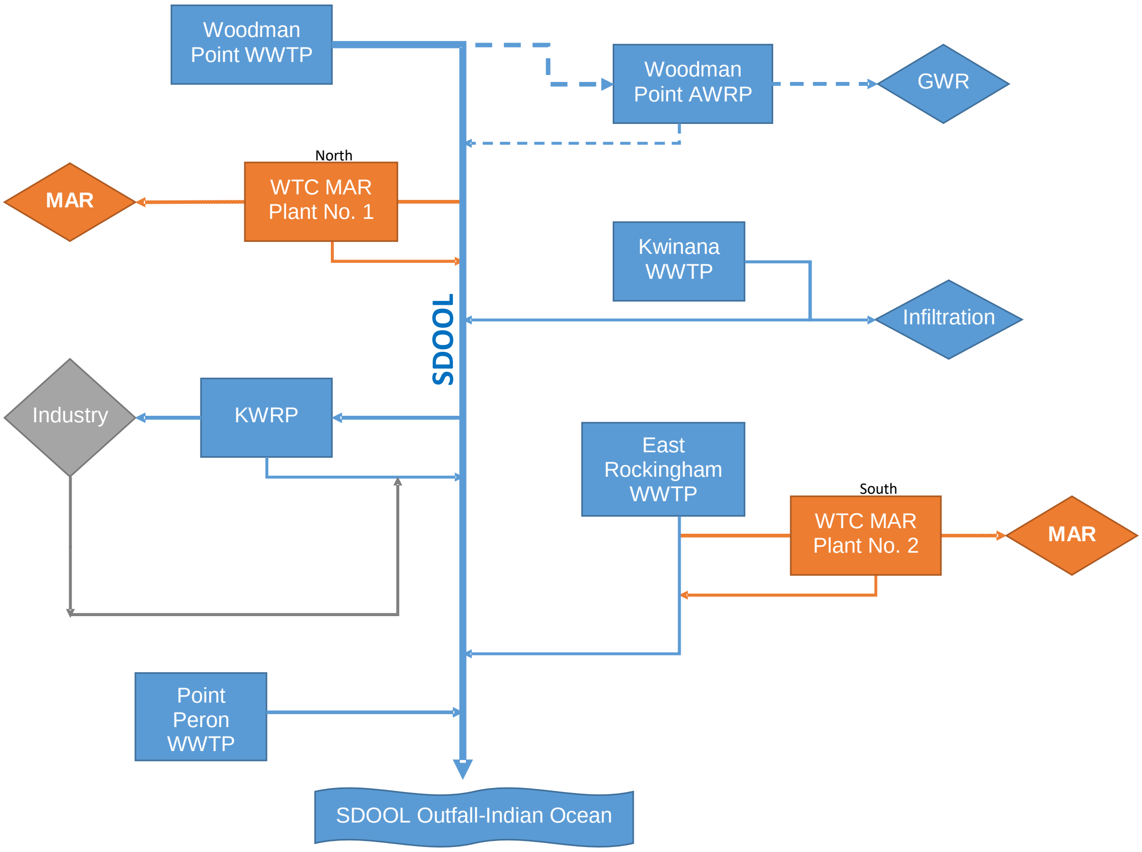


Figure 3-5 Schematic illustration of SDOOL assets and connections

3.5.1 TWW quality

GHD developed a mass balance model for the SDOOL based on historical and forecast TWW flow and quality data from future upgrades (refer Appendix A for further details). The model accounts for TWW volumes, mass flows and key water quality parameters, and has been used to analyse flow and quality of SDOOL water to 2060. Table 3-1 and Table 3-2 show a comparison of the forecast median TWW quality (for key parameters only) in the SDOOL and East Rockingham, in 2030 and 2050 respectively.

Evidently, concentrations of Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Dissolved Solids (TDS) in TWW from the Woodman Point WWTP are higher than TWW from the East Rockingham WWTP.

Table 3-1 Comparison of forecast median TWW quality in 2030

Parameter	Units	SDOOL – Woodman Pt TWW	SDOOL – Woodman Pt TWW + AWRP brine	East Rockingham TWW
Biochemical oxygen demand (BOD)	mg/L	5	7	5
Suspended solids (TSS)	mg/L	14	20	10
Total dissolved solids (TDS)	mg/L	620	760	360
Total nitrogen (TN)	mg/L	15	21	5

Table 3-2 Comparison of forecast median TWW quality in 2050

Parameter	Units	SDOOL – Woodman Point TWW	SDOOL – Woodman Point TWW + AWRP brine	East Rockingham TWW
BOD	mg/L	5	8	5
TSS	mg/L	14	25	10
TDS	mg/L	620	890	360
TN	mg/L	15	26	5

The proposed target recycled water quality for MAR within the WTC area is shown in Table 3-3, which are based on regulatory requirements, relevant MAR guidelines, a previous study of recycled water for heavy industry use (GHD, 2018; McFarlane, DJ (ed), 2015), and further assessment as part of the Stage 2 risk assessment for the schemes (refer Section 6). A comparison of the above tables with Table 3-3 demonstrates that further treatment of the TWW is likely to be necessary, and this requirement is discussed further in Sections 4.2.3 and 4.3.3.

Table 3-3 Target recycled water quality

Parameter	Value	Consideration / requirement
BOD	< 20 mg/L	DoH *Guidelines* for 'Medium Risk' application
TSS	< 5 mg/L	Prevent clogging of infiltration galleries. Up to 10 mg/L is likely acceptable for recharge basins.
TDS	≤ 760 mg/L	Maintain ambient groundwater salinity and quality for Kwinana industries' production bore
Turbidity	N/A	
pH	6.5 – 8.5	DoH *Guidelines* for 'Medium Risk' application
Total nitrogen	< 5 mg/L	Prevent eutrophication of wetlands and Cockburn Sound
Ammonia-N	< 2 mg/L	Refer to Note 1
Total phosphorus	N/A	Residual phosphorus in TWW will be removed by adsorption and precipitation in the calcareous sands and limestones underlying and downgradient of the recharge facilities (refer Section 6.4.4)
Pathogens	N/A	Controlled/restricted access to infiltration sites and long aquifer retention times expected prior to extraction and use (refer Section 6.4.1).

Notes:

1. Total nitrogen is the sum of several nitrogen species:
   - Ammonia-N (soluble),
   - Nitrate-N (soluble),
   - Soluble organic-N (typically 1.0 – 1.5 mg/L in secondary treated wastewater), and
   - Particulate organic-N (approximately 0.5 – 1.0 mg/L for TWW with 5 mg/L SS).

   A well-designed, well-operated and appropriately loaded WWTP will typically achieve Ammonia-N < 1 or 2 mg/L, via nitrification processes. Hence, most of the TN in the TWW from Woodman Point, East Rockingham and SDOOL is in the form of Nitrate-N.

3.5.2 TWW flow

Flow projections for the SDOOL at the off-take for Site 1 are shown in Figure 3-6. At this point, SDOOL flows are comprised of TWW from Woodman Point and brine returned to the SDOOL from the future AWRP. Clearly, this flow is sufficient for the proposed 10 ML/d MAR scheme at Site 1.

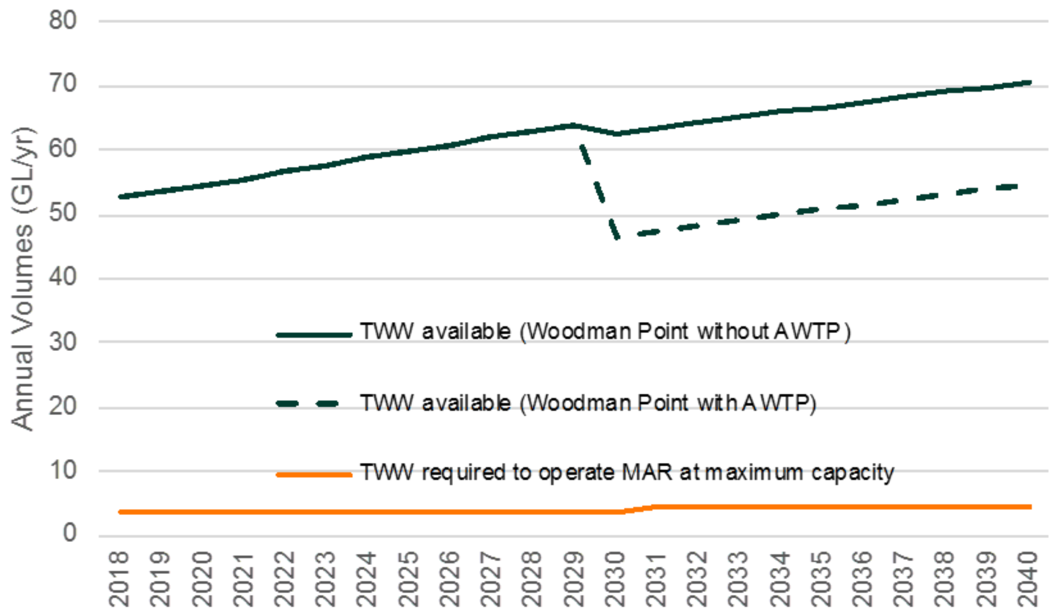


Figure 3-6 SDOOL flow projections (Synergies, 2018)

Flow projections for the East Rockingham WWTP are shown in Figure 3-7. There is sufficient source water for a 5 ML/d MAR scheme from 2019; and a 10 ML/d MAR scheme from 2027 at Site 2.

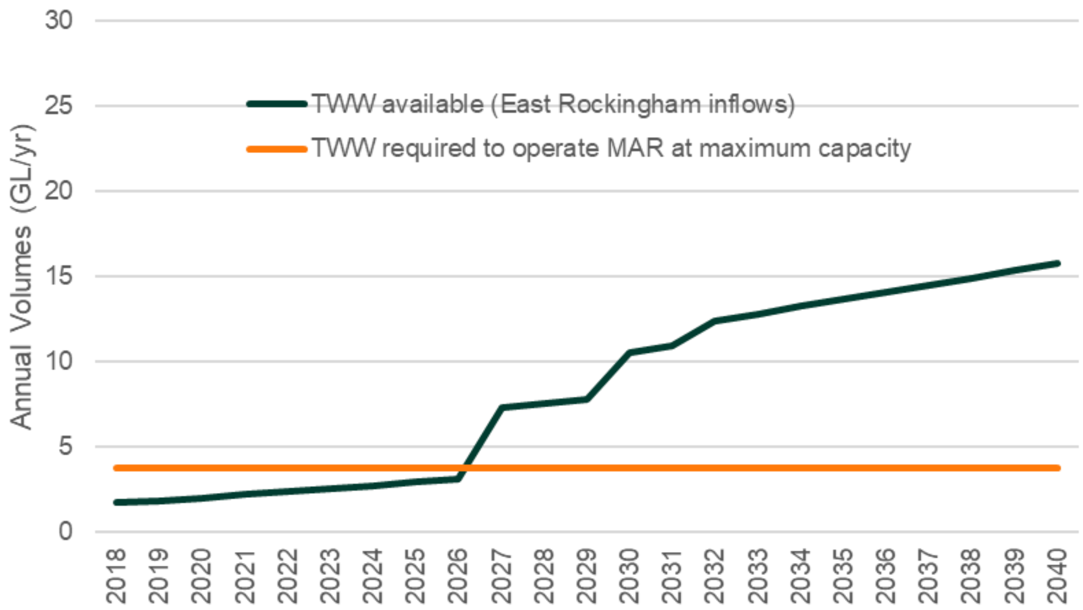


Figure 3-7 East Rockingham WWTP flow projections (Synergies, 2018)

4. Engineering design

4.1 Approach

The designs for the two sites draw upon the outcomes of previous feasibility studies along with investigations and analysis undertaken as part of the Engineering Design and Costing Study (GHD, 2018). The latter study comprised 13 work packages, as depicted in blue in Figure 4-1.

The engineering design initially involved a high-level preliminary assessment of the proposed MAR sites (Stage 1), followed by a refinement of water quality and quantity requirements and constraints analysis (Stage 2). The design work was then undertaken (Stage 3), and supporting implementation planning (Stage 4). It is noted that the design is conceptual in nature and a number of key assumptions are involved in its establishment that will need to be confirmed, as highlighted in Section 9.1.

This section provides an overview of the key aspects of the engineering design required to implement a 10 ML/d MAR scheme for each site, and highlights the critical assumptions and basis for design involved.

The information provided below is further presented in design drawings in Appendix A, and additional design details are available in the Engineering Design and Costing Study (GHD, 2018).

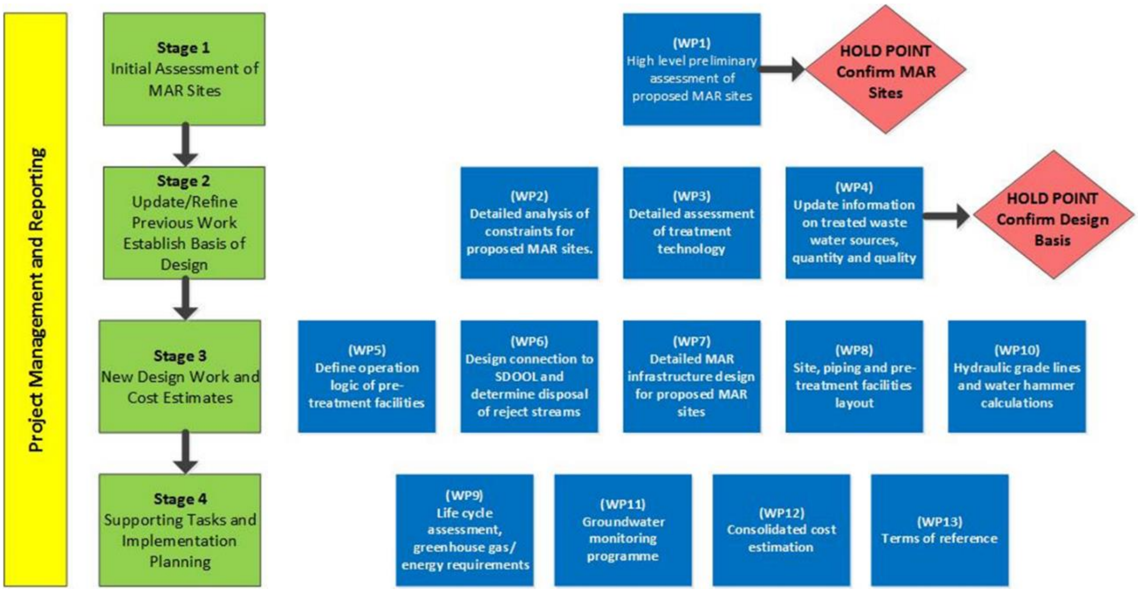


Figure 4-1 Engineering Design and Costing Study work packages

4.2 Site 1

4.2.1 Overview

A Process Flow Diagram (PFD) for the scheme is included as Figure 4-3, and a snippet of the general arrangement for the Site 1 MAR scheme is provided in Figure 4-2.

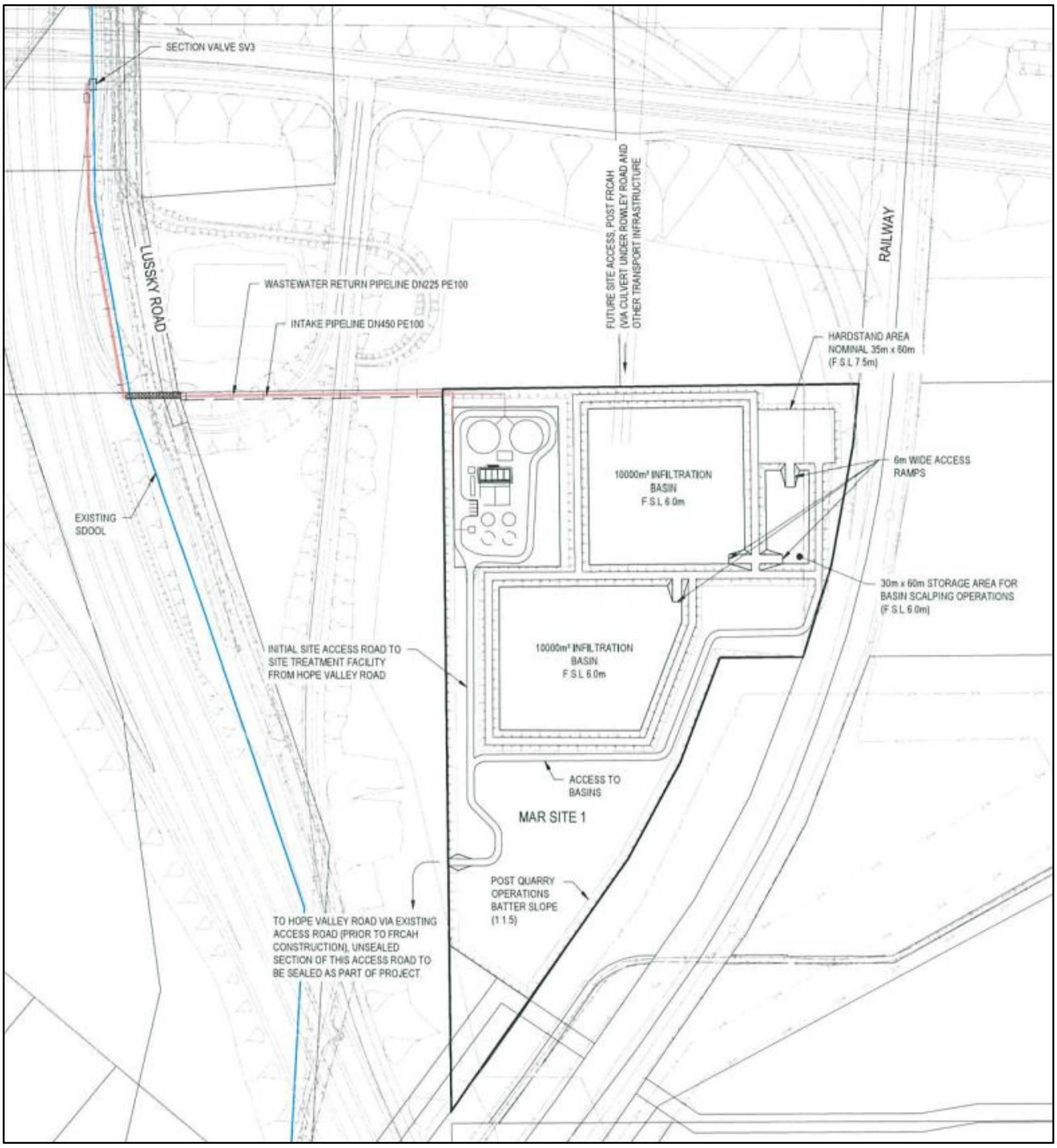


Figure 4-2 Site 1 MAR scheme general arrangement (from Engineering Drawing 61-35557-C004) (GHD, 2018)

TWW sourced from the SDOOL (via offtake from SDOOL section valve bypass pipework) will be transferred to onsite balance tanks via pipeline under pressure available in the SDOOL, when the Woodman Point WWTP TWW pumps are operating.

From the balance tanks, TWW will be processed through MAR pre-treatment facilities developed in two stages. The Stage 2 facilities will need to be installed to accommodate water quality changes in the SDOOL resulting from the proposed AWRP at Woodman Point WWTP (refer to Table 3-2). The recycled water will then be stored in recycled water storage tanks, and the filter backwash stored in wastewater storage tanks. The majority of the recycled water will discharge under gravity flow to one of two open infiltration basins operated on a duty/resting regime. Sizing of the infiltration basins was based on the performance of Water Corporation's Gordon Road WWTP which operates in similar geophysical conditions.

The balance of the recycled water will be used to backwash the filters, and the filter backwash (as well as brine and other wastewater generated from the Stage 2 facilities) will be disposed via pumped transfer to the SDOOL bypass pipework.

4.2.2 Feed and return pipelines

The intake and return pipeline are proposed to be installed in a common trench between the bypass pipework and the boundary of Site 1. The proposed route for these services runs parallel to the SDOOL to a point west of Site 1's northern boundary, then runs east to Site 1.

It may be necessary to relocate these pipelines, and potentially sections of the SDOOL, prior to construction of the FRCAH. Consideration of this major realignment is beyond the scope of works to date.

4.2.3 MAR pre-treatment facility

The Site 1 MAR pre-treatment facility will be located on-site and designed to achieve the target recycled water quality outlined in Table 3-3 using unit processes detailed in Table 4-1 and illustrated in Figure 4-3. Further description of Stage 1 technologies, and their operation for the MAR scheme, is provided in Appendix F of the engineering design report (Appendix A).

Table 4-1 Site 1 pre-treatment facility overview

Stage 1 SDOOL – Woodman Point TWW only	Stage 2 SDOOL – Woodman Point TWW + AWRP brine
Balance tanks (x2) and duty/standby TWW feed pumps to ensure constant 24 h/d feed	Per Stage 1, but pump at higher rate
Denitrifying filters (x4), with carbon dosing, for removal of solids and nitrogen	Per Stage 1 plus one filter
Re-aeration weir to entrain oxygen and minimise nuisance odour emissions	Per Stage 1
Duty/standby backwash pumps	Per Stage 1
Duty standby air blowers	Per Stage 1
Sucrose storage tank to provide 7 days storage	Per Stage 1
Infiltration basins (duty/standby)	Per Stage 1
Wastewater storage tank for 1 day of backwash and duty/standby return pumps for 20 h/d return to SDOOL	Per Stage 1 plus one additional tank
-	Reverse osmosis membrane modules and associated facilities, for removal of dissolved solids (i.e. salinity)
-	Flow splitter and low pressure feed pumps to reverse osmosis plant
Expected recovery rate = 95%	Expected recovery rate = 81%

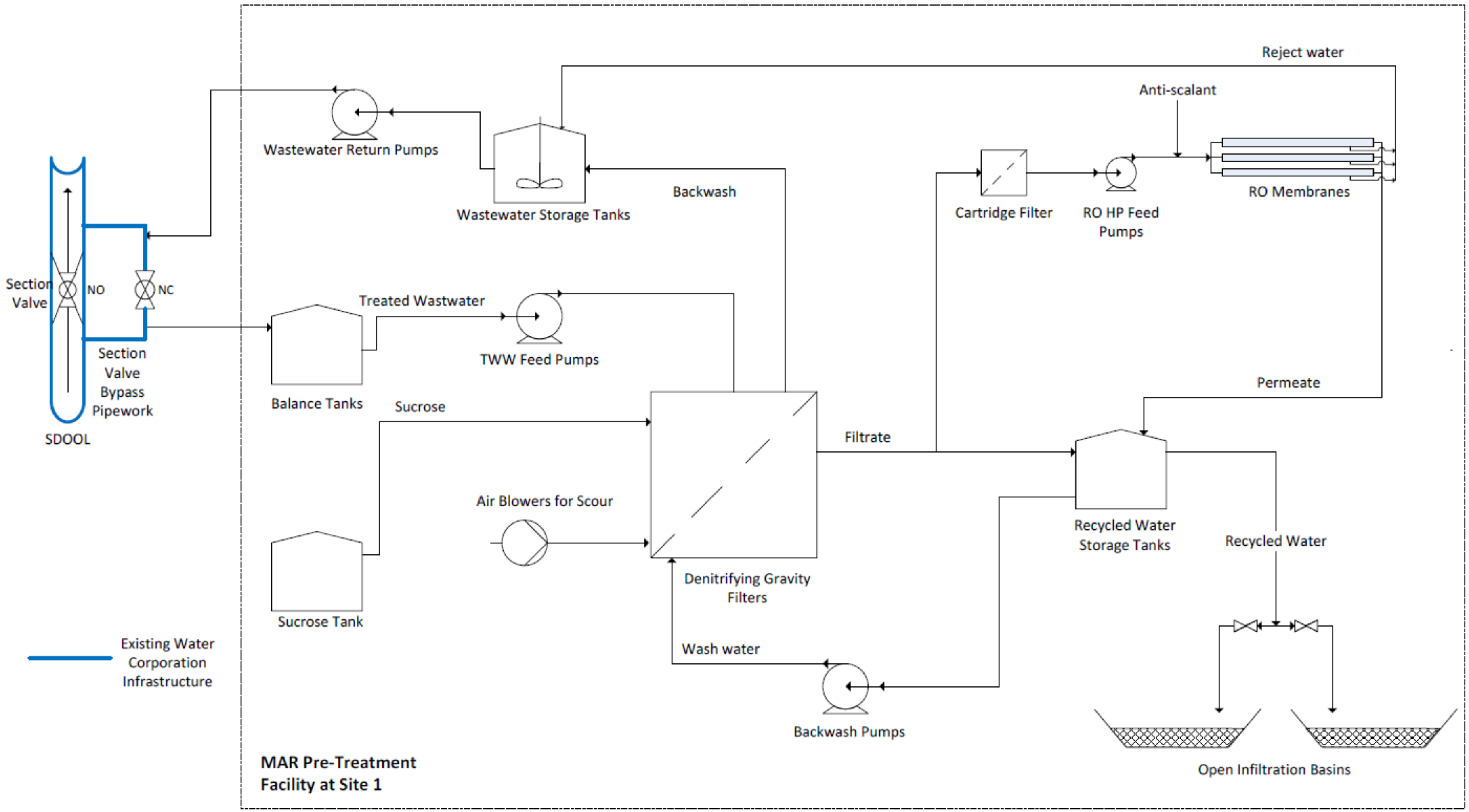


Figure 4-3 Site 1 MAR scheme – Process flow diagram

4.2.1 Lifecycle assessment

A life cycle assessment of potential greenhouse gas (GHG) emissions from Site 1 has also been undertaken, which includes both construction and operation of the MAR scheme. It is estimated that the total life cycle emissions (for Stage 1 and Stage 2) is 106 kt CO_2-e (GHD, 2018).

4.3 Site 2

4.3.1 Overview

A schematic PFD for the scheme is included as Figure 4-8 and Figure 4-4 provides a snippet of the general arrangement of the concept scheme, as described further below.

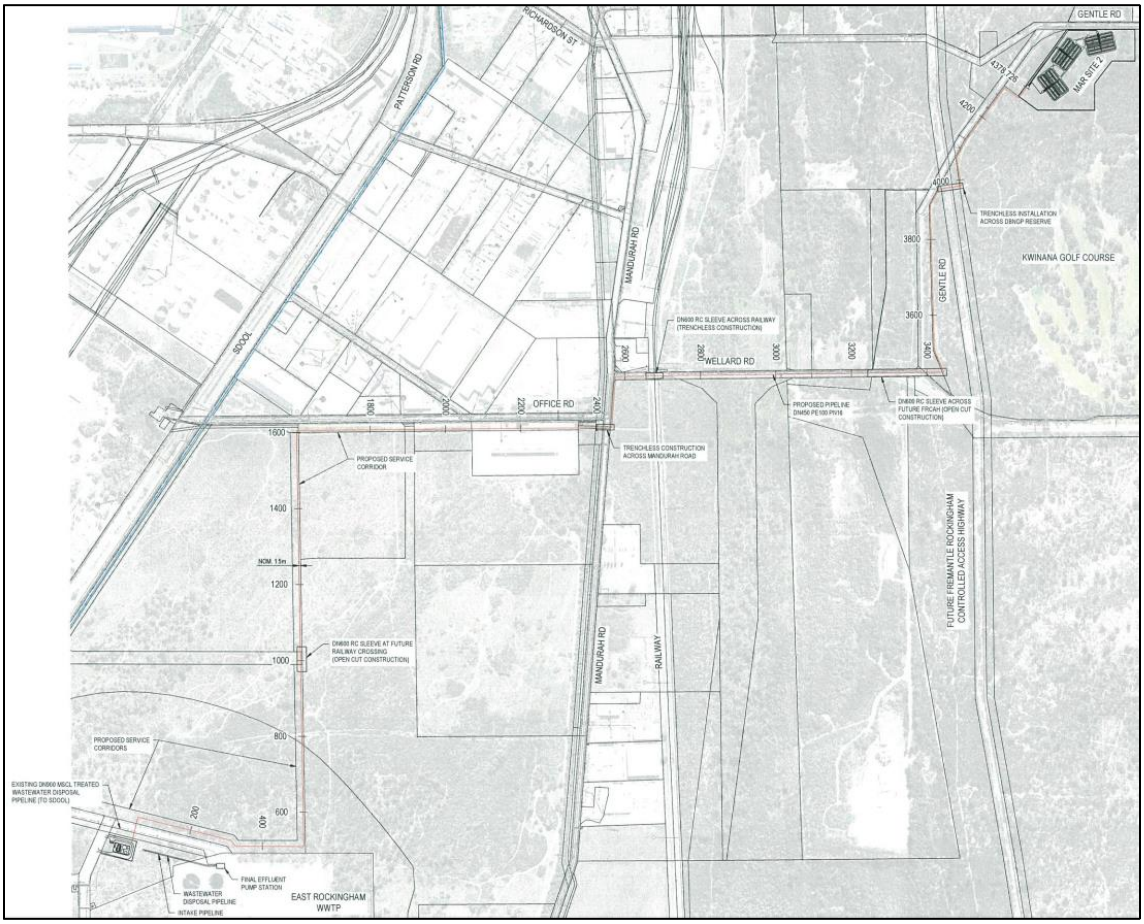


Figure 4-4 Site 2 general arrangement (from Engineering Drawing 61-35557-C003) (GHD, 2018)

TWW will be sourced from the East Rockingham WWTP via an offtake from the temporary Final Effluent Pump Station (FEPS) suction manifold (refer Figure 4-5) [9].

[9] It is assumed a pump can be installed in the fourth pump bay of the existing temporary FEPS for the purpose of this design. Water Corporation indicated that use of the plant's existing temporary FEPS is possible, however further commercial negotiation and agreements regarding operations and maintenance arrangements of MAR scheme infrastructure on the Water Corporation site would be required.

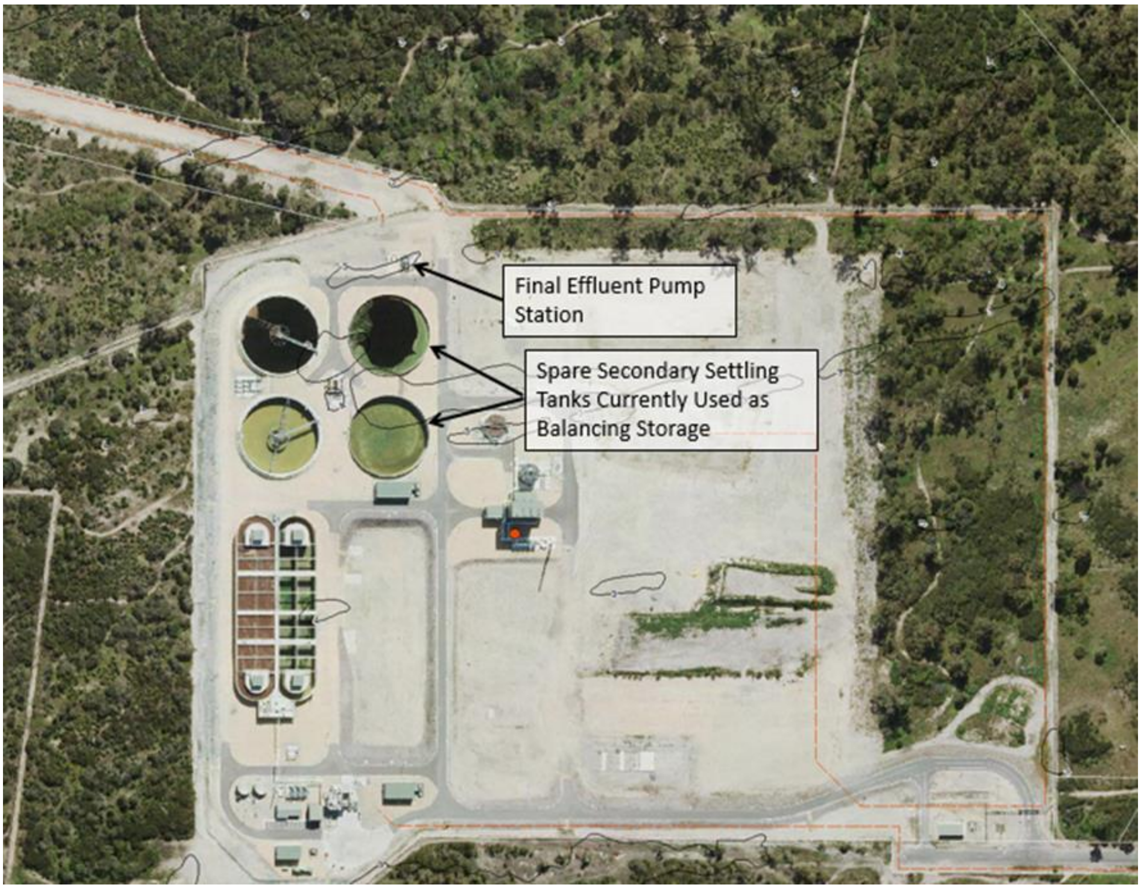


Figure 4-5 East Rockingham WWTP temporary final effluent pump station

From the offtake, the TWW will be pumped via duty/standby variable speed pumpsets direct to the MAR pre-treatment facility, assumed to be located on a site west of the East Rockingham WWTP within land zoned for industrial use. Treated water will be stored in recycled water storage tanks, and filter backwash stored in wastewater storage tanks. The majority of the recycled water will be pumped to a primary flow splitting structure at Site 2, from which it will be gravity fed to two of the three down gradient infiltration galleries operated on a rotating duty/duty/resting regime.

The infiltration galleries consist of three banks comprising five individual 'sub' galleries 70 m long × 8 m wide and 100 mm deep, with a soil cover of at least 900 mm, as shown in Figure 4-6. Secondary flow splitters will split the water evenly amongst the five 'sub' galleries. Several access chambers will be installed to allow visual inspection and monitoring of gallery performance. The gallery design is based on DS Agency's DoH approved "flatbed leach drain" design (DS Group, 2018). Images of this leach drain system are included in Figure 4-7.

The balance of the recycled water will be used to backwash the filters. Wastewater (filter backwash) will be disposed via pumped transfer to the SDOOL, with the wastewater pipeline discharging into the East Rockingham temporary FEPS' delivery manifold.

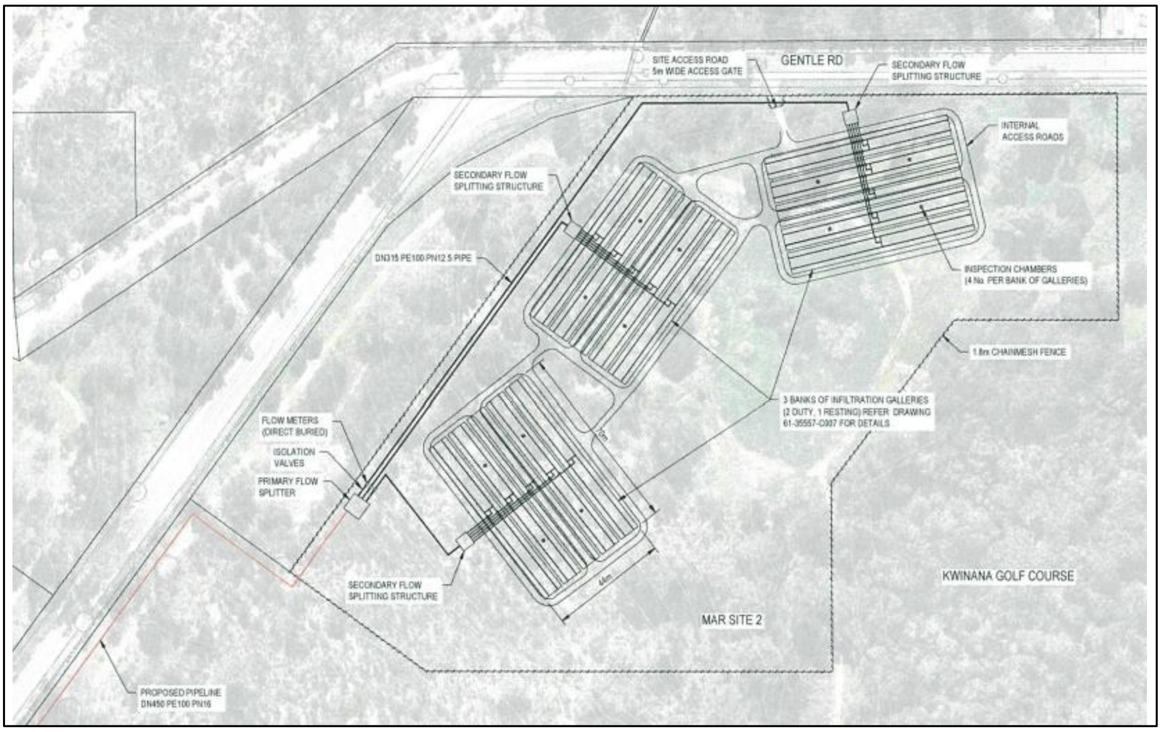


Figure 4-6 Site 2 infiltration gallery (from Engineering Drawing 61-35557-C006) (GHD, 2018)

Figure 4-7 Images of DS Agency's Flatbed Leach Drain System

(from http://www.rainsmartsolutions.com/50mm_nero_pave.html and https://www.ds.com.au/flatbed-leach-drain/)

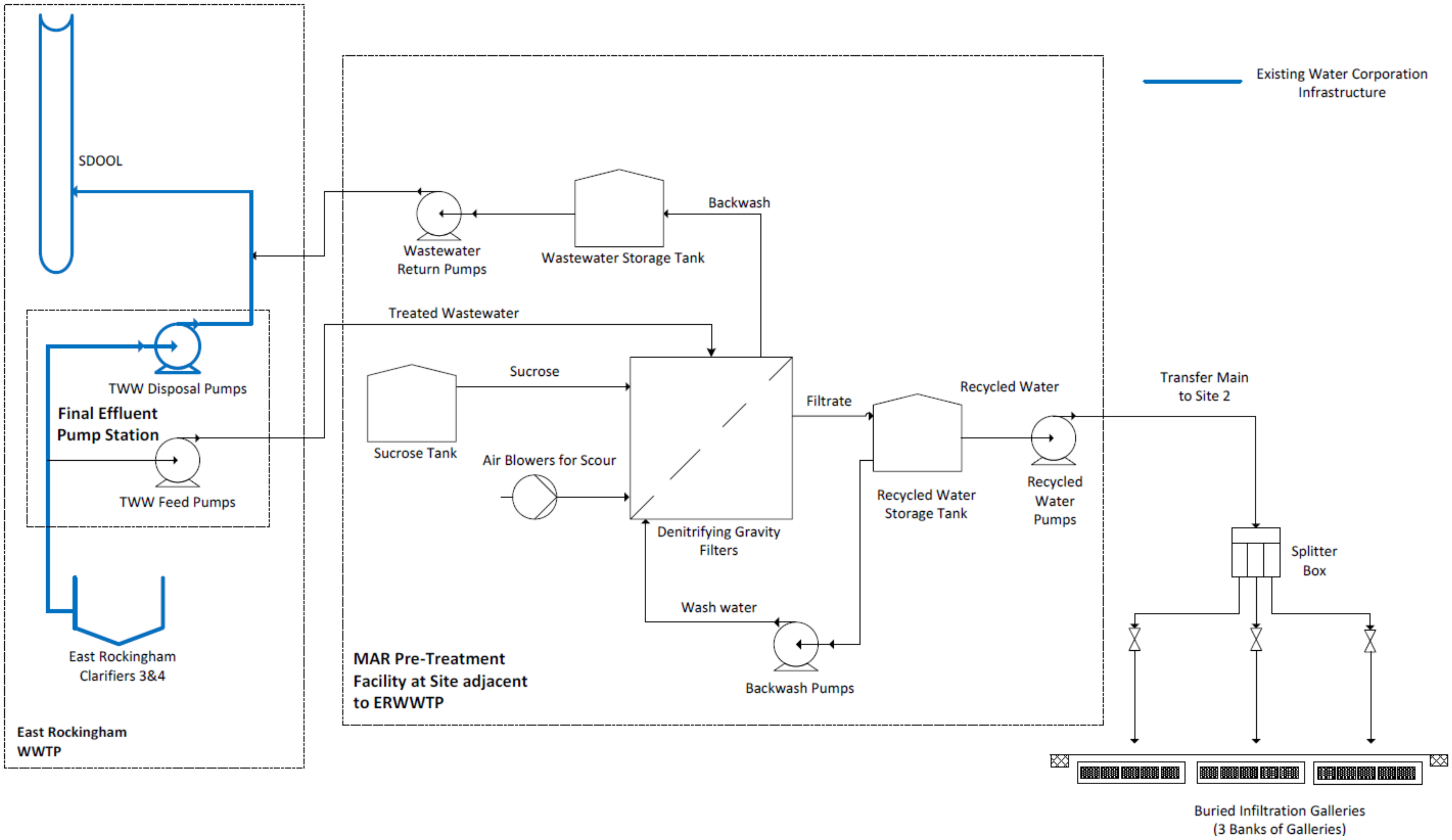


Figure 4-8 Site 2 MAR scheme – Process flow diagram

4.3.2 Pipeline infrastructure

The proposed recycled water pipeline route from the FEPS to the flow splitter at the MAR site utilises service corridors in the Rockingham Industry Zone (RIZ), road reserves and traverses some private property. LandCorp is a majority landowner in the RIZ, however they are not the landowners for the full length of the proposed pipeline route. Further negotiation with the landowners along the entire route will be required in design stages to follow.

The route crosses the following major assets:

- Mandurah Road,
- Existing and proposed rail corridor,
- Proposed FRCAH, and
- Existing Dampier to Bunbury Natural Gas Pipeline (DBNGP).

To cross these major assets it is assumed that trenchless techniques will be used to install the pipeline under existing infrastructure, while open trench construction methods will be used to construct the pipeline across the alignment of proposed infrastructure.

Wastewater from the MAR pre-treatment facility will be returned to the temporary FEPS' discharge manifold at the East Rockingham WWTP only at times when the large Woodman Point TWW pumps are not operating (the FEPS is inhibited from operating when the large Woodman Point TWW pumps are operating).

The addition of the MAR pre-treatment facility represents a 3% to 5% increase in total flowrate in the existing effluent discharge pipeline and is therefore expected to have no significant effect on the operation of the existing FEPS. Supply of TWW to the MAR pre-treatment facility will also reduce the FEPS operating time, particularly in the short to medium term future when a large proportion of the East Rockingham WWTP's TWW will be diverted to the MAR scheme.

4.3.3 MAR pre-treatment facility

The MAR pre-treatment facility is proposed to be located adjacent to the East Rockingham WWTP on approximately 4,000 m^2 of land currently owned by LandCorp and located in the RIZ. The Site 2 MAR pre-treatment facility is designed to achieve the target recycled water quality outlined in Table 3-3 using denitrifying filters with carbon dosing for removal of solids and nitrogen (refer to discussion in Appendix F of engineering report (Appendix A)). The need for supplementary carbon dosing to reduce nitrogen levels is marginal for this site and will depend on environmental licence conditions applied by DWER. The potential need for carbon dosing has nonetheless been included at this stage of design.

Table 4-2 outlines the various components of the pre-treatment facility and their roles.

4.3.4 Lifecycle assessment

A life cycle assessment of potential GHG emissions from Site 2 has also been undertaken which includes both construction and operation of the MAR scheme. It is estimated that the total life cycle emissions is 55 kt CO_2-e (GHD, 2018).

Table 4-2 Site 2 pre-treatment facility

East Rockingham TWW supply only
TWW fed pumps to provided constant feed to filters
Denitrifying filters (x4), with carbon dosing, for removal of solids and nitrogen
Backwash pumps (duty/standby)
Air blowers (duty/standby)
Sucrose storage tank to accommodate 7 days chemical storage
Recycled water storage and recycled water pumps to provide constant transfer from pre-treatment facility to infiltration galleries
Flow splitters (primary: 1 duty, secondary: 2 duty / 1 standby)
Infiltration galleries (2 duty / 1 standby) aim for 2 m/d infiltration rate
Wastewater storage tank to accommodate 1 day of backwash and wastewater return pumps to reinject water to SDOOL
Expected recovery rate = 95%

4.4 Groundwater monitoring

A preliminary groundwater monitoring program has been developed for the two MAR schemes which aims to understand baseline groundwater levels and quality, and provide validating information for existing model assumptions. The program includes ten monitoring locations for Site 1 and eight for Site 2, targeting areas within the MAR sites as well as off-site sensitive receptors. Drilling methods and monitoring parameters are also defined. The provisional program was developed based on a desktop review of the sites, and it is likely that it will need to be refined as the schemes are progressed. In particular, further revision should consider shorter screen wells to avoid intra-borehole flow that may occur in the proposed long screen bores. Prior to implementation the provisional program will also need to be reviewed and approved by DWER.

An appropriate suite of groundwater quality analytes will need to be developed for the monitoring program. The suite will need to include those parameters typical of treated wastewater, together with any site specific contamination indicators. An example groundwater quality sampling suite is presented below as Table 4-3.

Table 4-3 Example groundwater quality sampling suite

Parameters	
Physical/chemical pH, Temperature, Electrical conductivity, Oxidation-reduction potential, Dissolved oxygen, Total dissolved solids, Total suspended solids, Total Alkalinity, Dissolved organic carbon, Chemical oxygen demand	***Nutrients*** Ammonia, Nitrate, Nitrate, Nitrite, Total dissolved nitrogen, Total nitrogen, Total phosphorus, Soluble reactive phosphorus
Hydrocarbons and trace organic compounds Total Recoverable Hydrocarbons (TRH), Polycyclic aromatic Hydrocarbons (PAH), Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Pesticides, Herbicides	***Heavy metals*** Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Nickel, Silver, Zinc,

Additional details of the program can be found in GHD's Engineering Design and Costing study (GHD, 2018).

5. Cost estimates

5.1 CAPEX

CAPEX estimates (accuracy +/- 25%) developed for Sites 1 and 2 are summarised in Table 5-1. The cost estimate exclusions applicable to the estimate are summarised in Table 5-2. A more detailed breakdown of the estimates, including details of the assumptions made in developing the estimate and the basis of the rates used, is provided in Appendix C. The rates and cost estimates were derived from a mix of project-specific vendor quotes (treatment facilities, tanks, pump stations, infiltration galleries), (Rawlinsons , 2017), estimates developed by GHD and Synergies for this project or previous projects, and for some items nominal allowances.

Table 5-1 CAPEX estimate summary

Item	CAPEX (2018 $M)		
	Site 1		Site 2
	Stage 1	Stage 2	
DIRECT COSTS			
Transfer infrastructure			
SDOOL connection works	0.3	-	-
TWW Pump Station (East Rockingham WWTP)	-	-	0.4
Pipelines	0.8	-	3.9
MAR pre-treatment facility (and infiltration basins for Site 1)			
Import/place/compact sand fill to raise and form infiltration basins	6.7	-	-
General site/civil works and access roads	0.6	-	0.2
Vendor package	4.4	3.9	4.0
Balance of plant	1.8	0.7	1.3
Infiltration galleries			
General site/civil works and access roads	-	-	0.7
Infiltration galleries and pipework	-	-	1.1
Monitoring bores	0.1	-	0.1
Total Direct Costs	**14.7**	**4.6**	**11.7**
INDIRECT COSTS			
Investigations and Approvals	0.2	0.0	0.4
Design and Project Management	2.2	0.7	1.7
Contingency (25%)	4.3	1.3	3.5
Total Indirect Costs	**6.7**	**2.0**	**5.6**
Total CAPEX, by stage	**21.5**	**6.6**	**5.6**
TOTAL CAPEX		**28.1**	**17.3**

Table 5-2 CAPEX estimate exclusions

Item	Description
Site 1	
1	Land acquisition and easement costs.
2	Future cost to construct new access to site from north, under Rowley Road etc., after FRCAH constructed.
3	Service/pipeline/valve relocation costs required prior to construction of FRCAH and associated road/rail works etc.

Item	Description
4	Site pre-work (removal or rock, filling of excavations) prior to placement of fill at site of pre-treatment and recharge facilities.
5	Additional groundwater modelling studies (assuming CSIRO studies satisfy regulatory agencies and adequate to inform environmental impact assessment).
Site 2	
1	Land acquisition and easement costs
2	Bush Forever offset costs
3	Additional groundwater modelling studies (assuming CSIRO studies satisfy regulatory agencies and adequate to inform environmental impact assessment).

5.2 OPEX

An OPEX estimate (accuracy +/- 25%) developed for Sites 1 and 2 is summarised in Table 5-3. The cost estimate exclusions applicable to the estimate are summarised in Table 5-4. A more detailed breakdown of the estimate, including details of the assumptions made in developing the estimate and the basis of the rates used, is provided in Appendix C. Of note a conservative approach was adopted when estimating the cost of the supplementary carbon required to be dosed to the denitrifying filters. Given the marginal need for sucrose dosing at Site 2 (as discussed in Section 4.3.3), the cost with and without this item has been provided.

Table 5-3 OPEX estimate summary

Item	OPEX (2018 $k/year)			
	Site 1		Site 2	
	Stage 1	Post Stage 2 upgrade	With sucrose dosing	Without sucrose dosing
Ongoing Costs				
Operator and vehicle	173	436	173	173
Power	181	307	309	309
Chemicals - Sucrose	214	307	53	0
RO plant chemicals and pre-treatment filter consumables	0	60	-	-
Pre-treatment facility laboratory analysis costs	7	7	7	7
Major planned maintenance and unplanned maintenance	22	44	26	26
Infiltration gallery site maintenance	41	41	6	6
Groundwater monitoring program	53	53	39	39
Sub Total	***691***	***1,174***	***613***	***560***
Contingency (20%)	138	235	123	112
Licensed service provider profit margin (15%)	124	211	110	101
TOTAL	**950**	**1,620**	**850**	**773**
Periodic costs				
Infiltration gallery renovation/reconstruction	-	-	598	
Contingency	-	-	120	
Licensed service provider profit margin	-	-	108	
TOTAL	**-**	**-**	**830**	

Table 5-4 OPEX estimate exclusions

Item	Description
1	Water Corporation TWW supply charges
2	Water Corporation wastewater disposal charges
3	Capital replacement costs

5.3 Unit cost of MAR water

The above capital and operating costs were used to develop a levelised unit cost of the water. The levelised cost was calculated by dividing the net present value of water supply cost by the discounted value of all future annual volumes of water delivered by the scheme (Synergies, 2018). The unit costs for each site are summarised in Table 5-5.

Table 5-5 Levelised unit cost of MAR water (Synergies, 2018)

Levelised unit cost	Site 1		Site 2
	Stage 1 (construction 2020, commissioning 2022)	Stage 2 (commencing 2030)	
100% utilisation	$0.95/kL	$1.13/kL	$0.60/kL
10% utilisation	$9.46/kL	$11.3/kL	$5.97/kL

6. Stage 2 risk assessment

6.1 Approach

The *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) - Managed Aquifer Recharge* (MAR guidelines) (NRMMC-EPHC-NHMRC, 2009) outline a staged approach to risk assessment and development of MAR projects. This provides investment decision points for a MAR scheme, based on an informed understanding of the next required level of investigation. These stages are:

1. **Stage 1 Desktop study**: Entry-level assessment – a) viability assessment and b) degree-of-difficulty assessment (completed prior to this study, (DoW, 2016)).
2. **Stage 2 Investigations and assessment**: Maximal risk assessment and pre-commissioning residual risk assessment,
3. **Stage 3 Construction and commissioning**: Operational residual risk assessment, and
4. **Stage 4 Operation**: Risk management plan.

An entry-level assessment was conducted as part of the WTC local water supply strategy (DoW, 2016). It was identified that the following areas had a moderate to high level of difficulty and required additional information and assessment:

- Site-specific information relating to the chemical and physical properties of the source water and groundwater for MAR,
- Groundwater modelling and assessment of how infiltrated water affects groundwater-dependent ecosystems, in particular Cockburn Sound (discussed further in Section 6.2), and
- How experienced a proponent is to design, construct and operate a MAR scheme, including the management of appropriate buffer zones around infiltration points.

This chapter considers aspects for the first two points in the form of a Stage 2 maximal risk assessment and pre-commissioning residual risk assessment, conducted by CSIRO (Donn, et al., 2017). The full report can be found in Appendix B. A summary of the receiving environments are identified in Section 6.3, hazards in Section 6.4, and their evaluated likelihood and impact or consequence in Section 6.5.

6.2 Groundwater understanding

A conceptual groundwater model and subsequent probabilistic groundwater model were developed to support the risk assessment.

Development of the conceptual groundwater model was based on a review of the geology, hydrogeology, and groundwater fluxes in the WTC, incorporating new data collected since the MAR pre-feasibility study completed in 2015. This conceptual model established a framework for the development of a numerical representation of a groundwater model of the WTC, including appropriate boundary conditions, plausible ranges for groundwater fluxes and hydraulic parameters, and focal points for calibration (Castilla, et al., 2018).

The probabilistic groundwater model evaluates the potential hydrological change in the Western Trade Coast superficial aquifer system due to implementation of MAR, relative to the baseline (no MAR) case. The model was calibrated using a global search optimisation algorithm (Cui & Donn, 2019).

Assessment of the impact of MAR was undertaken based on the hydraulic head changes, particle tracking to evaluate plume behaviour and residence time, and induced inundation. Forecast scenarios were undertaken to examine the impact of projected climate change and the impact of different proportions of additional groundwater abstraction within the MAR zone (Cui & Donn, 2019).

The results of the groundwater modelling work are detailed throughout Section 6.4, and further detail on the conceptual and probabilistic groundwater model can be found in Castilla, et al. (2018) and Cui & Donn (2019), respectively.

6.3 Receiving environments/receptors

The recharge and storage of TWW to the superficial aquifer is proposed as an alternative to extraction of native (natural) groundwater. Thus, the impacts for the risk assessment process undertaken herein are related to groundwater, including users and environmental receptors.

Given existing groundwater use, and the lack of available information on end use quality, it is assumed that existing groundwater quality is sufficient for industry requirements and other existing non-potable uses. The main environmental receptors in the study area are groundwater dependent ecosystems, wetlands (fresh and brackish/saline) and the marine environment of Cockburn Sound (McFarlane, DJ (ed), 2015). There is also native vegetation associated with the Bush Forever classification of Site 2.

Site 1 is located near three Geomorphic Wetlands (DPaW, 2013) including Lake Mount Brown ~1,400 m to the north (conservation), Long Swamp ~900 m to the south (conservation) and an unnamed wetland ~1,000 m to the west (resource enhancement) (Figure 6-1). Both Long Swamp and Lake Mount Brown are ecological monitoring sites for the Cockburn Groundwater Area management plan (DWER, 2018).

Site 2 is in the vicinity of four unnamed Geomorphic Wetlands, two resource enhancement wetlands up-gradient and in close proximity (~100 m and 280 m east), one resource enhancement wetland down-gradient (~600 m west) and one conservation wetland down-gradient (~710 m south west).

Site 1 and Site 2 are situated ~1,900 m and ~3,300 m east of Cockburn Sound, respectively. Cockburn Sound is particularly sensitive to nutrient additions, and additions via groundwater as a result of MAR may alter the nitrogen balance (Greenwood, et al., 2016; McFarlane, DJ (ed), 2015). Further detail on wetlands and Cockburn Sound can be found in McFarlane et al. (2015).

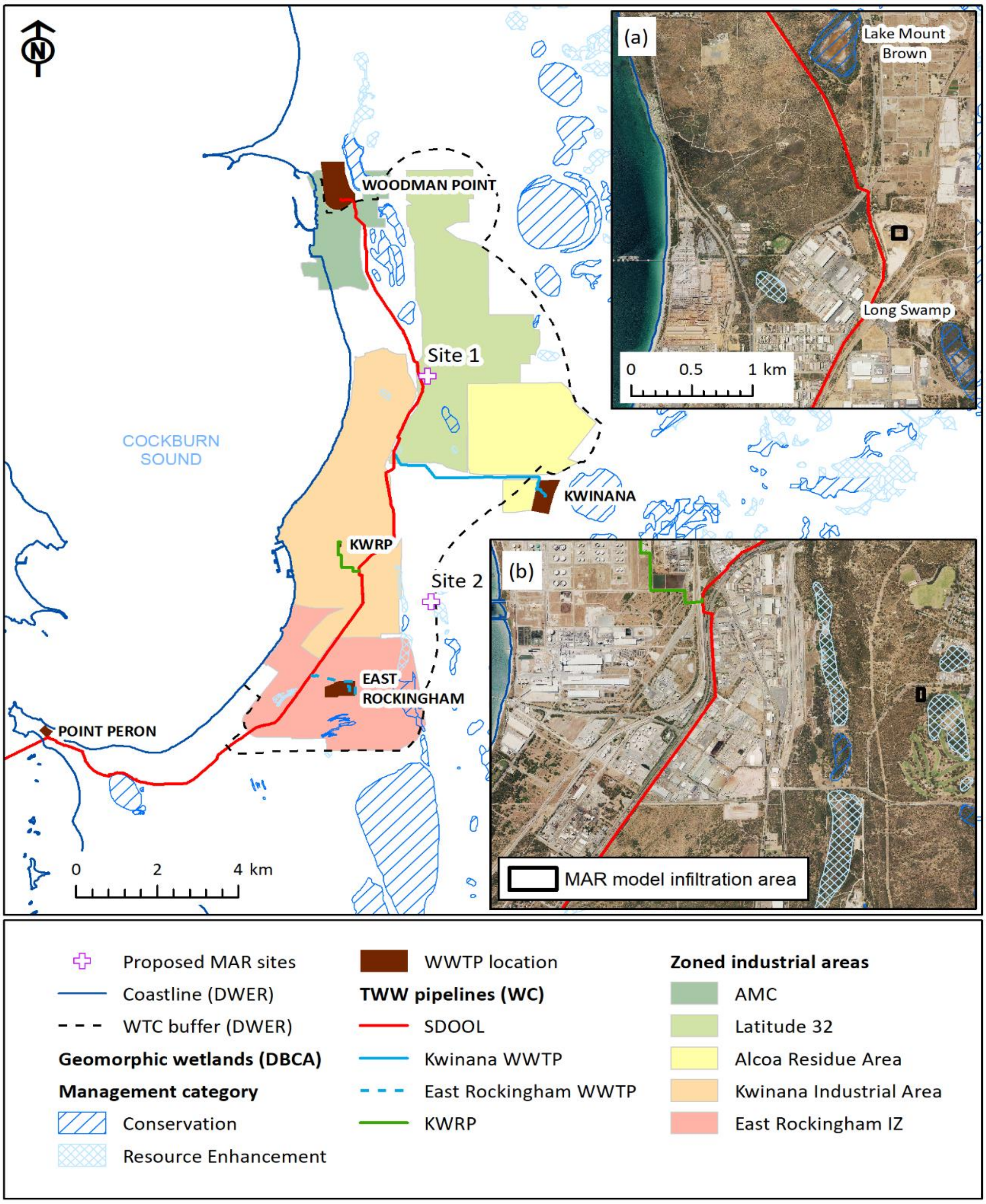


Figure 6-1 Receiving environments (Donn, et al., 2019)

6.4 Hazard identification

CSIRO undertook a detailed review of the potential hazards that could result from the proposed MAR schemes, that is:

- Pathogens,
- Inorganic chemicals,
- Salinity and sodicity,
- Phosphorous,
- Nitrogen,
- Organic chemicals,
- Turbidity and particulates,
- Radionuclides,
- Pressure, flow rates, volumes and levels,
- Contaminant migration,
- Aquifer dissolution and stability of well and aquitard,
- Groundwater depended ecosystems, and
- Greenhouse gases.

These potential hazards are summarised below (Donn, et al., 2019). It is noted that information on the quality of TWW from the various WWTPs has been sourced from Water Corporation.

6.4.1 Pathogens

Little is known about the microbial impact of MAR on the environment, hence the focus of this section is on the human impact of pathogens only (NRMMC, EPHC, NHMRC, 2009). Given the large number of pathogenic hazards in source waters for MAR, three reference pathogens are typically used to represent bacterial, viral and protozoan risks; *Campylobacter*, rotavirus and *Cryptosporidium* (NRMMC–EPHC–AHMC, 2006). However, *Escherichia coli* and *Enterococci* are the only routinely monitored microbial indicators in the source wastewater of interest (Donn, et al., 2017).

Escherichia coli (E. coli) concentrations in source TWW from the Woodman Point (median ~43,000 cfu/100 mL) and East Rockingham WWTPs (median 18,000 cfu/100 mL) exceed the typical medium risk criteria of <10 cfu/100 mL for health impacts from industrial uses (Donn, et al., 2019).

However, monitoring indicates removal of *E. coli* occurs quickly once TWW is infiltrated at the Kwinana WWTP infiltration basins, which is reflective of typical removal rates in aquifers (generally 3 days for 90% loss) (Donn, et al., 2019). Under conditions similar to those expected at the proposed MAR sites, 90% bacteria losses were observed in less than 2 days (Sidhu and Toze, 2012; Sidhu et al., 2015).

Generally, a compliance or operational monitoring level of <10 MPN or cfu/100 mL is suggested for *E. coli* concentration in the end-product water for industrial use (DoH, 2015). This is the only local guideline available to provide quantitative comparison. The source TWW would therefore fail this criterion, while the median quality of groundwater abstracted from the proposed MAR sites is likely to meet this criteria given evidence from TWW infiltration sites (Donn, et al., 2017) and the proposed pre-treatment process.

Protozoa (*Clostridium perfringens)* measured in TWW sources considered in this study (KWRP influent, TWW from Kwinana and East Rockingham WWTPs) varied from 160 spores/100 mL to greater than the detection limit (1,000 spores/100 mL); however were not detected in groundwater at the Kwinana WWTP (i.e. <10 spores/100 mL). This suggests the protozoa risks associated with TWW use for industrial purposes can be mitigated by pre-treatment and MAR, though validation would be required to substantiate this at the proposed MAR sites (Donn, et al., 2019).

Viruses on the other hand typically take longer to remove than bacteria, with a study showing up to 50 days of aquifer residence time required for 90% removal (Sidhu and Toze, 2012; Sidhu et al., 2015). Significant variability in the length/distance required for removal is evident, with another study showing that aquifer residence times as low as 15 days can achieve 99% removal (Betancourt, et al., 2014). This emphasises the need for validation post-MAR implementation.

Conservatively, aquifer residence times of 60 days may be required before recovering MAR water with respect to mitigating pathogen impacts. Modelled residence times suggest greater than 1 year's travel time occurs before a before an existing licenced pumping bore is intercepted (Figure 6-2). Within the WTC area, the majority of abstraction would occur after significant residence times (Site 1: >2 years and Site 2 >5 years). Due to the more restricted access to MAR water and the ability of industry to implement controls on water use, the potential for human contact is lower than is the case for the general public (Donn, et al., 2019).

For Site 2 a greater concern might be the discharge of impacted groundwater to the wetlands within the golf course, however as this wetland is represented by a 'drain' in the groundwater model (i.e. a sink for groundwater discharge) it represents the worst case scenario (Cui et al., 2019). Further modelling to better reflect the groundwater-surface water interaction of these wetlands should be undertaken.

Licenced abstraction bores within the golf course are beyond the MAR impact area, thus the risk is considered to be low (pending confirmation through monitoring). However as exempt use or non-licenced bore locations are not recorded there still remains a higher risk associated with groundwater abstraction near the MAR sites (Donn, et al., 2019). Additional surveys of businesses and residences near the MAR sites is needed to confirm the presence or absence of these bores, the residence time from the MAR site and nature of groundwater use.

Natural treatment processes in the subsurface can be used in combination with on-site preventive measures to meet the minimum health-based reduction targets for pathogens, which were quantified based on the *Australian Guidelines for Water Recycling* (NRMMC, EPHC, NHMRC, 2006). However, as aquifer residence time less than 6 months is unlikely to provide sufficient treatment for viral hazards, residence time to exempt use bores remains to be assessed (Donn, et al., 2019).

While quantification of performance targets for pathogenic hazards during MAR and microbial indicator monitoring data suggest that microbial hazards can be reduced to an acceptable level, this remains to be demonstrated at the sites under consideration. It is necessary to quantify reference pathogen numbers in TWW and groundwater, to validate removal rates locally prior to MAR implementation, and to establish appropriate operational monitoring for pathogen hazards as part of the MAR water quality management plan (Donn, et al., 2019).

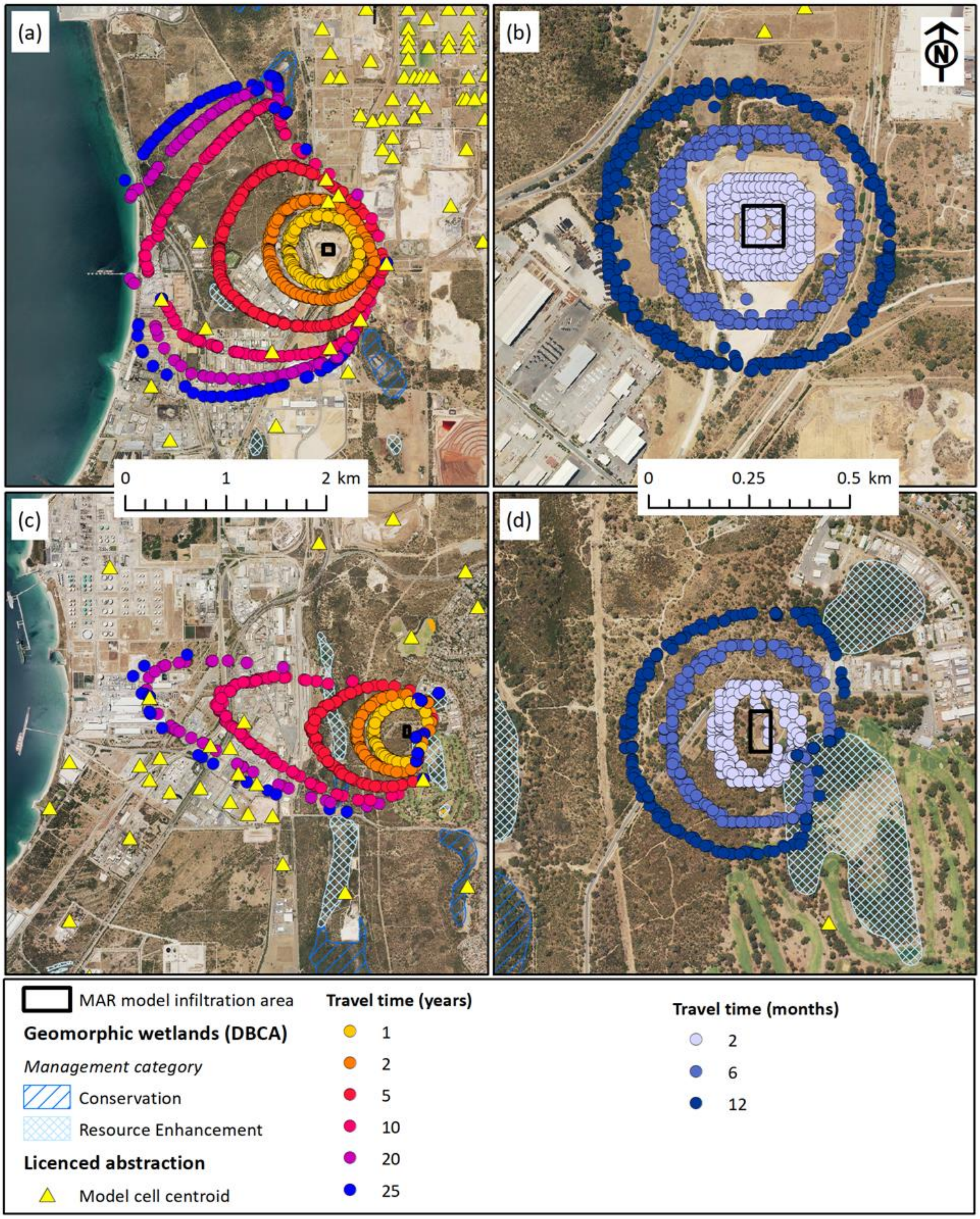


Figure 6-2 Modelled travel time for TWW infiltrated at Site 1 (a and b) and Site 2 (c and d). Both long term and short term travel times are depicted (Donn, et al., 2019)

6.4.2 Inorganic chemicals

The main environmental risk with relation to inorganic chemicals in infiltrated TWW is the input of, or release of metals due to interactions between the TWW and the aquifer. Figure 6-3 illustrates metal concentrations in TWW sources as box and whisker plots. The TWW sources under consideration exceed the trigger values for slightly to moderately disturbed freshwater ecosystem protection (ANZECC – ARMCANZ, 2000) for chromium (Cr), copper (Cu) and zinc (Zn) of 1.0 µg/L, 1.4 µg/L and 8.0 µg/L, respectively. However, it should be noted that the concentration of Cr, Cu and Zn were also exceeded in the background groundwater (up-gradient of the Spectacles wetland; Cr 1.5 to 2.6 mg/L, Cu 1.8 to 2.1 mg/L, and Zn 6 to 22 mg/L).

In a study of Superficial groundwater between Gingin and Mandurah, Zn and Cu concentrations at 51 locations were observed to exceed the trigger values at greater than 90% and 95% of sites, respectively (DoW, 2010), indicating the likelihood of naturally high groundwater concentrations of these metals.

The site-specific background groundwater metal concentrations may be a more appropriate trigger value for ecosystem value, than the generic trigger values given in ANZECC-ARMCANZ Guidelines (2000). Pending background groundwater metal concentrations at the two proposed MAR sites, investigation of metal fate is likely to be required following initiation of MAR at the proposed sites. One difference between the proposed MAR sites and the Kwinana WWTP is the presence of calcium carbonate in the soil and aquifer materials; compared to a largely quartz dominated aquifer in the vicinity of the Kwinana WWTP. Carbonate minerals are known to remove metals through sorption (Shaheen, et al., 2013), thus may potentially limit the impacts of metals in the TWW. The capacity of the soils and aquifer materials however would need to be confirmed at the proposed sites.

Limited information is available for metals in groundwater used for industrial supply; and while uses such as cooling, wash down, process water and dust suppression/slurry transport have been identified, further consultation with industry is required to determine impacts on operations from metals (Donn, et al., 2019).

Metals and metalloids may also be associated with the aquifer matrix and the infiltration of TWW may result in the mobilisation via dissolution and ion exchange reactions. For example the release of adsorbed metals/metalloids upon the reductive dissolution of iron oxyhydroxides has been shown to occur associated with wastewater plumes. While metals and metalloids are likely to be resorbed to other minerals such as calcite, confirmation of aquifer sediment mineralogy and metal/metalloid content (e.g. through analysis by X-ray fluorescence or acid extractable metals) would be suggested for the MAR sites (Donn, et al., 2019). The potential for metal/metalloid mobilisation is deemed to be acceptably low, based on available data and understanding gained through existing TWW infiltration operations. However, it is recommended that this is validated by monitoring during the commissioning phase (commissioning trials).

Aside from metals, major ions are considered to present a low risk via MAR on current groundwater use practices, provided that additional pumping does not induce saltwater intrusion (Donn, et al., 2019). Furthermore, saturation indices determined via the geochemical equilibrium model PHREEQC[10] determined that the TWW sources are close to equilibrium with calcite. As calcite is the major reactive mineral in the aquifer there is unlikely to be substantial changes in the major ion composition as a result of the infiltration of the TWW. However, the TWW is supersaturated with respect to iron oxides, which may represent a potential risk for clogging

[10] A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations (https://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/)

through the precipitation of iron oxyhydroxides during infiltration, though due to low concentrations of iron in TWW, the risk is low (Donn, et al., 2019).

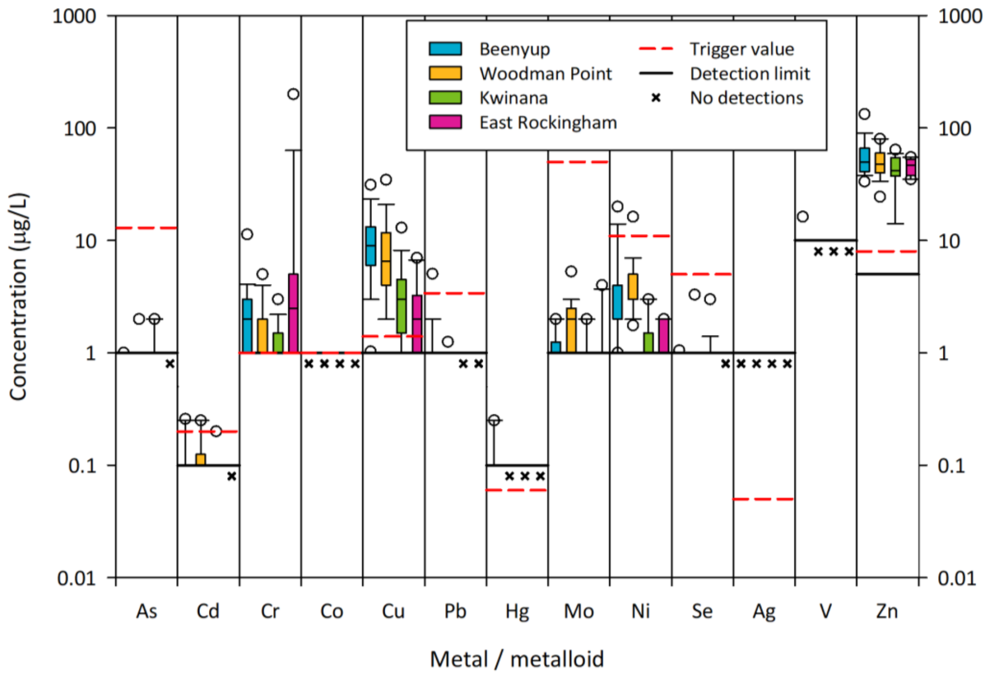


Figure 6-3 Heavy metal/metalloid concentrations in TWW, trigger values as per footnote (Donn, et al., 2019)

6.4.3 Salinity and sodicity

Figure 6-4 displays measured salinity from the TWW sources in consideration as well as from a reference WWTP (Beenyup), nearby wetlands (Thomson's Lake and The Spectacles Swamp), and existing groundwater. Boxes in the figure represent the interquartile range, the whiskers the 10^{th} and 90^{th} percentiles and the points the 5^{th} and 95^{th} percentiles.

With respect to the TWW sources, 40% lower salinity is observed at East Rockingham and Kwinana (median ~380 mg/L) than at Woodman Point (median ~630 mg/L). The future GWR is expected to increase SDOOL salinity to 760 mg/L and 890 mg/L in 2030 and 2050, as discussed in Section 3.5.1 (GHD, 2018). The salinity of the TWW sources is generally lower than that of groundwater abstracted by industry in the WTC.

As such, using the TWW sources would provide a comparable or lower salinity to existing groundwater in use in the WTC. Utilising TWW from the SDOOL following the GWR would marginally increase salinities in 2030 with greater impacts in 2050 as TWW salinity increases.

Initial groundwater salinity measurements at the two proposed MAR sites vary with depth from 576 to 840 mg/L at Site 1; and 348 to 648 mg/L at Site 2 (Donn, et al., 2019). The infiltration of TWW would therefore potentially freshen groundwater at both sites.

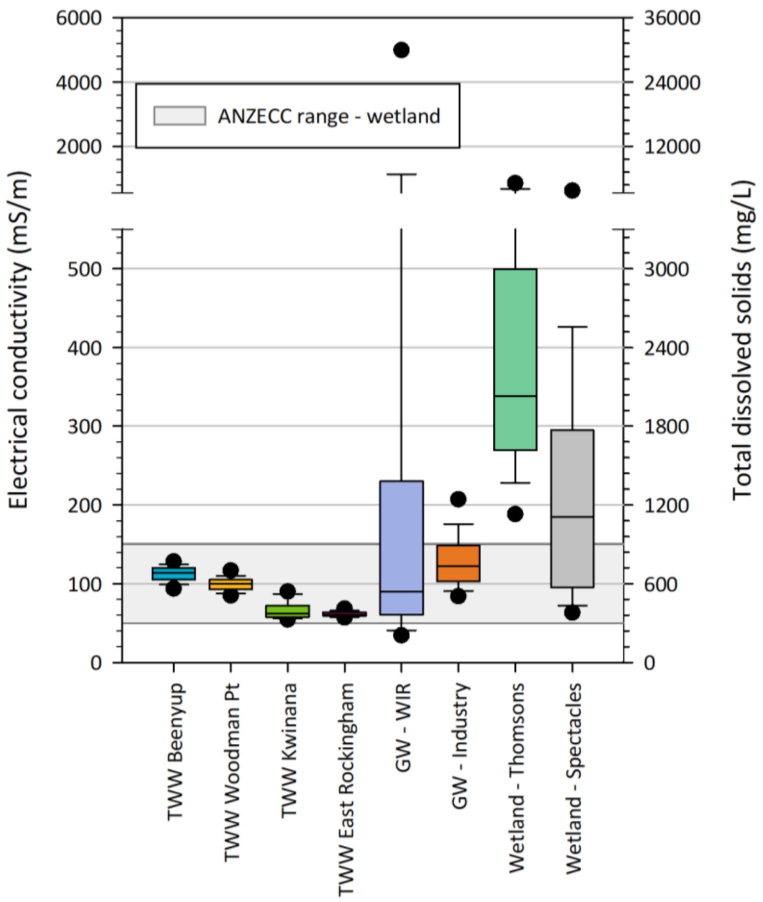


Figure 6-4 Salinity of TWW sources, groundwater and important wetlands (Thomson's Lake and The Spectacles Swamp) (Donn, et al., 2019)

Depending on the time of the year MAR water is likely to be fresher than water within the nearby wetlands as evidenced by the broad range of salinities in the two examples in Figure 6-4. As outlined in McFarlane et al. (2015), the impact will depend on the wetlands potentially affected and at present there are not sufficient surface water salinity data to make an assessment on the golf course at Site 2. Lake Mt Brown (Figure 6-2) is saline with a TDS of 6,859 mg/L (winter 1989), thus any impacts from Site 1 are unlikely to differ from natural groundwater inputs (Donn, et al., 2019).

Sodicity can indicate whether a soil's structure will be impacted (high sodicity can lead to soil dispersion and can cause clogging of infiltration basins). Sodicity is typically measured by the sodium adsorption ratio (SAR) which is a proportion of sodium to that of calcium and magnesium. The SAR from the SDOOL at KWRP and the Kwinana and East Rockingham WWTPs range from 1.3 to 2.5, which are significantly less than the value (10) considered not to impact soil structure (Donn, et al., 2019). Sodicity is therefore not likely to present a risk.

6.4.4 Phosphorus

Figure 6-5 illustrates the phosphorus concentrations in TWW from the WWTPs as box and whisker plots. Between the sources of interest, TWW from the Woodman Point/SDOOL (4.6 mg/L) is lower than from East Rockingham (7.0 mg/L).

Carbonate minerals in the vadose zone and aquifer are likely to attenuate phosphorus through either precipitation as highly insoluble calcium phosphate or by adsorption to the aquifer matrix. This has been observed in previous infiltration trials using TWW, and has been reinforced at other TWW infiltration sites (Bekele et al., 2011; Bekele et al., 2015) (Donn et al., 2017). Substantial changes to the TWW acidity would be needed to either dissolve the precipitate or adsorbed phosphorus, as discussed further in Section 6.4.11.

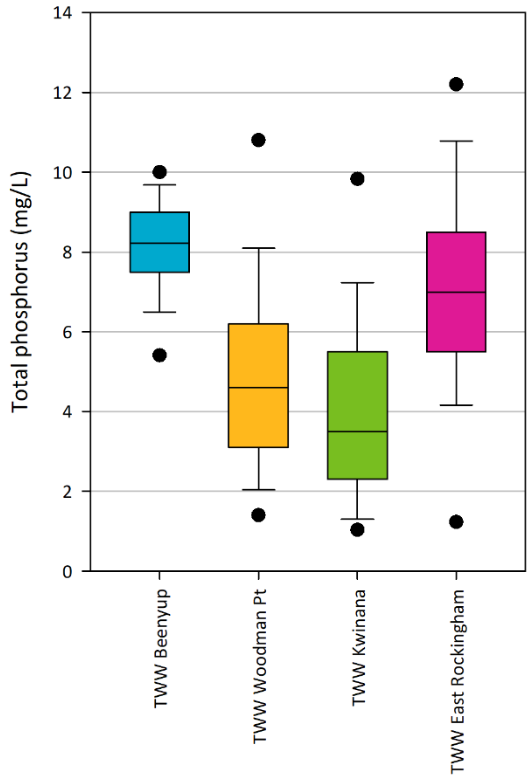


Figure 6-5 Total phosphorus concentrations in TWW sources (Donn, et al., 2019)

6.4.5 Nitrogen

Effluent from the Woodman Point WWTP (median > 15 mg/L) exhibits higher total nitrogen concentrations than the East Rockingham WWTPs (median < 5 mg/L) (Figure 6-6). Depending on the WWTP different nitrogen species dominate, however inorganic forms (nitrate, nitrite and ammonium) dominate generally.

Limited nitrogen concentration data are available for wetlands potentially impacted by the proposed MAR. Given the potential for native groundwater and wetland total nitrogen concentrations to exceed the ANZECC-ARMCANZ Guidelines (2000) wetland trigger value (1.5 mg/L in south-west Australia) a better understanding of local conditions prior to MAR is required.

The capacity of the aquifer to attenuate nitrogen depends on the species in the source water and the redox conditions in the aquifer. While it is still uncertain as to the capacity of the aquifer to provide nitrogen removal through denitrification, the interception of the MAR plume through additional abstraction is expected to reduce the loads to Cockburn Sound to a greater extent than determined by McFarlane et al. (2015), thus posing a decreased risk. The pre-treatment of TWW before infiltration, especially at Site 1, will reduce the impact of nitrogen on both wetlands and Cockburn Sound. However for wetlands at Site 2 the impact of TWW infiltration is uncertain

due to the lack of water quality data and the proximity to the golf course which is likely to influence groundwater and consequently wetland nitrogen concentrations due to fertiliser application (Donn, et al., 2019).

Total nitrogen greater than 10 mg/L poses a high risk of clogging (NRMMC-EPHC-NHMRC, 2009), thus indicating pre-treatment would be required for TWW from Woodman Point. Approximately 4.7 ML/d of TWW is successfully infiltrated at the Kwinana WWTP indicating that nitrogen may not strongly contribute to clogging. However due to the gallery design proposed for Site 2 verification of the impact of nitrogen on clogging is required (Donn, et al., 2019).

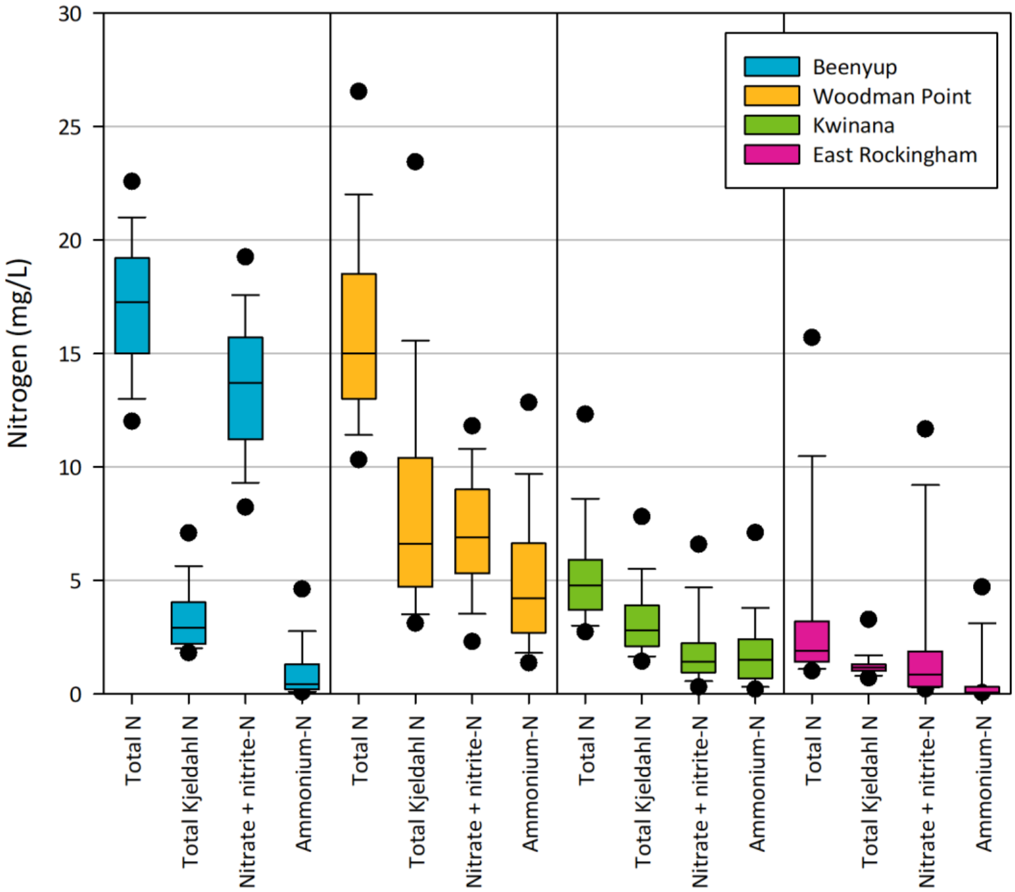


Figure 6-6 Concentration of nitrogen species in TWW sources (Donn, et al., 2019)

6.4.6 Organic chemicals

A wide range of trace organic chemicals have been detected in secondary TWW in the Perth metropolitan area (including the TWW sources in consideration), of which most had low to very low risk to human health (Department of Health, 2009a). Some pesticides, disinfection by-products, and N-nitrosamines had median concentrations that were potentially harmful to human health. Only one (Chlorpyrifos) had a median concentration exceeding its environmental toxicity trigger value (ANZECC-ARMCANZ, 2000).

In addition to the above, CSIRO undertook two rounds of sampling to determine the trace organic chemical concentrations in TWW from KWRP influent, Kwinana WWTP, East Rockingham WWTP and groundwater associated with TWW infiltration at the Kwinana WWTP. The analysis detected 20 of the 34 trace chemicals in the groundwater, and some of these

compounds (e.g. caffeine, imidacloprid and simazine) appeared to be attenuated within the aquifer as they were only detected in bores closer to the infiltration location. However, groundwater at the Kwinana site demonstrates anaerobic conditions while the MAR sites proposed exhibit aerobic conditions, which is a key factor in the attenuation of organic chemicals (Donn, et al., 2019).

Analysis of groundwater associated with wastewater infiltration into the aerobic Tamala Limestone aquifer in consideration may provide a better understanding of the fate of trace organic chemicals and inform the assessment of the hazard. Further characterisation of organic chemicals in the source water is also required to provide a more robust assessment (Donn, et al., 2019).

6.4.7 Turbidity and particulates

Turbidity (commonly measured as TSS) is primarily an operational hazard for the MAR scheme due to potential for clogging of the infiltration basin or gallery at its surface. There is low risk of increased groundwater turbidity due to the filtration of the infiltration basin or gallery. As discussed in Section 3.5.1, TSS is higher in Woodman Point effluent than in East Rockingham effluent, which is further illustrated in Figure 6-7. Woodman Point effluent also demonstrates higher variability in TSS. The projected median TWW quality by 2030 is expected to be at or above the MAR guideline value of 10 mg/L for TSS (refer Section 3.5.1).

To maintain efficient infiltration at both MAR sites, pre-treatment (denitrifying filter, TSS < 5 mg/L) with on-line turbidity screening to monitor for poor influent water quality has been proposed (refer Sections 4.2.3 and 4.3.3). This will reduce the risk of clogging and extend maintenance intervals. It is noted that clogging will occur regardless of the TSS concentration/load in the source water due to biological processes.

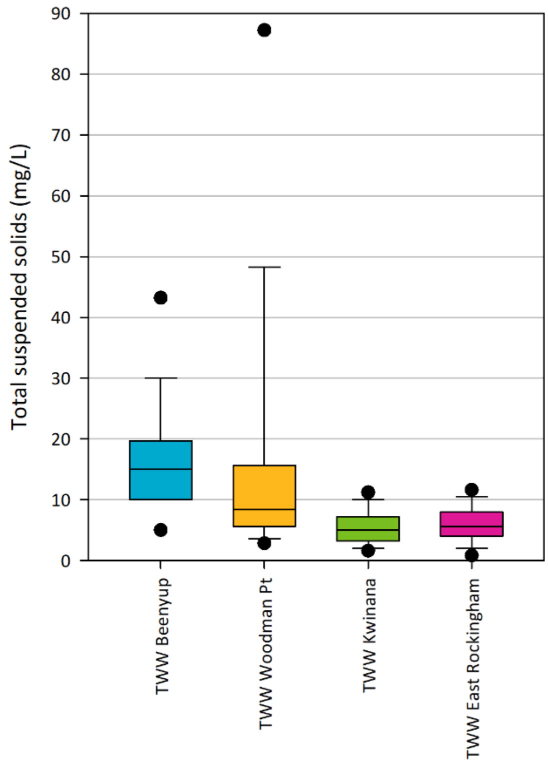


Figure 6-7 TSS concentration in TWW sources (Donn, et al., 2019)

6.4.8 Radionuclides

According to the MAR guidelines "*The main radionuclide concern is recovery of water posing a risk to human health by ingestion of drinking water or foods via crop irrigation, stock watering, or food chain accumulation (radium and radon), or inhalation of gas released from the water supply (radon)*" (NRMMC-EPHC-NHMRC, 2009). In the absence of specific criteria for the end uses, the Australian Drinking Water Guidelines (ADWG) have been used as a conservative approach.

The ADWG recommends an initial screening of total radioactivity in the form of alpha and beta radiation to determine whether further analysis is required (NHMRC and NRMMC, 2011). The maximum gross alpha and beta particle activities (0.11 Bq/L and 0.05 Bq/L, respectively), detected in a study of TWW in the Woodman Point/SDOOL, Subiaco WWTP, and Beenyup WWTP are lower than the screening level for both particle activities (0.5 Bq/L) (DoH, 2009). The risk of radionuclides existing in source water for Site 1 is therefore low. No data exists for East Rockingham WWTP, but similarly the risk is expected to be low.

Radionuclides in groundwater used as drinking water from the Wanneroo Water Treatment Plant were also found to be below the drinking water screening level (DoH, 2009). Although this groundwater is from the north of Perth, this suggests that the hazard related to radionuclides in groundwater is also low (Donn, et al., 2019).

6.4.9 Pressure, flow rates, volumes, and levels

Groundwater modelling undertaken by CSIRO aimed to understand the potential groundwater mounding caused by TWW infiltration and the associated waterlogging and infrastructural impacts that could occur (Cui & Donn, 2019). Figure 6-8 indicates modelled inundation areas in 2045 with and without the MAR schemes at both sites (Donn, et al., 2019). Figure 6-9 illustrates the maximum mound height modelled for the two MAR sites both with and without 10 ML/d of additional groundwater abstraction (Donn, et al., 2019).

While greater inundation is predicted surrounding Site 1, the model is poorly calibrated in this area (Figure 6-8a) due to the limited number of bores available. This is clearly illustrated by the predicted area of inundation in the vicinity of Long Swamp which is double the extent currently mapped (Donn, et al., 2019). Nonetheless, groundwater levels are predicted to rise by ~5 m at Site 1 both with and without additional abstraction (Figure 6-9a and b). Groundwater level rise at this site and in surrounding areas may constrain the maximum recharge rate able to be realised at this site to less than 10 ML/d. Further collation of groundwater level data is needed to improve model accuracy at Site 1 and provide additional confidence in these results.

Generally the infiltration of TWW at Site 2 does not cause any increase in the extent of inundation in the vicinity of the infiltration site(Figure 6-8c and d). The smaller impact is related to smaller mounding of groundwater with up to only ~2 m rise in groundwater levels (Figure 6-9c and d).

Groundwater contamination is present between the MAR sites and Cockburn Sound and alteration of groundwater flow regimes has the potential to modify the groundwater plumes associated with these contaminant sources (McFarlane et al., 2015; Trefry et al., 2006). Abstraction of the MAR water would potentially negate these impacts as fluxes to the Sound would be effectively reduced (provided that abstraction is equal to infiltration).

The groundwater modelling results to date are unable to provide evidence that the introduction of TWW infiltration will not mobilise existing groundwater contamination plumes. Further detailed data from known adjacent contaminated sites are required to determine if the activity would impact on existing groundwater contamination plumes.

MAR water will take some time to travel to the areas where it is potentially to be abstracted. The positioning of the MAR sites east of the potential users was deliberate so as to enable natural attenuation to occur in the aquifer and provide MAR water over an increased area. The results from the CSIRO groundwater model and mounding of the MAR plume(s) can be used to support development of a more detailed local area model that will be required during the DWER's 5C licensing approval process to define the MAR Management Zone. Modelling suggests that changes to groundwater level will likely be limited to areas east of existing contaminated sites and reduced due to groundwater reuse (Figure 6-9).

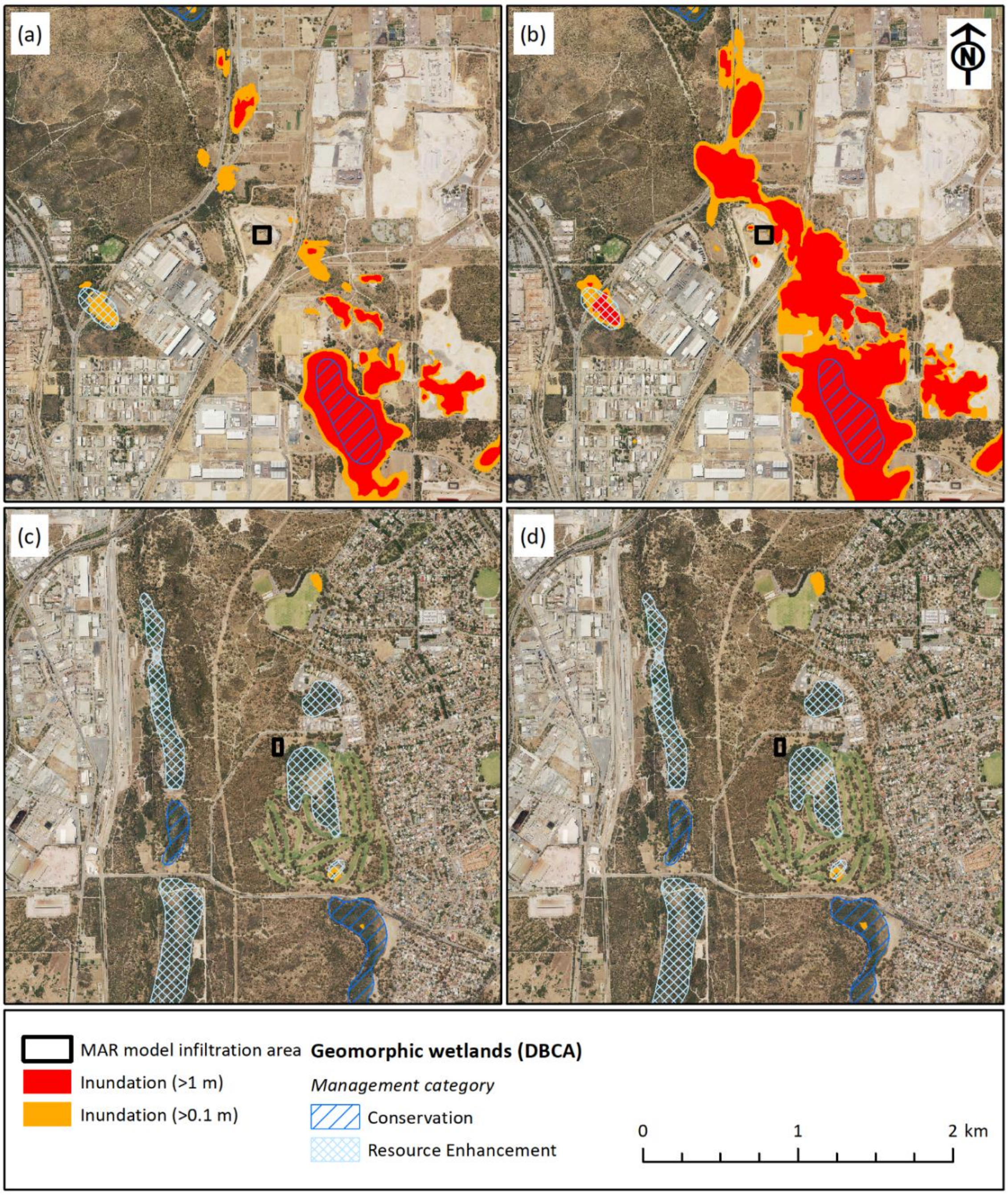


Figure 6-8 Median inundation extent across all models for Site 1 (a and b) and Site 2 (c and d) for the no MAR scenario (a and c) and the MAR no recovery scenario (b and d) under the DWER dry climate scenario (2030). End of model (2045) results shown. (Donn, et al., 2019)

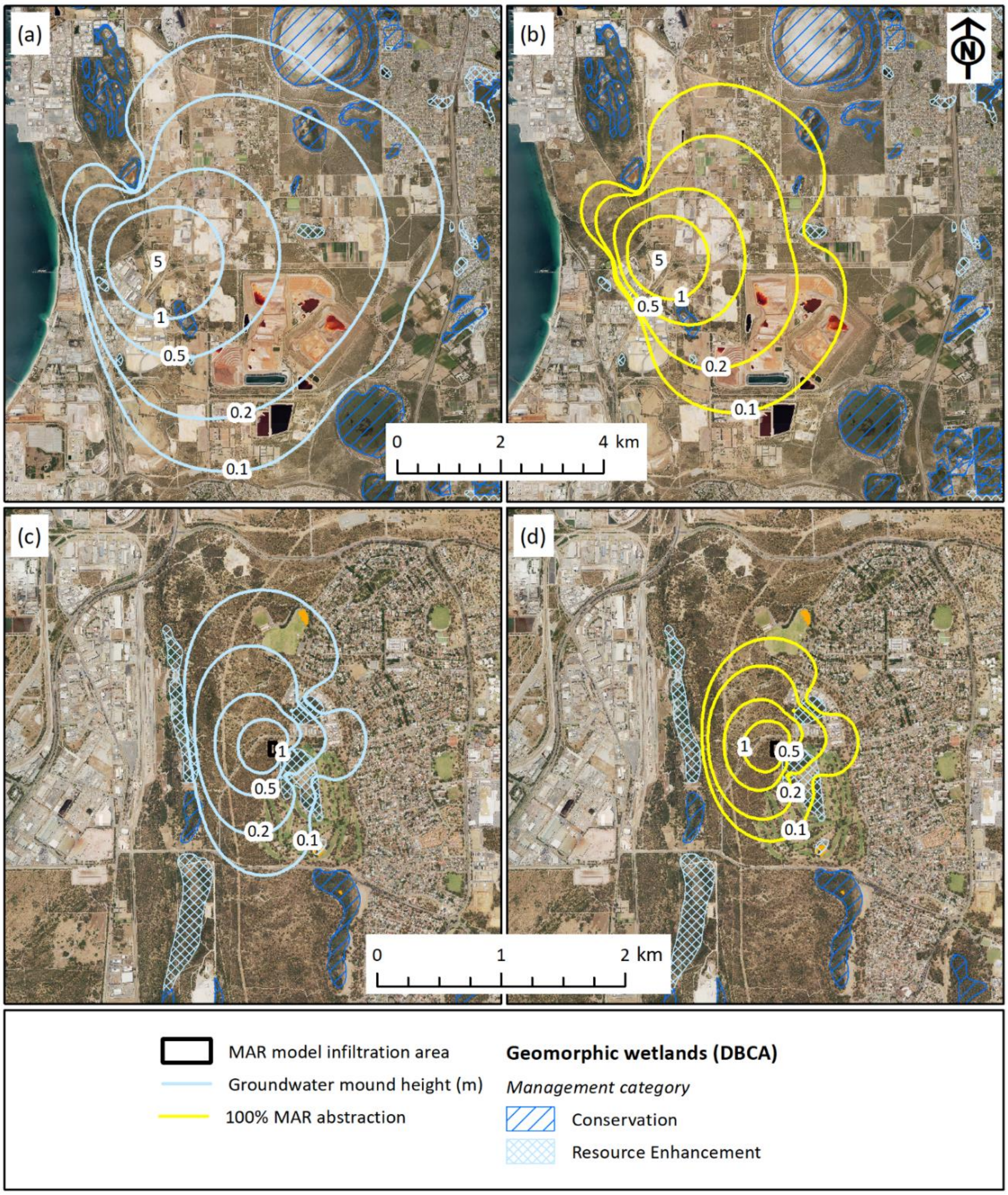


Figure 6-9 Median maximum mound height across all models at Site 1 (a and b) and Site 2 (c and d) both with (left) and without (right) 10 ML/d of additional groundwater abstraction down gradient of the sites (Donn, et al., 2019)

6.4.10 Contaminant migration

Both proposed MAR sites are situated on Tamala Limestone which has been characterised to exhibit diffuse-flow rather than the conduit flow that would be expected in limestone (Smith et al., 2011; Vacher and Mylroie, 2002). However, the large to very large transmissivity of the aquifer means that the diffuse-flow is not slow. Nonetheless, removal of contaminants such as pathogens and nutrients is still likely to occur relatively close to the infiltration point. Monitoring

of TWW tracers and groundwater levels along with solute/reactive transport modelling is required to verify this once the MAR scheme is operational (Donn, et al., 2019).

6.4.11 Aquifer dissolution and stability of well and aquitard

The potential exists for TWW infiltration to dissolve the aquifer material as both the vadose zone and aquifer contain calcite (calcium carbonate). This could occur if the infiltrated water is acidic (low pH); aerobic with oxidising sulfide minerals; or under-saturated with respect to the carbonate minerals present (Donn, et al., 2019).

The pH of the source TWW in consideration is neutral to slightly basic with median pH ranging from 7.2 to 7.6 (Figure 6-10). Furthermore, the sodicity of TWW source waters from Woodman Point and East Rockingham are close to being in equilibrium with calcite (saturation index ranges from -0.04 to -0.38) (Donn, et al., 2019). Infiltration of the TWW is therefore unlikely to result in significant dissolution of the aquifer.

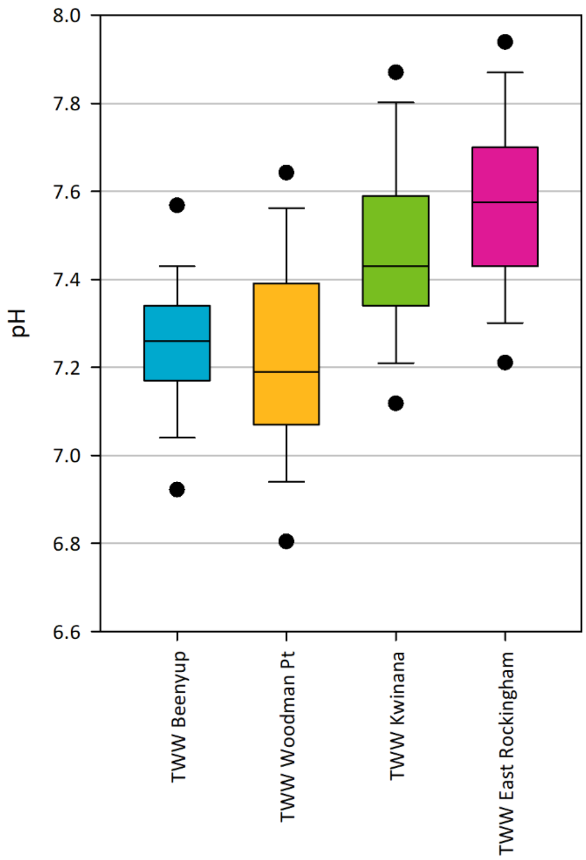


Figure 6-10 TWW pH

6.4.12 Groundwater dependent ecosystems

The main groundwater dependent ecosystems (GDEs) likely to be impacted by MAR are the wetlands identified in Section 6.3. Long Swamp and Lake Mount Brown have negligible information (apart from salinity and nutrient measurements at Lake Mount Brown) on ecosystem condition or water quality despite their conservation category status. Without further assessment of current wetland water quality it is therefore difficult to assess the hazard posed by MAR on these wetlands from a water quality perspective.

Furthermore, it appears that the mapping of these wetlands has not been recently assessed, since roads and golf course infrastructure for example are mapped within the wetland extents (Figure 6-1) (Donn, et al., 2019).

Increased groundwater levels in response to MAR may counteract the drying impacts of climate change on vegetation within and surrounding the wetlands and thus benefit the wetlands.

Baseline and validation monitoring of water quality, and wetland and groundwater levels is evidently required for the potentially impacted wetlands to assess the impact of MAR, especially at Site 2 where MAR water residence times in the aquifer are relatively low (60 days).

6.4.13 Greenhouse gases

To assess the lifecycle GHG emissions from the MAR schemes, the emissions determined for the proposed sites (refer Sections 4.2.1 and 4.3.4) have been compared to other alternative water supplies, as shown in Table 6-1. Ideally the KWRP and scheme water from the IWSS would have been used as the alternative sources (as discussed in Section 2.1), however, a life cycle assessment has not been undertaken for these sources. To this end, a literature review of GHG emissions from seawater reverse osmosis desalination and brackish water desalination are assessed instead given that these sources rely at least partially on desalination.

The MAR pre-treatment schemes proposed by GHD are equivalent to or less than a similar sized volume of water (10 ML/d) produced from a desalination plant over an assumed 50 year life cycle. Therefore relative to other sources of water available the risk associated with greenhouse gas emissions is low.

Table 6-1 Life cycle GHG emissions (Donn, et al., 2019)

Source	Life cycle (50 years) GHG emissions (t CO_2-e)	Reference
Site 1 (north)	106,000	(GHD, 2018)
Site 2 (south)	55,000	(GHD, 2018)
Seawater desalination	73,000 – 1,222,750	(Cornejo, et al., 2014)
Brackish water desalination	73,000 – 456,250	(Cornejo, et al., 2014)
Southern Seawater Desalination Plant (Western Australia)	710,000	(Biswas, 2009)
TWW desalination Groundwater Replenishment Trial (Western Australia)	187,000	(Simms, et al., 2017)

6.5 Maximal and pre-commissioning residual risk assessment

A maximal risk assessment has been conducted based on a qualitative assessment of the likelihood and consequences of the hazards identified above without mitigation measures (for example pre-treatment and/or other engineering controls) or accounting for natural treatment in the aquifer. This includes health risks, environmental risks, risks associated with impacts on industrial groundwater use and with the operation of the proposed MAR schemes.

The pre-commissioning residual risk assessment then considers preventative measures such as pre-treatment or natural treatment in the aquifer, based on previous experience with MAR or TWW infiltration in the superficial aquifer, predictions of groundwater flow and solute transport for the prospective sites and the proposed engineering controls (refer Sections 4.2.3 and 4.3.3).

Qualitative measurements are based on those modified from *Phase 1 Australian Guidelines for Water Recycling* (NRMMC, EPHC, NHMRC, 2006) and are shown in Table 6-2.

The maximal and pre-commissioning residual risk assessment for Site 1 is shown in Table 6-3. The same assessment outcomes apply for Site 2, with some exceptions, as shown in Table 6-4.

Table 6-2 Risk assessment method adapted from Phase 1 Australian Guidelines for Water Recycling (Donn, et al., 2019)

LIKELIHOOD		
Level		Example description
1	Rare	Rare May occur only in exceptional circumstances. May occur once in 100 years
2	Unlikely	Unlikely Could occur within 20 years or in unusual circumstances
3	Possible	Possible Might occur or should be expected to occur within a 5- to 10- year period
4	Likely	Likely Will probably occur within a 1- to 5- year period
5	Almost certain	Almost certain Is expected to occur with a probability of multiple occurrences within a year
CONSEQUENCE / IMPACT		
Level		Example description
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health – Minor impact for small population Environment - Potentially harmful to local ecosystem with local impacts contained to site
3	Moderate	Health – Minor impact for large population Environment – Potentially harmful to regional ecosystem with local impacts primarily contained to on-site
4	Major	Health – Major impact for small population Environment – Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts
5	Catastrophi c	Health – Major impact for large population Environmental – Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts

		CONSEQUENCES / IMPACT				
		1	2	3	4	5
LIKELIHOOD	1	Low	Low	Low	High	High
	2	Low	Low	Moderate	High	Very high
	3	Low	Moderate	High	Very high	Very high
	4	Low	Moderate	High	Very high	Very high
	5	Low	Moderate	High	Very high	Very high

Table 6-3 Maximal risk assessment for Site 1 (Donn, et al., 2019)

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Pathogens (health risk)	Re-use for industrial water supply and incidental use for irrigation (health hazard only)	Possible MAR water to be intercepted by groundwater users	Major Industrial users and exempt use bores may intercept groundwater impacted by pathogens	Very high	Unlikely Predicted groundwater residence times adequate to provide sufficient time for pathogen removal.	Insignificant For industrial water supply. While ingestion of sprays is still possible the volume would be low and pathogen number are also likely to be low. Minor Exempt use bores may intercept groundwater though likely to be small due to location of infiltration site. Confirmation required.	Low
Inorganic chemicals (environmental risk)	Wetlands / Cockburn Sound Industrial water supply	Moderate TWW major ion chemistry and metal concentrations are similar to groundwater. There is the potential to release metals from the aquifer	Minor Impact not likely to be detectable	Moderate	Unlikely	Minor Impact not likely to be detectable outside management (attenuation) zone due to sorption.	Low

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
		sediments, though this and the aquifers potential to attenuate (sorption) metals is not yet quantified. Other sources (industry) are likely to impact groundwater before discharge to the Sound					
Salinity and sodicity (environmental risk)	Wetlands Industrial water supply	Unlikely Current salinity of TWW sources within range of groundwater salinities associated with wetlands and industrial water supply. Predicted salinity due to GWR in 2030 also within upper bounds and initial evidence exists for higher salinity closer to Site	Insignificant Environmental receptors distant from infiltration location (Lake Mt Brown is saline already) Similar groundwater salinities to existing industrial supply.	Low	Unlikely	Insignificant	Low

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
		1. No sodicity impacts due to TWW and aquifer composition.					
Nutrients – Phosphorus	Wetlands / Cockburn Sound Industrial water supply	Likely	Catastrophic Widespread off-site impacts on environmental receptors and industrial water supply	Very high	Rare Attenuation of phosphorus through precipitation and/or adsorption close to infiltration location	Insignificant Environmental receptors and industrial water users distant from infiltration location	Low
Nutrients – Nitrogen (environmental risk and operational risk)	Wetlands / Cockburn Sound Industrial water supply	Likely Median TWW nitrogen concentrations over 5 mg/L target Almost certain Current TN likely to result in biological clogging	Catastrophic Widespread off-site impacts on environmental receptors and industrial water supply. Moderate Impacts contained to on-site	Very high	Unlikely With pre-treatment options suggested and plume interception by abstraction within the MAR zone will	Minor Local impacts contained to site	Low

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
					reduce the likelihood		
Organic chemicals	Wetlands / Cockburn Sound	Unable to determine environmental risk based on existing data • Further assessment of TWW required to define trace organic chemicals present • Assessment of TWW tracer organic chemicals at analogous sites may inform risk assessment (Kwinana WWTP not suitable due to matrix effects during analysis) Treatment capacity of the aquifer will differ for different organic chemicals					
Turbidity and particulates (operational risk)	Clogging of infiltration basin	Almost certain Current TWW particulate load likely to clog basins quickly	Moderate Impacts contained on-site	High Clogging of infiltration basins will need to be managed	Unlikely Pre-treatment (filtration) and basin management (rotation, vegetation management and scraping) will minimise clogging	Minor Impacts contained on-site	Low Clogging of infiltration basins will need to be managed
Radionuclides (health and environmental risk)	Wetlands / Cockburn Sound Industrial water supply	Rare Based on gross alpha and beta particle activity in TWW	Insignificant	Low	Unlikely Pre-treatment (filtration) and basin management (rotation, vegetation	Minor Impacts contained on-site	Low Clogging of infiltration basins will need to be managed

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
					management and scraping) will minimise clogging		
Pressure, flow rates, volumes and levels (operational risk)	Inundation of land surface	Possible Based on current groundwater modelling inundation could occur near Site 1. However there are inconsistences between measured and modelled groundwater levels that additional data may improve.	Major Based on current modelling.	Very high Further groundwater model validation and ground-truthing required, pending additional data being supplied	Unable to assess at present, additional data required to determine depth to groundwater in vicinity of Site 1.		
Contaminant migration in fractured rock and karstic aquifers	Wetlands / Cockburn Sound Industrial water supply	Rare Based on geohydrology of Tamala Limestone not exhibiting conduit flow	Catastrophic Widespread on-site and off-site impacts (e.g. increased loading of nutrient to Cockburn Sound)	High	Rare	Moderate Monitoring of TWW tracers through the groundwater monitoring scheme for evidence of conduit flow	Low

MAR hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Aquifer dissolution	Infiltration infrastructure	Rare Based on current TWW acidity	Minor Impacts to aquifer locally on site	Low	Rare	Minor	Low
Impacts on groundwater dependent ecosystems	Wetlands	Possible There is the potential to indirectly (positively) impact wetlands due to groundwater table rise (e.g. Long Swamp)	Minor This impact is uncertain due to lack of information on wetland ecological condition and water quality (including Long Swamp and Lake Mount Brown). It is not clear what the impact of increasing water levels would be.	Moderate	Unlikely Based on groundwater residence times MAR water is not likely reach the wetlands under 10 years	Insignificant Monitoring program required to validate that impacts will be insignificant	Low
Greenhouse gases	Relative to other sources of non-potable water supply, i.e. desalinated TWW (KWRP) or scheme water (a proportion of which is derived from desalination)	Unlikely	Minor Energy use and greenhouse gas emission are likely to be equivalent to or lower than alternative sources of non-potable water	Low	Unlikely	Minor	Low

Table 6-4 Maximal risk assessment for Site 2, where different to Site 1 (Table 6-3) (Donn, et al., 2019)

MAR Hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Nutrients – Nitrogen (environmental and operational risk)	Wetlands / Cockburn Sound Industrial water supply	Possible Median TWW nitrogen concentrations less than 5 mg/L target Likely Current TN likely to result in biological clogging	Moderate Potentially harmful to regional ecosystem and industrial water supply with local impacts Moderate Impacts contained to on-site, due to buried gallery infrastructure the impact of clogging will involve gallery renewal	High	Unlikely Pre-treatment options suggested and plume interception by abstraction within MAR zone will reduce likelihood	Minor Local impacts contained to site, monitoring of golf course wetland required to assess impact particular to TWW infiltration	Low Clogging of infiltration galleries will need to be managed, including provision for renewal
Turbidity and particulates (operational risk)	Clogging of infiltration galleries	Likely Current TWW particulate load is not overly high however clogging is still likely to develop	Moderate Due to buried gallery infrastructure the impact of clogging will involve gallery renewal	High Clogging of infiltration galleries will need to be managed	Unlikely Pre-treatment (filtration) and gallery management (rotation and vegetation management) will minimise clogging	Minor Impacts contained to on-site (gallery renewal)	Low Clogging of infiltration galleries will need to be managed, including provision for renewal

MAR Hazard	Environmental receptor / Intended uses / infrastructure	Maximal risk assessment			Pre-commissioning residual risk assessment		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Pressure, flow rates, volumes and levels (operational risk)	Water logging, inundation of land surface, effects of anoxia on vegetation, increased road maintenance costs	Unlikely Water levels may increase within wetlands east of infiltration site	Minor Based on current modelling	Low	Unlikely	Minor	Low
Impacts on groundwater dependent ecosystems	Wetlands (east of infiltration site including golf course)	Likely Nitrogen (and potentially organic chemicals) from TWW is likely to impact wetlands	Major This impact is uncertain and therefore the impact is conservative as no information on wetland ecological condition/health and nutrient status	Very high	Likely Monitoring of groundwater and wetland required to determine impact	Minor Impacts likely to occur at the golf course wetland but the impacts needs to be determined relative to existing wetland conditions	Moderate Verification required through monitoring

7. Financial, economic and commercial analysis

7.1 Approach

Financial, economic and commercial analyses for heavy industry water demand were undertaken by Synergies (2018) (refer Appendix C for full report) to determine the viability of the scheme from a monetary perspective, including:

- **Financial viability** – the project viability and attractiveness to a potential MAR scheme operator (i.e. project revenues vs project costs) (refer Section 7.2).
- **Economic viability** – the project's benefit to the Western Australian community (i.e. economic benefits vs economic costs) (refer Section 7.2).
- **Commercial requirements** – the commercial models required to deliver the scheme, and the associated commercial risks involved (refer Section 0).

The financial and economic analysis were conducted in the following sequence:

1. Estimate value per unit of MAR water, termed Marginal Revenue for financial analysis and Marginal Economic Benefit for economic analysis.
2. Application of REU demand forecasts with additional supply and demand influences.
3. Predict net present values (NPVs).
4. Test sensitivity of key parameters to gauge project risks.

7.2 Financial and economic analysis

7.2.1 Marginal revenue

Present value

The marginal revenue of MAR water to a potential supplier is estimated as the price of potable scheme water less the unit cost of TWW supply and less the cost of further water treatment by users:

$$Marg.Rev._{MAR} = Price_{Scheme} - Cost_{TWW\ supply} - Cost_{User\ treatment}$$

The reasoning for the latter subtraction is that it is assumed users would only be willing to pay up to the price of scheme water less any cost incurred themselves to treat the water to their required industry standard, as described in Section 2.3.

The cost assumptions highlighted in Table 7-1 have been adopted. These assumptions result in a marginal revenue of MAR water of \$0.70/kL, as illustrated in Figure 7-1. This otherwise means that the costs for the MAR scheme can be no more than \$0.70/kL to be financially viable. This suggests MAR water from Site 2 (costing \$0.60/kL) would be cost-competitive with scheme water at its current price, while Site 1 (costing \$0.95/kL to \$1.13/kL) would not be viable at the present time.

Table 7-1 Water pricing assumptions

Source	Price	Justification
Scheme water	$2.4/kL, increasing over time	As estimated by the Economic Regulation Authority [11]
TWW	$0.5/kL	Nominal value. Variation may occur through negotiations.
On-site treatment	$1.2/kL, with sensitivity analysis $0.50/kL and $0.80/kL	Cost of treating MAR water with small reverse osmosis plant is quite uncertain, hence sensitivity analysis.

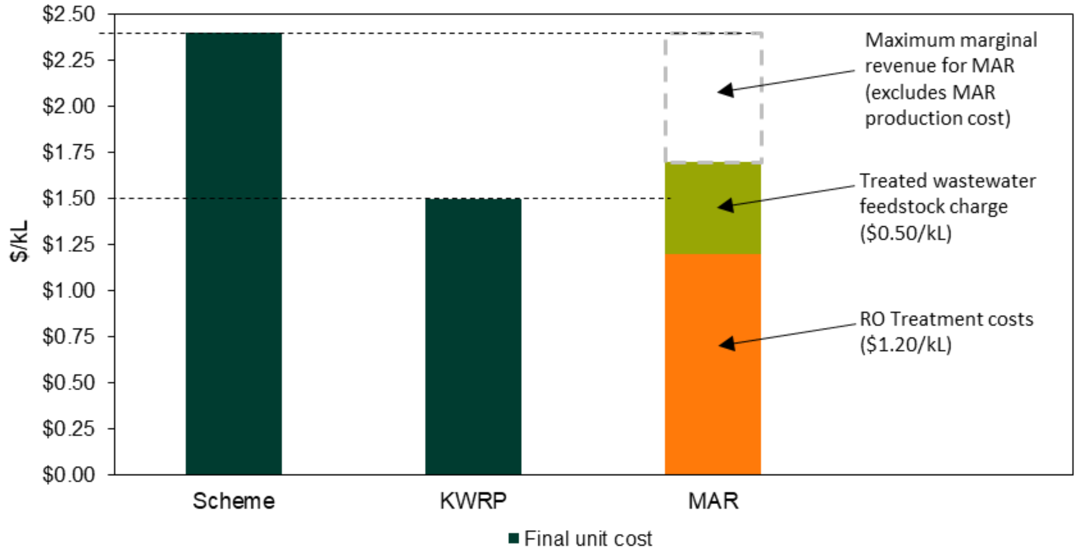


Figure 7-1 Marginal revenue relative to existing sources (Synergies, 2018)

Projected value

Figure 7-2 depicts the projected marginal revenue of MAR water. This figure indicates that higher costs of MAR (up to $2.50/kL) may be viable going forward. This representation of marginal revenue shows how it (green line) follows the cost of scheme water (orange line), less deductions for:

- TWW supply to the MAR facility,
- user treatment cost of MAR water prior to use, and
- a 10% price discount as an incentive payment to switch to the MAR scheme.

The key assumptions of note with respect to this figure are:

- The assumed price of scheme water is predicted to rise to $4.30/kL by 2040 as the proportion of 'low cost' sources (e.g. dams and groundwater) decreases and 'high cost' sources (e.g. desalination) increase (Economic Regulation Authority, 2017).
- Use of KWRP water will reach capacity before the MAR scheme commences.
- A discount of 10% will apply for MAR water.

[11] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105

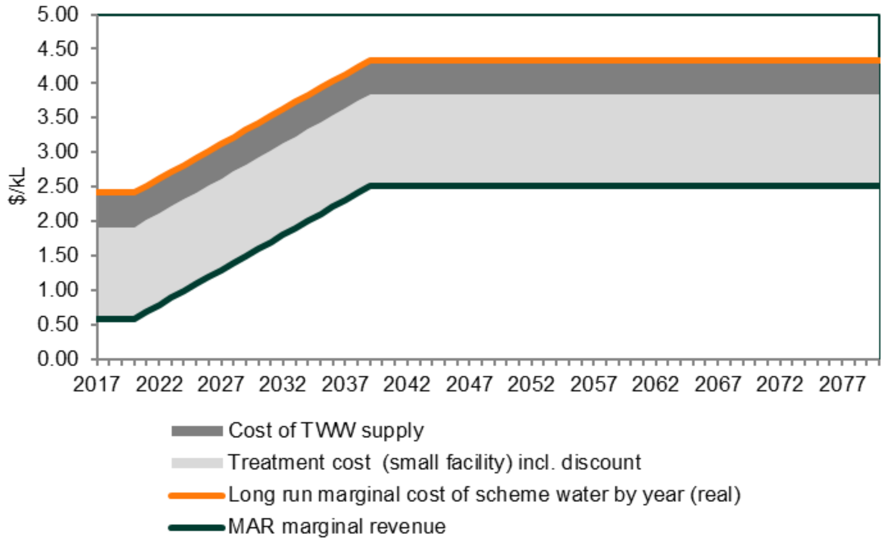


Figure 7-2 MAR marginal revenue (real), 2017 to 2080 (Synergies, 2018)

7.2.2 Projected demand

Synergies developed a model that combines the underlying demand forecasts from REU with expected demand and supply events in a probabilistic manner. The demand and supply events were identified based on interviews with Water Corporation and major water users in the WTC. Figure 7-3 depicts the predicted total potential demand for MAR water in any given year, as given by the 'realised' supply shortfall in that year (Synergies, 2018).

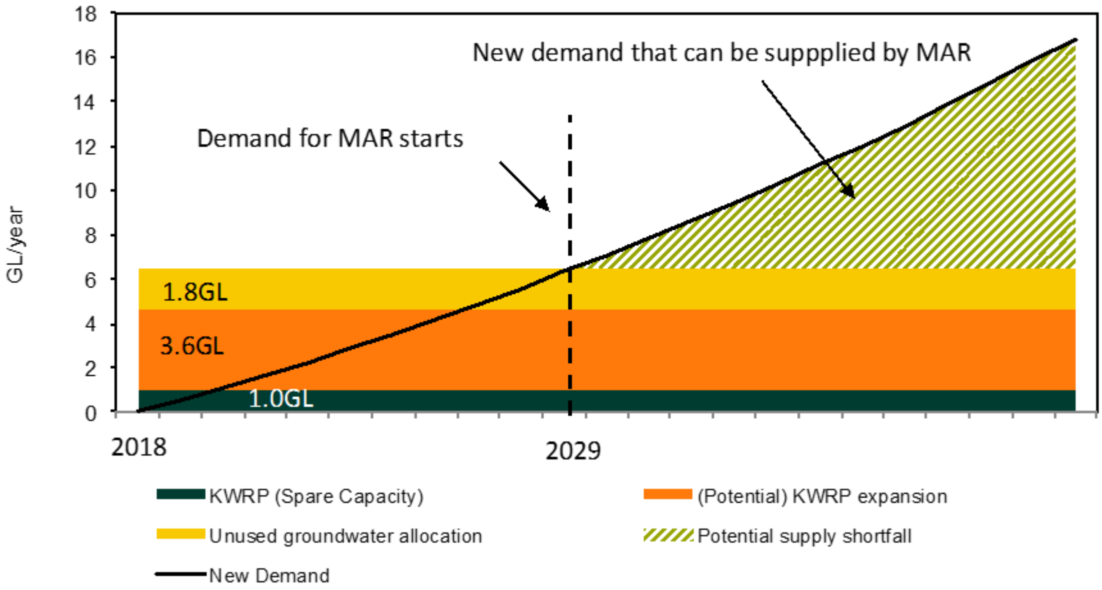


Figure 7-3 MAR demand relative to other supply sources (Synergies, 2018) [12]

[12] It is acknowledged that some customers may not be able to physically access KWRP water due to their geographic location within the WTC, or the cost of installing new reticulation infrastructure would be prohibitive. In practice, there could be scope for MAR to be developed ahead of all KWRP capacity being used. To the extent that this occurs, the financial returns to MAR would somewhat higher than what is estimated in this analysis (Synergies, 2018).

7.2.3 Criteria-based assessment

Prior to undertaking a detailed financial analysis of both sites, a criteria-based assessment determined that Site 2 is significantly more likely to provide a positive net financial return compared to Site 1 (Synergies, 2018). This conclusion is made as a result of the following factors:

- Site 2 can supply both the Valley and Wellard subareas whereas Site 1 can only supply Valley.
- Site 1 could supply the Thompson subarea, however no new industrial demand for that region is expected for the foreseeable future.
- Projected demand in proximity to Site 1 starts lower and grows slower than Site 2
- All demand events uncovered in interviews were only associated with Site 2, while three of the five supply events were associated with Site 1.
- Site 1 is also expected to be costlier to develop and will require a major modification in 2030. GHD estimates the total capital expenditure (including the 2030 modification) for developing Site 1 to be $28.0 million. Site 2 is expected to cost $17.3 million.

To this end, the financial analysis is focused on Site 2 only.

7.2.4 Net financial value

The financial viability of the MAR Scheme is measured by its Financial Net Present Value (FNPV), calculated as the sum of all discounted revenues minus the sum of all discounted costs. Synergies (2018) modelled FNPV as:

- A random (uniformly distributed) draw from the growth rates and a set of demand and supply events,
- The marginal revenue shown in Figure 7-2, and
- The capital and operating costs summarised in Section 5, based on commissioning in any year between 2020 and 2040.

Figure 7-4 shows the optimal start years as determined for 1000 iterations. In most cases the model predicts the optimal start date for Site 2 to be very likely to fall in 2022 or 2023. Commissioning after 2030 is only NPV maximising under very specific circumstances. In only 4% of runs the model predicted the project to be unviable.

Figure 7-5 further indicates the modelled FNPV based on 1000 model iterations for the identified optimal start dates, with values shown as the average of all FNPVs returned for that year (excluding any negative FNPVs [13]). The average value across all instances with a positive FNPV is $29.8 million (in 2018 terms).

[13] In this context cases with negative NPVs are irrelevant. Each model run can be interpreted as a separate business case and if it finds a negative NPV, it is assumed the project does not go ahead.

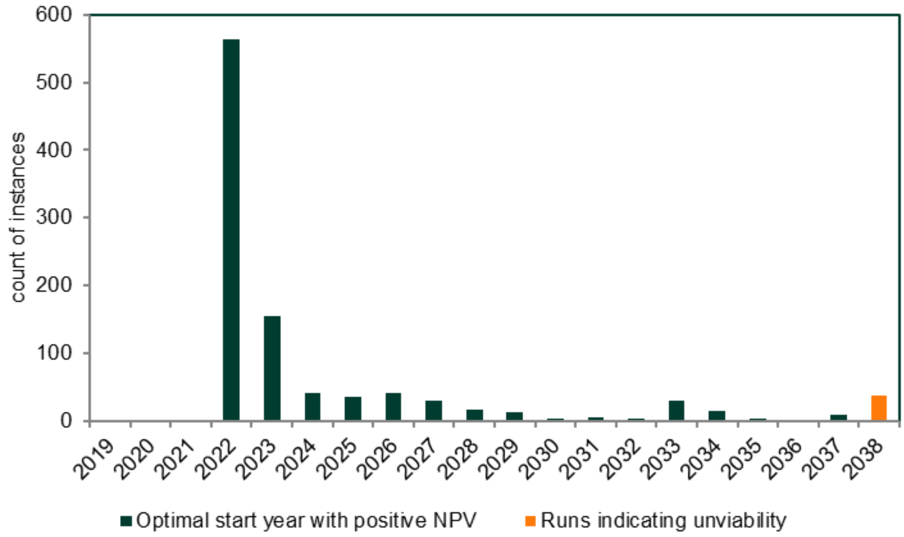


Figure 7-4 Site 2: optimal MAR scheme start years (Synergies, 2018)

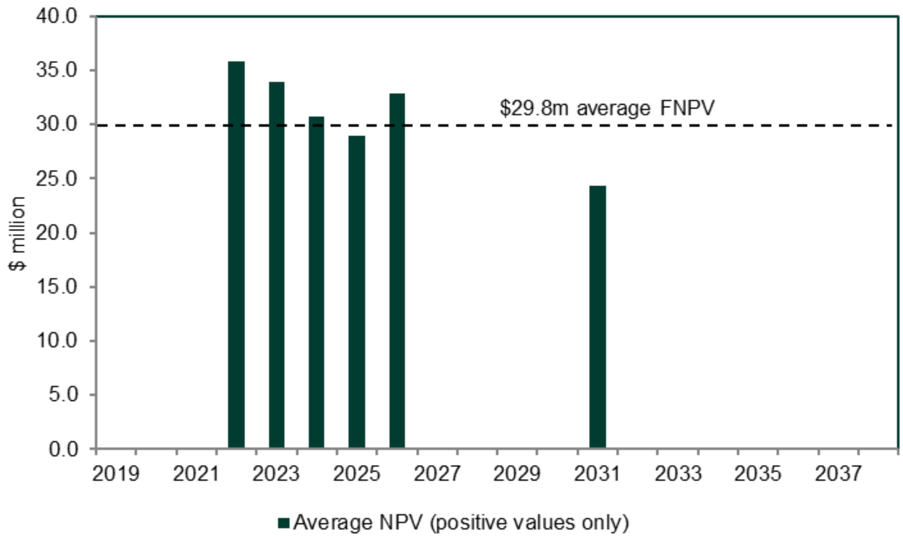


Figure 7-5 Site 2: average NPV by optimal commencement year, 2019 to 2038 (Synergies, 2018)

7.2.5 Sensitivity and economic analysis

Synergies (2018) note that the only difference between the economic analysis and financial analysis of the above sections is that the calculation of Marginal Economic Benefit excludes:

- TWW resource cost,
- Facilitation costs,
- Wastewater treatment and infrastructure upgrade costs, and
- Material environmental benefits [14] or costs.

[14] Noting that MAR schemes could be used to deliver environmental benefits, the analysis assumes that the MAR facility is built for commercial purposes and previous research did not assess the possibility of environmental side-benefits from a MAR scheme that sees all additional recharge offset by additional abstractions.

A sensitivity analysis was therefore undertaken of the financial and economic analyses where each key parameter was changed one at a time, and key results are shown in Table 7-2 and summarised below:

- MAR breaks-even, on average, at a potable scheme water price of $2.45/kL, and would not be viable if prices remained at today's price of $2.40/kL.
- If the scheme water price only rises to $3.00/kL over the study timeframe, the project still returns a positive NPV of $13.6 million.
- If the incentive discount is increased from 10% to 40%, expected NPV reduces to $15.3 million.
- If the wastewater input can be acquired at no cost, the NPV becomes $45.8 million.
- If the unit cost of MAR water treatment by customers can be reduced to $0.80/kL (down from $1.20/kL), expected NPV increases to $42.0 million. At a treatment cost of $0.50/kL, the NPV increases to $53.5 million.

Furthermore, a detailed analysis of demand risk indicates that risk faced by developers of the scheme during its start-up phase could be mitigated due to the magnitude of the expected demand events identified (Synergies, 2018). If the REU forecasts hold, filling the remaining capacity with demand from currently unknown customers will not be an issue, however the key outcomes noted is that the MAR scheme will be financially viable even without this demand. However, without the demand events, the project may face considerable risks.

Table 7-2 Summary of sensitivity analyses (Synergies, 2018)

Assumed parameter	Customer treatment cost ($/kL)	Price of scheme water ($/kL)	Expected NPV (Economic)	TWW resource cost ($/kL)	Incentive discount (%)	Expected NPV (Financial)
Base case			$46.1 million		10%	$29.8 million
Trade of all spare groundwater[a]	$1.20	$2.40 growing to $4.30	$40.4 million	$0.50	10%	$27.3 million
40% incentive discount			N/A		***40%***	$15.3 million
Alternative assumptions for cost of scheme water						
Fixed at $2.40/kL	$1.20	***$2.40 constant***	$5.1 million	$0.50	10%	N/A – never viable
Growing to $3.00/kL	$1.20	***$2.40 growing to $3.00***	$28.8 million	$0.50	10%	$13.6 million
Growing to $3.50/kL	$1.20	***$2.40 growing to $3.50***	$36.5 million	$0.50	10%	$21.6 million

Assumed parameter	Customer treatment cost ($/kL)	Price of scheme water ($/kL)	Expected NPV (Economic)	TWW resource cost ($/kL)	Incentive discount (%)	Expected NPV (Financial)
No charge for wastewater input	$1.20	$2.40 growing to $4.30	N/A	***$0.00***	10%	$45.8 million
Customer treatment cost						
Medium RO facility	***$1.20***	$2.40 growing to $4.30	$46.1 million	$0.50	10%	$31.2 million
Large RO facility	***$0.80***		$57.2 million	$0.50	10%	$42.0 million
Other treatment	***$0.50***		$64.1 million	$0.50	10%	$53.5 million
Scheme water price at which economic NPV ~ 0 (Break Even Point)	$1.20	$1.82 constant	~$0.1 million	N/A	N/A	N/A

Notes:

Presented results are based on 50 iterations and measured in 2018 terms. Bold and italicised values represent tested variables. Blue cells represent key results.

(a) Sets the probability of trade of unused allocations (after allowing for recouping of unused entitlements) at 100%.

7.3 Commercial analysis

7.3.1 Considerations in development of MAR scheme

Risks

A summary of the key commercial risks to be assigned and managed are provided in Table 7-3 below. Further details of these risks is provided in Synergies (2018) report (refer Appendix C).

Table 7-3 Risk summary (Synergies, 2018)

Risk type	Risk definition	Control
Demand risk	Demand for product is less than forecast. Demand likely to occur in step-changes due to small number of large water requirements for industrial requirements.	Incorporated in financial and economic modelling (Section 7.2.5). Little to no control over this risk.
Competition risk	Potential competition from other water supply options.	Incorporated in financial and economic modelling (Section 7.2.4). MAR scheme operator could be a MAR water user.
Regulatory risk	State Government has significant discretion over licencing of MAR water, and may create additional procedural, institutional or legislative changes that may limit demand.	Long-term investments from MAR scheme proponent. Long-term customer commitments.
Feedstock risk	TWW supply is interrupted or withdrawn resulting in loss of revenue, contractual damages, and fines for failure to comply with licence obligations.	Contractual assurances and indemnities from Water Corporation (incorporated in financial modelling). Water Corporation could act as MAR service provider.
Construction and engineering risk	MAR facilities: Are more expensive than expected (CAPEX & OPEX) resulting in limited demand. Underperform with respect to water quality and/or quantity resulting in restrictions to infiltration and/or abstraction.	-
Operational risk	Complex interactions between broader water infrastructure leading to commercial risk to MAR operator e.g. Water Corporation may temporarily not permit discharges to SDOOL. Potential deferral of capacity upgrades to SDOOL.	Water Corporation could act as MAR service provider.
Other risks (not assessed)	Hydrological risks (water losses in aquifer greater than assumed). Production risks (equipment failure). Environmental risks (new restrictions on MAR or new treatment requirements).	-

Contractual arrangements and pricing

An assessment of long term versus short term contractual arrangements found that the MAR Scheme operator will strongly prefer long-term contracts covering the majority of its MAR production capacity, while customers, at least initially, may prefer a lower level of commitment. Unless there are other drivers for MAR, for instance reputation enhancement, this mismatch could see the development of a MAR scheme deferred for some time.

A number of potential pricing strategies have been explored to generate the required revenue for a viable scheme, including for example, charging a temporary operating contribution from MAR customers or an ongoing customer tariff. These strategies are detailed as part of the Synergies report (Synergies, 2018).

7.3.2 Service models

The following commercial arrangements for structuring a MAR scheme have been assessed:

- The Water Corporation owns and operates the scheme and establishes supply contracts with licensed MAR customers in the WTC.
- A private, independent water utility (IWU) owns and operates the scheme and establishes supply contracts with licensed MAR customers in the WTC.
- A joint venture (JV) of major water users in the WTC develops, owns and operates the MAR scheme and grants the members of the JV rights to water under that scheme.

It is noted that additional service models may also be possible.

The three service models considered present different trade-offs and issues that should be managed and understood, as summarised in Table 7-4. Additional detail and advice with regards to these service models is provided in Synergies report (Synergies, 2018).

Table 7-4 Overview of service provision options (Synergies, 2018)

Criteria	Model 1 Water Corporation		Model 2 IWU		Model 3 JV	
Complexity of governance arrangements	✓ moderate	Single organisation assuming responsibility for decisions and implementation.	✓ simplest	Single organisation assuming responsibility for decisions and implementation.	✓ highest	Sophisticated negotiations and legal execution, consensus across multiple parties regarding risk, control and rewards.
Capacity to bear and manage risk	✓ moderate	Manage demand and competition risks through (long-term) bilateral contracts. Potentially better at managing regulatory risks as it is Government owned.	✓ lowest	Manage demand and competition risks through (long-term) bilateral contracts. Susceptible to regulatory risks.	✓ highest	Directly manage demand and competition risk. Likely higher financial flexibility to bear risks. Susceptible to regulatory risks.
Whether regulatory changes could be required for successful implementation	✓ few issues	Unrestricted access to TWW.	✓ manageable issues	Reliant on Water Corporation supply of TWW on "reasonable terms". May require regularisation of permitting and control of water quality for MAR purposes.	✓ manageable issues	Reliant on Water Corporation supply of TWW on "reasonable terms". May require regularisation of permitting and control of water quality for MAR purposes.
Local or interstate precedents	✓ proven	Numerous MAR Schemes established across Australia under statutory water service providers.	✓ unproven	-	✓ unproven	-

Criteria	Model 1 Water Corporation		Model 2 IWU		Model 3 JV	
Suitability for supply of incumbents compared to new customers	✓ straightforward	Same as IWU, though may be directed to take greater demand risk to meet state development objectives.	✓ straightforward	Commercially driven to maximise new business, though may reduce demand risk through supplying majority of MAR to incumbents.	✓ favours incumbents	JV could refuse to supply MAR water to new businesses. This risk (unlikely) may be managed through its Water Services Licence.
Impacts on State budget and public risk burden	✓ direct impact	Affects net operating balance, net worth and net debt of the Total Public Sector. Imposes risks, such as asset stranding, on Western Australian public.	✓ no direct impact		✓ no direct impact	
Alignment with service preferences of major customers	✓ less control	Interviews with large water users suggest degree of impatience with longer lead times perceived to be required by Water Corporation.	✓ less control	As per Water Corporation.	✓ customer controlled	Customers have greater control over services.

8. Conclusions

8.1 Environmental considerations

A number of key environmental hazards were identified, and a maximal and pre-commissioning risk assessment of these hazards for both sites found the majority to have a low risk rating, with some exceptions as outlined below, which were found to have moderate, high or very high risk ratings. While the residual risk assessment for these hazards could be reduced to low to moderate, there still remains concern regarding certain aspects:

- **Turbidity and particulates** – Over time clogging (physical and/or biological) will occur in the infiltration basins/galleries at each site, even with the proposed pre-filtration. It will be important to establish influent (TWW/pre-treated TWW) water quality targets to minimise clogging processes (removal of TSS and nutrients) as remediation of clogging in a buried infiltration gallery will be more difficult than for an open infiltration basin. This risk will also need to be managed through monitoring and periodic maintenance (basins: maintenance to remove and dispose of fine solids/biological matter from the basin floor, nominally every 2 months) or major renovation (galleries: remove galleries, remove and dispose of underlying fine solids/biological matter, reconstruct galleries, nominally every 5 to 10 years).
- **Pathogens** – Validation monitoring is required to determine concentrations following filtration and to ensure aquifer residence times are sufficient to remove bacteria, protozoa and viruses.
- **Nitrogen** – Nitrogen removal potential of the aquifer (i.e. through denitrification) is still to be verified at the two potential MAR sites. However the long residence time in the aquifer suggests that should denitrification be occurring the risk to Cockburn Sound will be low especially with additional abstraction in the MAR plume zone. The impacts on wetlands at Site 2 is uncertain due to the lack of water quality data available. Given that the closest wetland is within a golf course it is likely that the wetland is already impacted by nitrogen.
- **Contaminant migration in Tamala Limestone aquifer** – Hydrogeology of the Tamala Limestone aquifer indicates that conduit flow is unlikely, resulting in a low residual risk, however validation is required to confirm this.
- **Groundwater dependent ecosystems** – Very little is known about the current ecosystem health, water regimes and water quality in wetlands potentially impacted by MAR at the proposed sites, especially for Site 2. Additional wetland assessments and monitoring is required to determine these baseline values and conditions before MAR impacts can be fully assessed.
- **Mobilisation of pollutants from a nearby contaminated site** – The infiltration of large volumes of water through MAR will alter local groundwater flow patterns. In an area so heavily industrialised as the WTC which has a high density of contaminated sites, it is likely that groundwater contaminant plumes would be altered. However due to a lack of publicly available information on specifics of contaminants and their distribution in the aquifer, it is not possible to determine the implications of MAR with respect to alteration of contaminant plume behaviour. Also the impacts may not always be negative, for example the delivery of electron acceptors (e.g. nitrate) to a hydrocarbon plume may result in increased biodegradation.

Furthermore, the assessment of the following risks are incomplete and require further investigation prior to scheme development:

- **Organic chemicals** – There is insufficient information regarding the TWW concentrations and the environmental persistence and impact of trace organic chemicals in groundwater. Due to the wide range and large number of trace organic chemicals the potential risks may alter in the future as new information on TWW constituents arises. Additional monitoring of TWW and groundwater is required to validate both the hazard and the potential risk to the environment.
- **Inundation due to groundwater table rise** – Preliminary groundwater modelling indicates inundation could occur near Site 1, however the model appears inaccurate in this area and requires further validation and ground-truthing.

8.2 Engineering considerations

The following project assumptions have been adopted in the development of the engineering design for Site 1 and 2. These assumptions will need to be checked and confirmed during the next stage of design development:

- General:
  - Under the MAR *Operational Policy* (DoW, 2011) and the DoH Guidelines (DoH, 2015), it is a requirement to prepare a risk assessment and Recycled Water Quality Management Plan (RWQMP) to gain approval for the scheme which will include a health and environmental risk assessment. For this level of design, it has been assumed the scheme would be classified as **medium risk**. Completion of the full four-stage risk assessment in accordance with the *Australian Guidelines for Water Recycling* (NRMMC, EPHC, NHMRC, 2009) will be required in subsequent stages of design to confirm this assumption (refer to Section 6.1).
- Infiltration site location (Site 2 only):
  - Additional work will need to be completed to confirm that the clearing required to develop Site 2 site will be allowed given that it is a Bush Forever site. If significant portions of Site 2 are unable to be cleared and developed based on environmental constraints, additional land could be sought, or lower capacity infiltration galleries could be installed to minimise the footprint required for the recharge works.
  - The MAR pre-treatment site is owned by LandCorp and support has been gained from LandCorp to include the identified option within this report. The inclusion is conditional on LandCorp retaining the right to negotiate site selection and commercial terms for lease or sale of the land with any future investor/operator of the MAR facility. Further consideration to potential future expansion of the pre-treatment facility to allow recycled water to be distributed to multiple recharge sites is also required.
- Pre-treatment facility:
  - It has been assumed that East Rockingham WWTP will remain a conventional oxidation ditch type plant for the foreseeable future.
  - It has been assumed that the filter backwash from the Site 2 pre-treatment facility will be injected into the East Rockingham WWTP FEPS discharge manifold. This is to be confirmed and agreed with Water Corporation.

- Offtake and conveyance:
  - It has been assumed that the conveyance pipes and appurtenances shall be designed in accordance with relevant Water Corporation standards due to the connection into existing Water Corporation assets. This assumption is to be confirmed during the next design phase.

8.3 Financial viability

A MAR scheme at Site 2 appears financially viable and has the potential to deliver large financial returns if REU growth scenarios are realised (FNPV ~$30 million). The project could be almost riskless if demand events are considered (i.e. several major users switching from scheme water to MAR, and several proceeding with expansion plans), but it faces considerable risk without them. The project can be viable even if zero underlying growth is assumed, but the service provider would need to secure the event demand (i.e. obtain contractual commitments with the identified user(s) that they will switch from scheme water to MAR) before being confident of proceeding.

A financial analysis of Site 1 has not been undertaken given that it is more costly and located in an area where significant demand growth is not expected.

8.4 Commercial considerations and service models

A MAR scheme in the WTC faces several significant risks that would need to be managed, including supply and demand, competition, regulatory, design, construction and operational risks. Different service models will have varying exposures and mitigations to these risks.

A Water Corporation service model whereby Water Corporation owns and operates the scheme and establishes supply contracts with licensed MAR customers in the WTC provides the following key considerations:

- Some complexity in governance but relatively little risk in implementation and operation.
- Avoids issues concerning potential discriminatory access to MAR water.
- Increases the debt burden on Government and may expose the public to asset stranding risks.

A private IWU could own and operate the scheme and establish supply contracts with licensed MAR customers in the WTC. Key considerations for this approach include:

- Requirement to secure commercial agreements with Water Corporation to access TWW and (potentially) discharge wastewater from tertiary treatment facilities to the SDOOL.
- Provides a simple model at arms' length from Government that leaves customers to negotiate the services they require.
- Potentially large demand risks may mean investment is deferred longer, pending highly favourable expected return.
- No impact on State finances.
- Greater exposure to regulatory risks than the Water Corporation model.

A JV of major water users in the WTC could develop, own and operate the MAR scheme and grant the members of the JV rights to water under that scheme. Key considerations for this approach include:

- Requirement to secure commercial agreements with Water Corporation to access TWW and (potentially) discharge wastewater from tertiary treatment facilities to the SDOOL.
- Relatively complex initial multi-party negotiations to secure JV agreement.
- Customers retain demand and competition risk which is the optimal allocation.
- Greater exposure to regulatory risks than the Water Corporation model.
- Introduces potential risk of discrimination between customers in providing access to water.
- No impact on State finances.

The most important risk mitigation for any operator will be to secure foundation contracts with existing water users that reduce demand and competition risks. It will also be important to ensure that operator rights are well protected by the regulatory regime and that suitable contractual commitments are secured regarding the supply of TWW (Synergies, 2018).

The requirements of a MAR scheme operator for long-term contractual commitments is likely to conflict with customers' preference for flexibility. However, there is sufficient reason to expect that a MAR scheme will offer some users a compelling product (e.g. avoiding the cost of increasingly expensive scheme water or offering environmental reputational benefits). To this end, it seems reasonable to expect that the MAR scheme operator and customers would negotiate mutually satisfactory arrangements, though it may take several years before users are willing to commit (Synergies, 2018).

9. Next steps

9.1 Knowledge gaps and further investigations

9.1.1 Site 1

The further work required to confirm the project assumptions or to close out the project gaps is summarised in Table 9-1 below.

Table 9-1 Site 1 terms of reference summary

Gap/assumption/constraint	Stakeholder(s) involved	Required work
Medium risk operation under the AGWR	Project proponent, DWER and DoH	Completion of the full risk assessment in accordance with the *Australian Guidelines for Water Recycling* will be required in subsequent stages of design.
Organic chemicals and metals	CSIRO / DWER / Project proponent	Further analysis of metals and organic chemicals in groundwater and aquifer sediments associated with Site 2.
Wetland condition and groundwater-surface water interactions	CSIRO / DWER / Project proponent	Complete baseline assessments of nearby wetlands condition/health, and investigate groundwater-surface water interactions to refine groundwater model.
Exempt use bores	CSIRO / DWER / Project proponent	Survey of businesses and residences near the MAR site to confirm presence / absence of exempt use or non-licenced bore locations.
Industrial demand for water of differing quality	Project proponent, Kwinana Industries Council	Further investigation as to whether industrial users would incur additional on-site costs of treating MAR water prior to use.
Design standards adopted for offtake and conveyance infrastructure	Water Corporation Project proponent	Confirmation of preferred standards prior to detailed design.
Salinity levels at the future Woodman Point AWRP	Water Corporation	Confirmation of timing of AWRP and design salinity levels.
Biofouling approach at the Site 1 reverse osmosis system	Project proponent DWER	Further assessment of the appropriate biocide to adopt for biofouling to minimise any environmental harm.
Disposal of pre-treatment residuals to SDOOL	Water Corporation	Confirmation of water quality acceptance limits and access arrangements.
Impacts raised groundwater levels may have on FRCAH	CSIRO MRWA Project proponent	Further refinement of estimated groundwater level rise as a result of MAR.
FRCAH timing and alignment	MRWA Department of Transport	Confirmation of any relocation to SDOOL as a result of FRCAH and/or installed MAR offtake and conveyance infrastructure. Agreement of construction methodology for new MAR conveyance infrastructure under the future FRCAH.

Gap/assumption/constraint	Stakeholder(s) involved	Required work
Ultimate site access	MRWA Department of Transport Public Transport Authority and Arc Infrastructure City of Kwinana Utility / Service Providers	Investigation and confirmation of the location for the ultimate site access once FRCAH is constructed.
Required fill to achieve the finished infiltration basin surface levels	LandCorp Project proponent	Investigation and understanding into the future quarry operations ultimate depth. Assessment of potential fill sources and suitability to achieve the required infiltration rates.
Design infiltration rate	Project proponent Water Corporation	Investigation to quantify actual infiltration rates achieved at Kwinana WWTP's infiltration basins. Confirm appropriate design infiltration rate that can be used for sizing of infiltration basins installed as part of this project.

9.1.2 Site 2

The further work required to confirm the project assumptions or to close out the project gaps is summarised in Table 9-2 below.

Table 9-2 Site 2 terms of reference summary

Gap/assumption/constraint	Stakeholder(s) involved	Required work
Medium risk operation under the AGWR	DWER and DoH	Completion of the full risk assessment in accordance with the *Australian Guidelines for Water Recycling* will be required in subsequent stages of design.
Organic chemicals and metals	CSIRO / DWER / Project proponent	Further analysis of metals and organic chemicals in groundwater and aquifer sediments associated with Site 2.
Wetland condition and groundwater-surface water interactions	CSIRO / DWER / Project proponent	Complete baseline assessments of nearby wetlands condition/health, and investigate groundwater-surface water interactions to refine groundwater model.
Exempt use bores	CSIRO / DWER / Project proponent	Survey of businesses and residences near the MAR site to confirm presence / absence of exempt use or non-licenced bore locations.
Infiltration site location	Project proponent/ DWER	Confirm that the clearing required to develop this Bush Forever site will be allowed (refer Section 9.4 and Appendix F of the engineering report (Appendix A)). Review infiltration system requirements (additional land or

Gap/assumption/constraint	Stakeholder(s) involved	Required work
		modified infiltration approach) if clearing is not permitted.
Design standards adopted for the offtake and conveyance infrastructure	Water Corporation / project proponent	Confirmation of preferred standards prior to detailed design.
Pre-treatment site location	LandCorp / project proponent	Further discussions and negotiations are required with LandCorp regarding the site selection and commercial terms for lease or sale of the land with any future investor/operator of the managed aquifer recharge facility. Further consideration to potential future expansion of the pre-treatment facility to allow recycled water to be distributed to multiple recharge sites is also required.
East Rockingham WWTP: • no process change • space available for pre-treatment • pre-treatment backwash returned to the WWTP	Water Corporation and proponent	Future designs to consider the future TWW supply arrangement required at the time of: a) Water Corporation utilise all available bays within the existing temporary FEPS; b) Water Corporation construct new final effluent balance storage tanks and permanent FEPS; and c) potential for a smaller capacity initial stage scheme involve pumping TWW from East Rockingham WWTP (without further treatment) to infiltration basins located at Site 2. Commercial negotiations with Water Corporation regarding the MAR pump station and pipeline on their site. Confirmation of timing and volume of flow increases to ER WWTP.
Pipeline conveyance route	Landowners/ project proponent	Complete additional investigations and consultation to confirm the viability of the proposed recycled water pipeline route.
Pipeline crossings at Mandurah Road, Dampier Bunbury Natural Gas pipeline and rail crossings	Asset owners	Confirmation of design standards, approvals and construction methodology at detailed design phase.
Design infiltration rate	Project proponent Water Corporation	Investigation to quantify actual infiltration rates attainable from infiltration galleries at this site (over the long term).

9.2 Design development

Upon confirmation of the aforementioned gaps and further investigations, the next design phase will need to encompass the following items when the final site(s) and alignments are confirmed:

- Complete level and feature surveys (including underground service location where required).
- Complete geotechnical/ASS investigations for all proposed infrastructure including pipelines.
- Complete detailed design and prepare tender documentation for proposed conveyance and recharge infrastructure.
- Develop reference design for tertiary treatment facilities and prepare performance-based design/construct tender and documentation for these facilities.
- Refine CAPEX and OPEX estimates for the project.
- Complete constructability/operability/safety in design reviews for the proposed SDOOL offtake arrangement with the Water Corporation.

9.3 Stage 3 risk assessment

It is further noted that upon construction and commissioning of the scheme, the preventative measures applied will need to be assessed in alignment with Stage 3 of the MAR guidelines (NRMMC, EPHC, NHMRC, 2009), which will involve refinement of the groundwater monitoring program (Section 4.4) and a monitoring plan for the nearby wetlands in order to:

- Assess pathogen, nitrogen, and organic chemicals removal in groundwater,
- Assess potential metal release from aquifer sediments,
- Assess potentially affected GDEs (wetlands), and
- Validate the groundwater and solute transport model and monitor and assess groundwater level rise.

9.4 Approvals

Figure 9-1 summarises the approval flow required to implement the MAR scheme(s), and further detail of these requirements are provided as Appendix D, including the relevant agency, application requirements, approximate timeframes involved as well as the potential issues that may need to be resolved, most of which have been discussed in Section 9.1. These approval requirements are an outcome of a regulatory workshop between the stakeholders referred held on 31 July 2018 and facilitated by DJTSI.

The following key points are noted with respect to Figure 9-1:

- The required approvals and pathway should be confirmed through early consultation with the relevant agencies at the time that a MAR scheme is proposed to be developed.
- The required approvals and pathway apply to both sites with the exception of an *Environmental Protection Act 1986* Part IV referral to the WA Environmental Protection Authority (EPA) and an *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* referral to the federal Department of Environment and Energy (DoEE), which is likely to only be required for Site 2.
- While some approvals are shown in sequential manner, it is expected that many applications can be progressed concurrently, including:

  - The environmental referrals to the EPA and Federal DoEE if required for Site 2,
  - The application under Part V, which can be progressed concurrently with EPA's assessment under Part IV, but cannot be issued until the EPA has concluded the process under Part IV, and
  - The application for development approval to the City of Kwinana and the Western Australian Planning Commission (WAPC) can be progressed concurrently with the Part V application, however the DWER cannot issue a works approval until the Joint Development Assessment Panel (JDAP), under the recommendation of the City and WAPC, has determined the development application.
- Access to land tenure through leases, easements and licences will be required prior to seeking approvals. This includes pipeline and other conveyance infrastructure installations:
  - Within the RIZ infrastructure corridors (LandCorp and DJTSI),
  - Adjacent to local and State roads (City of Kwinana, Department of Transport, MRWA, Department of Transport), rail crossings Public Transport Authority, Arc Infrastructure) and services and utilities (water, power, gas providers), and
  - Sub-lease for MAR infrastructure installations at Site 2 (WAPC, Department of Planning, Lands and Heritage (DPLH), City of Kwinana and current Lessee).
- It is expected that approvals and access to land tenure will be sought following further consultation with local and state agency stakeholders and landowners.

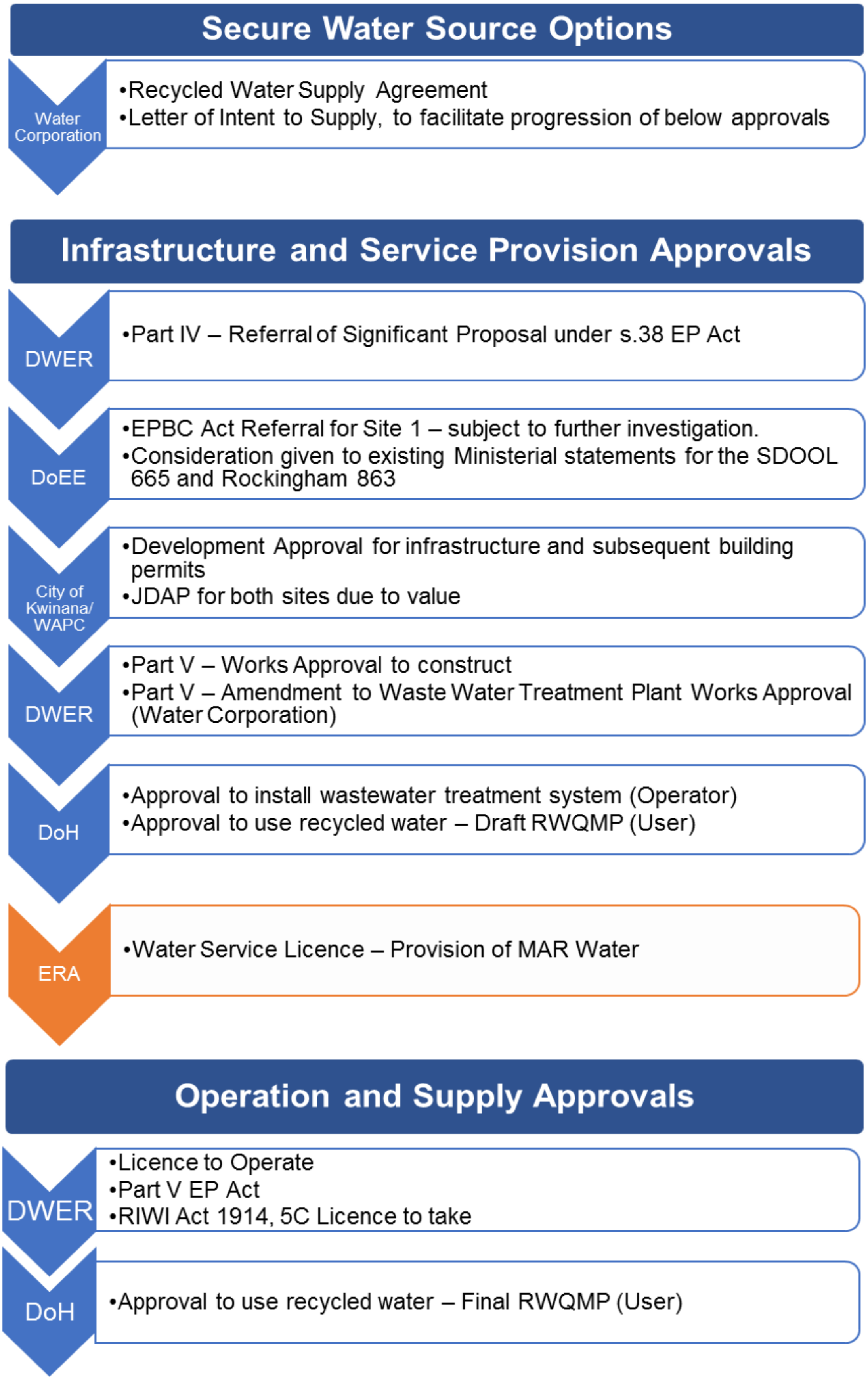


Figure 9-1 Approvals flow diagram (DJTSI, 2018)

9.5 Government involvement

9.5.1 Clarify objectives of further Government involvement

As the WTC continues to develop and the demand for water from industry increases, a MAR scheme servicing the WTC is considered potentially desirable to supplement the region's water supply options. To this end, the Government may consider identifying and removing potential barriers to development of a MAR scheme by private entities as a priority objective (Synergies, 2018).

9.5.2 Access to treated wastewater

There appears to be a continuing surplus of potential TWW which Water Corporation can provide from a strong position given its monopoly over this supply. As well as being a cost barrier, this also gives Water Corporation a competitive advantage in becoming the project proponent compared to an IWU. This may therefore require policy attention from State Government if it wishes to encourage private sector competition. The principles in the Economic Regulation Authority's (ERA) 2009 inquiry into pricing of recycled water provide a good starting basis, but further work is likely needed to operationalise these principles (Synergies, 2018).

9.5.3 Confirm that regulatory framework offers sufficiently clear and stable rights for MAR Scheme operators

No issues have been identified with the existing regulatory framework relating to operation of a MAR scheme. However, DWER's current MAR Policy does grant DWER considerable discretion over the granting of water rights and the structure of each MAR scheme. The Government could consider developing more detailed policies to provide the necessary regulatory certainty to a MAR scheme operator to ensure a secure investment can be made (Synergies, 2018).

9.5.4 Site 2 availability

Site 2 is currently vested with a management order to the City of Kwinana. The site has apparent value as the location of a MAR facility, but may also be suitable for other competing uses (Synergies, 2018).

9.6 Commercial considerations

Should Site 1 be considered a preferable alternative to Site 2 by a potential scheme proponent, the financial viability of Site 1 should be assessed in similar detail to that of Site 2.

Regardless, four potential customers expressed interest in substituting their current scheme water usage with an alternative source, which has the potential to utilise up to 76% of the MAR facility's capacity and make it commercially viable. These four parties could be made the facility's foundation customers to minimise risk of project development from a commercial perspective. Modelling indicates that the operator should have scope to offer supply for these foundation customers at a significant discount to scheme water, providing them with a commercial incentive to enter into long term contracts (Synergies, 2018).

In practice, it is expected that a proponent would likely build its business case around identified tranches of demand for which it believed it could secure foundation contracts. The proponent may then build some capacity in addition to the level required to meet the foundation demand as a calculated risk that there will be reasonably strong underlying demand growth, from which the service provider could earn additional returns. Thus, the proponent might intend to offer subsequent customers lower discounts relative to scheme water than it negotiates with its foundation customers (Synergies, 2018).

9.7 Service models

9.7.1 Water Corporation

The Water Corporation could establish and operate the MAR Scheme. It is an existing water service provider that has already demonstrated:

- The engineering and financial capacity to fund, build and operate a MAR facility, and
- The commercial capacity to enter into and manage contracts to deliver recycled water.

The Water Corporation could commit to a MAR facility without needing to enter into separate contracts to ensure continued access to the TWW source.

Under the *Water Corporation Act 1995*, the Water Corporation has a duty to evaluate, fund and market the MAR scheme in accordance with prudent commercial principles, unless directed otherwise by the Minister under the Act.

9.7.2 IWU

An IWU could establish and operate the MAR Scheme. This could be any company with the engineering, financial and commercial capacity to develop and operate the MAR Scheme. An IWU could only develop a MAR scheme if the Water Corporation provides a long-term TWW supply commitment to the IWU on viable terms, hence negotiations with Water Corporation would be one of the first key steps for an IWU to establish the scheme.

9.7.3 JV

A JV between water users in the region could establish and operate the MAR Scheme. The JV could comprise any number of water users although for practical reasons it would most likely comprise a small number of large users. The members of the JV would fund and/or underwrite the facility and the legal, regulatory and commercial costs in return for the right to abstract a proportion of the MAR water and, potentially, a share of future commercial opportunities. The JV might size the facility to produce more water than required for the JV members, with the intention of profiting from the sale of surplus MAR water to other users in the region.

A JV could only develop the scheme if Water Corporation provides a long-term TWW supply commitment on viable terms, and this should therefore be one of the first steps of negotiations once the JV is established.

10. References

Betancourt, W. Q. et al., 2014. Assessment of virus removal by managed aquifer recharge at three full-scale operations. *Journal of Environmental Science and Health,* Part A 49(14), pp. 1685-1692.

Biswas, W. K., 2009. Life cycle assessment of seawater desalinization in Western Australia. *World Academy of Science, Engineering and Technology,* Volume 56, pp. 369-375.

Castilla, J. C., Donn, M. J. & Charles, S. P., 2018. *Western Trade Coast Hydrological Model - Conceptual Model Report. Western Trade Coast managed aquifer recharge of treated wastewater for industrial water supply - Feasibility study. Milestone update to National Water Infrastructure Development Fund.,* Perth, Australia: CSIRO.

Cornejo, P. K. et al., 2014. Carbon footprint of water reuse and desalination: a review of greenhose gas emissions and estimation tools. *Journal of Water Reuse and Desalination,* pp. 4(4), 239-252. DOI: 10.2166/wrd.2014.058.

Cui, T. & Donn, M. J., 2019. *Calibration and scenario modelling of the WTC groundwater model. Western Trade Coast managed aquifer recharge of treated wastewater for industrial water supply - Feasibility study,* Australia: CSIRO.

Davidson, W. A. & Yu, X., 2008. *Perth regional aquifer modelling system (PRAMS) model development: Hydrogeology and groundwater modelling,* Perth, Western Australia: Department of Water.

Department of Water and Environmental Regulation, 2018. *Water Information Reporting.* [Online] Available at: http://www.water.wa.gov.au/maps-and-data/monitoring/water-information-reporting

DJTSI, 2018. *Assessment of regulatory and licensing requirements.* Perth, Western Australia: Department of Jobs, Tourism, Science and Innovation.

DoH, 2009. *Characterising treated wastewater for drinking purposes following reverse osmosis treatment,* Perth, Western Australia: Department of Health.

DoH, 2015. *Guidelines for the Non-potable Uses of Recycled Water in Western Australia,* Perth: Department of Health.

Donn, M. J., Page, D. W. & Vanderzalm, J. L., 2017. *Treated wastewater disposal via infiltration environmental research project: Final report (Commercial-in-confidence).,* Australia: CSIRO.

Donn, M. J., Vanderzalm, J. L. & Cui, T., 2019. *Western Trade Coast Managed Aquifer Recharge - Risk Assessment,* Perth: CSIRO.

DoW, 2010. *Hydrogeochemical assessment of the Superficial aquifer: Perth metropolitan area,* Perth: Department of Water.

DoW, 2011. *Operational policy 1.01 - Managed aquifer recharge in Western Australia,* Perth: Department of Water.

DoW, 2016. *Western Trade Coast heavy industry local water supply strategy, Securing Western Australia's water future,* Perth: Department of Water.

DPaW, 2013. *Geomorphic Wetlands Swan Coastal Plain. ,* Perth, Western Australia: Department of Parks and Wildlife.

DPLH, 2018. *Kwinana Industrial Area Overview Map.* Perth: Department of Planning, Lands, and Heritage.

DS Group, 2018. *Flatbed Leach Drain.* [Online]
Available at: https://www.ds.com.au/flatbed-leach-drain/
[Accessed 16 10 2018].

DWER, 2018. *Cockburn groundwater allocation plan - for public comment. Water Resource Allocation and Planning Report Series. Report No. 60.,* Perth, Western Australia: Department of Water and Environmental Regulation.

Economic Regulation Authority, 2017. *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report, page 105,* Perth: s.n.

GHD, 2018. *Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study,* Perth: a report prepared for DJTSI.

GHD, June 2017. *WTC MAR Scheme - Engineering Design & Costing Study: Report on Assessment of Selected MAR Sites (WP1),* Perth: a report to the Department of State Development (now Department of Jobs, Tourism, Science and Innovation.

Greenwood, J., Keesing, J. K., Donn, M. J. & McFarlane, D. J., 2016. *Nitrogen budget for Cockburn Sound, Western Australia,* Perth, Western Australia: Report to the Cockburn Sound Management Council and the Western Australian Department of Water. CSIRO.

McFarlane, DJ (ed), 2015. *Recycled water for heavy industry and preventing sea water intrusion,* Brisbane: A report to the Australian Water Recycling Centre of Excellence and industry partners from the CSIRO Land and Water Flagship.

NRMMC, EPHC, NHMRC, 2006. *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1),* Canberra: National Resource Management Ministerial Council, Environmental Protection and Heritage Council, National Health and Medical Research Council.

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

Rawlinsons , 2017. *Australian Construction Handbook Editition 35,* Perth: Rawlinsons Publishing.

REU, 2014. *Local economic growth projections for the Western Trade Coast to 2031,* Perth: a report for Department of Water.

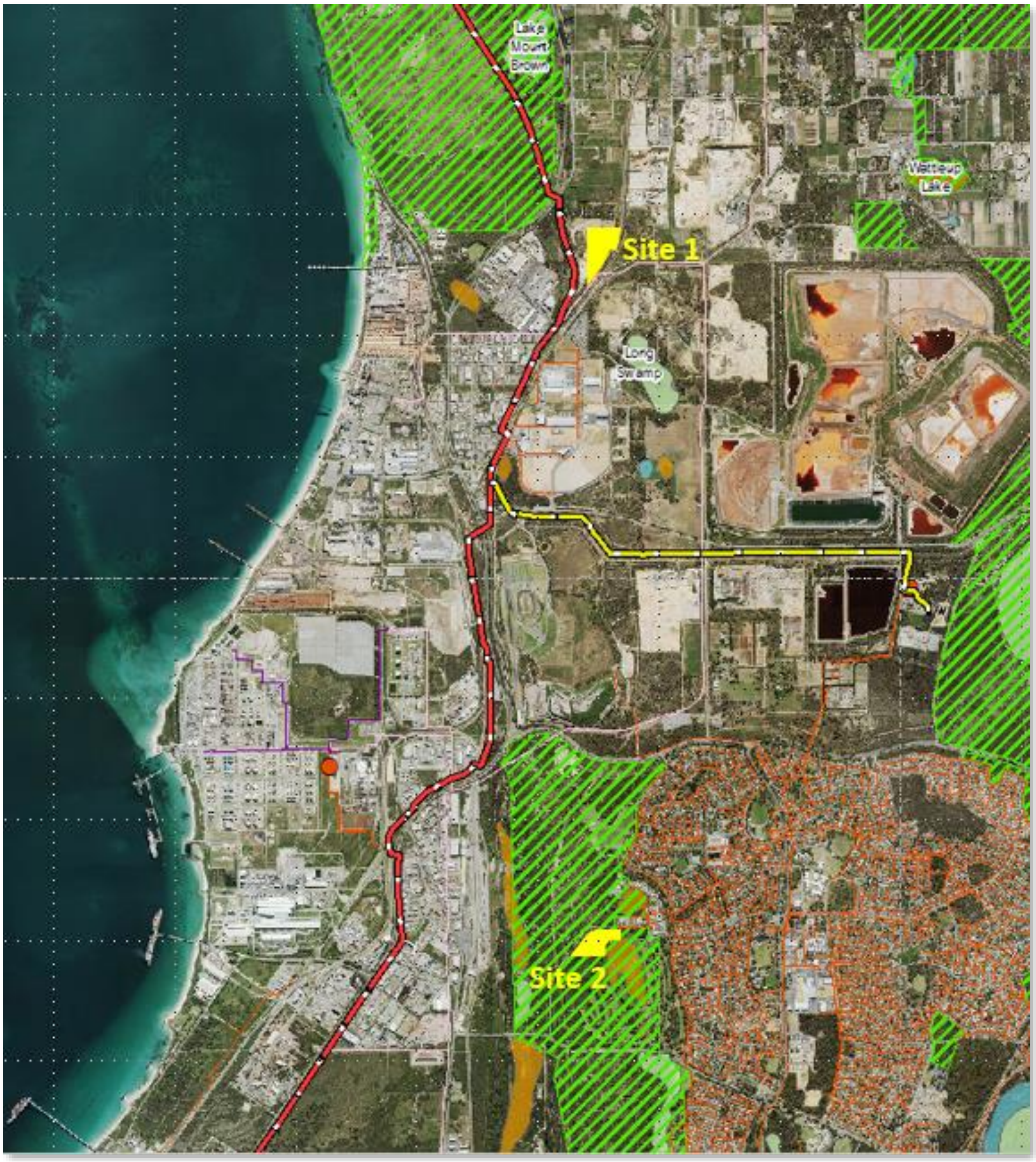
Shaheen, S. M., Tsadilas, C. D. & Rinklebe, J., 2013. A review of the distribution coefficients of trace elements in soils: Influence of sorption system, element characteristics, and soil colloidal properties.. *Advances in Colloid and Interface Science,* December, Volume 201-202, pp. 43-56.

Simms, A., Hamilton, S. & Biswas, W. K., 2017. Carbon footprint assessment of Western Australian Groundwater Recycling Scheme. *Environmental Management ,* 59(4), pp. 557-570.

Synergies, 2018. *Commercial Feasibility Assessment: Managed Aquifer REcharge of Treated Wastewater for Industrial Supply in the Western Trade Coast,* Perth: report for DJTSI.

Appendices

Appendix A – Engineering Design and Costing Study



Department of Jobs, Tourism, Science and Innovation

Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study

June 2018

Executive summary

Previous pre-feasibility studies led by CSIRO (McFarlane, DJ (ed), July 2015) have concluded that, as well as benefiting the environment, a well-designed managed aquifer recharge (MAR) scheme with treated wastewater (TWW) could enable industry in the Western Trade Coast (WTC) to cost-effectively access greater volumes of groundwater.

Managed by the Department of Jobs, Tourism, Science and Innovation (DJTSI), this report forms part of more detailed studies that will build on the previous pre-feasibility studies. This report focuses on two sites – Site 1 (North) and Site 2 (South) – for the recharge infrastructure and associated tertiary treatment facilities and includes:

- Reviewing and refining the conceptual design work,
- Completing more detailed and site-specific design work for several key elements of the scheme,
- Cost estimates for each scheme,
- Groundwater monitoring program, and
- Terms of reference that provide a high level summary of the next stage of work required to advance the project to “shovel ready” status.

The MAR two sites are identified in Figure ES-1.

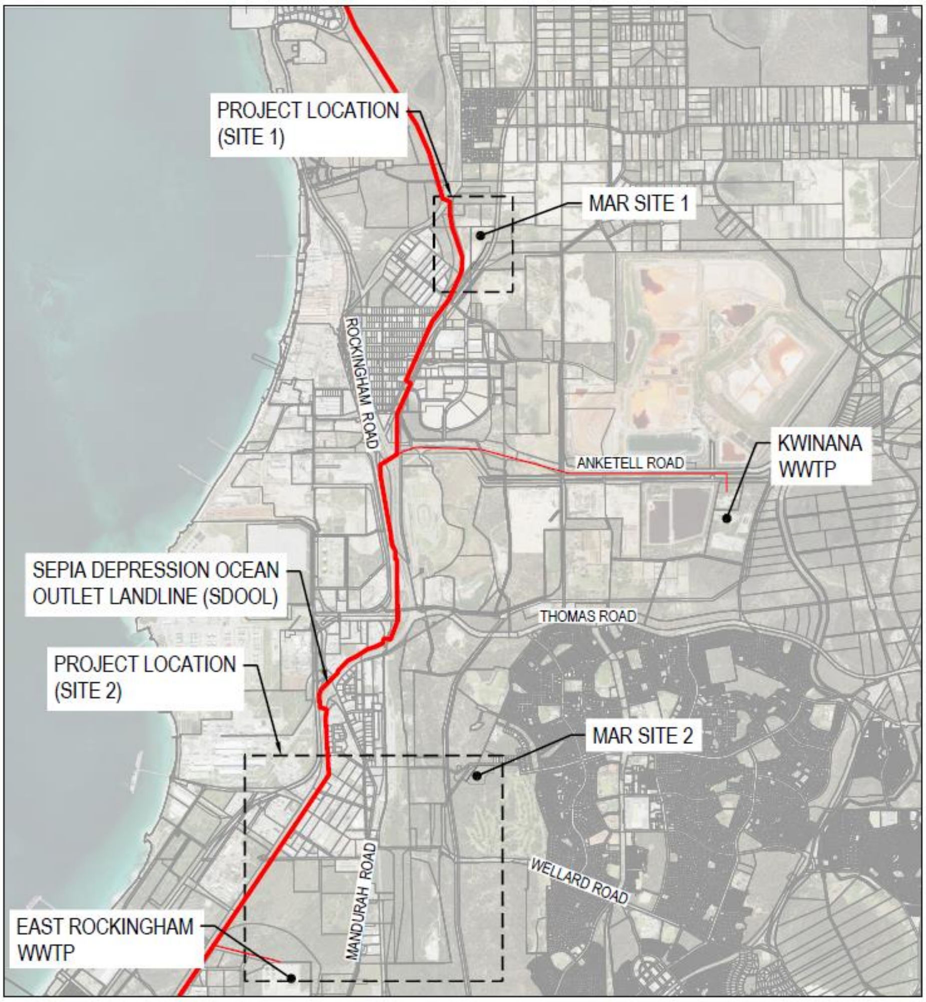


Figure ES-1 Locality plan

Site 1 (North)

Site 1 is located near the northern end of the City of Kwinana, and lies on the western side of the Kwinana freight railway line, and east to north-east of the Naval Base industrial area. The northern end of the site is approximately 600 m east of Rockingham Road and 200 m east of Water Corporation's Sepia Depression Ocean Outlet Landline (SDOOL).

The site is constrained by existing utility services and planned future Fremantle Rockingham Controlled Access Highway (FRCAH) and associated road/rail works in the vicinity of Site 1 and the nearby SDOOL. Given the uncertainties regarding timing for the future infrastructure, for this study it is assumed that the SDOOL offtake and supply main to Site 1 will be constructed prior to development of the FRCAH, and that any future modifications required as a consequence of the FRCAH (e.g. relocation of offtake and supply main) would be completed at that time. Based on the constraints assessment, Site 1 should have adequate useable area to accommodate 10 ML/d capacity infiltration basins and associated tertiary treatment facilities.

The preferred water source for the Site 1 MAR facility is the SDOOL, with an off-take at the section valve located approximately 300 m north-west of the site. The Site 1 (North) MAR pre-treatment facility is designed in two stages noting that the expected feed water quality will change markedly in the future, following commissioning of an Advanced Water Recycling Plant (AWRP) at Woodman Point. The pre-treatment facility will consist of denitrifying filters; and reverse osmosis for the future stage. It has been assumed that the pre-treatment residuals will be returned to the SDOOL. Further consultation with Water Corporation will be required to confirm the viability of this.

Recharge of the recycled water at Site 1 will be achieved using two (duty/resting) 10,000 m^2 infiltration basins, at a design recharge rate of 10 ML/d.

Capital and operating cost estimates (accuracy ±25%) for Site 1 are summarised below.

Table ES-1 Site 1 cost summary

	CAPEX (2018 $M)	OPEX (2018 $M/year)
Stage 1	21.5	0.95
Stage 2	6.6	1.62
TOTAL	28.1	N/A

A life cycle assessment of potential greenhouse gas emissions from Site 1 has also been undertaken. It is estimated that the total life cycle emissions (for Stage 1 and Stage 2) is 106 kt CO_2-e.

There is additional work, including stakeholder engagement and design, required to progress the project further. A summary of the additional work is provided in Table 6-1.

Site 2 (South)

Site 2, also within the City of Kwinana, is located west of the Kwinana Golf Course and adjacent to Gentle Road. The site is approximately 1.5 km east of the SDOOL, and 3 km north east of the Water Corporation's East Rockingham wastewater treatment plant (WWTP). The boundary assumed for Site 1 in this report includes Crown Reserve P157953, and portion of Reserve R25309 (which the Kwinana Golf Course lies within).

This investigation considered sourcing TWW from either the SDOOL or East Rockingham WWTP. Whilst requiring a longer pipeline to supply TWW to Site 2 (4.6 km versus 3.1 km to 4.3 km for supply from the SDOOL), the higher quality TWW available from the East Rockingham

WWTP will significantly reduce the additional treatment required prior to recharge, more than offsetting the additional costs resulting from the longer supply pipeline. As such, the preferred water source is East Rockingham WWTP. As an interim measure, a new pumpset for supply to Site 2 will be installed in the spare bay of the East Rockingham WWTP's existing temporary Final Effluent Pump Station (FEPS).

The Site 2 pre-treatment facility shall be located on industrial land fronting Alumina Rd, near the East Rockingham WWTP. The Site 2 (South) MAR pre-treatment facility will consist of denitrifying filters, and conveyance of residuals back to the East Rockingham WWTP - SDOOL connection has been adopted.

The recycled water shall be pumped from the pre-treatment facility to the recharge site at Gentle Rd, crossing several major assets. It is proposed that these crossings will be trenchless and the final construction methodology is to be confirmed during future stages:

- Proposed railway crossing,
- Mandurah Road,
- Existing rail corridor,
- Proposed Fremantle Rockingham Controlled Access Highway, and
- Existing Dampier to Bunbury Natural Gas Pipeline.

Due to topographic considerations and clearing constraints at Site 2, the recharge method shall be via three buried infiltration galleries with a design recharge rate of 10 ML/d.

Capital and operating cost estimates (accuracy ±25%) for Site 1 are summarised below.

Table ES-2 Site 2 cost summary

	CAPEX (2018 $M)	OPEX (2018 $M/year)	
		Annual costs	Periodic gallery renovation costs (notionally every 10 years)
Site 2	17.3	0.85	0.83

A life cycle assessment of potential greenhouse gas emissions from Site 2 has also been undertaken. It is estimated that the total life cycle emissions is 55 kt CO_2-e.

There is additional work, including stakeholder engagement and design, required to progress the project further. A summary of the additional work is provided in

Table 6-2.

Table of contents

1. Introduction 1
   - 1.1 Background 1
   - 1.2 Purpose of this report 2
   - 1.3 Scope of work 2
   - 1.4 Limitations 3
2. Background and preliminary investigations 5
   - 2.1 MAR sites 5
   - 2.2 MAR water sources and water quality 11
   - 2.3 MAR source selection and offtake arrangements 14
   - 2.4 Water quality requirements 17
3. Site 1 (North) 21
   - 3.1 Water source assessment 21
   - 3.2 Basis of design 23
   - 3.3 Engineering design 26
   - 3.4 Cost estimates 37
   - 3.5 Lifecycle assessment 39
4. Site 2 (South) 44
   - 4.1 Water source assessment 44
   - 4.2 Basis of design 46
   - 4.3 Engineering design 48
   - 4.4 Cost estimates 58
   - 4.5 Lifecycle assessment 59
5. Groundwater monitoring 65
   - 5.1 Introduction 65
   - 5.2 Proposed monitoring program 65
6. Terms of reference 74
   - 6.1 Introduction 74
   - 6.2 General considerations 74
   - 6.3 Site 1 75
   - 6.4 Site 2 78
7. References 82
   - Denitrifying filters 90
   - Desalination 91

Table index

Table ES-1 Site 1 cost summary ii

Table ES-3 Site 2 cost summary iii

Table 1-1 Scope of work 2

Table 2-1 Comparison of forecast median TWW quality in 2030 13

Table 2-2 Comparison of forecast median TWW quality in 2050 13

Table 2-3 Target recycled water quality 19

Table 3-1 Site 1 TWW quality design conditions 25

Table 3-2 Site 1 pre-treatment facility 25

Table 3-3 Site 1 (North) – Pre-treatment facility design summary (Stage 1) 32

Table 3-4 Site 1 (North) – Pre-treatment facility design summary (Stage 2) 34

Table 3-5 Site 1 CAPEX estimate summary 37

Table 3-6 Site 1 CAPEX estimate exclusions 37

Table 3-7 Site 1 OPEX estimate summary 38

Table 3-8 Site 1 OPEX estimate exclusions 38

Table 3-9 Global warming potentials 41

Table 3-10 Operating phase inventory data used for Site 1 (North) 41

Table 3-11 Site 1 (North) life cycle GHG emissions 43

Table 4-1 Site 2 TWW quality design conditions 47

Table 4-2 Site 2 pre-treatment facility 47

Table 4-3 Site 2 (south) – Pre-treatment facility design summary 52

Table 4-4 Site 2 CAPEX estimate summary 58

Table 4-5 Site 2 CAPEX estimate exclusions 58

Table 4-6 Site 2 OPEX estimate summary 59

Table 4-7 Site 2 OPEX estimate exclusions 59

Table 4-8 Operating phase inventory data used for Site 2 (South) 62

Table 4-9 Site 2 (South) life cycle GHG emissions 64

Table 5-1 Proposed monitoring locations – Site 1 66

Table 5-2 Proposed monitoring locations – Site 2 69

Table 5-3 Nominal bore details 72

Table 5-4 Groundwater quality sampling suite 73

Table 6-1 Site 1 terms of reference summary 77

Table 6-2 Site 2 terms of reference summary 80

Figure index

Figure ES-1 Locality plan i

Figure 1-1 Engineering Design and Costing Study work packages 1

Figure 2-1 Prospective MAR sites identified in prefeasibility studies, from (McFarlane, DJ (ed), July 2015, p. 152) 5

Figure 2-2 Locality plan – Site 1 (North) 6

Figure 2-3 Future road and rail works planned near Site 1 7

Figure 2-4 Locality plan – Site 2 (South) 9

Figure 2-5 Bush Forever and wetlands near Site 2 10

Figure 2-6 Schematic illustration of SDOOL assets 12

Figure 2-7 East Rockingham WWTP Temporary Final Effluent Pump Station 17

Figure 2-8 Forecast SDOOL treated wastewater salinity 19

Figure 3-1 SDOOL flow projections 21

Figure 3-2 TWW infiltration basins at Gordon Road WWTP (Mandurah), October 2017 24

Figure 3-3 Site 1 MAR scheme – Process flow diagram 28

Figure 3-4 HGL for TWW intake pipeline from SDOOL to MAR Pre-treatment Facility, Site 1 30

Figure 3-5 HGL for wastewater return pipeline from MAR Pre-treatment Facility to SDOOL, Site 1 31

Figure 3-6 Life cycle assessment framework 39

Figure 3-7 System boundary for Site 1 (North) MAR scheme 40

Figure 3-8 Site 1 (North) operational phase GHG emissions 42

Figure 4-1 East Rockingham WWTP flow projections 44

Figure 4-2 Site 2 MAR scheme – Process flow diagram 50

Figure 4-3 HGL for recycled water pipeline from MAR pre-treatment facility to Site 2 55

Figure 4-4 Images of DS Agency’s Flatbed Leach Drain System 56

Figure 4-5 System boundary for Site 2 (South) MAR scheme 61

Figure 4-6 Site 2 (South) operational phase GHG emissions 63

Figure 5-1 Site 1 – constraints and conceptual monitoring locations 68

Figure 5-2 Site 2 – constraints and conceptual monitoring locations 70

Figure E-1 Example schematics of denitrifying filter 91

Figure E-2 Example schematic and image of BWRO (ref: MAK Water) 92

Appendices

Appendix A – Figures

Appendix B – Mass balance model

Appendix C – SDOOL hydraulic grade lines

Appendix D – Functional control descriptions

Appendix E – Engineering design drawings

Appendix F – Treatment technologies

Appendix G – Cost estimates

Appendix H – Review of potential to source TWW from East Rockingham WWTP for multiple MAR sites

Acronyms

AGWR	– Australian Guidelines for Water Recycling
AHD	– Australian height datum
AWRP	– Advanced Water Recycling Plant
BOD	– Biological oxygen demand
CIP	– Clean in place
DBNGP	– Dampier Bunbury Natural Gas Pipeline
DJTSI	– Department of Jobs, Tourism, Science and Innovation
DoH	– Department of Health
DoW	– Department of Water (former department)
DWER	– Department Water and Environmental Regulation
FCD	– Functional control description
FEPS	– Final Effluent Pump Station
FRCAH	– Fremantle Rockingham controlled access highway
GHG	– Greenhouse Gas
GWP	– Global warming potential
GWR	– Groundwater replenishment
HGL	– Hydraulic grade line
KIC	– Kwinana Industries Council
MAR	– Managed aquifer recharge
MLE	– Modified Ludzack-Ettinger
MRWA	– Main Roads Western Australia
MSCL	– Mild steel cement lined
NBN	– National Broadband Network
NGER	– National Greenhouse and Energy Reporting
NWIDF	– National Water Infrastructure Development Fund
PFD	– Process flow diagram
P&ID	– Piping and instrumentation diagram
PSV	– Pressure sustaining valve
RIZ	– Rockingham Industrial Zone
RO	– Reverse osmosis
RWQMP	– Recycled water quality management plan
SDOOL	– Sepia Depression Ocean Outlet Landline
SEA	– Strategic Environmental Assessment
SPP	– State Planning Policy

TN	– Total nitrogen
TP	– Total phosphorus
TSS	– Total suspended solids
TWW	– Treated wastewater
WSAA	– Water Services Association of Australia
WTC	– Western Trade Coast
WWTP	– Wastewater treatment plant
TDS	– Total dissolved solids
NH_4-N	– Ammonia (as nitrogen)

1. Introduction

1.1 Background

Previous pre-feasibility studies led by CSIRO (McFarlane, DJ (ed), July 2015) have concluded that, as well as benefiting the environment, a well-designed managed aquifer recharge (MAR) scheme with treated wastewater (TWW) could enable industry in the Western Trade Coast (WTC) to cost-effectively access greater volumes of groundwater.

Managed by the Department of Jobs, Tourism, Science and Innovation (DJTSI), more detailed studies are currently being undertaken that will build on the previous pre-feasibility studies by CSIRO (McFarlane, DJ (ed), July 2015), as well as the *Western Trade Coast heavy industry local water supply strategy* subsequently developed by the former Department of Water (DoW) (now Department of Water and Environmental Regulation) (Department of Water, 2016). These studies are supported by funding from the Australian Government's National Water Infrastructure Development Fund (NWIDF), an initiative of the Northern Australia and Agricultural Competitiveness white paper.

The current studies focus on two sites for the recharge infrastructure and associated tertiary treatment facilities, as selected by DJTSI and other key stakeholders including CSIRO. One component of this work is an Engineering Design and Costing Study, and in March 2017 GHD was awarded this commission. This study involves reviewing and refining the conceptual design work completed in the prefeasibility studies, and completing more detailed and site-specific design work for several key elements of the scheme to improve the accuracy of cost estimates. A terms of reference will also be developed that details what work (administrative and technical) will need to be completed to advance the project to "shovel-ready" status (for investment).

The Engineering Design and Costing Study comprises 13 work packages, as depicted in Figure 1-1. Previously, a Basis of Design Report (GHD, 2017) was prepared as the key deliverable from Work Packages 1 to 4. This current report documents the overall findings from all work packages and forms the engineering design and costing study report.

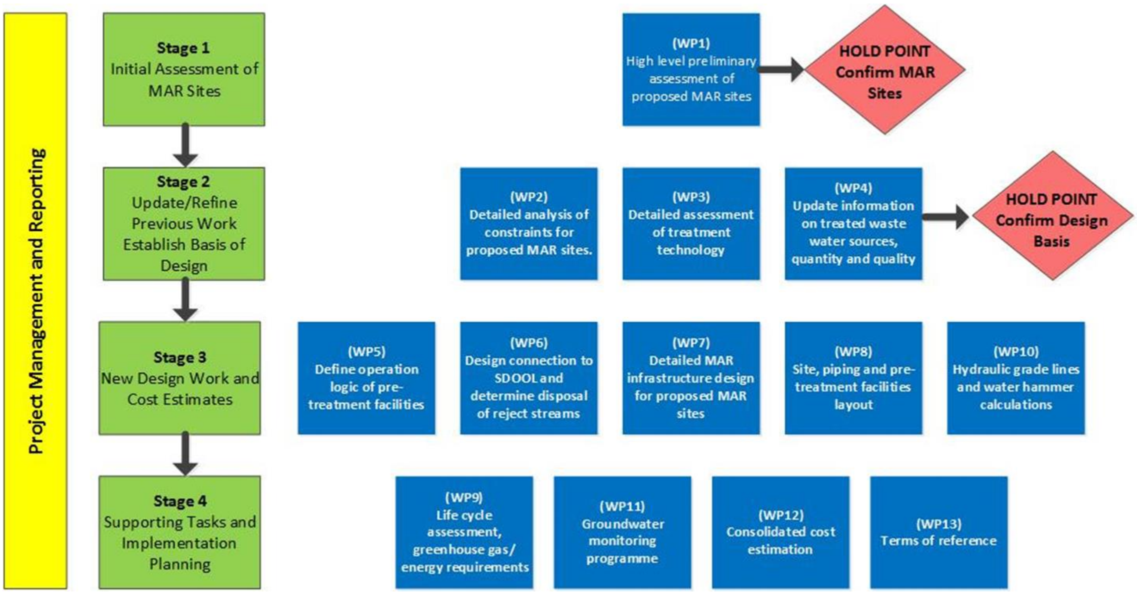


Figure 1-1 Engineering Design and Costing Study work packages

1.2 Purpose of this report

The purpose of this report is to document the findings from the work undertaken in completing this study, and present the engineering designs and cost estimates for two selected MAR recharge sites.

Additionally, the report outlines the additional work required to advance the project to "shovel ready" status (that is, Section 6 - Terms of reference). "Shovel ready" status is defined as being sufficiently developed in terms of planning, engineering and costing to allow an investor and scheme operator to make a financial commitment to deliver the project.

The primary focus of this study is engineering considerations. Others project participants are responsible for assessing the likely availability of the land, planning approvals, economic assessments and for confirming that operation of recharge facilities at these sites would not lead to unacceptable environmental impacts.

1.3 Scope of work

The scope of work for this WTC MAR Engineering Design and Costing Study is outlined in Table 1-1.

Table 1-1 Scope of work

Phase	Scope of work
Preliminary Investigations	• Complete preliminary high level assessment of proposed MAR sites, to confirm their potential suitability as sites for the proposed recharge facilities and associated works prior to commencement of field investigations and detailed groundwater and solute modelling by others. • Undertake detailed constraints analysis to identify existing (and proposed) infrastructure that could pose significant constraints to project development. • Assess the volume of TWW available from the Sepia Depression Ocean Outlet Landline (SDOOL) and East Rockingham WWTP. • Characterise the quality of TWW along the SDOOL, and the quality of TWW from the East Rockingham WWTP. • Assess alternative filtration and nitrogen removal technologies, and review the need to reduce the salinity of the recycled water discharged to the recharge facilities. • Review options available to dispose of residual waste streams (filter backwash etc.) from MAR pre-treatment facilities. • Develop the basis of design for the project.
Design	• Define operational logic of pre-treatment facilities and develop a Functional Control Description (FCD) for the proposed project. • Design: – Infrastructure to source TWW from the SDOOL and East Rockingham WWTP, and to dispose of residual waste streams from MAR pre-treatment facilities; – Infiltration type recharge facilities; Recycled water and wastewater conveyance infrastructure; and – MAR pre-treatment facilities.

Phase	Scope of work
	• Develop site plans, MAR pre-treatment facility site layouts, general arrangement drawings and piping & instrumentation diagrams (P&IDs). • Develop groundwater monitoring programme.
Cost estimating and life cycle assessment	• Develop CAPEX and OPEX estimates. • Complete life cycle assessment of greenhouse gas emissions.
Implementation planning and reporting	• Develop terms of reference that outlines the additional work required to advance the project to investment or "shovel ready" status. • Develop Draft Report to document findings from study. • Develop Final Report that reflects feedback provided on the Draft Report.

1.4 Limitations

This report has been prepared by GHD for Department of Jobs, Tourism, Science and Innovation and may only be used and relied on by Department of Jobs, Tourism, Science and Innovation for the purpose agreed between GHD and the Department of Jobs, Tourism, Science and Innovation as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Department of Jobs, Tourism, Science and Innovation arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Department of Jobs, Tourism, Science and Innovation and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary cost estimates set out in sections 3.4 and 4.4 of this report ("Cost Estimate") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD.

The Cost Estimate has been prepared for the purpose of informing a preliminary evaluation of the potential commercial feasibility of this project, and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the project can or will be undertaken at a cost which is the same or less than the Cost Estimate.

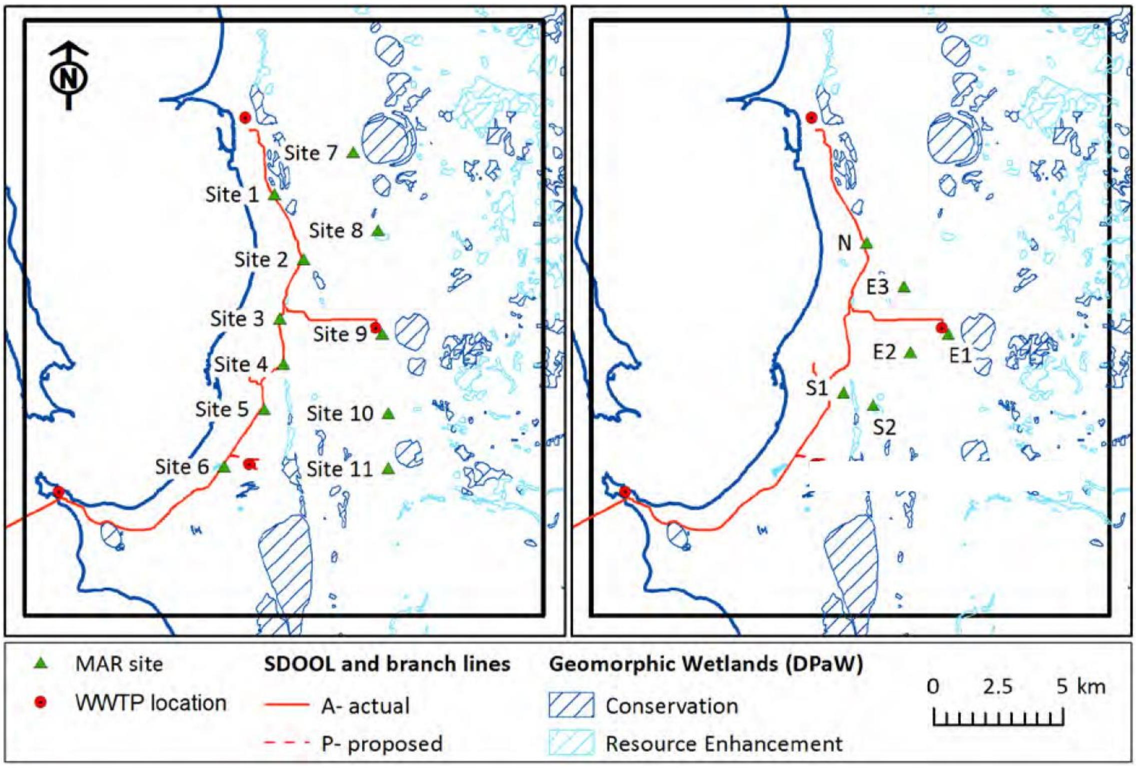
Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

2. Background and preliminary investigations

2.1 MAR sites

2.1.1 General

Significant work was completed during CSIRO's prefeasibility studies (McFarlane, DJ (ed), July 2015) to identify prospective sites for recharge works. Figure 2-1 depicts the sites that were identified in these studies.



Location of eleven initial sites (left) and six final locations (right) used for assessing the most prospective areas for managed aquifer recharge

Figure 2-1 Prospective MAR sites identified in prefeasibility studies, from (McFarlane, DJ (ed), July 2015, p. 152)

The two sites that are the focus of the current study are in close proximity to locations N and S2 shown in Figure 2-1 (on the right). Further detail on these two sites, including the constraints that existing services and planned future projects will pose to development of MAR infrastructure, is provided below. More comprehensive information on the sites is provided in the report prepared to document the findings from Work Package 1 (GHD, June 2017).

2.1.2 Site 1 (North)

Site 1 is located near the northern end of the City of Kwinana, and lies on the western side of the Kwinana freight railway line, and east to north-east of the Naval Base industrial area (refer to Figure 2-2). The northern end of the site is approximately 600 m east of Rockingham Road and 200 m east of Water Corporation's Sepia Depression Ocean Outlet Landline (SDOOL). The total area of the site is approximately 7.4 ha.

Figure 2-2 Locality plan – Site 1 (North)

Ownership

This site, owned by LandCorp, is currently leased to WA Limestone who are mining sand and limestone from the area.

Topography

Ground surface levels across Site 1 vary from approximately 3 m AHD to 18 m AHD, with the majority of the site having a surface level between 5 and 15 m AHD. Of note, quarrying operations at this site are ongoing, and WA Limestone has advised that the “approved” final ground level across the site is 4.0 m AHD.

Future road and rail projects

In the future it is planned to construct major road and rail works in the vicinity of Site 1, as depicted in Figure 2-3. Once these road works are completed, Site 1 will be bounded by the existing freight railway line (to the east/south), the Fremantle Rockingham Controlled Access Highway (FRCAH, to the west) and Rowley Road as well as a future freight railway line (to the north).

Planning for transport corridors in the vicinity of Site 1 is also affected by considerations for an Outer Harbour in Cockburn Sound. This is subject to on-going strategic planning by several state government agencies, and hence the detailed impacts on Site 1 are not entirely known at this point. The DJTSI is part of the inter-agency Outer Harbour strategic planning exercise and is aware of the potential impacts of this strategic planning on this MAR project.

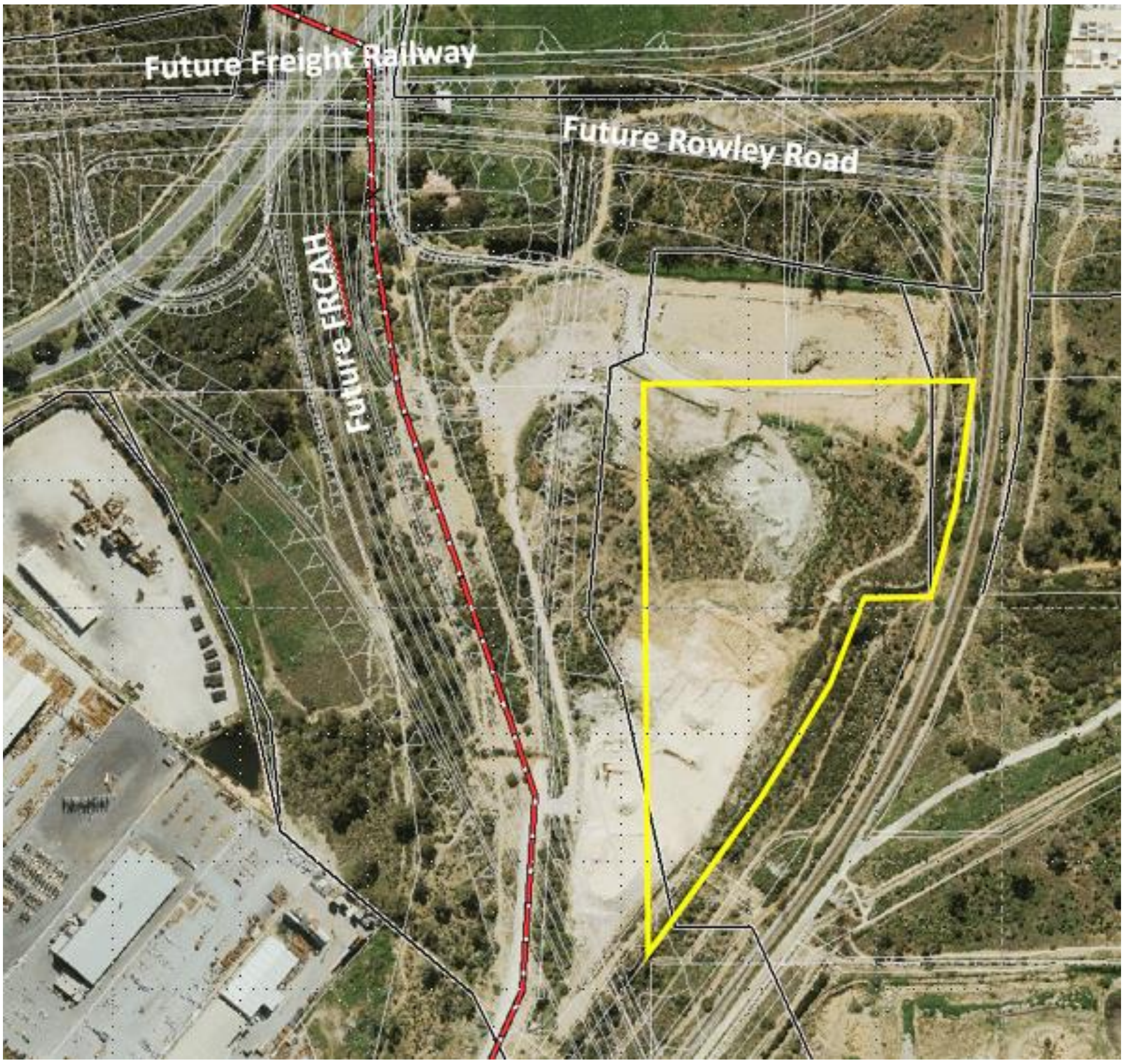


Figure 2-3 Future road and rail works planned near Site 1

Constraints analysis

A map showing (available) existing utility services and planned future FRCAH and associated road/rail works in the vicinity of Site 1 and the nearby SDOOL is included as Figure A1 in Appendix A. The closest SDOOL section valve, and preferred SDOOL offtake location for this site, is shown on the map and located approximately 300 m north-west of Site 1.

As shown on the map no existing services run through Site 1 with the exception of a single Water Corporation water supply main. This main is a significant pipeline, being a DN1200 steel trunk main. Given its location and that the full site area does not need to be developed, it would be possible to leave this portion of the site (and the pipeline) undisturbed, in which case this pipeline will not pose any significant constraints to development of MAR infrastructure on this site.

With planning for the FRCAH and associated rail/works under review as part of the outer harbour planning study, the ultimate alignment and design of this infrastructure may differ from the preliminary planning shown on the map in Appendix A. The extent of SDOOL and other service realignment works in this location is also unclear at this time. Given these uncertainties, for this study it is proposed to assume that the SDOOL offtake and supply main to Site 1 will be constructed prior to development of the FRCAH, and that any modifications required to be made to these works as a consequence of the FRCAH (e.g. relocation of offtake and supply main) would be completed at that time. Based on this approach, with respect to existing services construction of the offtake and supply pipeline will only be constrained by the Fremantle Black Oil Pipeline and communication services which run parallel with and east of the SDOOL in this area. Whilst the design will need to account for crossing (likely under) these services, it is unlikely that this will present a major constraint to the project.

Suitability for MAR infrastructure

The initial assessment of this site's suitability for MAR infrastructure (GHD, June 2017) concluded that:

- The site should have adequate useable area to accommodate 10 ML/d capacity infiltration basins and associated tertiary treatment facilities.
- This site is immediately adjacent to an existing railway line (to east and south), and to the planned alignment of the future FRCAH (to the west) as well as the future Rowley Road extension and a future freight railway line (to the north). After these future works are built, at an estimated cost of at least $5 million, provision of unconstrained access to the site would likely require construction of an access culvert under the future Rowley Road and freight railway line, and a new road connecting from the culvert to existing roads to the north which would require agreement from a number of landholders.
- Development of MAR facilities at this site will raise groundwater levels under the proposed alignment of the FRCAH, by approximately 1.0 to 1.5 m based on groundwater modelling undertaken by CSIRO during prefeasibility studies. As currently designed FRCAH is planned to be built under the Rowley Road extension and the adjacent freight railway. Just north of this intersection the FRCAH pavement level will be approximately RL 2.8 m AHD only, and verbal advice from MRWA[1] indicates that there is very little scope to vary the vertical profile of the FRCAH in this general locality by more than 100 mm or so given the numerous constraints associated with design of the grade separated road (and future rail) crossing. To provide adequate clearance between the FRCAH road pavement and groundwater, the proposed vertical profile of FRCAH (plus Rowley Road and the planned freight rail line) may need to be raised by more than is possible if 10 ML/d MAR facilities are to be built at this site and operated year-round. As a consequence it may alternatively be necessary to reduce the recharge rate (and hence the height of the mound created by the scheme) during periods when groundwater levels are high.

  GHD understands that CSIRO will be more accurately quantifying the potential groundwater level resulting from MAR at this site, and discussing the findings from this work with MRWA, as part of their studies.

[1] Advice provided during meeting held in MRWA offices on 5 December 2017.

2.1.3 Site 2 (South)

Site 2, also within the City of Kwinana, is located west of the Kwinana Golf Course and adjacent to Gentle Road (refer to Figure 2-4). The site is approximately 1.5 km east of the SDOOL, and 3 km north east of the Water Corporation's East Rockingham wastewater treatment plant (WWTP). The boundary assumed for Site 1 in this report includes Crown Reserve P157953, and portion of Reserve R25309 (which the Kwinana Golf Course lies within). It has a total area of approximately 6.0 ha.

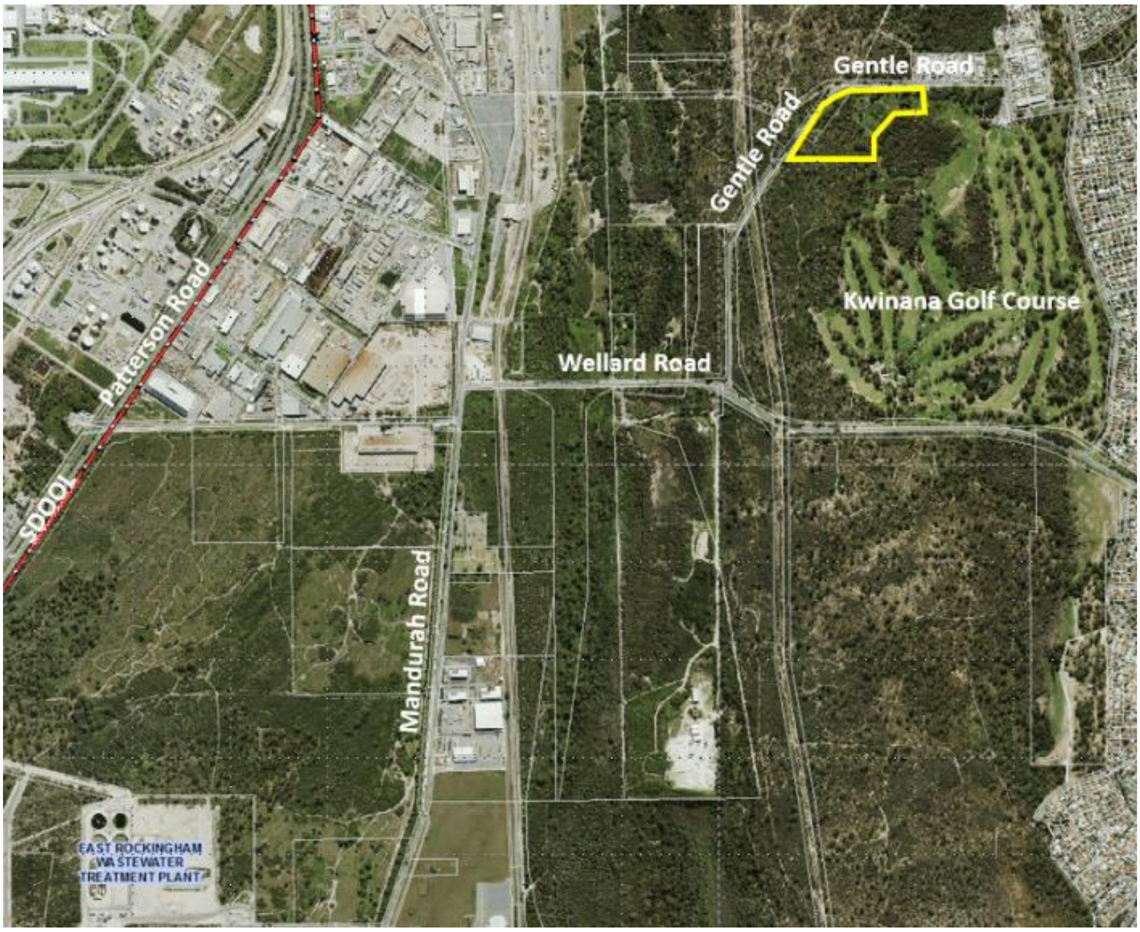


Figure 2-4 Locality plan – Site 2 (South)

Ownership

The majority of the site is within Reserve R25309 which is vested with the City of Kwinana.

Topography

Ground surface levels across Site 2 vary from approximately 4 m AHD in the north-east corner of the site to 31 m AHD in the south-west corner of the site. A significant portion of the site has a slope of 10% (1V:10H) or greater.

Environmental constraints

Site 2 is close to a number of resource enhancement category sumplands and one conservation category sumpland. It is also within reserves that have 'Bush Forever' status (refer Figure 2-5). Clearing to construct infrastructure in Bush Forever areas is likely to require a clearing permit from the Department of Water and Environmental Regulation (DWER).

Heritage constraints

The crown reserve adjacent to Gentle Road on the western side of the site is an area listed on the City of Kwinana's municipal heritage list (place number 16043 [2]), by virtue of it being the site of a former army camp. DJTSI was advised by the City of Kwinana that there are no structures remaining on the site. As a category C site, it is a place of some cultural heritage significance to the City of Kwinana, and is to be retained and conserved if possible.

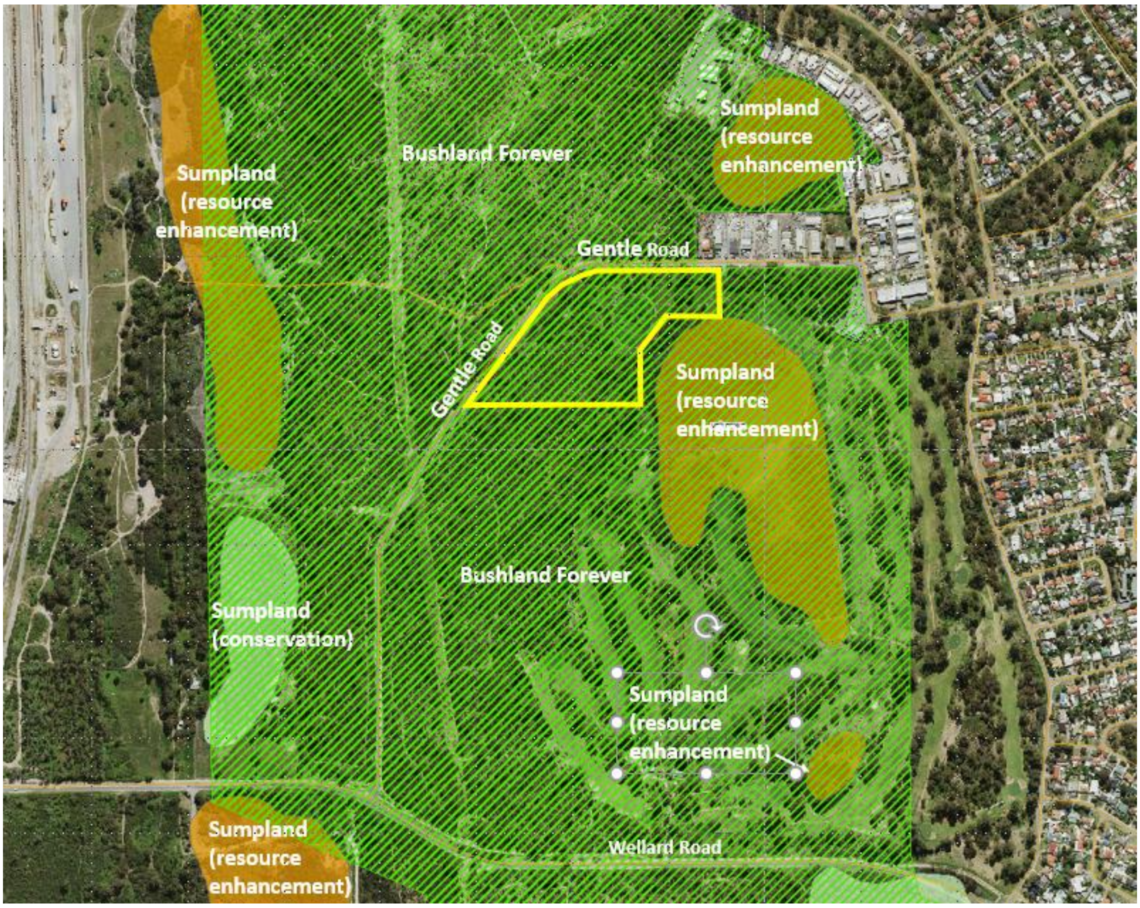


Figure 2-5 Bush Forever and wetlands near Site 2

Constraints analysis – Site 2

As shown on the figures included in Appendix A, available services information indicates that no existing utility services run through Site 2[3]. As a consequence, construction of new infrastructure on the site itself will not be constrained by existing utility services.

Constraints analysis - pipeline from SDOOL to Site 2

Treated wastewater could be sourced from the SDOOL for supply to this site at either of two locations. That is, it could either be sourced from the bypass pipework around the section valve located approximately 150 m south-west of the Rockingham Road/Thomas Road intersection, or from the bypass pipework around the section valve located just north of the Rockingham Road/Richardson Street intersection. Appendix A incudes a Locality Plan (Figure A3) depicting potential routes from each section valve to Site 2.

[2] http://inherit.stateheritage.wa.gov.au/Public/Search/PlaceNoSearch?placeNo=16043
[3] Note: underground and overhead power services, whilst not within Site 2, are erroneously not shown on these drawings.

The route from the section valve near the Rockingham Road/Thomas Road intersection follows Thomas Road to the east (crossing under high pressure gas pipelines at two locations) to Medina Avenue, then Medina Avenue/Bingfield Road West/Tucker Street/Beacham Crescent/Seabrook Way/Stanford Way to Gentle Road, then Gentle Road to the site. A possible deviation that follows an existing underground power line from the corner of Tucker Street/Beacham Crescent to Gentle Road is also shown. Aside from the high pressure gas pipelines, other services including water mains and communication cables would also need to be crossed along this route.

The route from the section valve near the Rockingham Road/Richardson Street intersection follows Richardson Street to Mandurah Road, then south along Mandurah Road to Wellard Road, then east to Gentle Road and north along Gentle Road to the site. This route would require crossings of high pressure gas pipelines (two locations), a rail line, communication cables and other services.

Constraints analysis – pipeline from East Rockingham WWTP to Site 2

For Site 2 TWW could alternatively be sourced from the East Rockingham WWTP. The pipeline route from East Rockingham WWTP to Site 2 proposed in this study is depicted in the Drawings included in Appendix E and follows Rockingham Industry Zone (RIZ) service corridors to Mandurah Road, then follows Mandurah Road/Wellard Road/future FRCAH corridor/Gentle Road to Site 2. This route crosses major existing assets (Mandurah Road, rail corridor, high pressure gas pipeline), and the proposed alignment of major future assets (proposed rail corridor, high pressure gas pipeline, FRCAH). The proposed pipeline route and the constraints posed by service/road/rail crossings along the route are described in further detail in Section 4.3.

Suitability for MAR infrastructure

The initial assessment of this site's suitability for MAR infrastructure (GHD, June 2017) concluded that:

- The site would be large enough to accommodate 10 ML/d capacity infiltration basins and associated tertiary treatment facilities, though extensive clearing and earthworks, and potentially significant rock excavation, would be required to construct these facilities at this site.
- Additional work will need to be completed to confirm that the clearing required to develop this Bush Forever site will be allowed under SPP 2.8. This is a potential "fatal flaw" associated with this site. DJTSI subsequently confirmed that this study is to be progressed assuming that MAR facilities are established at this site, noting that the potential to develop facilities at this site will not be known until formal approvals for this are sought.
- If significant portions of the site are unable to be cleared and developed based on environmental constraints, this site is unlikely to be large enough to accommodate 10 ML/d capacity infiltration basins. In that event additional land could be sought, lower capacity infiltration basins could be developed, or infiltration galleries (rather than infiltration basins) could be installed to minimise the footprint required for the recharge works.

2.2 MAR water sources and water quality

2.2.1 General

Previous pre-feasibility work has identified TWW from one or more of Water Corporation's southern metropolitan wastewater treatment plants (WWTP) as being potentially viable water sources for a MAR scheme at the Western Trade Coast. Shown below in Figure 2-6 is a simple

schematic illustration of the various assets connected to the SDOOL, from Woodman Point WWTP in the north, to the actual ocean outfall off Point Peron in the south. The figure also includes the future advanced water recycled plant (AWRP) at Woodman Point for (drinking water) groundwater replenishment (GWR). The AWRP is forecast to produce 16 GL/yr (or 50 ML/d [4]) of recycled water from 2030; and 32 GL/yr (or 100 ML/d [4]) from 2050.

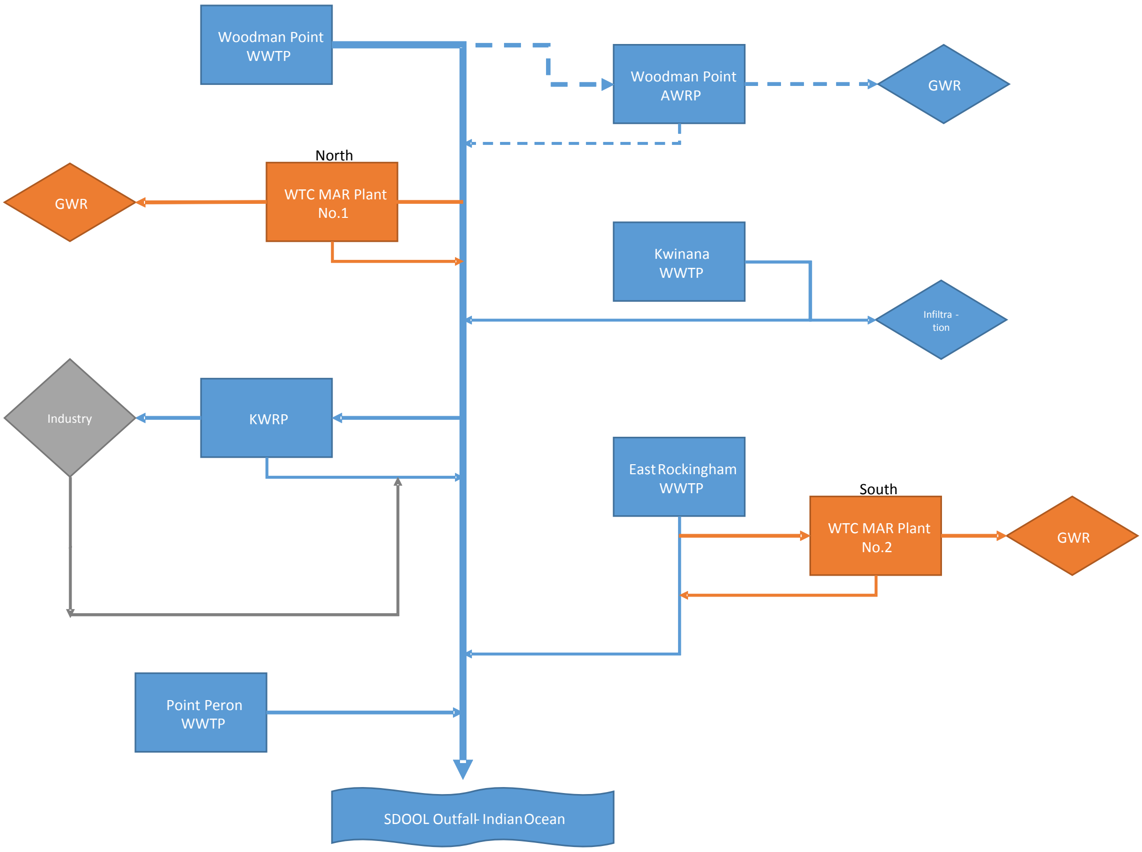


Figure 2-6 Schematic illustration of SDOOL assets

2.2.2 Treated wastewater quality

Using data provided by Water Corporation (Water Corporation, May 2017) on forecast TWW flows, historical TWW quality from operational WWTPs and forecast TWW quality from future upgrades, GHD has developed a mass balance model for the SDOOL. This model accounts for TWW volumes and mass flows of key constituents – BOD, TSS, TN, TKN, NH_3-N, NO_x-N, TP and TDS – and has been used to analyse and predict TWW flow and quality along the length of the SDOOL, out to 2060. A copy of this model is presented in Appendix B, together with key assumptions about the assets' operations (e.g. recovery rates) and design targets. The mass balance calculations assume that the first stage of the future Woodman Point AWRP (16 GL/year production) will be operational in 2030, and that the second stage of the plant (increasing production to 32 GL/year) will be operational in 2050.

Given the physical location of the two proposed MAR sites, the most likely TWW sources are either 1) an offtake from the SDOOL, or 2) from East Rockingham WWTP. Using the mass balance model, Table 2-1 and Table 2-2 show a comparison of the forecast median TWW

[4] Assuming 320 days per year plant availability

quality (for key parameters only) in the SDOOL and at East Rockingham, in 2030 and 2050 respectively.

The concentration of TSS, TN and TDS from the upgraded Woodman Point WWTP, currently the sole source of water for the initial 8.75 km length of the SDOOL, is clearly higher than levels in TWW from the East Rockingham WWTP. Further, the implementation of the AWRP will significantly increase these concentrations, especially from 2050 onwards. The long-term forecast of TWW quality from East Rockingham WWTP is also considered to be optimistic, particularly with respect to TN. The long-term process configuration of East Rockingham WWTP is not known at this point, but typically Water Corporation have adopted a Modified Ludzack-Ettinger (MLE) process for the large-scale metropolitan plants (i.e. at Beenyup, Subiaco and soon-to-be at Woodman Point). This process configuration typically has poorer nitrogen removal performance than the current oxidation ditch configuration at East Rockingham.

Table 2-1 Comparison of forecast median TWW quality in 2030

Parameter	Units	SDOOL – Woodman Point TWW	SDOOL – Woodman Point TWW + AWRP brine	East Rockingham TWW
Biochemical oxygen demand (BOD)	mg/L	5	7	5
Suspended solids (TSS)	mg/L	14	20	10
Total nitrogen (TN)	mg/L	15	21	5
Total dissolved solids (TDS)	mg/L	620	760	360

Table 2-2 Comparison of forecast median TWW quality in 2050

Parameter	Units	SDOOL – Woodman Point TWW	SDOOL – Woodman Point TWW + AWRP brine	East Rockingham TWW
Biochemical oxygen demand (BOD)	mg/L	5	8	5
Suspended solids (TSS)	mg/L	14	25	10
Total nitrogen (TN)	mg/L	15	26	5
Total dissolved solids (TDS)	mg/L	620	890	360

Nonetheless, from the simple viewpoint of minimising additional treatment requirements prior to MAR, the East Rockingham WWTP would be the preferred source for the WTC MAR scheme. Sourcing TWW from the East Rockingham WWTP is however constrained by:

- The high cost of the pipeline needed to convey TWW from this plant to both MAR sites, but particularly Site 1 in the north, and
- The limited flow available from this plant. Raw wastewater inflow to East Rockingham WWTP is not expected to reach 20 ML/d, sufficient to supply 10 ML/d to both MAR sites, until 2027, when a step change in inflow is experienced due to the diversion of a sewer district away from the Point Peron WWTP.

2.3 MAR source selection and offtake arrangements

2.3.1 Site 1

MAR source selection

Whilst a relatively short pipeline would be required to convey TWW from the SDOOL to Site 1, a pressure main of length greater than 13 km would be required to connect to the East Rockingham WWTP. The additional cost of this longer delivery pipeline would likely outweigh the cost to construct and operate the tertiary treatment facilities required if TWW is sourced from the SDOOL (GHD, June 2017). In addition, based on current flow projections the East Rockingham WWTP is unlikely to have enough flow to supply two 10 ML/d capacity MAR sites until 2027 or later.

For these reasons, the preferred TWW source for MAR Site 1 is the SDOOL, with an off-take at the section valve approximately 300 m north-west of the site (refer to Figure A1 Appendix A) which is downstream of Woodman Point WWTP and the future AWRP.

Aside: High level estimates of the cost to source TWW from the East Rockingham WWTP for both Site 1 and Site 2 was completed at a late stage of the study, and a net present value analysis was completed to compare (on a whole of life basis) these costs with the cost to source TWW (for Site 1) from the SDOOL. The findings from this review are summarised in Appendix H. The review indicates that it would be more effective to source TWW for Site 1 from the SDOOL if desalination is not required, but that supply from East Rockingham WWTP may be the lower cost option if desalination of TWW from the SDOOL is required. Additional work is warranted in the next stage to further investigate this possibility.

Significant potential exists for cost savings if the scheme can be developed from south to north over time as flows to East Rockingham WWTP increase, particularly if recharge is via infiltration basins and additional treatment of TWW is not necessary pre-recharge. If however the required scheme capacity in the short to medium term future exceeds the volume of TWW available from East Rockingham WWTP, TWW would also need to be sourced from the SDOOL.

Of note the notional north-south route assumed for the recycled water pipeline in this alternative scheme would require numerous major crossings (e.g. Thomas Road, Anketell Road, high pressure gas line, Alcoa slurry pipelines, rail line) and is subject to other constraints (e.g. proximity of Abercrombie Road alignment to overhead power lines, uncertainty around potential to construct final east-west leg of pipeline within major overhead transmission line corridor). A significant risk for this alternative scheme is that this pipeline route could prove to be non-viable, necessitating an alternative and potentially significantly longer (and thus higher cost) route for this pipeline.

Offtake arrangements

The Water Corporation advised that it would be possible to source TWW direct from the SDOOL via pipework connected into the (nominal DN300 MSCL) bypass pipework [5] around the SDOOL’s existing DN900 section valves; subject to the following requirements being met:

- The offtake would need to be designed in a way that it would not pose any risks to Water Corporation assets, e.g. introducing the potential for air-entry, water hammer or backflow. The key risk is seen to be the potential for air entry into the SDOOL (which would reduce the SDOOL’s hydraulic capacity) at times the offtake line is “drained down” when the Woodman Point WWTP TWW pumps are not operating.

[5] Connecting into (“hot-tapping”) the main pipeline itself would not be acceptable.

- Any offtake (with or without break tank) would need to include a pressure sustaining valve (PSV) set to prevent air entering the SDOOL from the offtake pipeline.
- It must be recognised that the flow and pressure received from the SDOOL will be a function of the SDOOL system pumping scenarios and headlosses across the aforementioned PSV. This is particularly relevant if it is not proposed to install a break tank and then pump TWW from this tank to the MAR site, but rather utilise the available pressure in the SDOOL to convey TWW to the MAR site.
- The spacing between the SDOOL's DN900 section valves varies, but is generally approximately 2 km. For Site 1 the nearest section valve is approximately 300 m north-west of the site.
- Woodman Point WWTP contributes the majority of the TWW conveyed by the SDOOL. At the present time the large TWW pumps at Woodman Point (pump rate approximately 2,500 – 2,600 L/s) run for approximately 12-14 hours per day, depending on weather conditions, and the small pumps (1,500 – 1,600 L/s) run the balance of the time. There is also a gravity flow mode when no pumps are running. Whilst the gravity flow mode is not currently utilised due to operational issues with the valves used to operate in this manner, it is planned to reintroduce this mode (for several hours per day) in the future due to the energy savings it realises.

The Water Corporation provided hydraulic grade lines (HGLs) depicting the current SDOOL pumping scenarios under steady state conditions, as attached in Appendix C. Review of this information indicates that when the Woodman Point TWW pumps are operating, the HGL in the SDOOL near Site 1 varies from approximately 29-69 m AHD [6]. Comparison of the SDOOL HGL range with the natural ground levels between the offtake location and Site 1 indicates that pressure in the SDOOL will be adequate to convey TWW from the SDOOL when the Woodman Point TWW pumps (large or small) are operating.

In this report it is assumed that TWW will be piped direct from the SDOOL offtake to balance tanks at Site 1, without any intermediate break pressure tank. With this arrangement, reintroduction of a gravity flow mode to TWW transfers from Woodman Point WWTP in the future may result in no flow being available during these periods. This has been accounted for in the sizing of the Site 1 balance tanks.

2.3.2 Site 2

MAR source selection

The preferred TWW source for Site 2 is the East Rockingham WWTP (GHD, June 2017). Whilst requiring a longer pipeline to supply TWW to the site (4.3 km versus 3.1 to 4.2 km for supply from the SDOOL, depending on SDOOL offtake location), the higher quality TWW available from the East Rockingham WWTP will significantly reduce the additional treatment required prior to recharge, more than offsetting the additional costs resulting from the longer supply pipeline.

Offtake arrangements

In relation to sourcing TWW from the East Rockingham WWTP, the Water Corporation has advised:

[6] The minimum HGL is when the small TWW pumps at Woodman Point (1,640 L/s) and the Point Peron WWTP TWW pumps (330 L/s) only are operating, and the maximum HGL is when the large TWW pumps at Woodman Point (2,530 L/s) and the Point Peron WWTP TWW pumps (255 L/s) only are operating.

- The plant's existing temporary Final Effluent Pump Station (FEPS) currently uses two spare secondary settling tanks as balancing storage (refer to Figure 2-7).
- The temporary FEPS is fitted with two pumpsets currently, and has two empty bays for future third and fourth pumpsets. The timing for the third and fourth pumpsets will depend on the timing of upgrades to the SDOOL system, but it is unlikely that the fourth pumpset will be required until after the spare secondary settling tanks revert to duty in approximately 2030.
- Subject to an operability review, it may be possible to use the bay for the future fourth effluent pumpset for a temporary pump station used to supply TWW to Site 2 or its associated pre-treatment facilities.
- In the future (possibly ~2030), the spare secondary settling tanks will revert to duty and dedicated wet-well/balancing storage will be required. A permanent dedicated MAR pumpset(s) could be included in the redesigned permanent FEPS.
- To explore this opportunity further there would need to be commercial negotiation and agreements with Water Corporation regarding operations and maintenance arrangements for the MAR delivery pump station on the Water Corporation site, as well any other infrastructure (e.g. pipelines) associated with the MAR scheme.

In this report it is assumed that it will be possible to install a TWW feed pump station in the fourth pump bay of the existing temporary FEPS, with the suction line connected to the FEPS suction manifold via the existing (blank flanged) DN700 suction offtake installed for the future fourth TWW pumpset. It is further assumed that filter backwash from the MAR pre-treatment facilities will be pumped to the SDOOL via connection to the temporary FEPS discharge manifold via the existing (blank flanged) DN600 delivery intake.

In subsequent stages of the project, Water Corporation will need to be further consulted in relation to this arrangement, and in relation to other infrastructure on the route for the required TWW supply main within the WWTP site.

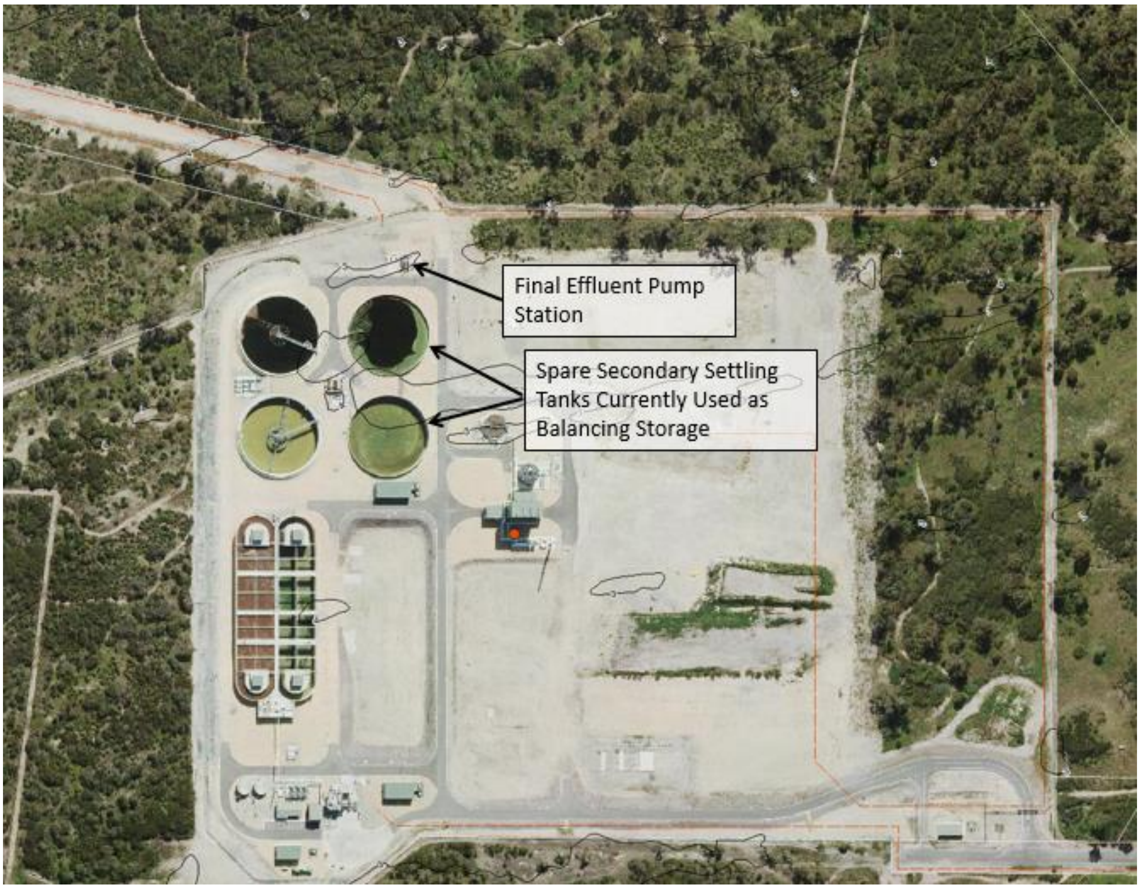


Figure 2-7 East Rockingham WWTP Temporary Final Effluent Pump Station

2.4 Water quality requirements

2.4.1 Regulatory requirements

MAR schemes in Western Australia are regulated through DWER, according to *Operational policy 1.01 – Managed aquifer recharge in Western Australia* (DoW, 2011). Under this policy, proponents need to identify and quantify the impacts of recharge and recovery operations; and demonstrate that these impacts can be managed appropriately so that risks to groundwater resources are minimised (including public health risks) and groundwater quality and environmental values are maintained for current and future generations.

Additionally, MAR schemes (including associated treatment facilities) that use TWW as the source water will be classified as prescribed premises and require regulation under Category 54 or 85 (Sewage facility), Schedule 1 of the Environmental Protection Regulations 1987.

Recycled water from human sewage in Western Australia is regulated by the Department of Health (DoH) under the *Western Australian Health Act 1911*, and guided by the *Guidelines for the Non-potable Uses of Recycled Water in Western Australia* (DoH, 2015). These guidelines provide a good framework for designing, implementing and managing the proposed MAR scheme, as they are consistent with the risk-based approach of the *Australian Guidelines for Water Recycling (AGWR): Managing Health and Environmental Risks (Phase 2): Managed aquifer recharge* (NRMMC, EPHC, NHMRC, 2009); which is also referenced in the DWER's MAR *Operational policy*.

2.4.2 Microbiological water quality requirements

Under the DWER *Operational* Policy and the DoH *Guidelines*, it is a requirement to prepare a risk assessment and Recycled Water Quality Management Plan (RWQMP) to gain approval for the scheme. In the RWQMP, the proponent needs to undertake a health and environmental risk assessment (as per AGWR) to determine the required recycled water quality and the management actions required to ensure compliance. Completion of such an assessment is beyond the scope of this study. However, for the purposes of concept design, the DoH *Guidelines* provides a table of typical end uses for various exposure risk levels – high, medium, low and extra low (refer Table 6 in DoH *Guidelines*). Based on this table, the proposed MAR scheme would likely be classed as **Medium Risk** – i.e. as "industrial use with potential human exposure", "urban application with some restricted access", or "water features". This classification then sets the required recycled water quality for certain parameters. For MAR schemes these water quality requirements apply to the quality of the MAR supplemented groundwater that is abstracted for use (e.g. industrial or irrigation water uses), rather than to the quality of the water discharged to the infiltration basins or galleries.

Of note a medium exposure risk classification is consistent with existing MAR-type indirect TWW reuse schemes in Mandurah where MAR-supplemented groundwater is used to irrigate some areas of public open space where public access is effectively unrestricted.

2.4.3 Other water quality requirements

Aside from microbiological water quality requirements there are several other considerations that will more strongly influence the target recycled water quality, such as:

- Depending on the level of post-recharge nitrogen loss occurring in the unsaturated zone and the aquifer itself, reduction of TWW nitrogen levels may be required to prevent eutrophication of receiving water bodies, with the main concern being the potential for eutrophication of wetlands and Cockburn Sound (McFarlane, DJ (ed), July 2015, p. 134). A design target of 5 mg/L Total Nitrogen (TN) has previously been proposed by CSIRO to represent the most stringent nitrogen target anticipated to be necessary [7].
- Residual phosphorus in the recycled water will be removed by adsorption and precipitation in the calcareous sands and limestones underlying and downgradient of the recharge facilities (McFarlane, DJ (ed), July 2015, p. 137). Hence, no further phosphorus removal is required prior to MAR [7].
- If recharge occurs via (buried) infiltration galleries, reduction of TWW suspended solids levels to less than 5 mg/L will be required to prevent clogging of the infiltration surface. This criterion is based on experience with infiltration gallery design for the Perry Lakes MAR project (McFarlane, DJ (ed), July 2015, p. 140). Somewhat higher suspended solids levels would be tolerable for open recharge basins, though higher suspended solids levels will increase the frequency and cost of solids removal operations (and reduce basin "run-times").

  Reduction of salinity may be required for TWW sourced from the SDOOL, especially under future scenarios that include the Woodman Point AWRP. Current TWW salinity from Woodman Point is approx. 620 mg/L, whilst ambient groundwater salinity across the MAR study area is approx. 720 mg/L (or EC 121 mS/m) (McFarlane, DJ (ed), July 2015, p. 55). In this case, no salinity reduction would be required.
- However, with the implementation of the Woodman Point AWRP in 2030, TWW salinity in the SDOOL will rise to approx. 760 mg/L, then be slowly diluted as the Woodman Point WWTP catchment population increases. When AWRP capacity is doubled in 2050, TWW

[7] Mike Donn, CSIRO, *pers. comms*, meeting 20 July 2017.

salinity in the SDOOL will rise to approx. 890 mg/L, before again being slowly diluted, as shown in Figure 2-8 below.

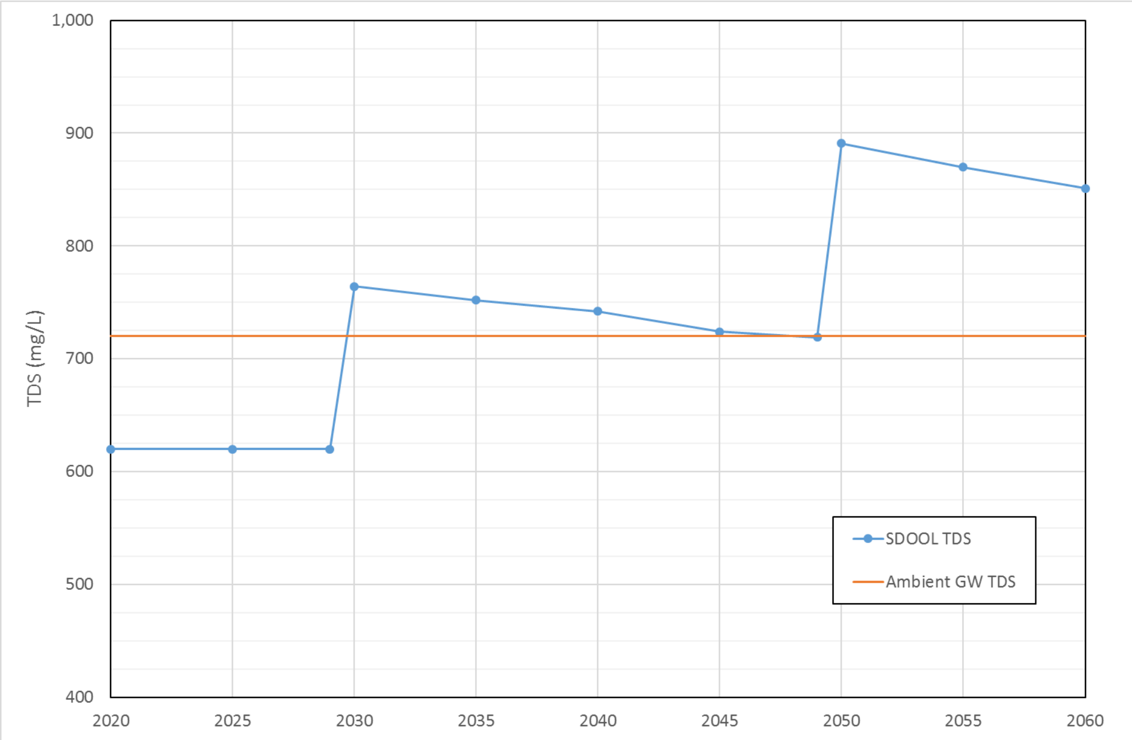


Figure 2-8 Forecast SDOOL treated wastewater salinity

- Consultation by DJTSI with the Kwinana Industries Council (KIC) has indicated that industries do not want to see any material change in the salinity from their groundwater production bores as a result of the MAR scheme. Confidential data provided by individual industries in the WTC area indicate production bore salinity in the range of 560 to 1,440 mg/L.
- Pre-treatment for pathogen removal prior to MAR is not considered to be necessary, due to the controlled/restricted access to the infiltration sites and the long aquifer retention times expected prior to extraction and use [7]. This assumption will need to be further investigated and confirmed as part of the risk assessment process for DoH and DWER. It is to be noted that the risk assessment is approved as part of the statutory approval process (DWER is unable to approve the risk assessment outside of the approvals process).

Drawing these considerations together, the proposed target recycled water quality for MAR within the Western Trade Coast area is shown in Table 2-3.

Table 2-3 Target recycled water quality

Parameter	Value	Consideration / requirement
Biochemical oxygen demand (BOD)	< 20 mg/L	DoH *Guidelines* for ‘Medium Risk’ application
SS	< 5 mg/L	Prevent clogging of infiltration galleries. Up to 10 mg/L is likely acceptable for recharge basins.
Turbidity	N/A	
pH	6.5 – 8.5	DoH *Guidelines* for ‘Medium Risk’ application
Total nitrogen	< 5 mg/L	Prevent eutrophication of wetlands and Cockburn Sound
Ammonia-N	< 2 mg/L	Refer to Note 1

Total phosphorus	N/A	
Total dissolved solids	≤ 760 mg/L	Maintain ambient groundwater salinity and quality for Kwinana industries' production bores
Pathogens	N/A	

Notes:

1. Total nitrogen is the sum of several sub-components:
   - Ammonia-N (soluble),
   - Nitrate-N (soluble),
   - Soluble organic-N (typically 1.0 – 1.5 mg/L in secondary treated wastewater), and
   - Particulate organic-N (approximately 0.5 – 1.0 mg/L for TWW with 5 mg/L SS).

   A well-designed, well-operated and appropriately loaded WWTP will typically achieve Ammonia-N < 1 or 2 mg/L, via nitrification processes. Hence, most of the TN in the TWW from Woodman Point /SDOOL is in the form of Nitrate-N.

   For the MAR pre-treatment plants, the soluble Nitrate-N can be removed by a post-denitrification process to levels < 1 mg/L. Limiting influent TWW ammonia-N to less than 2 mg/L will eliminate the need for a (energy intensive) nitrification process at the MAR pre-treatment plant. Hence, the recycled water TN composition would be (for example):
   - Ammonia-N (soluble) = 2 mg/L,
   - Nitrate-N (soluble) = 1 mg/L,
   - Soluble organic-N = 1.3 mg/L
   - Particulate organic-N = 0.7 mg/L
   - **Total N = 5.0 mg/L**

   Hence, it is proposed to limit the TWW intakes to the MAR pre-treatment plants to < 2 mg/L Ammonia-N, using on-line ammonia analysers.

2.4.4 Tertiary treatment technologies

Based on the assessment in section 2.2 and 2.3 of likely TWW sources and the target recycled water quality, further treatment of the TWW is likely to be necessary for one or both sites. If required the tertiary treatment (MAR pre-treatment) facilities will be a combination of:

- Filtration for solids removal,
- Nitrogen removal by denitrification, and
- Desalination (only if supply from SDOOL and Water Corporation's planned Woodman Point GWR scheme proceeds).

Further descriptions of the treatment technologies are provided as Appendix F and the treatment technologies required for MAR Site 1 and Site 2 are provided in section 3.3.3 and section 4.3.3 respectively.

3. Site 1 (North)

3.1 Water source assessment

As identified in Section 2.3.1, the preferred water source for Site 1 (North) is TWW from the SDOOL.

3.1.1 TWW flow projections

Flow projections for the SDOOL at the off-take for Site 1 (North) are shown in Figure 3-1. At this point, SDOOL flows are comprised of TWW from Woodman Point and brine returned to the SDOOL from a future AWRP. Clearly, this is a sufficient source water for the proposed 10 ML/d MAR scheme at Site 1.

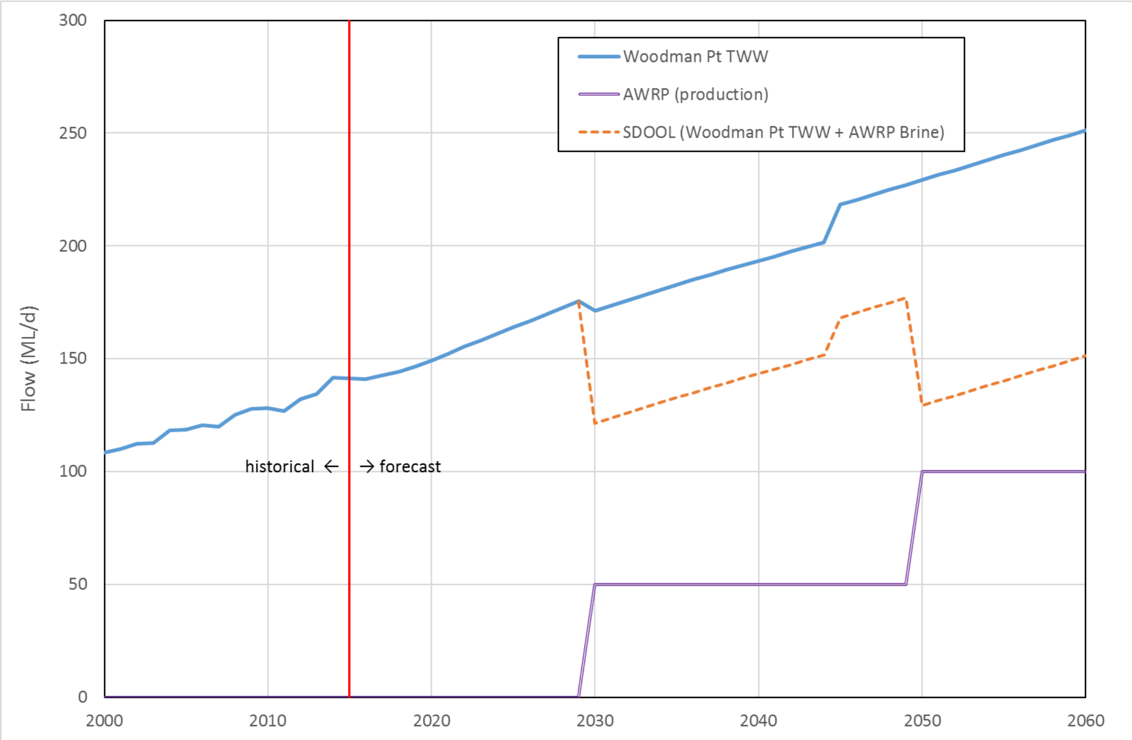


Figure 3-1 SDOOL flow projections

3.1.2 Predicted future TWW quality

The Woodman Point WWTP is currently being upgraded to increase capacity to 180 ML/d and improve process stability. When the upgraded plant is operating at its design capacity plant Water Corporation has advised that:

- Average TWW BOD will be < 10 mg/L,
- Average TWW TN will be < 15 mg/L, and
- Average TSS will be < 20 mg/L.

This forecast is reasonably consistent with historical performance (refer Table 2-1) and expected performance for this type of plant.

Forecast TWW salinity has been discussed, and is shown in Figure 2-8.

Risks

In terms of the source water quality for a Site 1 MAR pre-treatment plant, the following key risks should be considered:

- Woodman Point WWTP stability: Depending on loading conditions and process availability, it is likely that Woodman Point WWTP will suffer from occasional poor treatment performance, leading to spikes of suspended solids and associated organic matter and nutrients. For example, the historical median (or 50th percentile) TWW TSS concentration from Woodman Point is 14.4 mg/L; however the 90th percentile concentration is 101.1 mg/L – an extreme seven-fold increase. Historical TN concentrations have been less volatile with a median concentration of 15.0 mg/L versus a 90th percentile concentration of 20.5 mg/L.

  Historically, spikes in TSS have been associated with periodic flushing of the Woodman Point TWW balancing dam.

- The MAR pre-treatment facilities will need some level of design contingency and/or protection to accommodate occasional poorer source water quality. For example, the SDOOL off-take may include an automated ON/OFF valve linked to on-line turbidity and ammonia meters. When particulate concentrations and/or ammonia concentrations are above pre-determined trigger levels, the off-take valve is closed.
- The forecast SDOOL salinity is based on a number of assumptions associated with operation of the future AWRP. In particular, the target production TDS for the AWRP is assumed to be 270 mg/L, which is the ambient salinity for the Jandakot Mound. If a lower salinity target was stipulated for the AWRP, then brine concentrations and SDOOL salinity would increase.
- The forecast TWW quality from Woodman Point is based on historical data and assumptions about future plant upgrades. However, if the characteristics of the Woodman Point sewerage catchment were to substantially change, then the forecasts would also need to be revised. For example, changes in drinking water source (i.e. transition to more seawater desalination), reduction in per capita water consumption and/or substantial new sewerage inputs from industry could alter the raw wastewater characteristics for Woodman Point.

3.1.3 MAR pre-treatment requirements

Comparing the recycled water quality targets in Table 2-3 with the SDOOL water quality summarised in Table 2-1 and Table 2-2 indicates that:

1. Organic matter removal (as measured by BOD) is not a significant concern.
2. pH adjustment is not a significant concern.
3. Solids/particulate removal (as measured by TSS and turbidity) will be required.
4. Nitrogen removal will be required.
   – Based on advice from the Water Corporation that average TWW ammonia-N levels from an upgraded Woodman Point WWTPs will be 1–2 mg/L (Water Corporation, May 2017), it is considered that the required nitrogen reduction should target denitrification and particulate organic N removal.
5. Following denitrification, re-aeration of the recycled water prior to MAR will be required (to minimise the potential for nuisance odour emissions) and could be provided by a simple aeration weir on entry to the infiltration basins.
6. Desalination will be required, but only following the implementation of the Woodman Point AWRP.

7. Pathogen removal is not a significant concern.

3.2 Basis of design

The sections below summarise the basis of the engineering design work completed for Site 1. The basis of design draws upon the outcomes of previous studies as well as the additional investigations and analysis completed as part of this study, and includes the key design assumptions in this study.

3.2.1 Managed aquifer recharge rate

The design aquifer recharge rate is 10 ML/d. This is the maximum rate of the two rates considered by CSIRO in prefeasibility studies and associated predictive groundwater modelling (McFarlane, DJ (ed), July 2015).

3.2.2 Water source and offtake arrangements

The water source for Site 1 shall be the SDOOL, with an off-take at the section valve located approximately 300 m north-west of the site.

Design of the SDOOL offtake shall be based on a daily design flow of 10 ML/d plus treatment losses, and an instantaneous flow that accounts for the period of time when flow will be available from the SDOOL (assumed to be 20 hours per day – i.e. no flow available during gravity flow transfers from Woodman Point WWTP to SDOOL, refer to section 2.3.1).

The SDOOL offtake arrangement shall include:

- DN300 (TWW) offtake line connected into the DN300 MSCL section valve bypass pipework, drawing TWW from the upstream side of the section valve,
- DN150 (wastewater) return line connected into the DN300 MSCL section valve bypass pipework, isolated from the offtake line via a normally closed valve and discharging into the SDOOL downstream of the section valve,
- Pressure sustaining valve (PSV) to prevent return of liquid or air from the TWW supply main to the SDOOL,
- Open/close motorised isolation valve, to control the flow delivered to the MAR site,
- Magnetic flowmeters on both the offtake and return pipelines, and
- Turbidity and ammonia analysers to cut off supply to the MAR pre-treatment facilities located at Site 1 at times when the feed TWW quality is out of specification.

Additional detail design work should be completed to determine the most appropriate location of the motorised isolation valve and magnetic flowmeters (i.e. in a secure below ground pit at or near the section valve as assumed in this study, or at the MAR site).

It has been assumed that the conveyance pipes and appurtenances shall be designed in accordance with the relevant Water Corporation standards due to the connection into existing Water Corporation assets.

3.2.3 Recharge method

Recharge at Site 1 shall be achieved using open infiltration basins. The key reasons for this approach are:

- Site 1 has sufficient land to accommodate infiltration basins for the 10 ML/d design flowrate,

- Site 1 is located in an industrial area, remote from sensitive residential receptors and hence should not pose any significant odour risk,
- Infiltration basins are less prone to operational issues, such as clogging from excessive residual solids,
- There is substantial operating experience with infiltration basins in similar geophysical conditions (e.g. Kwinana WWTP, Gordon Road WWTP), and
- Infiltration basins are easier and cheaper to construct than infiltration galleries.

The open infiltration basins shall be sized based on:

- Infiltration rate = 1 m/d across basin floor area [8],
- 100% "redundancy" (i.e. active:resting = 1:1) [9],
- Max. water level = 1.0 m, plus 0.5 m free board, and
- Internal batters of 1V:3H, with a 4 m crest width for vehicular access.

The proposed design infiltration rate is based on the performance of the TWW infiltration basins at Water Corporation's Gordon Road WWTP in Mandurah (refer Figure 3-2).

Of note aerial imagery indicates that higher end-of-active cycle infiltration rates, potentially in the order of 1.5 m/d, are being achieved at the Kwinana WWTP's infiltration basins. Given this, in subsequent design stages additional work, including consultation with Water Corporation, is warranted to investigate whether a higher design infiltration rate can be adopted for this project, as this would reduce the size and thus cost of the infiltration basins. The potentially conservative design infiltration rate assumed in this report is however considered appropriate for this study.

Figure 3-2 TWW infiltration basins at Gordon Road WWTP (Mandurah), October 2017

[8] Based on the minimum 'end-of-active cycle' infiltration rate achieved at Gordon Road WWTP - Helen McGettigan, Water Corporation, *pers. comms*, 13 July 2017.
[9] As per current infiltration basin operating regime at Gordon Road WWTP – Craig Northy, Senior Operator, Water Corporation, *pers. comms*, May 2017.

3.2.4 Design TWW quality

As discussed in section 3.1.2, the TWW design conditions need to include some contingency to account for the likely variable performance of Woodman Point WWTP and the future AWRP. The Site 1 (North) MAR pre-treatment facilities shall be designed for the TWW quality (key parameters only) outlined in Table 3-1.

Table 3-1 Site 1 TWW quality design conditions

Parameter	Units	SDOOL – Woodman Point TWW only	SDOOL – Woodman Point TWW + AWRP brine
TSS	mg/L	Max. 20	Max. 35
TN	mg/L	Max. 15	Max. 25
NH_4-N	mg/L	Max. 2.0	Max. 2.0
TDS	mg/L	Max. 670	Max. 980

3.2.5 MAR Pre-treatment facility

The Site 1 (North) MAR pre-treatment facility shall be designed to achieve the target recycled water quality outlined in Table 2-3 using unit processes detailed in Table 3-2 (refer to discussion in Appendix F).

Table 3-2 Site 1 pre-treatment facility

SDOOL – Woodman Point TWW only	SDOOL – Woodman Point TWW + AWRP brine
Denitrifying filter, with carbon dosing, for removal of solids and nitrogen Re-aeration weir	Denitrifying filter, with carbon dosing, for removal of solids and nitrogen Reverse osmosis, for removal of dissolved solids (i.e. salinity) Re-aeration weir
Expected recovery rate = 95%	Expected recovery rate = 81%

3.2.6 Management of pre-treatment residuals

Adopting the unit processes outlined in Table 3-2, there will be approx. 0.5 – 2.3 ML/d of backwash and RO brine, and minor volumes of wastewater generated from the irregular RO membrane chemical cleaning (clean in place [CIP]) operations, that will require management and disposal. In the case of wastewater generated during CIP operations, this wastewater will be neutralised in the CIP wastewater collection tank prior to disposal.

For Site 1, conveyance of residuals back to the SDOOL is the most suitable solution. A discharge window of 20 h/d is assumed. To ensure that discharge of residuals to the SDOOL will not reduce the SDOOL's hydraulic capacity, a control interlock will be installed to inhibit operation of the wastewater disposal pumps during periods when TWW is not being abstracted from the SDOOL. Disposal to the SDOOL will require further consultation with Water Corporation to determine water quality acceptance limits and access arrangements.

3.2.7 Maintenance of infiltration basins

Based on practices at Water Corporation's Gordon Road WWTP the following infiltration basin maintenance regime is proposed:

- When the standing water level in the active basin reaches the maximum operating water level (nominally a water depth of 0.5 m), open/close basin inlet valves to switch flow to the resting basin.
- Once basin floor is dry, spray basins with herbicide to kill weeds and emergent vegetation.
- After herbicide has taken effect, scape (scalp) basin floor/batters (with small front end loader) to remove dead vegetation as well as build-ups of organic solids on the infiltration surface, depositing collected material into the unlined bunded area built to store this material.
  Aside: Approximately 20 to 40 wet tonnes of material are removed from the nominal 1 ha basins at Gordon Road each scalping event (email advice from VMS Contractors, March 2018).
- When the quantity of stockpiled material has reached approximately 200 WT (10 semi-trailer loads), conduct testing to classify this material in accordance with the *Western Australian guidelines for biosolids management* (DEC, 2012), and subsequently truck this material to landfill or Contractors able to use this material (after further treatment such as composting if required) in blended soils supplied to the landscape industry.

Based on experience at the Gordon Road WWTP it is expected that flow diversions between the two basins and maintenance of the formerly active basins will be required every 2 months.

3.2.8 Site access

Site 1 will require interim and long term access once the FRCAH is constructed.

The interim site access will be via Hope Valley Road and the current part-sealed access to the quarry. The long term access has been assumed to be via a new culvert arrangement under Rowley Road (and adjacent transport infrastructure which could include a freight rail line) connecting into a yet-to-be-planned new road north of this infrastructure. Further work in subsequent design stages is required to confirm the long term access arrangements.

3.3 Engineering design

Outlined below is a brief description of the overall design (Section 3.3.1), a description of each of the major assets required to implement a 10 ML/d MAR scheme at Site 1 (Section 3.3.2 to 3.3.4), and a discussion of the hazards that have been considered and in most cases will require further assessment to minimise the risks associated with constructing, operating and maintaining the scheme (Section 3.3.5).

The information provided below is further presented in the design drawings provided in Appendix E.

3.3.1 Overview and functional control

Scheme overview

Treated wastewater sourced from the SDOOL (via offtake from bypass pipework associated with SV3) will be transferred via pipeline under pressure available in the SDOOL, when the Woodman Point WWTP TWW pumps are operating, to balance tanks located at the head of pre-treatment facilities at Site 1. The initial MAR pre-treatment facilities will comprise denitrifying filters designed to reduce solids and nitrogen levels. The treated water from these facilities will

be stored in recycled water storage tanks, and the filter backwash will be stored in wastewater storage tanks. The majority of the recycled water will discharge under gravity flow to one of two infiltration basins operated on a duty/resting regime, with the balance used to backwash the filters. Wastewater (filter backwash) will be disposed of via pumped transfer to the SDOOL, with the wastewater pipeline discharging into the section valve bypass pipework at SV3.

Prior to Water Corporation commissioning their proposed AWRP at Woodman Point WWTP, the second stage MAR pre-treatment facilities will need to be installed. These facilities will comprise reverse osmosis desalination, designed to reduce the salinity of the recycled water discharged to the infiltration basins. The waste brine will be discharged to the wastewater storage tanks, where it will be blended with the filter backwash and disposed of via return to the SDOOL.

A schematic Process Flow Diagram (PFD) for the scheme is included as Figure 3-3, and the following drawings included in Appendix E depict the proposed design of the scheme in further detail:

- 61-35557-G001 Cover Sheet and Drawing Index
- 61-35557-C001 Conveyance Pipeline – Pipelines from SDOOL to MAR Site 1
- 61-35557-C002 SDOOL Offtake – General Arrangement
- 61-35557-C004 Infiltration System – General Arrangement
- 61-35557-C005 Infiltration System – Infiltration Basin Details
- 61-35557-C008 Pre-Treatment Facility – General Arrangement
- 61-35557-J001 Inlet and Denitrification Filter – P&ID
- 61-35557-J002 Outlet Waste and Infiltration – P&ID
- 61-35557-J003 Reverse Osmosis Unit – P&ID

Functional control

A functional control description (FCD) has been prepared for Site 1 and is included as Appendix D. Both the FCD and PFD provide the operating philosophy for the Site 1 MAR scheme including:

- SDOOL offtake,
- Flow balancing,
- Denitrifying filters,
- Reverse osmosis (future requirement),
- MAR infiltration basins, and
- Wastewater disposal.

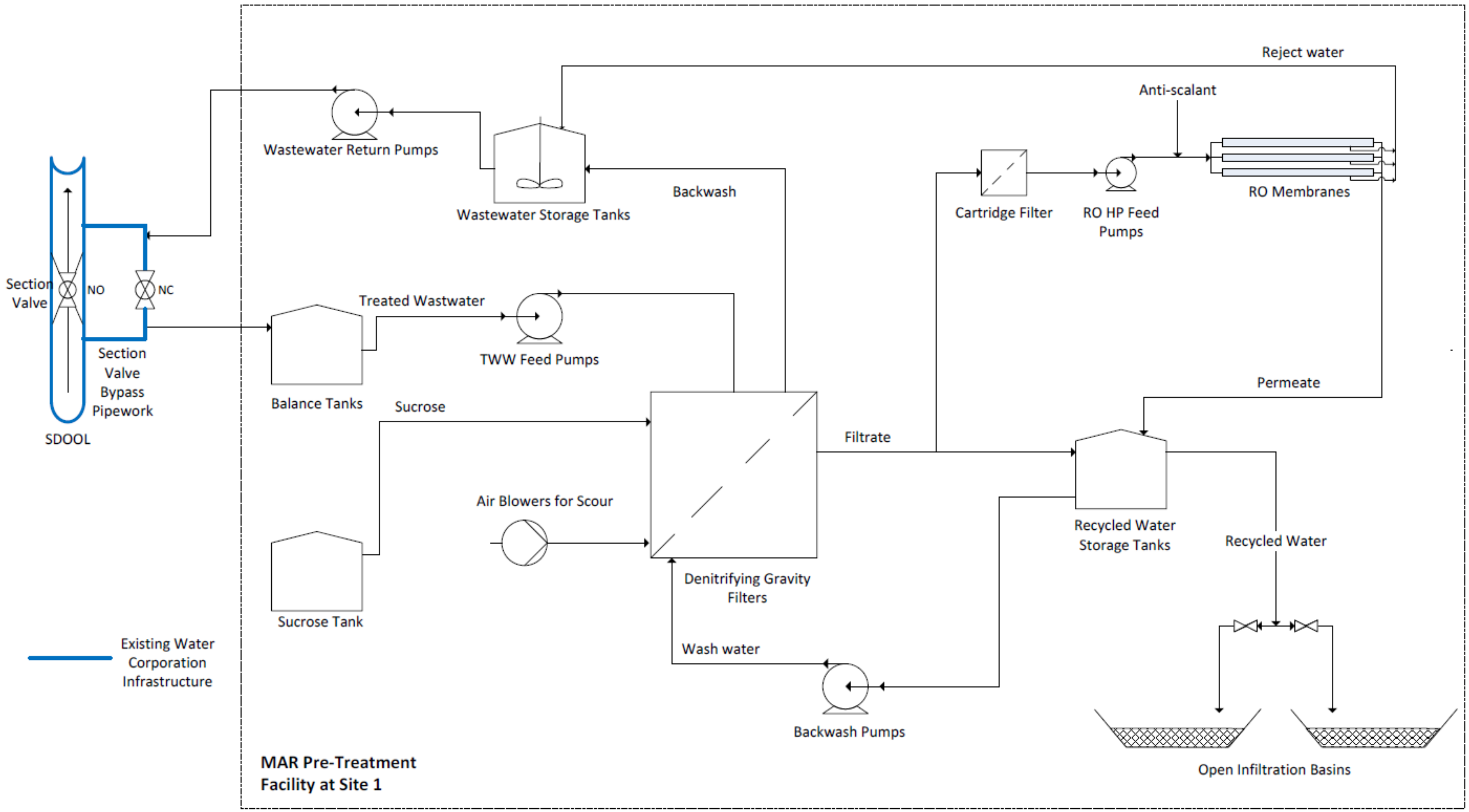


Figure 3-3 Site 1 MAR scheme – Process flow diagram

3.3.2 SDOOL offtake and TWW feed/wastewater return pipelines

SDOOL offtake

Treated wastewater for Site 1 will be sourced from the SDOOL pipeline, more specifically from SV3 DN300 MSCL bypass pipework, and transferred to the nearby MAR pre-treatment facility via a pipeline discharging into Balance Tanks at Site 1 (Refer to Drawing 61-35557-C001). The initial section of the pipeline will be DN300 MSCL, to match the existing section valve bypass pipework and minimise the size and cost of the new valves and flow meter. This initial section will (immediately downstream of new valve pit) transition into a DN450 PE100 PN16 pipeline sized to transfer TWW to the tanks using pressure available in the SDOOL (i.e. without pump boosting) when the Woodman Point TWW pumps are operating. Wastewater from the MAR pre-treatment facility will be returned to the SDOOL via injection into the same bypass pipework.

The SV3 bypass pipework will need to be modified to achieve the above. Some existing pipework will need to be replaced with new DN300 MSCL pipe specials, four new gate valves will need to be installed, and the valve pit's existing decking will need to be modified as required. The TWW offtake pipeline and wastewater return pipeline will need to penetrate the side wall of the existing reinforced concrete valve pit, requiring coring of holes through the pit wall and sealing of the annulus after the new pipework is installed. A new valve pit is proposed to be installed near SV3 to accommodate:

- A pressure sustaining valve on the TWW intake pipeline to prevent supply to Site 1 when the Woodman Point TWW pumps are not operating, and to prevent entry of air into the SDOOL via the TWW supply pipeline.
- A motorised isolation valve and water quality instrumentation (turbidity meter, ammonia analyser) on the TWW supply pipeline, to prevent transfer to the MAR pre-treatment facility when TWW quality is "out of specification".

Treated wastewater feed and wastewater return pipelines

The DN450 PE100 PN16 TWW intake pipeline, DN225 PE100 PN16 wastewater return pipelines and 2 x DN50 conduits for power and communications services are proposed to be installed in a common trench between SV3 and the boundary of Site 1 (Refer to Drawing 61-35557-C004). From SV3 the proposed route for these services runs parallel to the SDOOL to a point west of Site 1's northern boundary, then runs east to Site 1. This section of the route crosses the SDOOL and a number of other services within the FRCAH corridor and adjacent road reserve (Lusske Road), including the Fremantle Oil pipeline, NBN and other communication services. It is conservatively assumed that trenchless construction techniques will be used to cross these services.

It may be necessary to relocate these pipelines, and potentially sections of the SDOOL as well as SV3, prior to construction of the FRCAH. Consideration of this major realignment is beyond the scope of this report.

Hydraulic grade lines for the TWW intake pipeline and wastewater return pipeline are included in Figure 3-4 and Figure 3-5, respectively.

The diameter and pressure rating of each pipeline has been selected such that the maximum allowable working pressure (adjusted for a mean pipe wall temperature of 30ºC) exceeds the maximum surge pressure that could be generated by a sudden and uncontrolled valve closure interrupting the operation at the design flow rate. Pressure fluctuations during normal operation would be limited by the controlled rate of closure of the motorised isolation valves and by the ramping of the variable-speed wastewater return pumps. Setpoints for these controls will be determined as part of the future detailed design process.

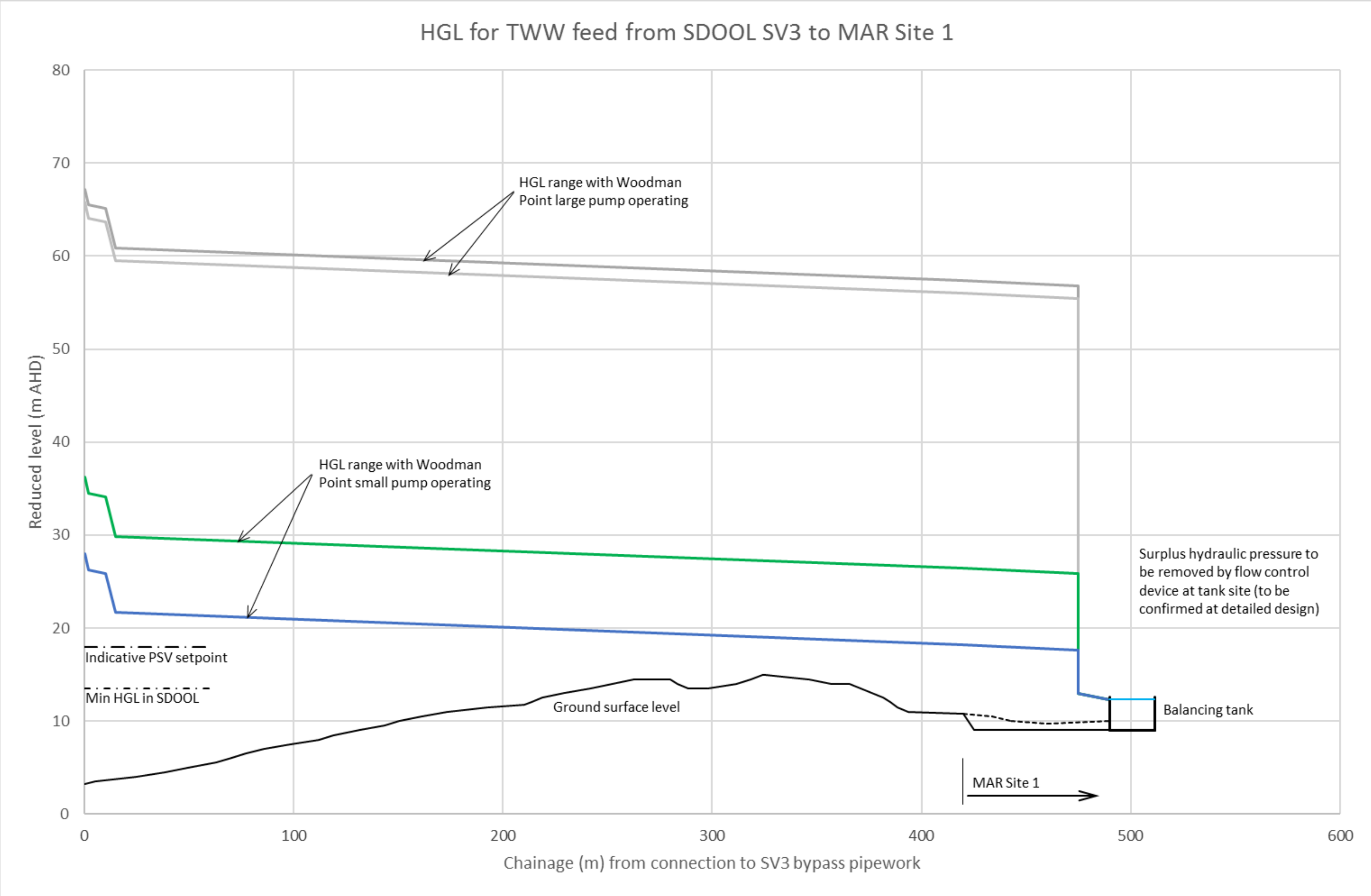


Figure 3-4 HGL for TWW intake pipeline from SDOOL to MAR Pre-treatment Facility, Site 1

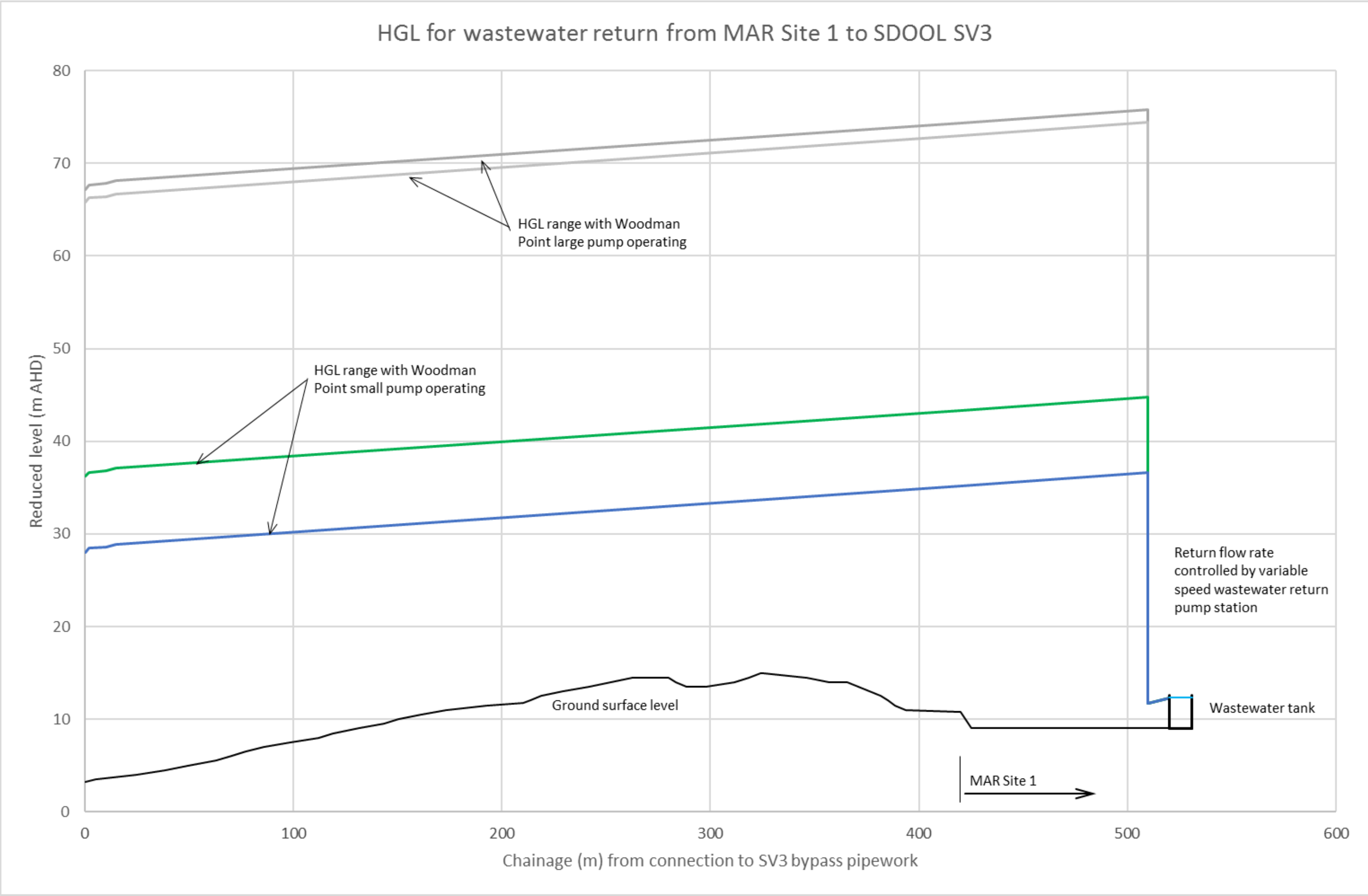


Figure 3-5 HGL for wastewater return pipeline from MAR Pre-treatment Facility to SDOOL, Site 1

3.3.3 Pre-treatment facility

Outlined below in Table 3-3 is a summary of the Site 1 (North) Stage 1 pre-treatment facility design. This should be read in conjunction with the process flow diagram in Section 3.3.1. Further description of these technologies, and their operation for the MAR scheme, is provided as Appendix F.

Table 3-3 Site 1 (North) – Pre-treatment facility design summary (Stage 1)

Unit process	Description	Design parameters	Operational requirements
Balance Tanks	2 × 1,290 kL lined tanks in corrugated zincalume steel 21.7 m dia., 3.6 m high Operated in parallel; covered and ventilated	Sized to accommodate and balance TWW inflow from SDOOL over 20 h/d, with constant feed to pre-treatment facility over 24 h/d.	None
TWW Feed Pumps	Duty / standby 22 kW centrifugal pumps 121 L/s @ 7.6 m head	Sized to provide constant feed to denitrifying filters	Estimated power draw = 11.8 kW @ 24 h/d Pump operation is interlocked to filter operation and also downstream Wastewater Storage Tanks
Denitrifying Filters	4 × duty filter cells, operated in parallel: each 6.10 m long × 3.66 m wide, with 1.83 m bed depth (silica sand) External carbon (D.Nitro sucrose solution) dosing for denitrification, controlled to achieve TN < 5 mg/L	Hydraulic loading rate = 4.9 m/h (increasing to 6.6 m/h during backwash of 1 cell) 95% recovery rate Dose rate = 5 mgCOD/mgNO_x-N	Backwash frequency approx. <1 per day per cell Filter cells “bumped” 3 times per day per cell to liberate N_2 gas Approx. 815 L/d sucrose solution (67wt%) Solids production = approx. 450 kg/d (inc. biomass production)
Backwash Pumps	Duty / standby 22 kW centrifugal pumps 105 L/s @ 10.0 m head	Sized to provide backwash rate = 15 m/h	Estimated power draw = 14.3 kW @ 1.0 h/d Backwash initiated on head loss, outlet turbidity or elapsed time
Air Blowers	Duty / standby 75 kW positive displacement air blowers 2,550 m^3/h @ 1.6 atm	Sized to provide air scour rate = 90 m/h	Estimated power draw = 64.3 kW @ 1.1 h/d

Unit process	Description	Design parameters	Operational requirements
Sucrose Storage Tank	1 x 5,000 L chemical storage tank + associated dosing pumps	Sized to provide approx. 7 days storage	Approx. weekly refills by delivery tanker Minor power draw for dosing pumps
Recycled Water Storage Tank	1 × 258 kL lined tank in corrugated zincalume steel 8.7 m dia., 4.3 m high Covered and ventilated	Sized to accommodate approx. 1 day of backwash water requirements Tank overflows to Site 1 infiltration basins	None
Re-aeration Weir	Stepped cascade entry to basins, 3 steps @ 0.2 m high, 3.3 m long	Turbulence over weir to entrain oxygen to approx. target DO = 2.0 mg/L	None
Infiltration Basins	Duty / standby 10,000 m^2 infiltration basins	Infiltration rate = 1 m/d across basin floor area Max. water level = 1.0 m, plus 0.5 m free board	Regular scalping / harvesting of residual solids – approx. 6 times per year – yielding approx. 40 wet tonnes per event
Wastewater Storage Tank	1 × 322 kL lined tank in corrugated zincalume steel 10.7 m dia., 3.6 m high Covered, mixed and ventilated 1 x 1.5 kW duty mixer (or recirculation pump)	Sized to accommodate 1 day of backwash and “bumping” wastewater, with reinjection to SDOOL over 20 h/d Mixing energy = 4 W/m^3	Estimated power draw for mixers = 1.5 kW @ 24 h/d
Wastewater Return Pumps	Duty / standby 45 kW centrifugal pumps 7 L/s @ max. 75 m head	Sized to allow reinjection into SDOOL at SV3	Estimated power draw = 7.6 kW @ 20 h/d Pump operation is interlocked to Wastewater Storage Tank, Inflow Isolation Valve and subject to Water Corporation SDOOL access requirements

Outlined below in Table 3-4 is a summary of the additional infrastructure required for Stage 2 of the Site 1 (North) pre-treatment facility design. This should be read in conjunction with the process flow diagram in Section 3.3.1.

Table 3-4 Site 1 (North) – Pre-treatment facility design summary (Stage 2)

Unit process	Description	Design parameters	Operational requirements
Balance Tanks	As per Stage 1		
TWW Feed Pumps	Duty / standby 22 kW centrifugal pumps 142 L/s @ 7.6 m head		Estimated power draw = 13.9 kW @ 24 h/d
Denitrifying Filters	As per Stage 1: + 1 additional duty filter cell	Hydraulic loading rate = 4.6 m/h (increasing to 5.8 m/h during backwash of 1 cell) 95% recovery rate	Approx. 1,170 L/d sucrose solution (67wt%) Solids production = approx. 775 kg/d (inc. biomass production)
Backwash Pumps	As per Stage 1		
Air Blowers	As per Stage 1		
Sucrose Storage Tank	As per Stage 1: + 1 additional 5,000 L chemical storage tank		
Recycled Water Storage Tank	As per Stage 1: + 1 additional 258 kL lined tank in corrugated zincalume steel		
Re-aeration Weir	As per Stage 1		
Infiltration Basins	As per Stage 1		
Wastewater Storage Tank	As per Stage 1: + 1 additional 322 kL lined tank in corrugated zincalume steel 1 x additional 1.5 kW duty mixer (or recirculation pump)		Estimated power draw for mixers = 3.0 kW @ 24 h/d
Wastewater Return Pumps	As per Stage 1		Estimated power draw = 33.1 kW @ 20 h/d
Flow Splitter	Flow splitter, with controllable weir length to provide flow split between RO unit and bypass	Target recycled water TDS = 500 mg/L RO feed flowrate = 6.7 ML/d	None

Unit process	Description	Design parameters	Operational requirements
Low Pressure Feed Pumps	Duty / standby 45 kW centrifugal pumps 77 L/s @ 35 m head	Sized for continuous feed to pre-RO cartridge filters	Estimated power draw = 36.7 kW @ 24 h/d
Cartridge Filters	2 No. duty in-line cartridge filters @ 5 micron / 1 micron filtration	Sized for removal of residual solids from denitrifying filters	Replacement of filter cartridges
Reverse Osmosis Feed Pumps	Duty / standby 110 kW centrifugal pumps 77 L/s @ approx. 80 m head	Sized for continuous feed to 2-stage RO unit	Estimated power demand = 84 kW @ 24 h/d
Reverse Osmosis Desalination	2-stage reverse osmosis process: 6.7 ML/d feed flowrate Stage 1 – 30 pressure vessels, with 6 membranes per PV Stage 2 – 15 pressure vessels, with 6 membranes per PV Inclusive of anti-scalant / CIP dosing facility, CIP tank and return pump	Target TDS of blended recycled water = 500 mg/L 75% overall RO recovery 98% RO rejection Membrane flux = 28 $L/m^2.h$	Clean-in-place using DBNPA biocide to control biofouling – 10-20 mg/L dose rate -> 10 kg/d consumption

3.3.4 Recharge infrastructure

The Site 1 infiltration system consists of two 10,000 m^2 infiltration basins, with a floor area 10,000 m^2 and basin floor level of 6 m AHD. To facilitate basin scalping operations (refer to Section 3.2.7) each basin will also have a single 6 m wide access ramp, and unlined storage and hardstand areas (30 m × 60 m and 35 m × 60 m, respectively) will be provided. Internal access roads will also be required to allow truck (semi-trailer) and earthmoving plant access to these facilities.

If the current quarry operator excavates the site down to the current approved finished surface level of 4 m AHD, a significant volume of fill will need to be imported to form the infiltration basins and associated works. The final volume of fill is dependent on the extent of quarrying undertaken at the site and this will need to be investigated further during subsequent design phases. The type of fill used will also need to be assessed to confirm it has adequate hydraulic conductivity for infiltration purposes.

The site (infiltration basins and MAR pre-treatment facility) will be surrounded by a 1.8 m high chainmesh fence and a 5 m wide vehicle access gate on the interim access road from Hope Valley Road.

3.3.5 Safety in design

For this site, the project involved development of designs for an offtake from the SDOOL, MAR pre-treatment facility, infiltration basins and associated works including conveyance facilities and access roads. Further development of the project will require consideration of a range of risks including those set out below. Given the conceptual nature of the engineering work completed in this study, the following list is not comprehensive.

Risks for further consideration and formal assessment include:

1. Management of potentially hazardous gases associated with confined spaces (e.g. work undertaken in the below ground pit built for SV3).
2. Management of traffic during construction, commissioning, operation and maintenance.
3. Deep excavation for construction of the SDOOL offtake.
4. Working around live services and implementing isolation / bypass procedures.
5. Confined space entry for SV3 offtake construction and subsequent operation and maintenance.
6. Working at height risks associated with the MAR pre-treatment facility during construction, commissioning, operation and maintenance.
7. Pathogen and other contaminants in sewage during construction, commissioning, operation and maintenance.
8. Working over and around open water during construction, commissioning, operation and maintenance.
9. General electrical, mechanical and chemical risks during construction, operation and maintenance
10. Protection of existing services and utilities.
11. General construction risks.

3.4 Cost estimates

3.4.1 CAPEX

CAPEX estimates (accuracy +/- 25%) developed for Site 1 are summarised in Table 3-5. The cost estimate exclusions applicable to the estimates are summarised in Table 3-6. More detailed breakdowns of these estimates, including details of the assumptions made in developing the estimates and the basis of the rates used, are provided in Appendix G. The rates and cost estimates were derived from a mix of project-specific vendor quotes (treatment facilities, tanks, pump stations, infiltration galleries), (Rawlinsons , 2017), estimates developed by GHD for this project or previous projects, and for some items nominal allowances.

Table 3-5 Site 1 CAPEX estimate summary

Item	CAPEX (2018 $M)	
	Stage 1	Stage 2
DIRECT COSTS		
SDOOL connection works	0.32	
Pipelines/conduits from SDOOL to MAR Pre-treatment Facility	0.76	
MAR Pre-treatment Facility and infiltration basins		
Import/place/compact sand fill to raise levels and form infiltration basins	6.66	
General site civil works and access roads	0.57	
Vendor packages	4.43	3.9
Balance of plant	1.84	0.7
Monitoring bores	0.14	
Total Direct Costs	**14.73**	**4.6**
INDIRECT COSTS		
Investigations and approvals	0.23	0.0
Design and project management	2.21	0.7
Contingency (25%)	4.29	1.3
Total Indirect Costs	**6.73**	**2.0**
TOTAL CAPEX, BY STAGE	**21.46**	**6.6**
TOTAL CAPEX, BOTH STAGES		**28.1**

Table 3-6 Site 1 CAPEX estimate exclusions

Item	Description
1	Land acquisition and easement costs.
2	Future cost to construct new access to site from north, under Rowley Road etc., after FRCAH constructed.
3	Service/pipeline/valve relocation costs required prior to construction of FRCAH and associated road/rail works etc.
4	Site pre-work (removal or rock, filling of excavations) prior to placement of fill at site of pre-treatment and recharge facilities.
5	Additional groundwater modelling studies (assuming CSIRO studies satisfy regulatory agencies and adequate to inform environmental impact assessment).

3.4.2 OPEX

OPEX estimates (accuracy +/- 25%) developed for Site 1 are summarised in Table 3-7. The cost estimate exclusions applicable to the estimates are summarised in Table 3-8. More detailed breakdowns of these estimates, including details of the assumptions made in developing the estimates and the basis of the rates used, are provided in Appendix G. Of note a conservative approach was adopted when estimating the cost of the supplementary carbon required to be dosed to the denitrifying filters.

Table 3-7 Site 1 OPEX estimate summary

Item	OPEX (2018 $k/year)	
	Stage 1	Post-Stage 2 Upgrade
Operator and vehicle	173	436
Power	181	307
Chemicals (Sucrose)	214	307
RO plant chemicals and pre-treatment filter consumables	0	60
Pre-treatment Facility laboratory analysis costs	7	7
Major planned maintenance and unplanned maintenance	22	44
Infiltration basin maintenance	41	41
Groundwater monitoring program	53	53
Sub Total	**691**	**1,174**
Contingency (20%)	138	235
Licensed service provider profit margin (15%)	124	211
TOTAL OPEX	**950**	**1,620**

Table 3-8 Site 1 OPEX estimate exclusions

Item	Description
1	Water Corporation TWW supply charges
2	Water Corporation wastewater disposal charges
3	Capital replacement costs

3.4.1 Unit Water Cost

Preliminary unit water cost estimates were also developed for the scheme, based on a simplistic net present value analysis over a project life of 50 years and using real (pre-tax) discount rates of between 4 and 12% per year. In this analysis it was assumed that the desalination modules and associated works will be commissioned at the end of Year 8.

The unit water cost estimates are included Appendix G. We understand that another consultant (Synergies Economic Consulting) has been commissioned to complete a more detailed financial analysis for the project, one output from which will be more refined unit water cost estimates for the project that will supersede the preliminary figures developed in this study.

3.5 Lifecycle assessment

3.5.1 Methodology

Overview

Life cycle assessment is an internationally recognised approach for assessing and comparing environmental impacts of products and processes. In this study, the life cycle impacts of greenhouse gas emissions from the proposed WTC MAR scheme have been assessed, in a manner consistent with the principles and framework outlined in ISO 14040:2006, *Environmental Management – Life cycle assessment – Principles and framework*.

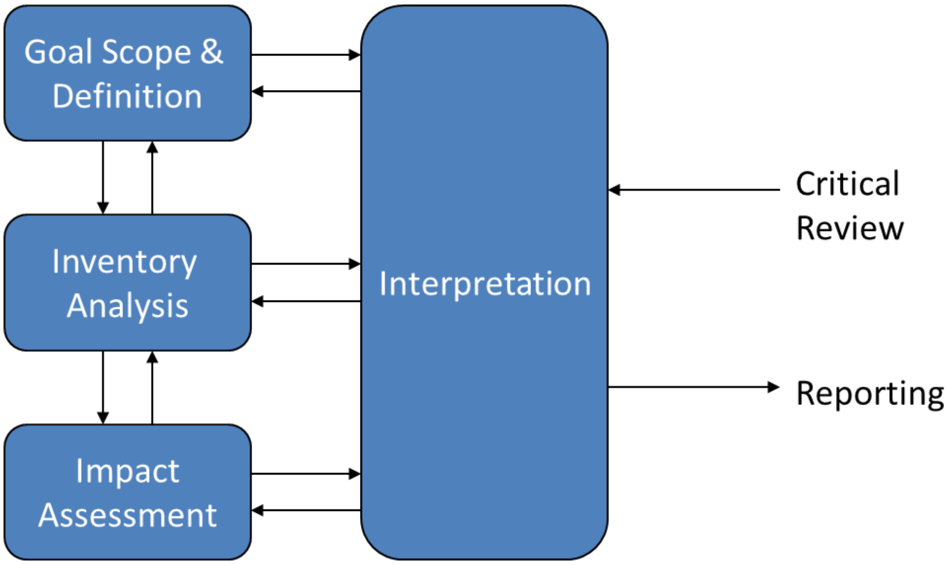


Figure 3-6 Life cycle assessment framework

Goal and scope

The goal of this life cycle assessment was to calculate the greenhouse gas (GHG) emissions associated with the construction and operation of the Site 1 (North) MAR scheme for the Western Trade Coast.

Functional unit

The functional unit for the assessment of the site was 10 ML/d of recycled water recharged to the aquifer, over the 50 year design life of the scheme.

This equates to a total recharge volume of 182.5 GL.

System boundaries

The system boundary for the MAR Scheme is outlined in Figure 3-7. The following life cycle stages were considered:

- Construction of the pre-treatment facility, infiltration basins and connecting pipework, and
- Operation of the pre-treatment facility (consumption of electricity and chemicals, fugitive emissions from denitrification, and transport / disposal of solids).

The following activities were excluded from the assessment:

- Upstream treatment facilities and infrastructure associated with the manufacture of TWW (i.e. Water Corporation's Woodman Point WWTP, and SDOOL), and
- Downstream infrastructure and receiving environments for residual liquid wastewater from the MAR Scheme (i.e. SDOOL and ocean outfall receiving environment).

The activities were excluded on the basis that they are existing operations, that will continue to occur independently of any MAR Scheme.

In addition, end-of-life decommissioning and deconstruction of the MAR scheme was also excluded. Emissions associated with this phase of the life cycle are likely to be negligible.

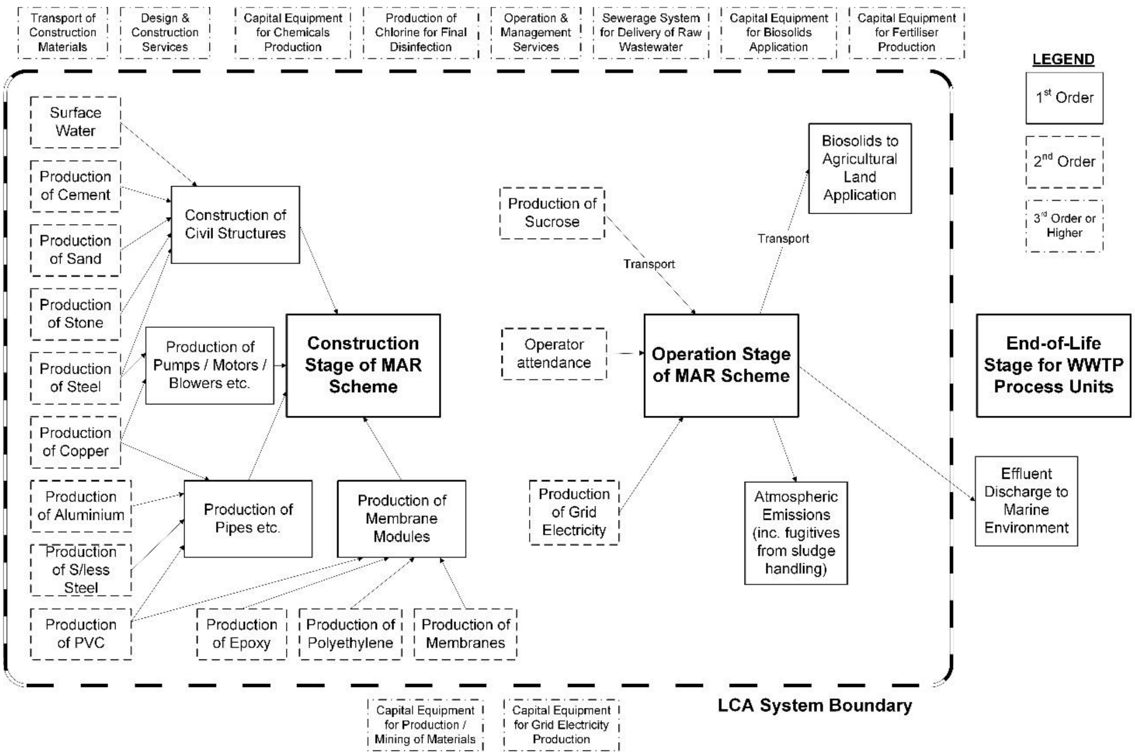


Figure 3-7 System boundary for Site 1 (North) MAR scheme

Calculation procedures

The assessment was undertaken using a spreadsheet model developed by GHD for the Water Services Association of Australia (WSAA), and the associated *National Greenhouse and Energy Reporting System: Guidelines for the Water Industry* (2011).

Data collection and assumptions

Inventory data was based on the MAR Scheme engineering design developed by GHD. A summary of inventory data and assumption is provided in Section 3.5.2.

Impact assessment method

The impact assessment method for this study was limited to greenhouse gas emissions only, expressed in units of tonnes of carbon dioxide-equivalents (t CO_2-e). This approach uses internationally recognised Global Warming Potentials (GWPs) of different greenhouse gases to convert back to a single indicator of CO_2-e. The major GWPs relevant to this study are outlined below.

Table 3-9 Global warming potentials

Greenhouse gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	298
Sulphur hexafluoride (SF_6)	22,800

Ref: *NGER (Measurement) Technical Guidelines 2017/18*, Appendix C

3.5.2 Inventory

The data used for the operating phase of the MAR Scheme are summarised in Table 3-10.

Table 3-10 Operating phase inventory data used for Site 1 (North)

Parameter	Units	Site 1
Consumables		
Electricity (Filter Plant)	kWh/y	689,151
Electricity (RO Plant)	kWh/y	735,840
Sucrose [10]	tonnes/y	377
Transportation		
Chemical deliveries [11]	km/y	2,600
Disposal of solid waste	km/y	3,000 [12]
Operator attendance [13]	km/y	7,800
Direct emissions		
Nitrogen removal in pre-treatment facility	tonnes/y	80 [14]
Solid waste applied to land	dry tonnes/y	283, with 5_{wt}% N

Given the relatively small size of the infrastructure required for the scheme, and the long operational design life (50 years), the construction phase GHG emissions are expected to be only a minor portion (i.e. << 5%) of the whole life cycle emissions (Foley, 2009). Hence, no detailed construction phase inventory has been developed for this study.

3.5.3 Impact assessment and interpretation

The annual operational phase GHG emissions for Site 1 (North) are shown below in Figure 3-8, broken down by Source and Scope [15].

Not unexpectedly, the majority of emissions are indirect and related to electricity consumption (Scope 2 and Scope 3). Other significant sources are Scope 3 emissions associated with the production and delivery of external carbon (i.e. sucrose) and direct Scope 1 nitrous oxide emissions from the denitrification process in the filters. Minor emissions are associated with solid waste disposal and other transportation activities.

Total emissions over the 50 year design life for the MAR scheme are shown in Table 3-11.

---

[10] Embodied emissions associated with the production of sucrose solution were estimated using methanol production as a proxy.

[11] Assuming weekly deliveries in a medium-sized truck, at 50 km per round trip.

[12] Assuming 6 scalping operations per year in a heavy truck, at 500 km per round trip.

[13] Assuming operator attends site 3 d/wk in a 4WD/utility vehicle, at 50 km per round trip.

[14] Assuming influent TN = 25 mg/L, and recycled water TN = 5 mg/L.

[15] Direct emissions from sources within the boundary of an organisation are known as “Scope 1” emissions. Indirect emissions from the consumption of purchased electricity, steam or heat are known as “Scope 2” emissions. All other indirect emissions as a consequence of an organisation’s activities, but are not from sources owned or controlled by the organisation are known as “Scope 3” emissions.

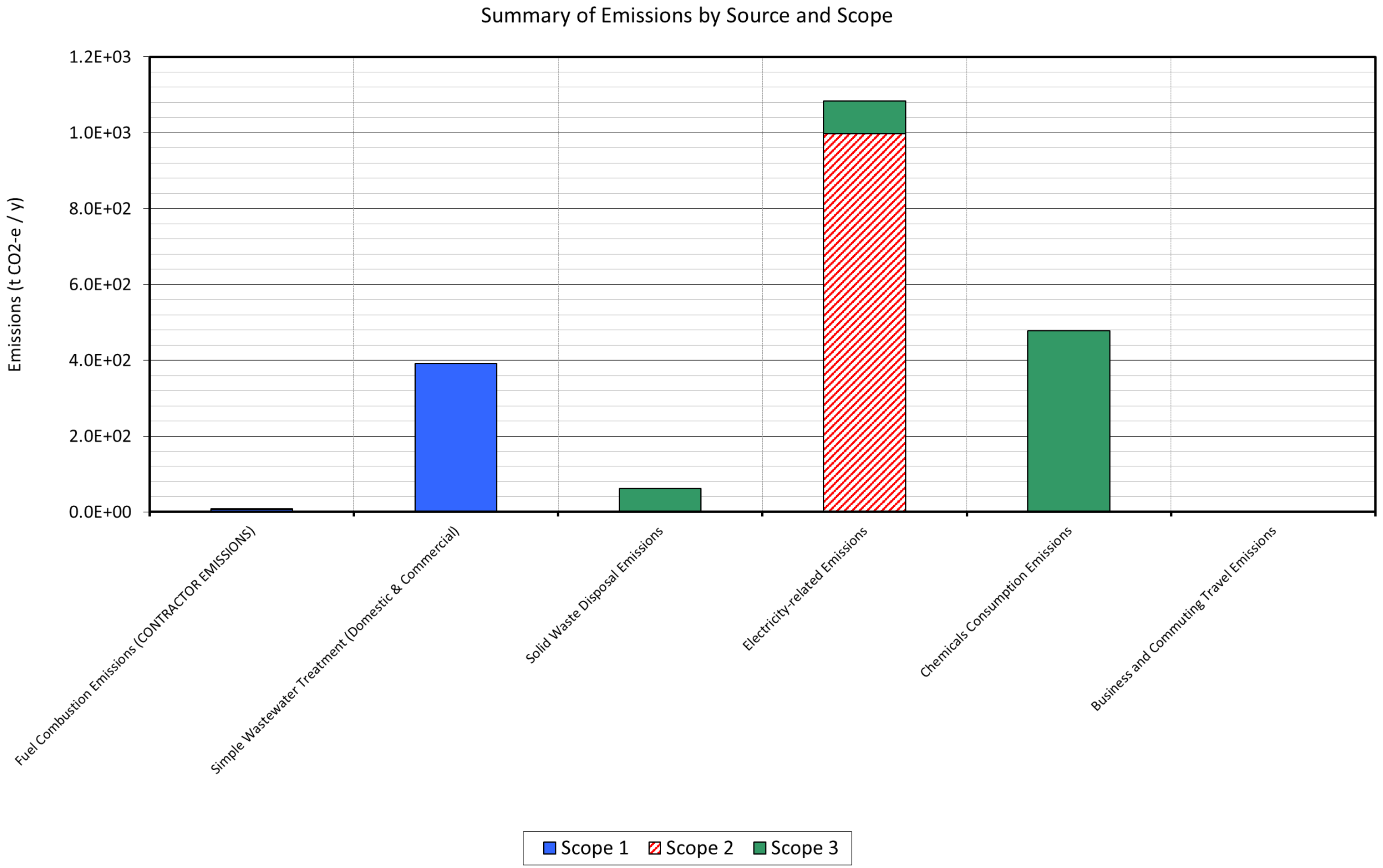


Figure 3-8 Site 1 (North) operational phase GHG emissions

Table 3-11 Site 1 (North) life cycle GHG emissions

Emission Source	Units	TOTAL	Scope 1	Scope 2	Scope 3
Fuel combustion emissions	t CO2-e / y	7	6	-	0
Wastewater treatment emissions	t CO2-e / y	391	391	-	-
Solid waste disposal emissions	t CO2-e / y	62	-	-	62
Electricity-related emissions	t CO2-e / y	1,083	-	997	85
Chemicals consumption emissions	t CO2-e / y	478	-	-	478
Business and commuting travel emissions	t CO2-e / y	2	-	-	2
Total operational phase emissions over 50 years	**t CO2-e**	**101,113**	**19,884**	**49,875**	**31,355**
Construction phase emissions	**t CO_2-e**	**5,056**			
Total life cycle emissions	**t CO_2-e**	**106,169**			

4. Site 2 (South)

4.1 Water source assessment

As identified in Section 2.3.2, the preferred water source for Site 2 (South) is TWW from the East Rockingham WWTP.

4.1.1 TWW flow projections

Flow projections for the East Rockingham WWTP are shown in Figure 4-1. There is sufficient source water for a 5 ML/d plant from 2019; and a 10 ML/d plant from 2027 at Site 2.

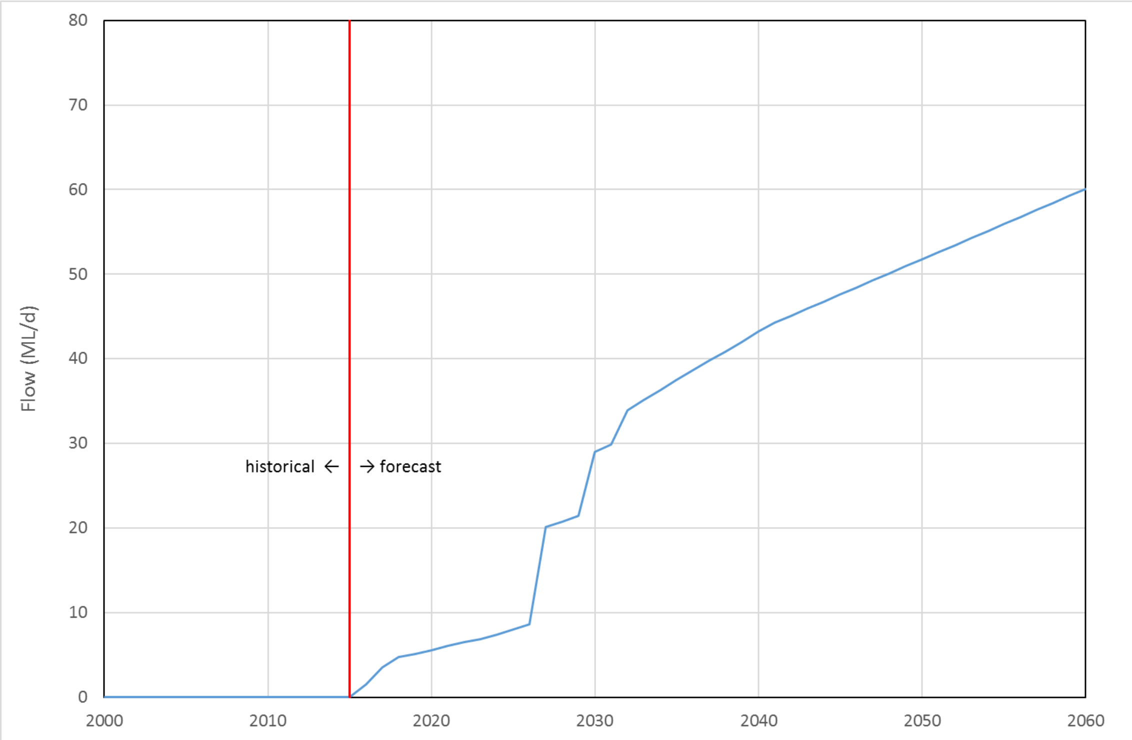


Figure 4-1 East Rockingham WWTP flow projections

4.1.2 Predicted future TWW quality

The first stage of the East Rockingham WWTP, operational since 2016, is a 20 ML/d capacity oxidation ditch plant. When operating at its design capacity the Water Corporation have advised that:

- Median TWW BOD will be < 5 mg/L,
- Median TWW TN will be < 5 mg/L, and
- Median TSS will be < 10 mg/L.

Current performance at East Rockingham WWTP is significantly better than this forecast, but the plant is only very lightly loaded (i.e. 2016 flows were only 1.5 ML/d). However, the forecast TWW quality is consistent with this type of plant.

No data on East Rockingham TWW salinity were available, however it is expected to be consistent with the recorded TWW salinity for Kwinana WWTP at approx. 360 mg/L (McFarlane, DJ (ed), July 2015, p. 56). There are no process upgrades or changes currently forecast at East Rockingham WWTP that would materially alter the TWW salinity.

Risks

In terms of the source water quality for a Site 2 MAR pre-treatment plant, the following key risks should be considered:

- In the very long term (50+ years) it is likely that the process configuration at the East Rockingham WWTP will be quite different to the current plant, and it is possible that the future plant will not achieve TWW TN levels < 5 mg/L, and/or TWW TSS levels < 10 mg/L.
- The MAR pre-treatment facilities will need some level of design contingency and/or protection to accommodate occasional poorer source water quality. For example, the TWW off-take may include an automated ON/OFF valve linked to an on-line turbidity and ammonia meters. When particulate concentrations and/or ammonia concentrations are above pre-determined trigger levels, the off-take valve is closed.
- The forecast TWW quality from East Rockingham is based on design targets and assumptions about future plant upgrades. However, if the characteristics of the East Rockingham sewerage catchment were to substantially change, then the forecasts would also need to be revised. For example, changes in drinking water source (i.e. transition to more seawater desalination), reduction in per capita water consumption and/or substantial new sewerage inputs from industry could alter the raw wastewater characteristics for East Rockingham.

For the purposes of this study, it has been assumed that no process changes at East Rockingham WWTP are currently forecast.

4.1.3 MAR pre-treatment requirements

Comparing the recycled water quality targets in Table 2-3 with the East Rockingham TWW quality summarised in Table 2-1 and Table 2-2 indicates that:

1. Organic matter removal (as measured by BOD) is not a significant concern.
2. pH adjustment is not a significant concern.
3. Solids/particulate removal (as measured by TSS and turbidity) will be required if infiltration galleries are used.
4. Nitrogen removal will not typically be required unless TWW nitrogen levels increase as a consequence of future process changes (unlikely for the short to medium term future, but possible in the long term). Contingency for nitrogen removal would be worthwhile, to accommodate TWW TN greater than the median 5 mg/L.
5. Re-aeration of the recycled water prior to MAR will be required (to minimise the potential for nuisance odour emissions) and could be provided by a simple aeration weir on entry to the infiltration basins or galleries.
6. Desalination will not be required.
7. Pathogen removal is not a significant concern.

4.2 Basis of design

The sections below summarise the basis of the engineering design work completed for Site 2. The basis of design draws upon the outcomes of previous studies as well as the additional investigations and analysis completed as part of this study, and includes the key design assumptions in this study.

4.2.1 Managed aquifer recharge rate

The design aquifer recharge rate is 10 ML/d. This is the maximum rate of the two rates considered by CSIRO in prefeasibility studies and associated predictive groundwater modelling (McFarlane, DJ (ed), July 2015).

4.2.2 Water source and offtake requirements

The water source for Site 2 shall be the East Rockingham WWTP. As an interim arrangement, a new pumpset for supply to Site 2 will be installed in the spare bay (Bay 4) of the East Rockingham WWTP existing temporary Final Effluent Pump Station (FEPS). This pumpset shall be designed to deliver a daily flow of 10 ML/d plus treatment losses, with flow balancing provided by the existing balancing tanks at East Rockingham WWTP.

The new facilities installed to pump TWW to the Site 2 pre-treatment facility shall include:

- Duty/standby pumps,
- Magnetic flowmeter,
- Turbidity and ammonia analysers to cut off supply to the pre-treatment facility at times when the feed TWW quality is out of specification, and
- SCADA link between East Rockingham WWTP and MAR pre-treatment facility to automatically inhibit the TWW pumps in the event of faults and/or high level alarms in the Recycled Water Storage Tank.

The Site 2 pre-treatment facility shall be located on industrial land fronting Alumina Rd, near the East Rockingham WWTP. The resultant recycled water shall then be pumped from the pre-treatment facility to the recharge site at Gentle Rd. Locating the pre-treatment facility close to East Rockingham WWTP assists with access, management of residuals and also reduces the environmental impacts (clearing, noise, odour) at Site 2.

4.2.3 Recharge method

Recharge at Site 2 shall be achieved using buried infiltration galleries. The key reasons for this approach are:

- With a higher design recharge rate than infiltration basins, and less redundancy required, infiltration galleries will have a significantly smaller footprint than equivalent capacity recharge basins. As a consequence the Bush Forever area loss (and clearing) will be significantly less if infiltration basins are installed,
- Whilst being within a vegetated reserve, Site 2 is located closer to sensitive residential receptors (approx. 650 m to the nearest residence, and approx. 300 m to the Kwinana Golf Clubhouse) and hence poses a potential odour risk, and
- Due to its steep terrain, Site 2 may not have sufficient land to accommodate terraced infiltration basins for the 10 ML/d design flowrate.

The buried infiltration galleries shall have an invert level at least 1.0 m below ground level, and be sized based on:

- Infiltration rate = 2 m/d across gallery floor area (GHD, June 2015, p. 16),
- 50% “redundancy” (i.e. active:resting = 1:0.5) (GHD, June 2015, p. 16).

4.2.4 Design TWW quality

As discussed in section 4.1.2, the TWW design conditions need to include some contingency to account for possible variable performance of East Rockingham WWTP and any future process modifications. The Site 2 MAR pre-treatment facilities are designed for the TWW quality (key parameters only) outlined in Table 4-1.

Table 4-1 Site 2 TWW quality design conditions

Parameter	Units	East Rockingham TWW
TSS	mg/L	Max. 12
TN	mg/L	Max. 8
NH_4-N	mg/L	Max. 2
TDS	mg/L	Max. 760

4.2.5 MAR Pre-treatment facility

The Site 2 (South) MAR pre-treatment facility shall be designed to achieve the target recycled water quality outlined in Table 2-3 using unit processes detailed in Table 4-2 (refer to discussion in Appendix F).

Table 4-2 Site 2 pre-treatment facility

East Rockingham TWW only
Denitrifying filter, with carbon dosing, for removal of solids and nitrogen Re-aeration weir
Expected recovery rate = 95%

Whether the denitrifying filter is required for this site is marginal, and will depend on the environmental licence conditions applied by DWER. Simple filtration may be sufficient to reduce the environmental discharge risk for this site. However, at this basis of design stage, it is considered prudent to allow for inclusion of carbon dosing for denitrification at Site 2.

Location

The pre-treatment facility for Site 2 is proposed to be located adjacent to the East Rockingham WWTP on approximately 4,000 m^2 of land currently owned by LandCorp and is included in the Rockingham Industry Zone (refer to Section 6.4 for additional work required to progress the pre-treatment design at this site). The product water would then be pumped to Site 2 for recharge.

Locating the pre-treatment facility close to East Rockingham WWTP assists with access, management of residuals and also reduces the environmental impacts (clearing, noise, odour) at Site 2.

4.2.6 Management of pre-treatment residuals

Adopting the unit processes outlined in Table 4-2, there will be approx. 0.5 ML/d of backwash that will require management and disposal. For Site 2, conveyance of residuals back to the East Rockingham WWTP – SDOOL connection (more specifically discharging into the flanged discharge manifold intake designed for the temporary FEPS' future fourth pump) is the most suitable solution. A discharge window of 9 h/d is assumed (to be agreed with Water Corporation).

4.2.7 Site access

Site access to the TWW feed pumps shall be via internal access roads within the East Rockingham WWTP, and the plant's main access road which comes off Mandurah Road.

Site access to the MAR pre-treatment facility shall be via Alumina Road.

Site access to the MAR infiltration site will be via the existing turn in off Gentle Road.

4.3 Engineering design

Building from the basis of design, background information and existing prefeasibility, the design for the Site 2 has been progressed to a level of detail to improve the accuracy of the cost estimates (Section 4.4). Outlined below is a brief description of each of the major assets required to implement the MAR trial site. The information provided below is further presented in the design drawings provided in Appendix E.

4.3.1 Overview and functional control

Scheme overview

Treated wastewater sourced from the East Rockingham WWTP (via offtake from temporary FEPS suction manifold) will be pumped direct to the denitrifying filter vessels at the MAR pre-treatment facility. The MAR pre-treatment facilities will comprise denitrifying filters designed to reduce solids and nitrogen levels. The treated water from these facilities will be stored in recycled water storage tanks, and the filter backwash will be stored in wastewater storage tanks. The majority of the recycled water will be pumped to a flow splitting structure at Site 2, and from this structure gravitate to two of the three downgradient banks of infiltration galleries that are operated on a rotating duty/duty/resting regime. The balance of the recycled water will be used to backwash the filters. Wastewater (filter backwash) will be disposed of via pumped transfer to the SDOOL, with the wastewater pipeline discharging into the future fourth pump's flanged intake to the East Rockingham temporary FEPS' delivery manifold.

A schematic Process Flow Diagram (PFD) for the scheme is included as Figure 4-2, and the following drawings included in Appendix E depict the proposed design of the scheme in further detail.

- 61-35557-G001 Cover Sheet and Drawing Index
- 61-35557-C003 Conveyance Pipelines from East Rockingham WWTP to MAR Site 2
- 61-35557-C006 Infiltration System – General Arrangement
- 61-35557-C007 Infiltration System – Infiltration Gallery Details
- 61-35557-C009 Pre-Treatment Facility– General Arrangement
- 61-35557-J004 Inlet and Denitrification Filter – P&ID
- 61-35557-J005 Waste Disposal and Infiltration – P&ID

Functional control

A functional description has been prepared for Site 2 and is included as Appendix D. A schematic Process Flow Diagram for these facilities is included as Figure 4-2. Both the functional description and the process flow diagram provide the operating philosophy for the Site 2 MAR system including:

- East Rockingham WWTP offtake,
- Denitrifying filters,
- MAR infiltration galleries, and
- Wastewater disposal.

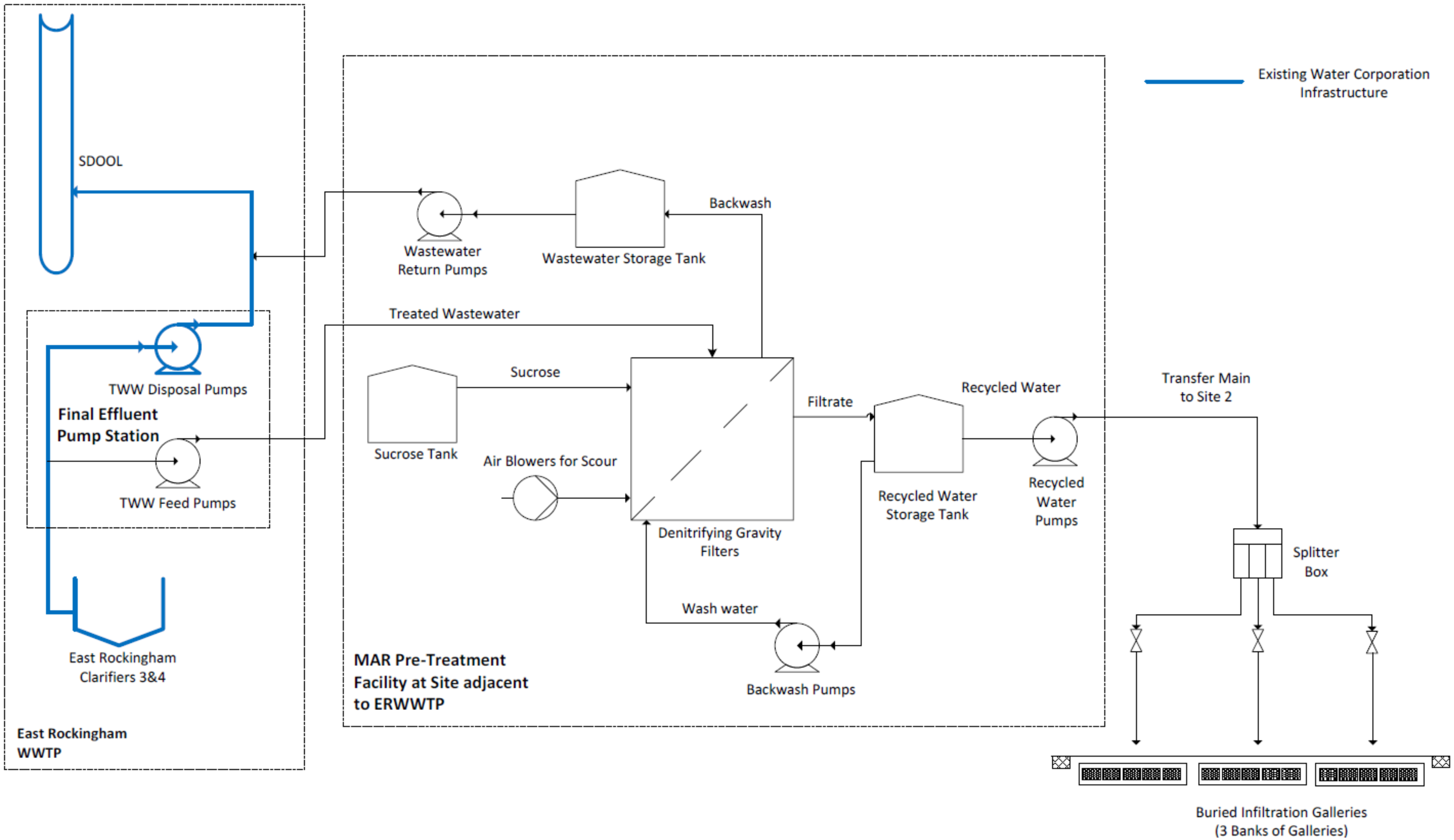


Figure 4-2 Site 2 MAR scheme – Process flow diagram

4.3.2 TWW feed/wastewater return pipelines

TWW sourced from the East Rockingham WWTP will be pumped to the MAR pre-treatment facility via duty/standby variable speed pumpsets and a DN355 PE100 PN16 pipeline.

Wastewater (filter backwash) from the MAR pre-treatment facility will be returned to the East Rockingham WWTP site via a DN125 PE100 PN16 pipeline that discharges into the temporary FEPS' discharge manifold at times when the large Woodman Point TWW pumps are not operating (when the latter pumps are running a control interlock will inhibit operation of the MAR pre-treatment facility's wastewater disposal pumpsets).

The diameter and pressure rating of each pipeline has been selected such that the maximum allowable working pressure (adjusted for a mean pipe wall temperature of 30ºC) exceeds the maximum surge pressure that could be generated by a sudden and uncontrolled valve closure interrupting the operation at the design flow rate. Pressure fluctuations during normal operation could be limited by the motor start controls of the pump stations. Setpoints for these controls will be determined as part of the future detailed design process.

The existing FEPS duties range from 277 L/s to 521 L/s with one pumpset operating, with much greater flows achievable by operating two pumpsets. The addition of 15 L/s from the MAR pre-treatment facility therefore represents a 3% to 5% increase in total flowrate in the DN900 effluent discharge pipeline and is expected to have no significant effect on the operation of the existing FEPS. Supply of TWW to the MAR pre-treatment facility will also reduce the operating time of the FEPS, particularly in the short to medium term future when a large proportion of the East Rockingham WWTP's TWW will be diverted to the MAR scheme.

4.3.3 Pre-treatment facility

Outlined below in Table 4-3 is a summary of the Site 2 (South) pre-treatment facility design. This should be read in conjunction with the process flow diagram in Figure 4-2. Further description of these technologies, and their operation for the MAR scheme, is provided as Appendix F.

Table 4-3 Site 2 (south) – Pre-treatment facility design summary

Unit process	Description	Design parameters	Operational requirements
TWW Feed Pumps	Duty / standby 30 kW centrifugal pumps 121 L/s @ 14.0 m head	Sized to provide constant feed to denitrifying filters	Estimated power draw = 21.7 kW @ 24 h/d Pump operation is interlocked to filter operation, ER WWTP and also downstream Wastewater Storage Tanks
Denitrifying Filters	4 × duty filter cells, operated in parallel: each 4.88 m long × 3.66 m wide, with 1.83 m bed depth (silica sand) External carbon (D.Nitro sucrose solution) dosing for denitrification, controlled to achieve TN < 5 mg/L	Hydraulic loading rate = 5.8 m/h (increasing to 7.8 m/h during backwash of 1 cell) 95% recovery rate Dose rate = 5 mgCOD/mgNO_x-N	Backwash frequency approx. <1 per day per cell Filter cells “bumped” 3 times per day per cell to liberate N_2 gas Approx. 200 L/d sucrose solution (67wt%) Solids production = approx. 150 kg/d (inc. biomass production)
Backwash Pumps	Duty / standby 15 kW centrifugal pumps 75 L/s @ 10.0 m head	Sized to provide backwash rate = 15 m/h	Estimated power draw = 10.2 kW @ 1.0 h/d Backwash initiated on head loss, outlet turbidity or elapsed time
Air Blowers	Duty / standby 45 kW positive displacement air blowers 1,610 m^3/h @ 1.6 atm	Sized to provide air scour rate = 90 m/h	Estimated power draw = 40.6 kW @ 1.1 h/d
Sucrose Storage Tank	1 x 1,500 L chemical storage tank + associated dosing pumps	Sized to provide approx. 7 days storage	Approx. weekly refills by delivery tanker Minor power draw for dosing pumps

Unit process	Description	Design parameters	Operational requirements
Recycled Water Storage Tank	1 × 204 kL lined tank in corrugated zincalume steel 7.8 m dia., 4.3 m high Covered and ventilated	Sized to accommodate approx. 1 day of backwash water requirements	None
Recycled Water Pumps	Duty / standby 110 kW centrifugal pumps 116 L/s @ 52.0 m head	Sized to provide constant transfer flow from pre-treatment facility to Gentle Rd infiltration galleries	Estimated power draw = 84.3 kW @ 24 h/d Pump operation is interlocked to Recycled Water Storage Tank
Flow Splitters	Primary Flow Splitter – 3 way split to 3 banks of infiltration galleries, with provision to manually take each bank off-line Secondary Flow Splitters (3 off) – 5 way split to 5 individual infiltration galleries	Two duty / one resting bank of infiltration galleries	None
Infiltration Galleries	Duty / duty / standby infiltration galleries	Infiltration rate = 2 m/d across gallery floor area 50% "redundancy" (i.e. active:resting = 1:0.5)	Periodic 'renovation' of infiltration galleries
Wastewater Storage Tank	1 × 385 kL lined tank in corrugated zincalume steel 10.7 m dia., 4.3 m high Covered, mixed and ventilated 1 x 1.5 kW duty mixer (or recirculation pump)	Sized to accommodate 1 day of backwash and "bumping" wastewater, with reinjection to SDOOL over 9 h/d Mixing energy = 4 W/m^3	Estimated power draw for mixers = 1.5 kW @ 24 h/d
Wastewater Return Pumps	Duty / standby 15 kW centrifugal pumps 13 L/s @ max. 55 m head	Sized to allow reinjection into transfer pipeline from ER WWTP to SDOOL	Estimated power draw = 10.0 kW @ 9 h/d Pump operation is interlocked to Wastewater Storage Tank and subject to Water Corporation SDOOL access requirements

4.3.4 Recycled water pipeline

A nominal 4.3 km long DN450 PE100 PN16 pipeline will be required to transfer recycled water from the MAR pre-treatment facility to the primary flow splitter at Site 2.

The nominated pipeline route has been refined from the initial background assessment. It was agreed with DJTSI that a pipeline along Mandurah Road would be difficult to construct the constraints of existing services. The proposed pipeline route utilises a north – south and an east – west service corridor which are part of the Rockingham Industry Zone (RIZ). The pipeline then continues under Mandurah Road and runs north in the land adjacent to Mandurah Road for a short distance before turning east and running within the Wellard Road road reserve. The pipeline route passes under the future FRCAH then turns north to run adjacent to and parallel with the FRCAH corridor and Gentle Road, crossing under the Dampier to Bunbury Natural Gas Pipeline, before reaching the nominated site. As shown on Drawing 61-35557-C003 the proposed pipeline route will cross the following major assets:

- Proposed railway corridor,
- Mandurah Road,
- Existing rail corridor,
- Proposed Fremantle Rockingham Controlled Access Highway, and
- Existing Dampier to Bunbury Natural Gas Pipeline (DBNGP).

With respect to the major road/rail/service crossings it is assumed that:

- Trenchless techniques (e.g. directional drilling) will be used to install the pipeline under Mandurah Road and the DBNGP corridor,
- The pipeline will be installed in a sleeve under the existing railway line using trenchless techniques. and
- The pipeline will be installed in sleeves across the corridor for the future FRCAH, and the corridor for the future railway line within RIZ, using open trench construction methods.

At detail design stage these road/rail/service crossings will need to be designed in accordance with the relevant asset owner standards.

With respect to the section of the pipeline proposed to be installed within RIZ service corridors, whilst LandCorp are the lead agency developing the RIZ and currently have included these service corridors into the planning for the zone, LandCorp are not the land owners for the land required to implement the service corridors and further negotiation is required to finalise the corridors. Additionally, the nominated pipeline route passes through private property and discussions will be required with the land owners during the next design stages.

A hydraulic grade line for the pipeline is included as Figure 4-3.

The diameter and pressure rating of the pipeline has been selected such that the maximum allowable working pressure (adjusted for a mean pipe wall temperature of 30ºC) exceeds the maximum surge pressure that could be generated by a sudden and uncontrolled valve closure interrupting the operation at the design flow rate. No requirement for surge mitigation measures is anticipated, but the pipeline operation will be confirmed during the future detailed design process.

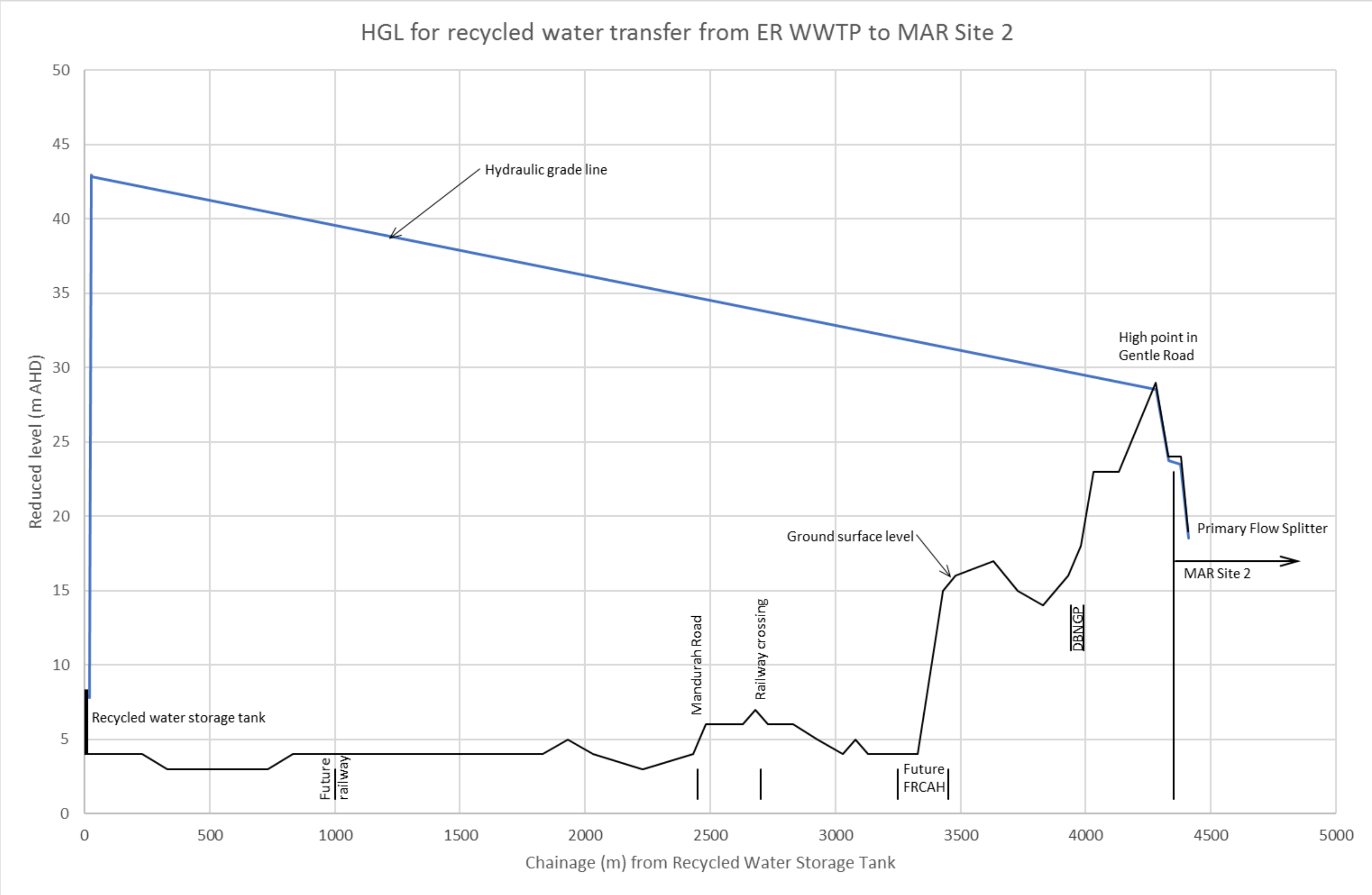


Figure 4-3 HGL for recycled water pipeline from MAR pre-treatment facility to Site 2

4.3.5 Recharge infrastructure

The Site 2 infiltration system consists of three banks of infiltration galleries, each comprising five 70 m long × 8 m wide individual 100 mm deep galleries formed from two layers of 50 mm deep proprietary interlocking drainage cell (Rainsmart Nero Pave®Cell or equivalent) covered with root-barrier type geotextile top and sides, with the gallery invert a minimum of 1.0 m below ground level. As this site has significant cross fall it is proposed that galleries would be oriented parallel to the contour and terraced down the slope to minimise their depth. Individual galleries are however proposed to be laid level to facilitate even distribution of recycled water across the available infiltration surface area.

The design for the galleries is based on DS Agency's DoH approved "flatbed leach drain" design. Images of this leach drain system are included in Figure 4-4.

Figure 4-4 Images of DS Agency's Flatbed Leach Drain System

(from http://www.rainsmartsolutions.com/50mm_nero_pave.html and https://www.ds.com.au/flatbed-leach-drain/)

To evenly distribute flow across the duty galleries' infiltration surface area it is proposed to use equal weir type flow splitting structures to evenly split flow between the duty galleries, and slotted distribution pipework to spread the flow across the length and width of individual galleries. The primary flow splitter and open/close isolation valves on the DN315 PE100 PN12.5 outlet pipework will be used to evenly split the recycled water flow and direct the flow to the two banks of duty galleries. Magnetic flowmeters will be installed on the outlet pipework from the primary flow splitter, to accurately monitor the volume of recycled water discharged to each bank of galleries.

Secondary flow splitters at the head of each bank of galleries will then evenly split flow between the five individual galleries. DN125 PE100 PN12.5 outlet pipework from the secondary flow splitters will discharge recycled water (via 2 × DN80 PE100 PN12.5 branches) into two slotted 100 mm × 50 mm rectangular section distribution pipes (or equivalent) that run the full length of the galleries.

Four open-bottomed precast concrete access chambers will be installed within each bank of galleries, to enable visual inspection of the infiltration surface and measurement/monitoring of the standing water height above the gallery invert level. Compacted limestone access tracks will be installed around the perimeter of each bank of galleries, and across the centre of each bank of galleries. The galleries will be overlain with a 100 mm deep layer of woodchips, and the gallery surface will be maintained vegetation/weed free to minimise the rate at which roots invade the gallery void volume.

The site will be surrounded by 1.8 m high chainmesh fence and 5 m wide vehicle access gate off Gentle Road.

4.3.6 Safety in design

For this site, the project involved development of designs for interim TWW pumping facilities at the Water Corporation's East Rockingham WWTP, a MAR pre-treatment facility, infiltration galleries and associated works including conveyance facilities and access roads. Further development of the project will require consideration of a range of risks including those set out below. Given the conceptual nature of the engineering work completed in this study, the following list is not comprehensive.

Risks for further consideration and formal assessment include:

1. Management of traffic during construction, commissioning, operation and maintenance.
2. Installation of pipelines/sleeves under major roads, railway lines and high pressure gas pipelines during construction, commissioning, operation and maintenance.
3. Working around live services and implementing isolation / bypass procedures.
4. Working at height risks associated with the MAR pre-treatment facility during construction, commissioning, operation and maintenance.
5. Pathogen and other contaminants in sewage during construction, commissioning, operation and maintenance.
6. Working over and around open water during construction, commissioning, operation and maintenance.
7. General electrical, mechanical and chemical risks during construction, operation and maintenance
8. Protection of existing services and utilities.
9. General construction risks.

4.4 Cost estimates

4.4.1 CAPEX

A CAPEX estimate (accuracy +/- 25%) developed for Site 2 is summarised in Table 4-4. The cost estimate exclusions applicable to the estimate is summarised in Table 4-5. A more detailed breakdown of the estimate, including details of the assumptions made in developing the estimate and the basis of the rates used, is provided in Appendix G. The rates and cost estimates were derived from a mix of project-specific vendor quotes (treatment facilities, tanks, pump stations, infiltration galleries), (Rawlinsons , 2017), estimates developed by GHD for this project or previous projects, and for some items nominal allowances.

Table 4-4 Site 2 CAPEX estimate summary

Item	CAPEX (2018 $M)
DIRECT COSTS	
TWW Pump Station (East Rockingham WWTP)	0.4
Pipelines	3.9
MAR Pre-treatment Facility	
General site/civil works and access roads	0.2
Filtration vendor package	4.0
Balance of plant	1.3
Infiltration galleries	
General site/civil works and access roads	0.7
Infiltration galleries and pipework	1.1
Monitoring bores	0.1
Total Direct Costs	**11.7**
INDIRECT COSTS	
Investigations and Approvals	0.4
Design and Project Management	1.7
Contingency (25%)	3.5
Total Indirect Costs	**5.6**
TOTAL CAPEX	**17.3**

Table 4-5 Site 2 CAPEX estimate exclusions

Item	Description
1	Land acquisition and easement costs
2	Bush Forever offset costs
3	Additional groundwater modelling studies (assuming CSIRO studies satisfy regulatory agencies and adequate to inform environmental impact assessment).

4.4.1 OPEX

An OPEX estimate (accuracy +/- 25%) developed for Site 2 is summarised in Table 4-6. The cost estimate exclusions applicable to the estimate are summarised in Table 4-7. A more detailed breakdown of the estimate, including details of the assumptions made in developing the estimate and the basis of the rates used, is provided in Appendix G. Of note a conservative approach was adopted when estimating the cost of the supplementary carbon required to be dosed to the denitrifying filters.

Table 4-6 Site 2 OPEX estimate summary

Item	OPEX (2018 $k/year)	
	With Sucrose Dosing	Without Sucrose Dosing
Ongoing Costs		
Operator and vehicle	173	173
Power	309	309
Chemicals - Sucrose	53	0
Pre-treatment Facility laboratory analysis costs	7	7
Major planned maintenance and unplanned maintenance	26	26
Infiltration gallery site maintenance	6	6
Groundwater monitoring program	39	39
Sub Total	**613**	**560**
Contingency (20%)	123	112
Licensed service provider profit margin (15%)	110	101
TOTAL	**850**	**773**
PLUS Periodic Costs		
Infiltration gallery renovation/reconstruction		598
Contingency		120
Licensed service provider profit margin		108
TOTAL		**830**

Table 4-7 Site 2 OPEX estimate exclusions

Item	Description
1	Water Corporation TWW supply charges
2	Water Corporation wastewater disposal charges
3	Capital replacement costs

4.4.2 Unit Water Cost

Preliminary unit water cost estimates were also developed for the scheme, based on a simplistic net present value analysis over a project life of 50 years and using real (pre-tax) discount rates of between 4 and 12% per year.

The unit water cost estimates are included Appendix G. We understand that another consultant (Synergies Economic Consulting) has been commissioned to complete a more detailed financial analysis for the project, one output from which will be more refined unit water cost estimates for the project that will supersede the preliminary figures developed in this study.

4.5 Lifecycle assessment

4.5.1 Methodology

Overview

Life cycle assessment is an internationally recognised approach for assessing and comparing environmental impacts of products and processes. In this study, the life cycle impacts of greenhouse gas emissions from the proposed WTC MAR scheme have been assessed, in a manner consistent with the principles and framework outlined in ISO 14040:2006, *Environmental Management – Life cycle assessment – Principles and framework*.

Goal and scope

The goal of this life cycle assessment was to calculate the greenhouse gas (GHG) emissions associated with the construction and operation of the Site 2 (South) Managed Aquifer Recharge (MAR) scheme for the Western Trade Coast.

Functional unit

The functional unit for the assessment of the site was 10 ML/d of recycled water recharged to the aquifer, over the 50 year design life of the scheme.

This equates to a total recharge volume of 182.5 GL.

System boundaries

The system boundary for the MAR Scheme is outlined in Figure 4-5. The following life cycle stages were considered:

- Construction of the pre-treatment facility, infiltration galleries and connecting pipework, and
- Operation of the pre-treatment facility (consumption of electricity and chemicals, fugitive emissions from denitrification, and transport / disposal of solids).

The following activities were excluded from the assessment:

- Upstream treatment facilities and infrastructure associated with the manufacture of TWW (i.e. Water Corporation’s East Rockingham WWTP, and SDOOL), and
- Downstream infrastructure and receiving environments for residual liquid wastewater from the MAR Scheme (i.e. SDOOL and ocean outfall receiving environment).

The activities were excluded on the basis that they are existing operations, that will continue to occur independently of any MAR Scheme.

In addition, end-of-life decommissioning and deconstruction of the MAR scheme was also excluded. Emissions associated with this phase of the life cycle are likely to be negligible.

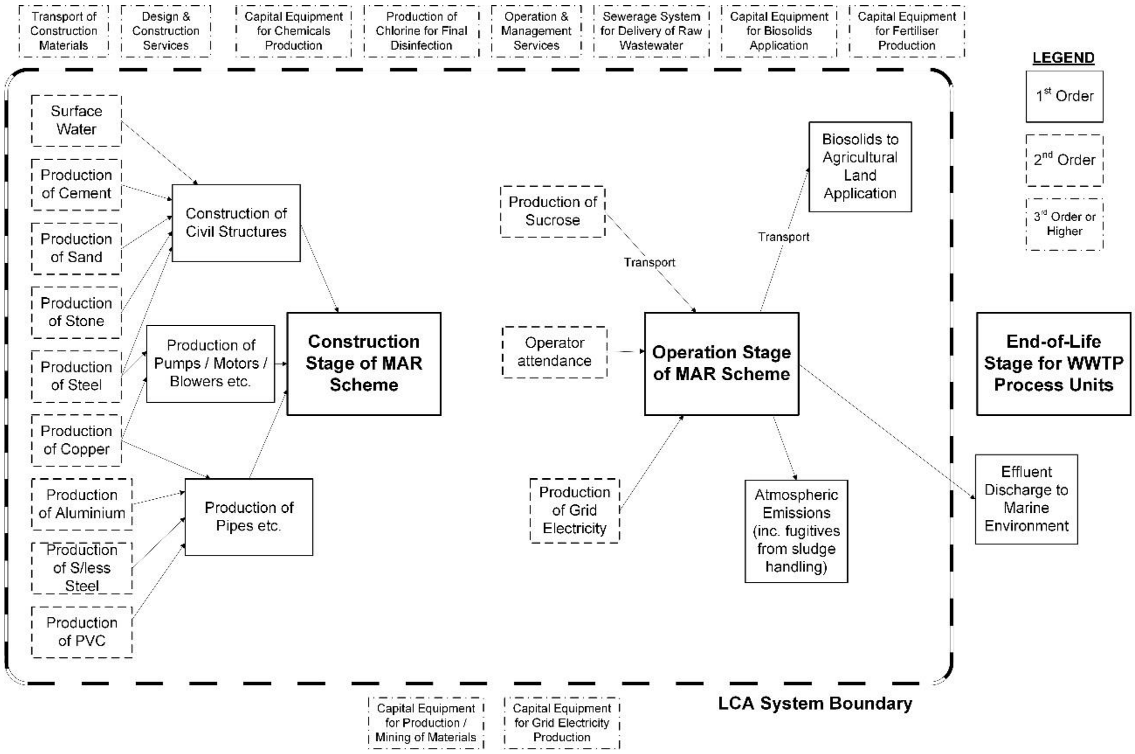


Figure 4-5 System boundary for Site 2 (South) MAR scheme

Calculation procedures

The assessment was undertaken using a spreadsheet model developed by GHD for the Water Services Association of Australia (WSAA), and the associated *National Greenhouse and Energy Reporting System: Guidelines for the Water Industry* (2011).

Data collection and assumptions

Inventory data was based on the MAR Scheme engineering design developed by GHD. A summary of inventory data and assumption is provided in Section 4.5.2.

Impact assessment method

The impact assessment method for this study was limited to greenhouse gas emissions only, expressed in units of tonnes of carbon dioxide-equivalents (t CO_2-e). This approach uses internationally recognised Global Warming Potentials (GWPs) of different greenhouse gases to convert back to a single indicator of CO_2-e. The major GWPs relevant to this study are outlined in Table 3-9.

4.5.2 Inventory

The data used for the operating phase of the MAR Scheme are summarised in Table 4-8.

Table 4-8 Operating phase inventory data used for Site 2 (South)

Parameter	Units	Site 1
Consumables		
Electricity (Filter Plant)	kWh/y	1,178,300 [16]
Sucrose [17]	tonnes/y	65
Transportation		
Chemical deliveries [18]	km/y	2,600
Disposal of solid waste	km/y	500 [19]
Operator attendance [20]	km/y	7,800
Direct emissions		
Nitrogen removal in pre-treatment facility	tonnes/y	10 [21]
Solid waste applied to land	dry tonnes/y	54, with 5_{wt}% N

Given the relatively small size of the infrastructure required for the scheme, and the long operational design life (50 years), the construction phase GHG emissions are expected to be only a minor portion (i.e. << 5%) of the whole life cycle emissions (Foley, 2009). Hence, no detailed construction phase inventory has been developed for this study.

4.5.3 Impact assessment and interpretation

The annual operational phase GHG emissions for Site 2 (South) are shown below in Figure 4-6, broken down by Source and Scope [22].

Not unexpectedly, the large majority of emissions are indirect and related to electricity consumption (Scope 2 and Scope 3). Other minor sources are Scope 3 emissions associated with the production and delivery of external carbon (i.e. sucrose) and direct Scope 1 nitrous oxide emissions from the denitrification process in the filters. Negligible emissions are associated with solid waste disposal and other transportation activities.

Total emissions over the 50 year design life for the MAR scheme are shown in Table 4-9.

---

[16] Includes electricity for Recycled Water Pumps to Gentle Rd site.

[17] Embodied emissions associated with the production of sucrose solution were estimated using methanol production as a proxy.

[18] Assuming weekly deliveries in a medium-sized truck, at 50 km per round trip.

[19] Assuming max. 1 renovation and disposal operation per year in a heavy truck, at 500 km per round trip.

[20] Assuming operator attends site 3 d/wk in a 4WD/utility vehicle, at 50 km per round trip.

[21] Assuming influent TN = 8 mg/L, and recycled water TN = 5 mg/L.

[22] Direct emissions from sources within the boundary of an organisation are known as “Scope 1” emissions. Indirect emissions from the consumption of purchased electricity, steam or heat are known as “Scope 2” emissions. All other indirect emissions as a consequence of an organisation’s activities, but are not from sources owned or controlled by the organisation are known as “Scope 3” emissions.

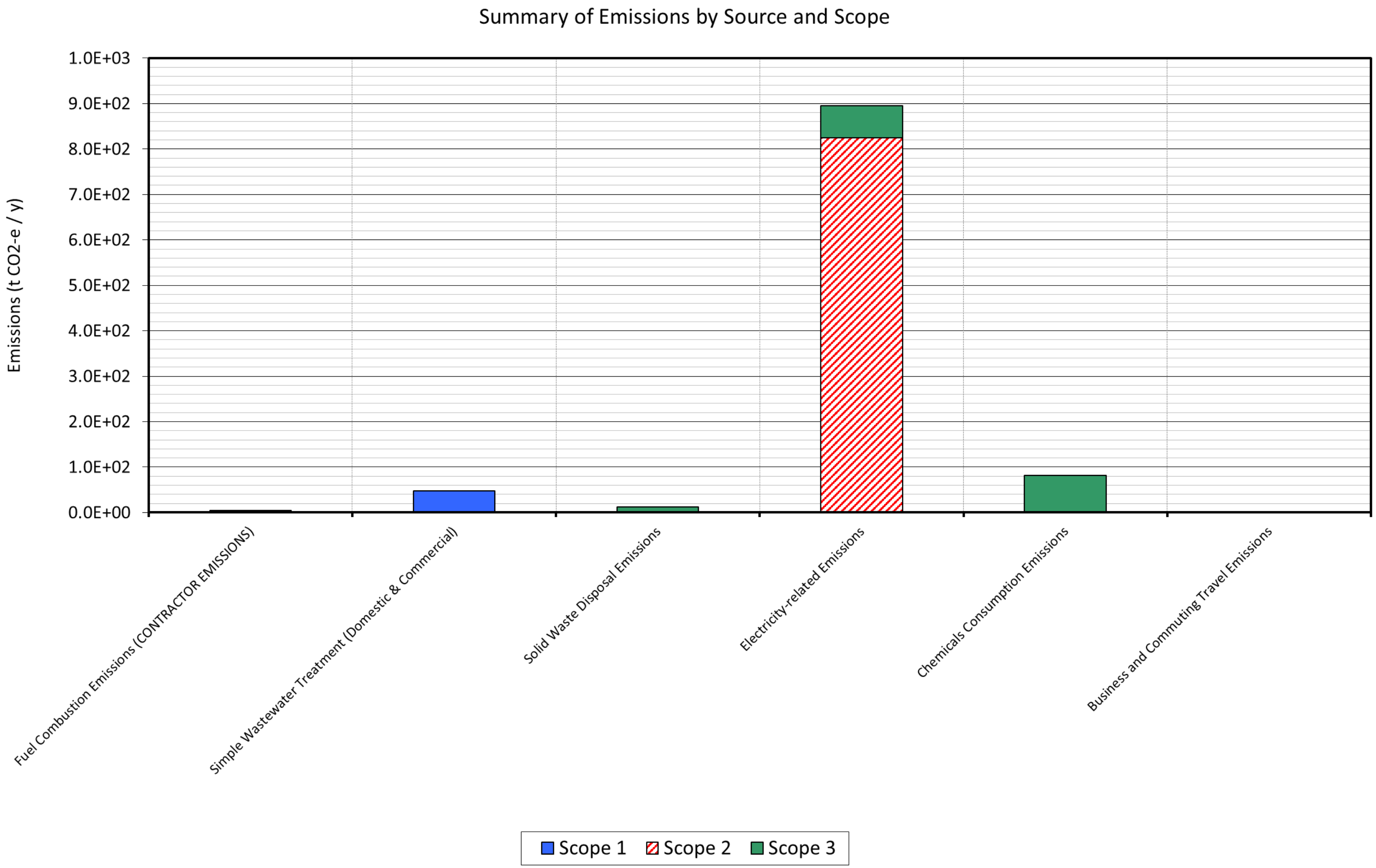


Figure 4-6 Site 2 (South) operational phase GHG emissions

Table 4-9 Site 2 (South) life cycle GHG emissions

Emission Source	Units	TOTAL	Scope 1	Scope 2	Scope 3
Fuel combustion emissions	t CO2-e / y	3	3	-	0
Wastewater treatment emissions	t CO2-e / y	48	48	-	-
Solid waste disposal emissions	t CO2-e / y	12	-	-	12
Electricity-related emissions	t CO2-e / y	896	-	825	71
Chemicals consumption emissions	t CO2-e / y	82	-	-	82
Business and commuting travel emissions	t CO2-e / y	2	-	-	2
Total operational phase emissions over 50 years	**t CO2-e**	**52,084**	**2,519**	**41,240**	**8,324**
Construction phase emissions	**t CO_2-e**	**2,604**			
Total life cycle emissions	**t CO_2-e**	**54,688**			

5. Groundwater monitoring

5.1 Introduction

A groundwater monitoring program has been developed for the MAR trial sites to provide:

- The establishment of baseline groundwater levels and groundwater quality, both at the trial sites and at key receptors,
- Determination on the extent and degree of impact from MAR operation - i.e. through providing a targeted monitoring network to allow ongoing groundwater monitoring, and
- Validation of groundwater modelling, including assumptions on aquifer properties and composition.

The installation of the groundwater monitoring bores will allow the detailed assessment of the site specific hydrogeology at each trial site, with site specific determination of local scale aquifer characteristics. This shall include detailed assessment of lithology, depth and composition of aquifers, and degree of interconnection. This is in turn will assist in the final design and operating expectations of the MAR trial infiltration basins and galleries through a more detailed understanding of the unsaturated and saturated zone properties.

The following sections outline the proposed monitoring program. The monitoring program has been developed using an understanding of the hydrogeological conditions and the key site receptors.

5.2 Proposed monitoring program

5.2.1 Aims

The aim of the monitoring program is to provide baseline groundwater level and groundwater quality data prior to the commencement of the MAR trials. Development of the monitoring program will also allow the site specific hydrogeological conditions to be determined. This will be important to validate model assumptions for the infiltration properties of the sites, and to further develop the site conceptual and numerical hydrogeological models.

Following the review of key site conditions, it has been determined that targeted monitoring should focus on:

1. Areas within the MAR trial sites, and
2. Off-site areas of potential impact/sensitive receptors.

It should be noted, that any monitoring program will need to adapt as further site information becomes available. For example, the drilling data may reveal differing hydraulic conditions to the assumptions used in the model, in which case receptor impacts may need to be re-assessed which could alter the proposed monitoring program.

Proposed monitoring locations are summarised below in Table 5-1 and Table 5-2, and illustrated on Figure 5-1 and Figure 5-2 for Site 1 (north) and Site 2 (south) respectively.

Table 5-1 Proposed monitoring locations – Site 1

Receptor / monitoring point	Reason	Approach	Monitoring location
On site	Determine site specific geological profile, baseline groundwater elevation and quality including seasonal ranges (validate model assumptions).	Install monitoring wells at up to three locations: Immediately down gradient of each basin and between basins. Bores to fully screen the superficial formation, including allowance for mounding.	On site
Groundwater abstraction / Contaminated site immediately east of site (Lot 1 On Plan 24276 Electricity Generation and Retail Corporation)	Potential for groundwater abstraction to be impacted. Assess upgradient mounding (as per modelled hydrographs).	New monitoring location at receptor location, or use existing site monitoring wells (assumed installed for contamination assessment).	N4 Or existing site monitoring wells
Immediately down gradient	Determine near site mounding and change in water quality. Confirm extent of site geological profile.	Two new monitoring locations down gradient of site, for example off Lussky Rd. 180-250 m from western edge of basins.-	N5, N6
Distant down gradient	Determine mid distance mounding and change in water quality – likely impacts at 2-5 yrs. Confirm extent of site geological profile.	Single monitoring location down gradient of site, off Rockingham Rd, 750 m from basins.	N7
Resource Enhancement wetland (unnamed) at Cockburn Rd/Rockingham Rd junction. 1 km west of site.	Potential for mounding/nutrients to impact swamp.	New monitoring location at receptor, or use new monitoring location immediately down gradient of Site 1.	N8
Long Swamp Conservation Wetland 700 m south east of Site	Potential for mounding/nutrients to impact swamp. Swamp has high salinity. However modelling suggest impacts are more north of here.	New monitoring location at receptor. There is an historic monitoring bore here (WIR bore 61410069), however this bore is not likely to still exist/be useable. Data from this bore may provide some historical contact/baseline data.	N9

Receptor / monitoring point	Reason	Approach	Monitoring location
Large scale groundwater abstraction - Alcoa. 1 km west of site.	Potential for groundwater abstraction to be impacted – likely to be significant time period after MAR starts.	Too distant – use new down gradient of site monitoring wells in the short term.	TBC
Lake Mount Brown Conservation Wetland 1500 m north west of Site	Potential for mounding/nutrients to impact swamp. Swamp has high salinity. However modelling suggest impacts only likely at 20 years under high MAR scenario	Possibly too distant, or use existing bore 61407112 which is near wetland and Establish baseline bore to determine current conditions.	N11 and/or 61407112 (N10)

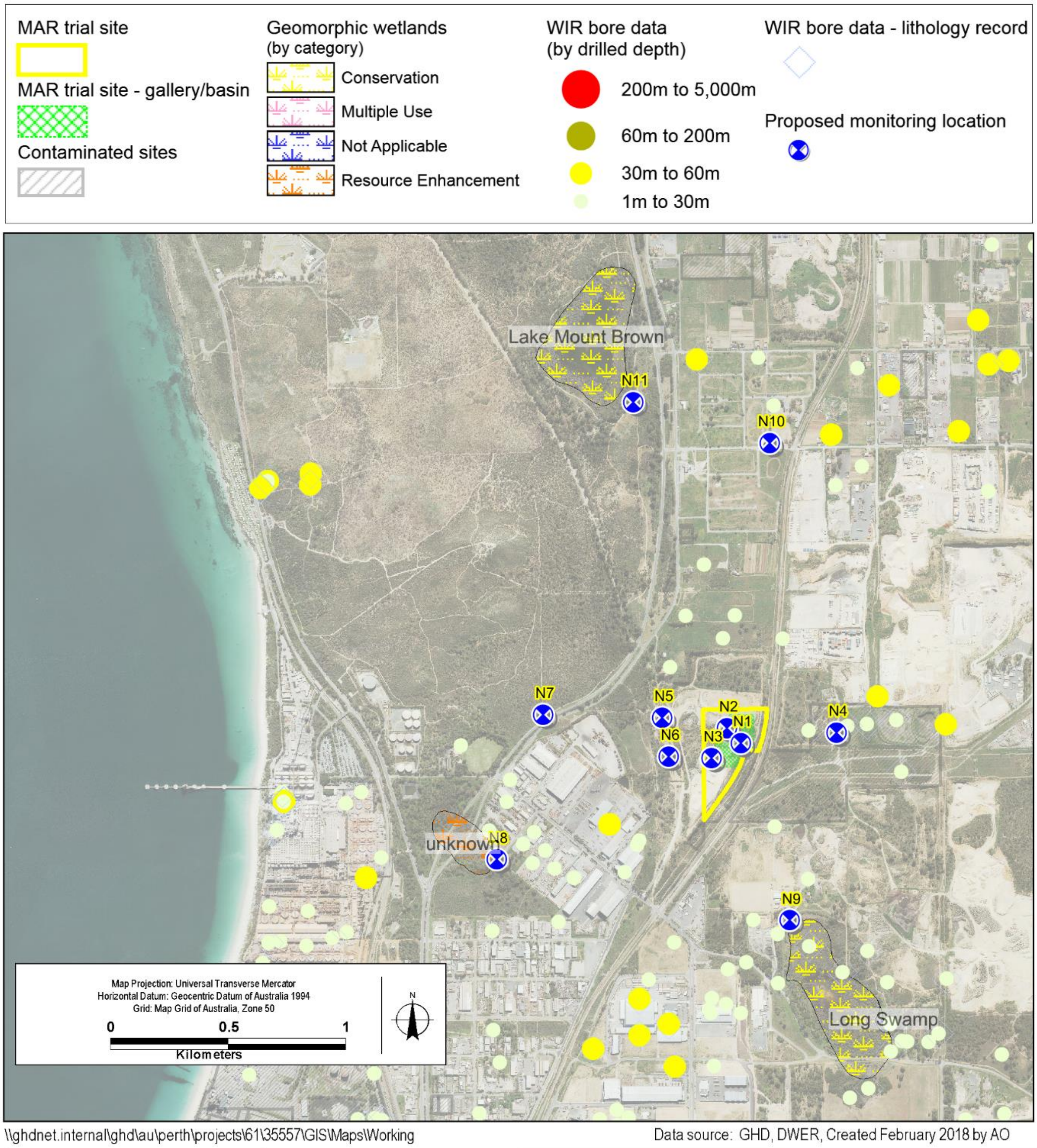


Figure 5-1 Site 1 – constraints and conceptual monitoring locations

Table 5-2 Proposed monitoring locations – Site 2

Receptor / monitoring point	Reason	Approach	Monitoring location
On site	Determine site specific geological profile, baseline groundwater elevation and quality including seasonal ranges (validate model assumptions).	Install monitoring wells at up to three locations. Immediately down gradient of galleries. Bores to fully screen the superficial formation, including allowance for mounding. Site to also include Leederville aquifer monitoring.	S1, S2, S3
Immediately up gradient and at Resource Enhancement Wetland	Determine near site mounding and change in water quality near gold course Resource Enhancement Wetland.	New monitoring location up gradient of site, approximately 60-100 m from galleries and adjacent to site edge/wetland.	S4
Close down gradient and at Resource Enhancement Wetland	Determine near site (300 m) mounding and change in water quality. Upgradient of unnamed wetland area on Tasker Rd (WIR bores indicates sand and limestone to 34 then siltstone (Leederville).	Potential to use existing WIR bore 61410053 (current and historic data) to establish baseline data	S5 or 61410053
Conservation Wetland 600 m south west of Site	Determine baseline conditions at Conservation (unnamed) wetland and monitor for mounding, water quality impacts.	Single monitoring bore adjacent to wetland.	S6
Distant down gradient near industrial strip abstraction	Determine baseline conditions and potential impacts from large scale industrial abstraction – see model for plume deviation. Plume to get there in >5 years.	Single monitoring bore down gradient of site, location off Patterson Rd.	S7
Distant down gradient	Determine baseline coastal and long term impacts. Close to large scale abstraction (down gradient of)	Single monitoring bore down gradient of site at existing WIR 61410035	S8 or WIR 61410035

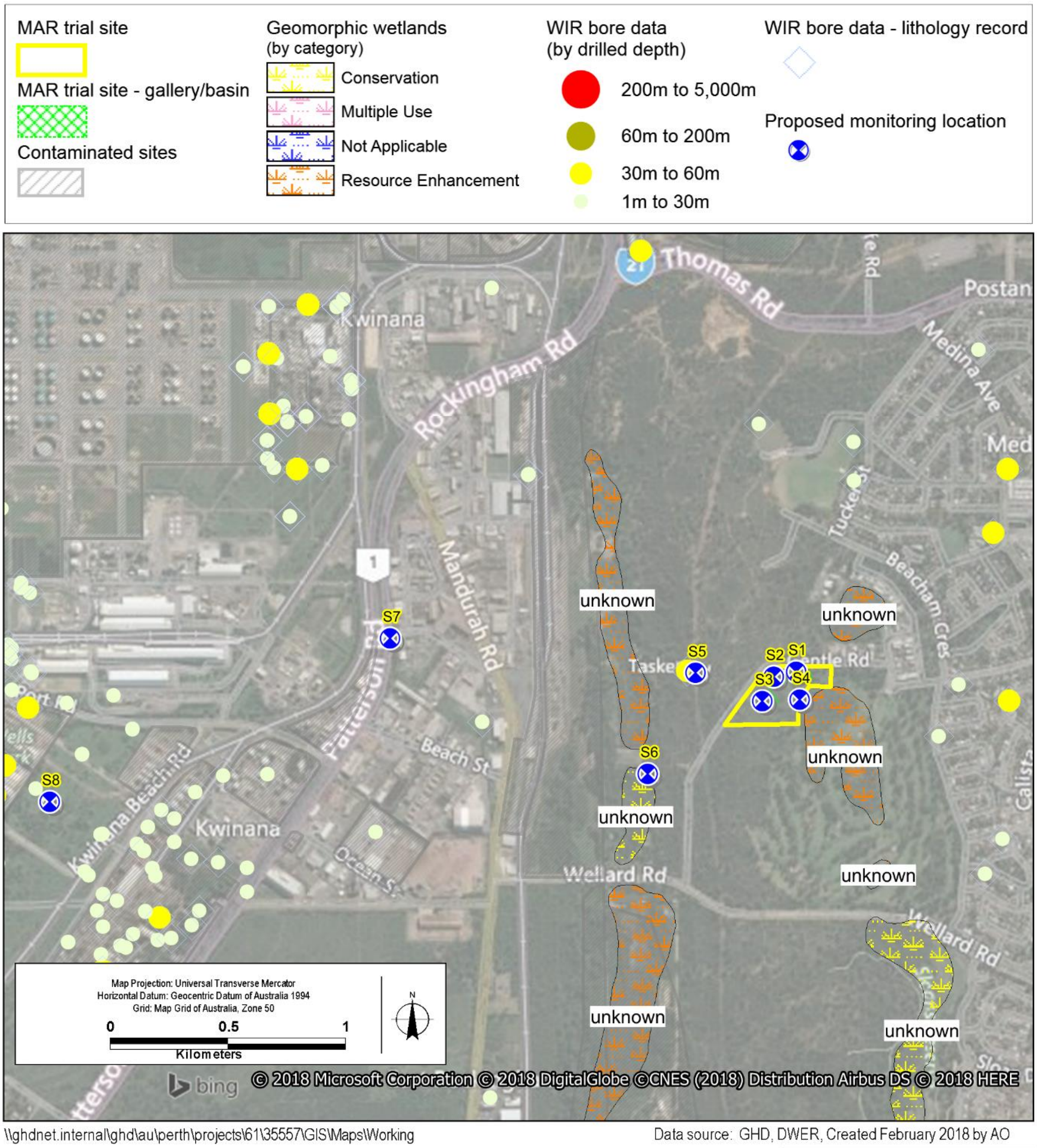


Figure 5-2 Site 2 – constraints and conceptual monitoring locations

5.2.2 Monitoring well installation and design

It is proposed that superficial aquifer monitoring locations be installed at the locations discussed in Table 5-1 and Table 5-2, and illustrated on Figure 5-1 and Figure 5-2 for Site 1 and Site 2 respectively. Monitoring bore drilling and construction should be completed in accordance with *Minimum Construction Requirements For Water Bores In Australia* (National Uniform Drillers Licensing Committee 2011).

The locations presented in the figures and tables are provisional and have been located in areas that are deemed accessible through a desktop review of site data. Where possible they have been positioned in open and accessible areas, however field assessment will be required to review site suitability, ownership and the presence of above and below ground services.

5.2.3 Drilling method

The installation of new groundwater monitoring bores should be completed using appropriate drilling methodologies depending on the lithology expected at each location. The preferred approach would be a drilling method that allows accurate assessment of the lithological profile, whilst also being able to monitor groundwater flow and groundwater quality. This could be achieved through dual-tube vacuum air-core techniques.

In accordance with the approach adopted by DWER for new monitoring bores, the drilling should be completed at an appropriate diameter to allow the installation of 100 mm diameter PVC casing. This larger diameter casing provides a greater range of sampling methodologies i.e. sampling and down-hole logging equipment, than traditional 50 mm diameter monitoring bores.

Bore installation methods should have the capacity to accurately seal off any units to be screened, with cement grouting of overlying formations. It should be noted that drillers completing monitoring bores within the confined Leederville Aquifer will need to be ADIA Class 2 licensed drillers. Drilling of Leederville Aquifer monitoring bores will also require a 26D licence application, made to the DWER (superficial aquifer monitoring bores are exempt from licensing).

Bore installations – Superficial aquifer

It is recommended that superficial aquifer monitoring bores be installed to the base of the superficial formations, with a screened interval extending from approximately 2 metres above the maximum groundwater level to the base of the superficial formations. Having a screen length extending across the entire depth of the superficial aquifer will allow vertical profiling of groundwater quality, a viable option in formations with high throughflow. Screening to above the maximum groundwater level will allow for monitoring of the full saturated thickness should mounding occur. Nominal bore depths and screen intervals are presented as Table 5-3.

Whilst a single fully screened superficial monitoring bore is the generalised approach, some flexibility will be required. For example, if during drilling any confining layers are noted (or perched groundwater), then the bore design will need to modified accordingly. This may result in more than one monitoring bore at each location, screening different units. Any monitoring bore targeting a specific unit will be required to be grouted off above the screen interval.

Bore installations – Confined aquifer

As presented as Table 5-3, it is recommended that at least one location includes the installation of a monitoring bore that is screened within the underlying Leederville Aquifer. Drilling to this depth will assist in further developing the site conceptual model through identifying the nature of the underlying formation, and particularly its degree of connectivity to the superficial formations.

It is expected that Kardinya Shale is present at Site 1. As the Kardinya Shale is considered a confining unit, monitoring bore installation should target the underlying Pinjar unit.

Table 5-3 Nominal bore details

Site ID	Easting MGA50	Northing MGA50	Elevation m AHD	Depth to base of superficial (mbgl)	Screen interval (mbgl)	Screen length (m)
N1	386,588	6,438,048	7.0	30	6 - 30	24
N1-C^	**386,589**	**6,438,049**	**7.0**	**30**	**40-46**	**6**
N2	386,530	6,438,112	7.5	31	7 - 31	24
N3	386,464	6,437,984	12.0	35	11 - 35	24
*N4**	*386,995*	*6,438,092*	*16.6*	*39*	*15 - 39*	*24*
N5	386,255	6,438,155	14.1	37	13 - 37	24
N6	386,282	6,437,991	16.3	39	15 - 39	24
N7	385,749	6,438,169	4.2	28	3 - 28	25
*N8**	*385,551*	*6,437,553*	*0.0*	*24*	*0.5 - 24*	*23.5*
N9	386,795	6,437,295	6.5	28	1 - 28	27
*N10**	*386,711*	*6,439,322*	*17.2*	*41*	*16 - 41*	*25*
*N11**	*386,131*	*6,439,495*	*1.9*	*27*	*1 - 27*	*26*
S1	386,571	6,432,204	8.9	29	6 - 29	23
S2	386,476	6,432,181	11.6	32	9 - 32	23
S2-C	**386,477**	**6,432,182**	**11.6**	**32**	**40 - 46**	**6**
S3	386,429	6,432,079	15.5	36	13 - 36	23
S4	386,588	6,432,087	5.1	26	3 - 26	23
*S5**	*386,144*	*6,432,194*	*13.4*	*34*	*11 - 34*	*23*
S6	385,945	6,431,765	6.3	28	4 - 28	24
S7	384,844	6,432,327	8.6	31	1 - 31	30
*S8**	*383,404*	*6,431,618*	*3.2*	*28*	*2 - 28*	*26*

^ Confined aquifer monitoring – located within the MAR sites

** Secondary targets – existing monitoring bores at these sites may be usable, or monitoring location can be adopted at a later date.*

5.2.4 Conceptual monitoring program

Once the monitoring network is established, baseline groundwater conditions should be determined through implementation of a monitoring program. Monitoring should be completed for at least an annual period before the MAR trial and then continue during the MAR trials to determine the groundwater impacts, and validate the predictive modelling.

The monitoring program should include the following assessments

Depth profiling

The fully screened nature of the superficial aquifer monitoring bores will allow baseline and ongoing records of salinity/conductivity profiles to be assessed for each bore. Monitoring of depth variable parameters will assist in developing the understanding of aquifer dynamics and assessing how the treated waste water is mixing through the aquifer. It will also provide important data on any saline intrusion that may occur through the base of the superficial formations, particularly those locations closest to the coast.

Depth profiling can be completed using various methods, such as down-hole induction logging (will provide formation conductivity) or running of level, temperature and conductivity data loggers within the screened profile (will provide water column conductivity data).

Groundwater levels

Regular groundwater level monitoring should be completed on the monitoring bores to establish the groundwater level ranges and to provide more detailed data on the potentiometric surface around the MAR trial sites.

It is advised that groundwater level data-loggers be installed in each bore as these will provide a near continuous record of groundwater level changes. This has considerable advantages over periodic manual groundwater level dips. The loggers will allow assessment of short term responses to recharge events (including rainfall and treated waste water infiltration), and a more accurate assessment of the seasonal range of groundwater levels.

Groundwater quality sampling

Baseline and ongoing groundwater quality sampling will be required on the new and existing monitoring bores. The baseline groundwater quality monitoring should be completed on the full network of monitoring locations, whereas ongoing groundwater quality monitoring may be scheduled to focus on those monitoring locations closest to the trial sites.

Based on the proposed approach of installing fully screened monitoring bores across the saturated thickness of the superficial aquifer, it will be possible to complete depth variable groundwater sampling. This can be achieved through use of no-purge sampling methods such as using Hydrasleeves. Hydrasleeves are a weighted sampling sleeve that is lowered into the monitoring bore and allowed to equilibrate for at least 24 hours. After equilibration, sleeves are filled and are retrieved without purging, collecting a “core” of representative groundwater at a consistent depth within the bore. Multiple sleeves can be deployed at various depths within the bore, with each sleeve representing around 2 m of screen length (depending on the volume of sample required for laboratory analysis). The action of retrieving (upward motion) the sleeve opens a check-valve which allows to sleeve to fill. Once filled, the sleeve cannot be cross contaminated by any stagnant water above the screened interval.

Hydrasleeves are a more time efficient monitoring method compared to low flow sampling (for deeper wells in particular). Hydrasleeves are single use, minimising the risks of any cross contamination. GHD trials of Hydrasleeves have confirmed they produce results consistent with low flow pumping.

A groundwater quality sampling suite should be developed for the monitoring program. The suite will need to include those parameters typical of treated waste water, together with any site specific contamination indicators. An example groundwater quality sampling suite is presented below as Table 5-4.

Table 5-4 Groundwater quality sampling suite

Parameters	
Physical/chemical pH, Temperature, Electrical conductivity, Oxidation-reduction potential, Dissolved oxygen, Total dissolved solids, Total suspended solids, Total Alkalinity, Dissolved organic carbon, Chemical oxygen demand	***Nutrients*** Ammonia, Nitrate, Nitrate, Nitrite, Total dissolved nitrogen, Total nitrogen, Total phosphorus, Soluble reactive phosphorus
Hydrocarbons and trace organic compounds Total Recoverable Hydrocarbons (TRH), Polycyclic aromatic Hydrocarbons (PAH), Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Pesticides, Herbicides	***Heavy metals*** Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Nickel, Silver, Zinc,
Micro-biological *E.coli, Total Coliforms*	***Major Ions*** *Calcium, Magnesium, Potassium, Sodium, Chloride, Sulfate, Bicarbonate, Carbonate*

6. Terms of reference

6.1 Introduction

This section provides a high level summary of the next stage of work required to advance the project to “shovel ready” status. The information contained herein aims to provide proponents with a guide for future work to close any gaps, confirm any project assumptions and understand the constraints.

Whilst the need to secure regulatory approvals is highlighted below, details of the approvals required are not described in this report as this is beyond the scope of this study.

6.2 General considerations

There are general considerations that are applicable to both Site 1 and Site 2 as discussed below which require further investigation and/or consultation to allow the project to proceed to the next stage of design:

- On completion of the CSIRO investigation/groundwater modelling/risk assessment work, the following will need to be confirmed:
  - Level of nitrogen and phosphorus reduction required, via Strategic Environmental Assessment (SEA) process or similar.
  - That further treatment to reduce the concentration of other potential contaminants of concern, such as heavy metals and pesticides, will not be required, via SEA process or similar.
  - That a higher level of filtration and/or disinfection will not be required (to mitigate human health risks to an adequate level) prior to groundwater recharge, via additional consultation with the Department of Health.
- Identify potential scheme operators (Licensed Service Providers).
- Complete negotiations with Water Corporation in relation to TWW feed and wastewater disposal arrangements and charges.
- Secure necessary planning consents and regulatory approvals for the scheme, including those associated with upgrade/modification works required at WWTPs and the SDOOL.
- Confirm required minimum floor level for infiltration galleries/basins, based on CSIRO investigations and modelling work completed to quantify expected mounding height.
- Next design phase:
  - Complete level and feature surveys (including underground service location where required) and geotechnical/ASS investigations for all proposed infrastructure including pipelines when final sites and alignments are confirmed.
  - Complete detailed design and prepare tender documentation for proposed conveyance and recharge infrastructure.
  - Develop reference design for tertiary treatment facilities and prepare performance-based design/construct tender and documentation for these facilities.
  - Refine CAPEX and OPEX estimates for the project.

6.3 Site 1

6.3.1 Project assumptions

The following project assumptions have been adopted in the development of the engineering design for Site 1. These assumptions will need to be checked and confirmed during the next stage of design development:

- General:
  - Under the DWER *Operational Policy* and the DoH Guidelines, it is a requirement to prepare a risk assessment and Recycled Water Quality Management Plan (RWQMP) to gain approval for the scheme which will include a health and environmental risk assessment. For this level of design, it has been assumed the scheme would be classified as **medium risk**. A full risk assessment in accordance with the Australian Guidelines for Water Recycling will be required in subsequent stages of design to confirm this assumption.
- Pre-treatment facility:
  - Pre-treatment for pathogen removal prior to infiltration at Site 1 is not considered to be necessary. This assumption will need to be further investigated and confirmed as part of the risk assessment process for DoH and DWER. It is to be noted that the risk assessment is approved as part of the statutory approval process.
  - Drawing on CSIRO investigation/groundwater modelling/risk assessment work, confirm need for/ level of total dissolved solids reduction via Strategic Environmental Assessment process or similar.
- Offtake and conveyance:

It has been assumed that the conveyance pipes and appurtenances shall be designed in accordance with the relevant Water Corporation standards due to the connection into existing Water Corporation assets. This assumption is to be confirmed during the next design phase.

Complete constructability/operability/safety in design reviews for the proposed SDOOL offtake arrangement with the Water Corporation.

6.3.2 Project gaps and further investigation

In addition to the project assumptions, there are gaps in the current data availability, timing of future infrastructure and application of some treatment processes. The gaps and the required work or consultation to close the gaps is as follows:

- Site location:
  - Complete investigations and landowner consultation to identify alternative less constrained site for infiltration basins in the vicinity of Site 1.
- Pre-treatment facility:
  - Desalination will be required for Site 1, but only following the implementation of the Woodman Point AWRP. The timing of the desalination requirements will need to be confirmed with Water Corporation in future design phases.
  - For proposed reverse osmosis system, more work is required to confirm the appropriate biocide to adopt to prevent biofouling of RO pre-treatment filtration system and RO membranes themselves. Whilst very effective and biodegradable chemicals are commercially available, they are toxic and may adversely affect microbiological purification processes in the vadose zone and aquifer beneath/downgradient of the

  infiltration basins; and potentially also affect the health of ecosystems in receiving waters.
  - The current approach for disposal of the pre-treatment residuals is conveyance back to the SDOOL. Disposal to the SDOOL will require further consultation with Water Corporation to determine water quality acceptance limits and access arrangements.
- MAR infrastructure:
  - Development of MAR facilities at Site 1 will raise groundwater levels under the proposed alignment of the FRCAH. GHD understands that CSIRO will be more accurately quantifying the potential groundwater level resulting from MAR at this site as part of their studies.
  - With planning for the FRCAH and associated rail/works under review as part of the outer harbour planning study, the ultimate alignment and design of this infrastructure may differ from the preliminary planning. The extent of SDOOL and other service realignment works in this location is also currently unclear. Given these uncertainties, for this study it was assumed that the SDOOL offtake and supply main to Site 1 will be constructed prior to development of the FRCAH, and that any modifications required to be made to these works as a consequence of the FRCAH would be completed at that time. When further planning and timeframes are available for the FRCAH, the impacts to the MAR infrastructure is to be reassessed and redesigned as required.
  - The nominated pipeline route will cross the future FRCAH and will then be contained within a pipeline easement if required. The construction methodology for the future highway will need to be confirmed in future design stages.
  - The ultimate site access will be constructed after the completion of the future FRCAH and will be via a culvert under Rowley Road and other transport infrastructure. When further planning and timeframes are available for the FRCAH, the ultimate site access is to be confirmed and designed.
  - A finished basin surface level of 6 m AHD has been assumed for Site 1’s infiltration system. Dependent on the extent of quarrying undertaken at the site, significant volumes of fill may be required to be sourced to achieve this finished level. Further assessment into the timing and extent of quarrying operations is required during subsequent design phases. The type of fill used will also need to be assessed for its suitable for infiltration purposes.
  - The design infiltration rate assumed in this study to size infiltration basins may be overly conservative based on the performance of the Kwinana WWTP’s infiltration basins as inferred from available aerial imagery. Further investigation work including consultation with Water Corporation is warranted during subsequent design stages to confirm an appropriate design infiltration rate for infiltration basins installed as part of this project.

6.3.3 Site 1 summary

The further work required to confirm the project assumptions or to close out the project gaps is summarised in Table 6-1 below.

Table 6-1 Site 1 terms of reference summary

Gap/assumption/constraint	Stakeholder(s) involved	Required work
Medium risk operation under the AGWR	DWER and DoH	A full risk assessment in accordance with the Australian Guidelines for Water Recycling will be required in subsequent stages of design.
Pre-treatment for pathogen removal is not required.	DWER and DoH	Further assessed during the future risk assessment.
Design standards adopted for the offtake and conveyance infrastructure	Water Corporation / project proponent	Confirmation of preferred standards prior to detailed design.
Salinity levels at the future Woodman Point AWRP	Water Corporation	Confirmation of timing of AWRP and design salinity levels.
Biofouling approach at the Site 1 reverse osmosis system	Project proponent DWER	Further assessment of the appropriate biocide to adopt for biofouling to minimise any environmental harm.
Disposal of pre-treatment residuals	Water Corporation	Confirmation of water quality acceptance limits and access arrangements.
Impacts raised groundwater levels may have on FRCAH	CSIRO MRWA Project proponent	Further refinement of groundwater level rise as a result of MAR.
FRCAH timing and alignment	MRWA	Confirmation of any relocation to SDOOL as a result of FRCAH and/or installed MAR offtake and conveyance infrastructure. Agreement of construction methodology for new MAR conveyance infrastructure under the future FRCAH.
Ultimate site access	MRWA City of Kwinana	Investigation and confirmation of the location for the ultimate site access once FRCAH is constructed.
Required fill to achieve the finished infiltration basin surface levels	LandCorp Project proponent	Investigation and understanding into the future quarry operations ultimate depth. Assessment of potential fill sources and suitability to achieve the required infiltration rates.

Gap/assumption/constraint	Stakeholder(s) involved	Required work
Design infiltration rate	Project proponent	Investigation to quantify actual infiltration rates achieved at Kwinana WWTP's infiltration basins. Confirm appropriate design infiltration rate that can be used for sizing of infiltration basins installed as part of this project.

6.4 Site 2

6.4.1 Project assumptions

The following project assumptions have been adopted in the development of the engineering design for Site 2. These assumptions will need to be checked and confirmed during the next stage of design development:

- General:
  - Under the DWER *Operational Policy* and the DoH Guidelines, it is a requirement to prepare a risk assessment and Recycled Water Quality Management Plan (RWQMP) to gain approval for the scheme which will include a health and environmental risk assessment. For this level of design, it has been assumed the scheme would be classified as **medium risk**. A full risk assessment in accordance with the Australian Guidelines for Water Recycling will be required in subsequent stages of design to confirm this assumption.
  - It has been assumed that the conveyance pipes and appurtenances shall be designed in accordance with the relevant Water Corporation standards due to the connection into existing Water Corporation assets. This assumption is to be confirmed during the next design phase
- Infiltration site location:
  - Additional work will need to be completed to confirm that the clearing required to develop this Bush Forever site will be allowed.
  - If significant portions of Site 2 are unable to be cleared and developed based on environmental constraints, additional land could be sought, or lower capacity infiltration galleries could be installed to minimise the footprint required for the recharge works.
  - The MAR pre-treatment site is owned by LandCorp and support has been gained from LandCorp to include the identified option within this report. The inclusion is conditional on LandCorp retaining the right to negotiate site selection and commercial terms for lease or sale of the land with any future investor/operator of the managed aquifer recharge facility. Further consideration to potential future expansion of the pre-treatment facility to allow recycled water to be distributed to multiple recharge sites is also required.
- Pre-treatment facility:
  - Pre-treatment for pathogen removal prior to infiltration at Site 2 is not considered to be necessary. This assumption will need to be further investigated and confirmed as part of the risk assessment process for DoH and DWER. It is to be noted that the risk assessment is approved as part of the statutory approval process.

  - Denitrifying filters have been included as part of the engineering design. The requirement for these is to be assessed as part of a risk assessment and confirmed with DWER.
  - For the purposes of this study, it has been assumed that no process changes at East Rockingham WWTP are currently forecast. Further consultation required with Water Corporation to confirm.
  - It has been assumed that the backwash from the pre-treatment facility will be returned this stream to an appropriate point in the East Rockingham WWTP. This is to be confirmed and agreed with Water Corporation.

6.4.2 Project gaps and further investigation

- General:
  - Assess potential for a smaller capacity initial stage scheme involve pumping TWW from East Rockingham WWTP (without further treatment) to infiltration basins located at Site 2.
  - Develop engineering design and cost estimate for future TWW supply arrangement required at the time of: a) Water Corporation utilise all available bays within the existing temporary Final Effluent Pump Station (FEPS); and b) Water Corporation construct new final effluent balance storage tanks and permanent FEPS.
  - Commercial negotiation and agreements with Water Corporation regarding operations and maintenance arrangements for the MAR delivery pump on the Water Corporation site, as well as the portion of the TWW supply pipeline that would run within the WWTP site.
- Recycled water conveyance route:
  - Complete additional investigations and consult with landowners plus planning/regulatory agencies to confirm the viability of the proposed recycled water pipeline route to Site 2. The focus of the additional work should be on:
    - the portion of the pipeline route within proposed east-west services corridor included in the Rockingham Industry Zone (LandCorp are the lead agency);
    - section alongside/east of the Mandurah Road reserve;
    - sections crossing major services/roads/railway;
    - section alongside Gentle Road reserve); and
    - methodology and approval process for crossing proposed and existing infrastructure (i.e., FRCAH, Mandurah Rd, rail corridors and Dampier Bunbury Natural Gas Pipeline).

6.4.3 Site 2 summary

The further work required to confirm the project assumptions or to close out the project gaps is summarised in

Table 6-2 below.

Table 6-2 Site 2 terms of reference summary

Gap/Assumption/Constraint	Stakeholder(s) involved	Required work
Medium risk operation under the AGWR	DWER and DoH	A full risk assessment in accordance with the Australian Guidelines for Water Recycling will be required in subsequent stages of design.
Infiltration site location	Project proponent/ DWER	Confirm that the clearing required to develop this Bush Forever site will be allowed Review infiltration system requirements (additional land or modified infiltration approach) if clearing is not permitted.
Design standards adopted for the offtake and conveyance infrastructure	Water Corporation / project proponent	Confirmation of preferred standards prior to detailed design.
Pre-treatment site location	LandCorp / project proponent	Further discussions and negotiations are required with LandCorp regarding the site selection and commercial terms for lease or sale of the land with any future investor/operator of the managed aquifer recharge facility. Further consideration to potential future expansion of the pre-treatment facility to allow recycled water to be distributed to multiple recharge sites is also required.
Pre-treatment facility: - pathogen removal is not required. - denitrifying filters have been included	DWER and DoH	Further assessed during the future risk assessment.

Gap/Assumption/Constraint	Stakeholder(s) involved	Required work
East Rockingham WWTP: - no process change - space available for pre-treatment - pre-treatment backwash returned to the WWTP	Water Corporation and DWER	Future designs to consider the future TWW supply arrangement required at the time of: a) Water Corporation utilise all available bays within the existing temporary Final Effluent Pump Station (FEPS); b) Water Corporation construct new final effluent balance storage tanks and permanent FEPS c) potential for a smaller capacity initial stage scheme involve pumping TWW from East Rockingham WWTP (without further treatment) to infiltration basins located at Site 2 Commercial negotiations with Water Corporation regarding the MAR pump station and pipeline on their site.
Pipeline conveyance route	Landowners/ project proponent	Complete additional investigations and consultation to confirm the viability of the proposed recycled water pipeline route
Pipeline crossings at Mandurah Road, Dampier Bunbury Natural Gas pipeline and rail crossings	Asset owners	Confirmation of design standards, approvals and construction methodology at detailed design phase

7. References

BOM. (2017, 09 08). *Climate statistics for Australian locations.* Retrieved from Medina Research Centre (009194): http://www.bom.gov.au/climate/averages/tables/cw_009194_All.shtml

Contaminated Sites Database. (2018, February). Retrieved from Department of Water and Environment Regulation: https://dow.maps.arcgis.com/apps/webappviewer/index.html?id=c2ecb74291ae4da2ac32c441819c6d47

Davidson. (1995). Hydrogeology and groundwater resources of the Perth region. *Western Australian Geological Survey*.

Department of Environment and Conservation;. (2012). *Western Australian guidelines for biodolids management.* Perth.

Department of Water. (2016). *Western Trade Coast heavy industry local water supply strategy, Securing Western Australia's water future.* Perth.

DoH. (2015). *Guidelines for the Non-potable Uses of Recycled Water in Western Australia.* Perth: Department of Health.

DoH, WorkSafe WA. (2011). *Guidance note for wash down facilities using recycled water.* Perth: Department of Health.

DoW. (2011). *Operational policy 1.01 - Managed aquifer recharge in Western Australia.* Perth: Department of Water.

Foley, J. (2009). *Life cycle assessment of wastewater treatment systems.* Brisbane: University of Queensland.

Geological Survey of Western Australia. (1983). Environmental Geology Series. *Fremantle part Sheets 2033 I & 2033 IV,*. Perth Metropolitan Region.

GHD. (February 2016). *Kwinana Managed Aquifer Recharge Study: MAR Infrastructure Concepts and Cost Estimates.* Perth: a report prepared for CSIRO.

GHD. (June 2015). *Kwinana Managed Aquifer Recharge Study: Industrial Water Supply Options Assessment.* Perth: a report prepared for CSIRO.

GHD. (June 2017). *WTC MAR Scheme - Engineering Design & Costing Study: Report on Assessment of Selected MAR Sites (WP1).* Perth: a report to the Department of State Development (now Department of Jobs, Tourism, Science and Innovation.

McFarlane, DJ (ed). (July 2015). *Recycled water for heavy industry and preventing sea water intrusion.* Brisbane: A report to the Australian Water Recycling Centre of Excellence and industry partners from the CSIRO Land and Water Flagship.

NRMMC, EPHC, NHMRC. (2006). *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1).* Canberra: National Resource Management Ministerial Council, Environmental Protection and Heritage Council, National Health and Medical Research Council.

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

Perth Groundwater Map. (2018, February). Retrieved from Department of Water and Environment Regulation: https://maps.water.wa.gov.au/#/webmap/gwm accessed February 2018

Rawlinsons . (2017). *Australian Construction Handbook Editition 35.* Perth: Rawlinsons Publishing.

Shuttle Radar Topography Mission (SRTM) data 1 second SRTM, . (n.d.). *2011*. obtained from Geoscience Australia (30m grid).

Tchobanoglous, G., Stensel, H., Tsuchihashi, R., & Burton, F. (2014). *Wastewater Engineering: Treatment and Resource Recovery (5th ed.).* New York: McGraw Hill.

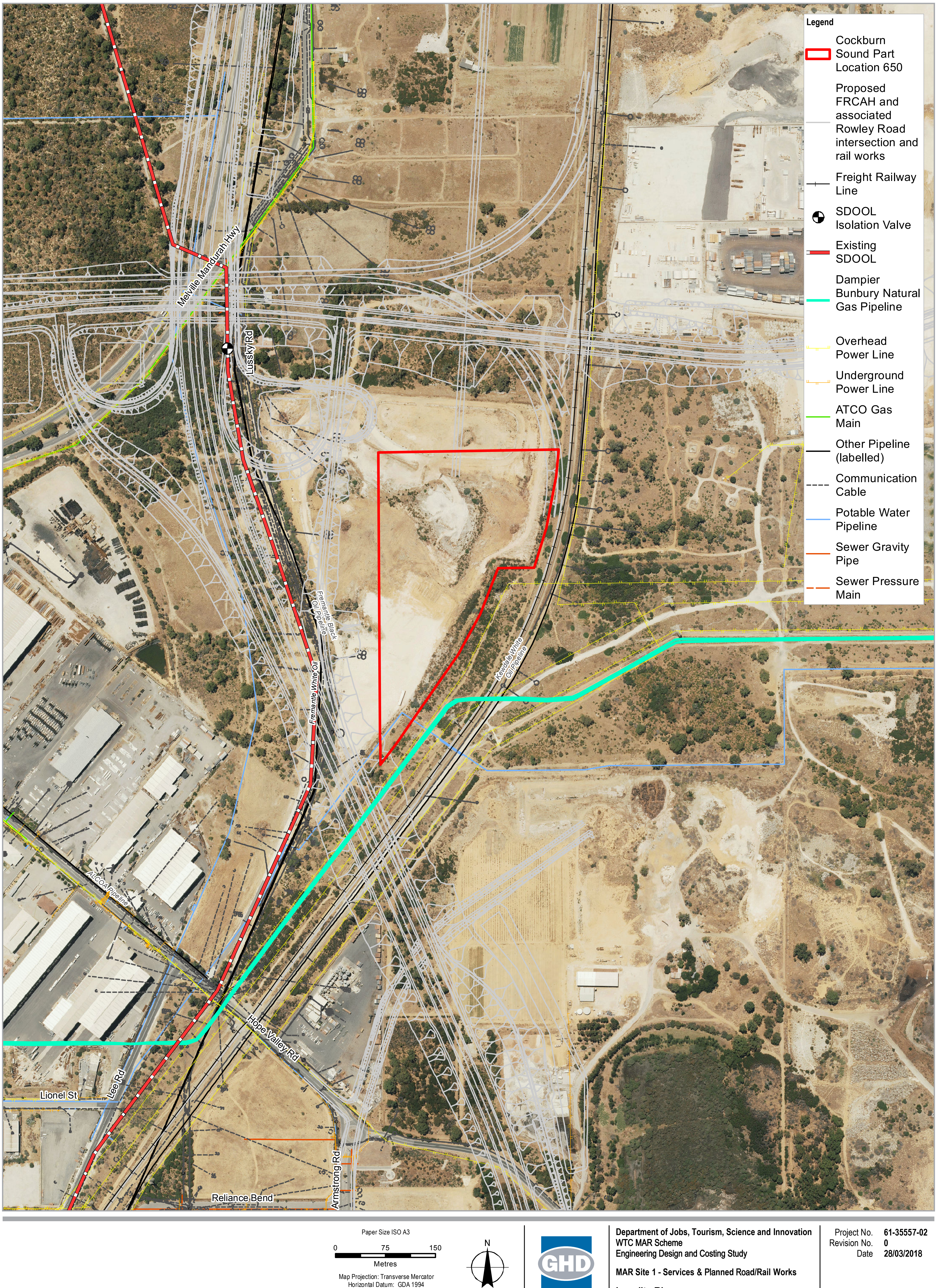
Water Corporation. (May 2017). *Western Trade Coast - MAR: Advice to Engineering Feasibility Study.* Perth: Water Corporation.

Water Information Reporting. (2018, February). Retrieved from Department of Water and Environment Regulation: http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx accessed February 2018

Water Register. (2018, February). Retrieved from Department of Water and Environment Regulation: https://maps.water.wa.gov.au/#/webmap/register

Appendices

Appendix A – Figures



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

Department of Jobs, Tourism, Science and Innovation
WTC MAR Scheme
Engineering Design and Costing Study

MAR Site 1 - Services & Planned Road/Rail Works

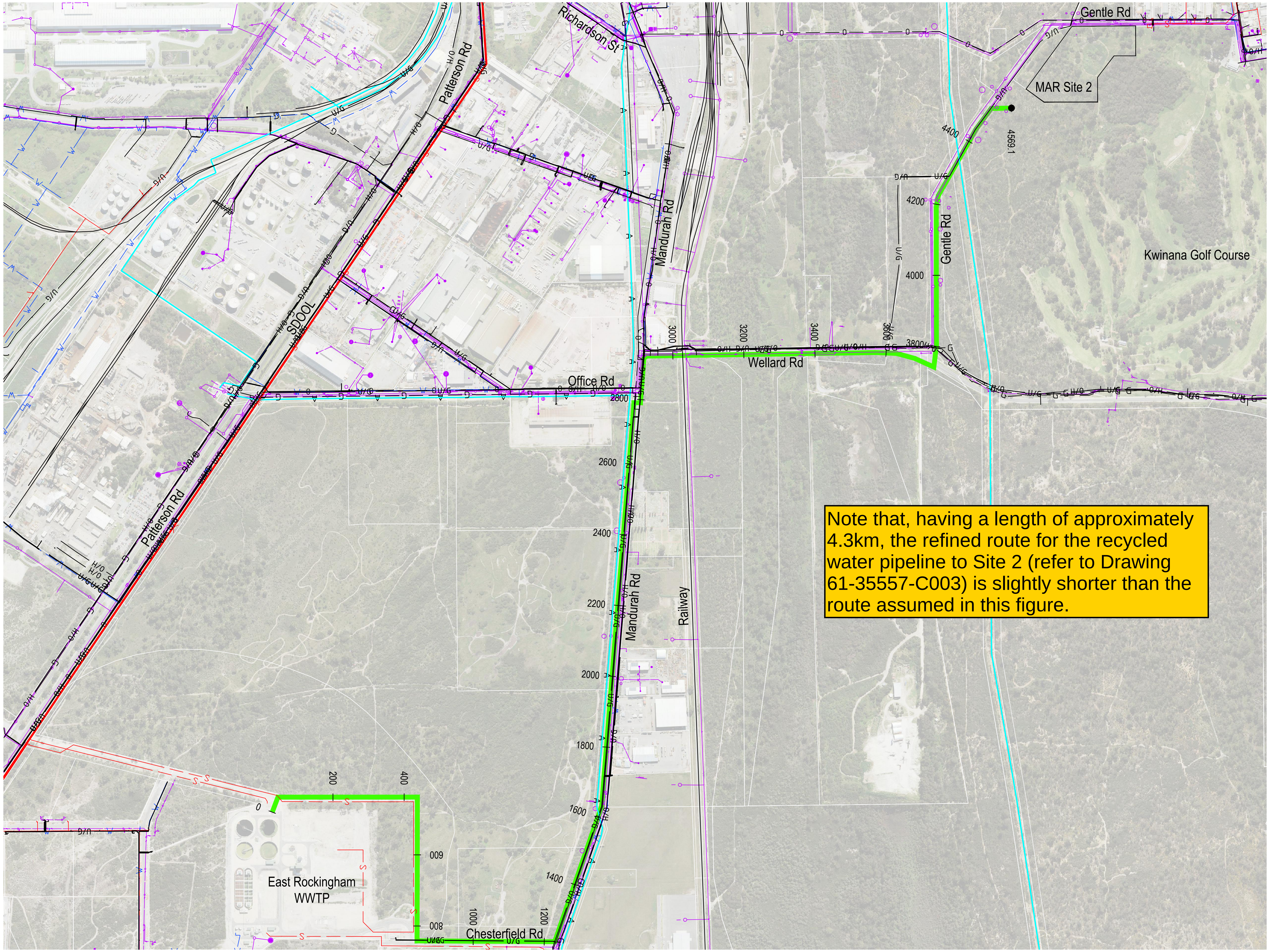
Locality Plan

Project No. 61-35557-02
Revision No. 0
Date 28/03/2018

FIGURE A1

G:\61\35557\GIS\Maps\Working\6135557_001_NorthernSiteConstraints_Rev0_A3P.mxd
Print date: 29 Sep 2017 - 11:14

Data source: GHD: Part Location 650 - 20170329, SDOOL Isolation Valves - 20140702, FRCAH Alignment - 20141217; Water Corporation: SDOOL - 20140702, Potable Mains and Sewers - 20170907; DBP: Dampier-Bunbury Pipeline; Western Power: Overhead and Underground Power Lines - 20170906; ATCO Gas: Gas Mains - 20170908; NBN. Nextgen: Communication Cables (digitised from plans) - 20170824; Telstra: Communication Cables - 20170829; Optus: Communication Cables - 20170828; BP: Other Pipelines; Landgate: Aerial Photography - Metro Central Feb. 2017, Roads - 20170619, Railway - 20170927. .



Note that, having a length of approximately 4.3km, the refined route for the recycled water pipeline to Site 2 (refer to Drawing 61-35557-C003) is slightly shorter than the route assumed in this figure.

Legend

- APA Gas
- Atco Gas
- Hydrogen
- Tail gas
- Dampier to Bunbury Pipeline
- Fremantle Oil
- NBN
- Next Gen
- Railways
- Optus
- Kwinana Oil
- Western Power Overhead
- Western Power Underground
- Telstra
- Water
- Sewer
- SDOOL
- MAR Site 2 Boundary
- TWW Pipeline from East Rockingham WWTP to MAR Site 2

0 110 220 330m
SCALE 1:11,000 AT ORIGINAL SIZE

N

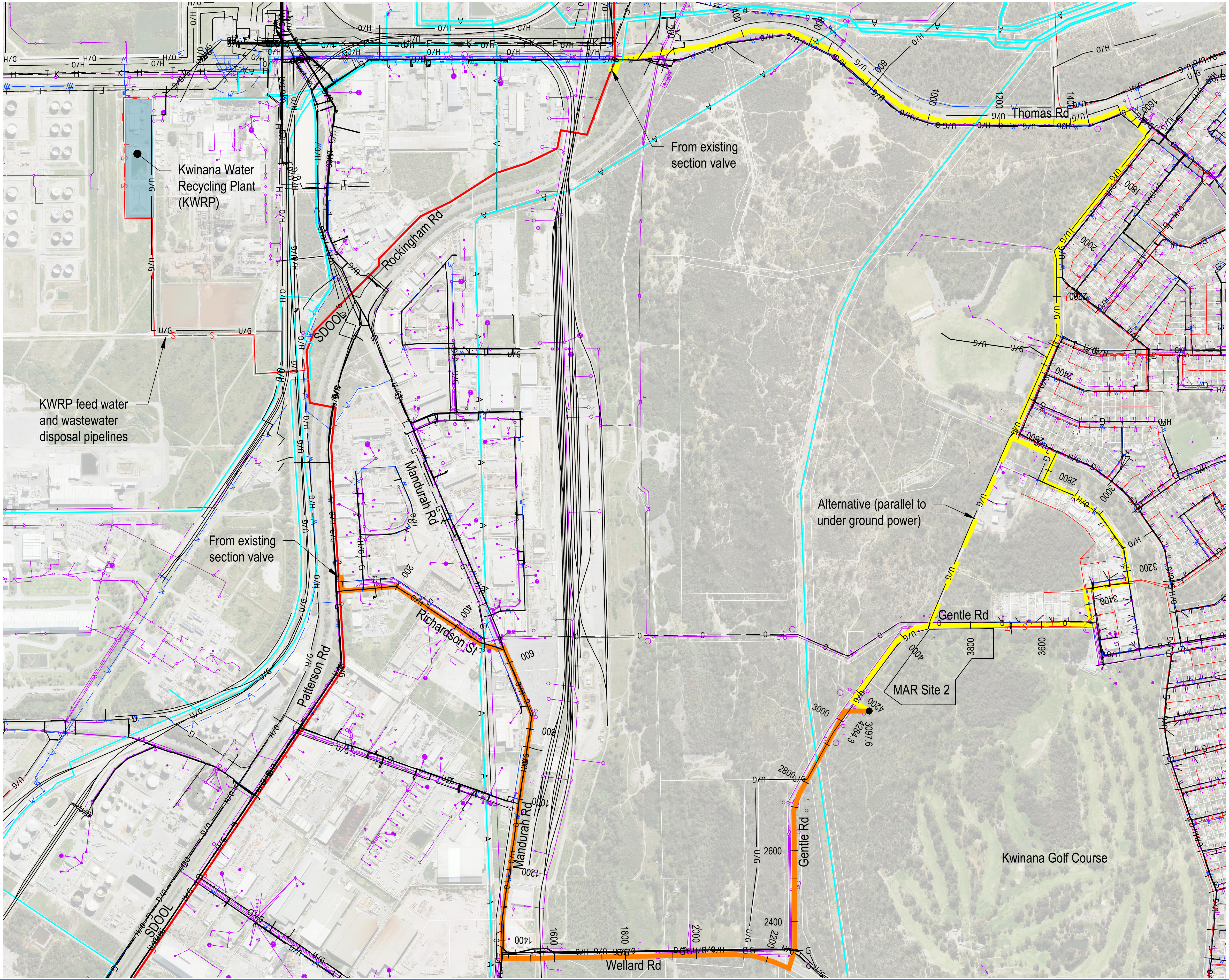
Department of Jobs, Tourism, Science and Innovation
WTC MAR Scheme
Engineering Design and Costing Study
TWW Pipeline from East Rockingham WWTP to MAR Site 2 - Locality Plan

Job Number	61-35557
Revision	A
Date	Mar 2018

Figure A2

Level 10, 999 Hay Street Perth WA 6000 **T** 61 8 6222 8222 **F** 61 8 6222 8555 **E** permail@ghd.com.au **W** www.ghd.com

Plot Date: 26 March 2018 - 1:36 PM Plotted by: Josh Vale Cad File No: G:\61\35557\CADD\Drawings\Figures\61-35557-CF01.dwg



Legend

APA Gas	A
Atco Gas	G
Hydrogen	H
Tail gas	T
Dampier to Bunbury Pipeline	
Fremantle Oil	F
NBN	N
Next Gen	C
Railways	
Optus	O
Kwinana Oil	K
Western Power Overhead	O/H
Western Power Underground	U/G
Telstra	
Water	W
Sewer	S
SDOOL	
MAR Site 2 Boundary	
TWW Pipeline from SDOOL SV CH11050m to MAR Site 2	
TWW Pipeline from SDOOL SV CH13000m to MAR Site 2	

0 110 220 330m
SCALE 1:11,000 AT ORIGINAL SIZE

N

GHD

Department of Jobs, Tourism, Science and Innovation
WTC MAR Scheme
Engineering Design and Costing Study
TWW Pipeline from SDOOL to MAR Site 2
Locatlity Plan

Job Number 61-35557
Revision A
Date Mar 2018

Figure A3

Level 10, 999 Hay Street Perth WA 6000 **T** 61 8 6222 8222 **F** 61 8 6222 8555 **E** permail@ghd.com.au **W** www.ghd.com

Plot Date: 26 March 2018 - 1:36 PM Plotted by: Josh Vale Cad File No: G:\61\35557\CADD\Drawings\Figures\61-35557-CF01.dwg

Appendix B – Mass balance model

Department of State Development
Western Trade Coast MAR Scheme

SDOOL Water and Mass Balance

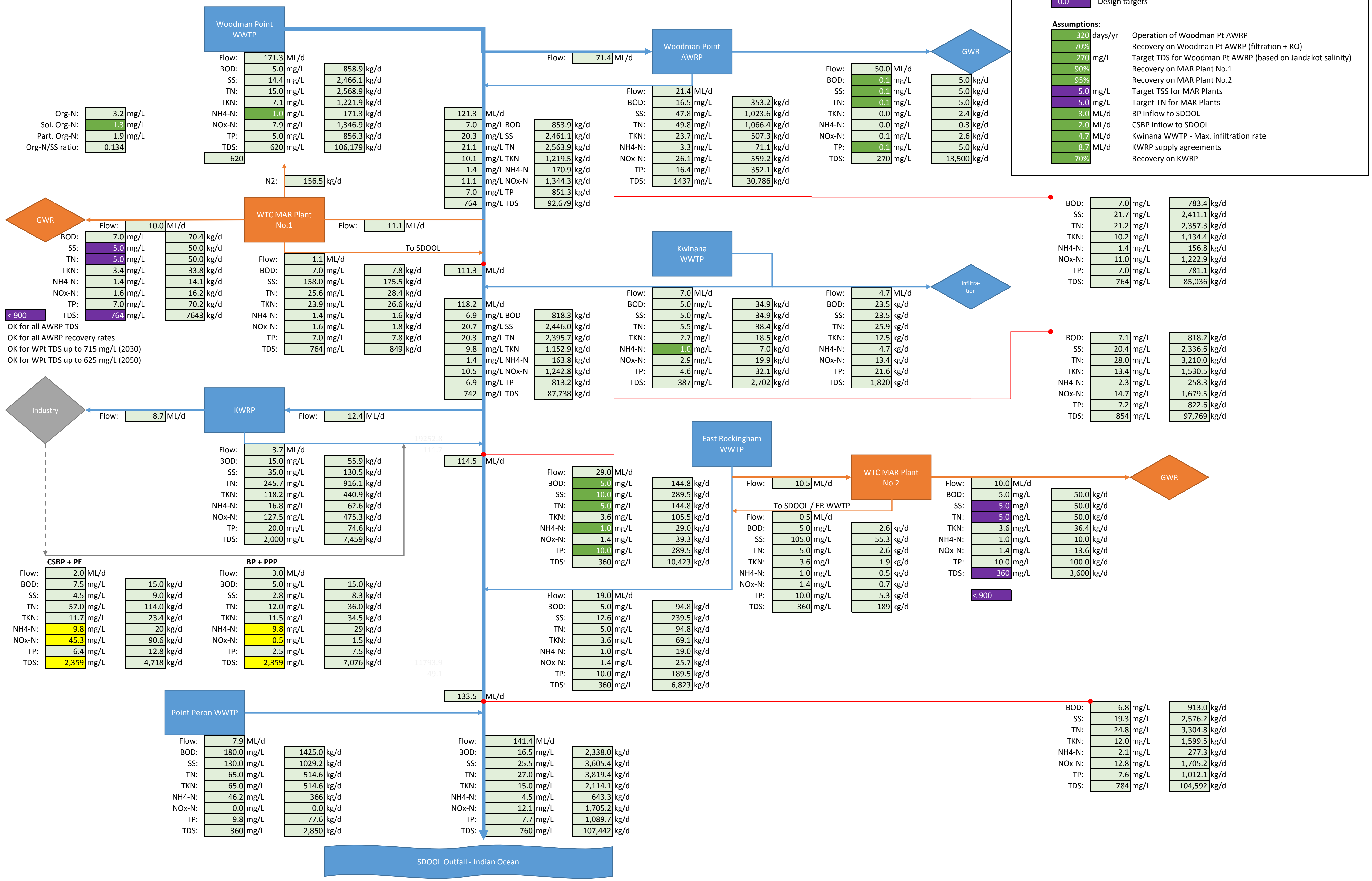
Year: 2030
MAR Plant No.1 Flow: 10.0 ML/d
MAR Plant No.2 Flow: 10.0 ML/d
WQ Design Condition: 50th percentile

Legend

	Water Corporation assets
	WTC MAR scheme assets
	Industry assets
0.0	User input
0.0	Calculated or referenced value
0.0	Design targets

Assumptions:

320	days/yr	Operation of Woodman Pt AWRP
70%		Recovery on Woodman Pt AWRP (filtration + RO)
270	mg/L	Target TDS for Woodman Pt AWRP (based on Jandakot salinity)
90%		Recovery on MAR Plant No.1
95%		Recovery on MAR Plant No.2
5.0	mg/L	Target TSS for MAR Plants
5.0	mg/L	Target TN for MAR Plants
3.0	ML/d	BP inflow to SDOOL
2.0	ML/d	CSBP inflow to SDOOL
4.7	ML/d	Kwinana WWTP - Max. infiltration rate
8.7	ML/d	KWRP supply agreements
70%		Recovery on KWRP



Department of State Development
Western Trade Coast MAR Scheme

SDOOL Water and Mass Balance

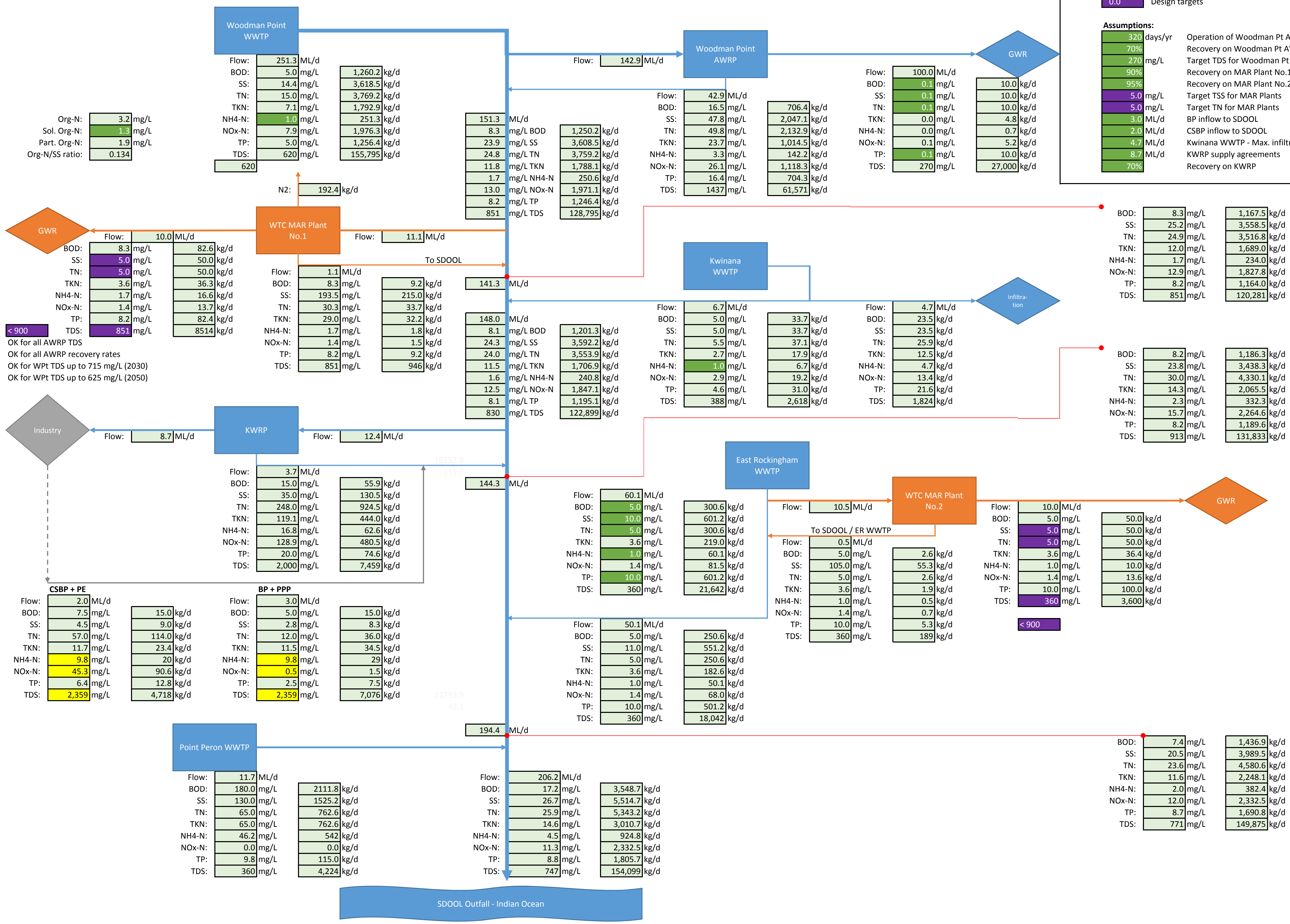
Year:	2060	
MAR Plant No.1 Flow:	10.0	ML/d
MAR Plant No.2 Flow:	10.0	ML/d
WQ Design Condition:	50th percentile	

Legend

(blue)	Water Corporation assets
(orange)	WTC MAR scheme assets
(grey)	Industry assets
0.0	User input
0.0	Calculated or referenced value
0.0	Design targets

Assumptions:

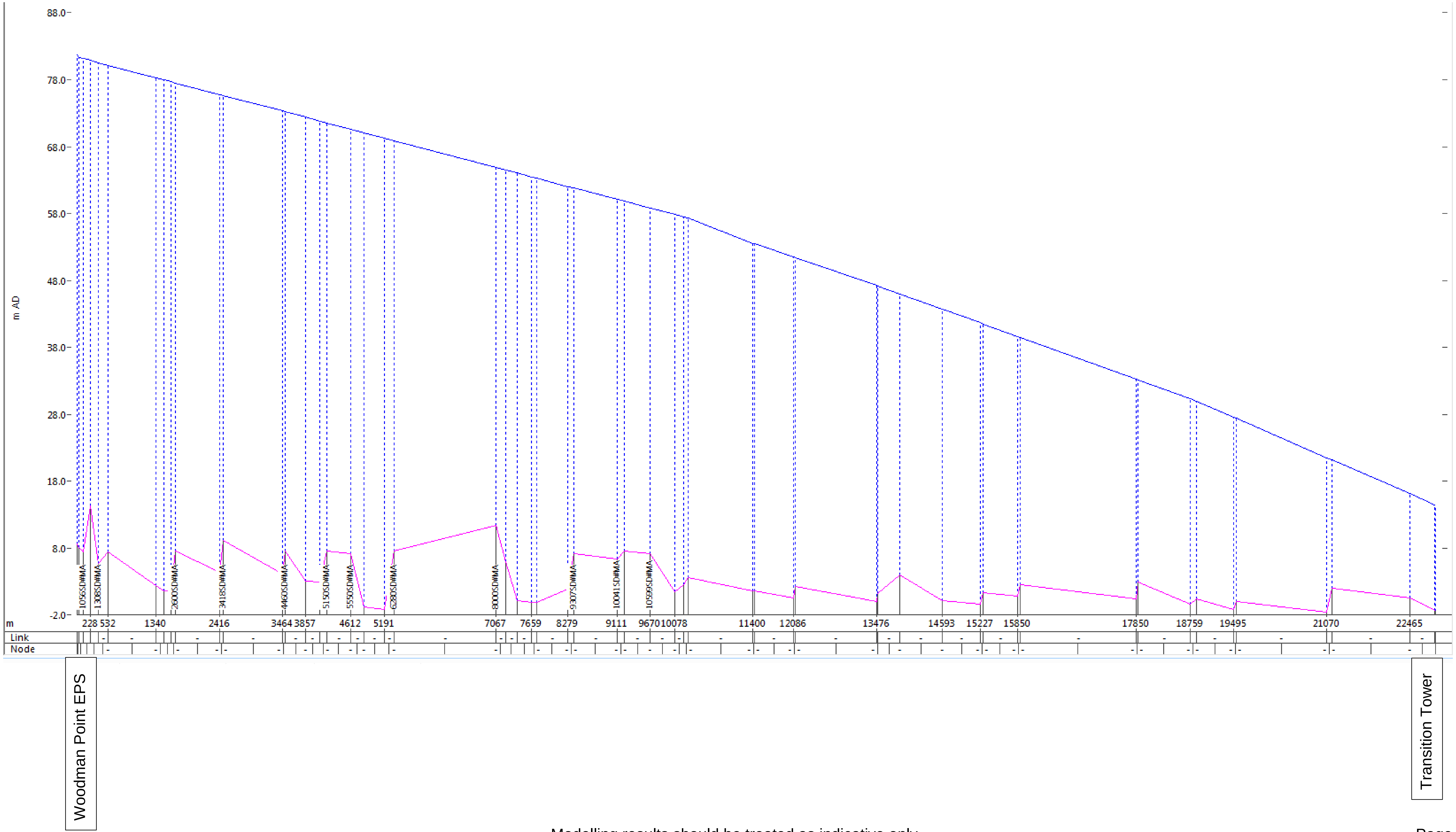
320	days/yr	Operation of Woodman Pt AWRP
70%		Recovery on Woodman Pt AWRP (filtration + RO)
270	mg/L	Target TDS for Woodman Pt AWRP (based on Jandakot salinity)
90%		Recovery on MAR Plant No.1
95%		Recovery on MAR Plant No.2
5.0	mg/L	Target TSS for MAR Plants
5.0	mg/L	Target TN for MAR Plants
3.0	ML/d	BP inflow to SDOOL
2.0	ML/d	CSBP inflow to SDOOL
4.7	ML/d	Kwinana WWTP - Max. infiltration rate
8.7	ML/d	KWRP supply agreements
70%		Recovery on KWRP



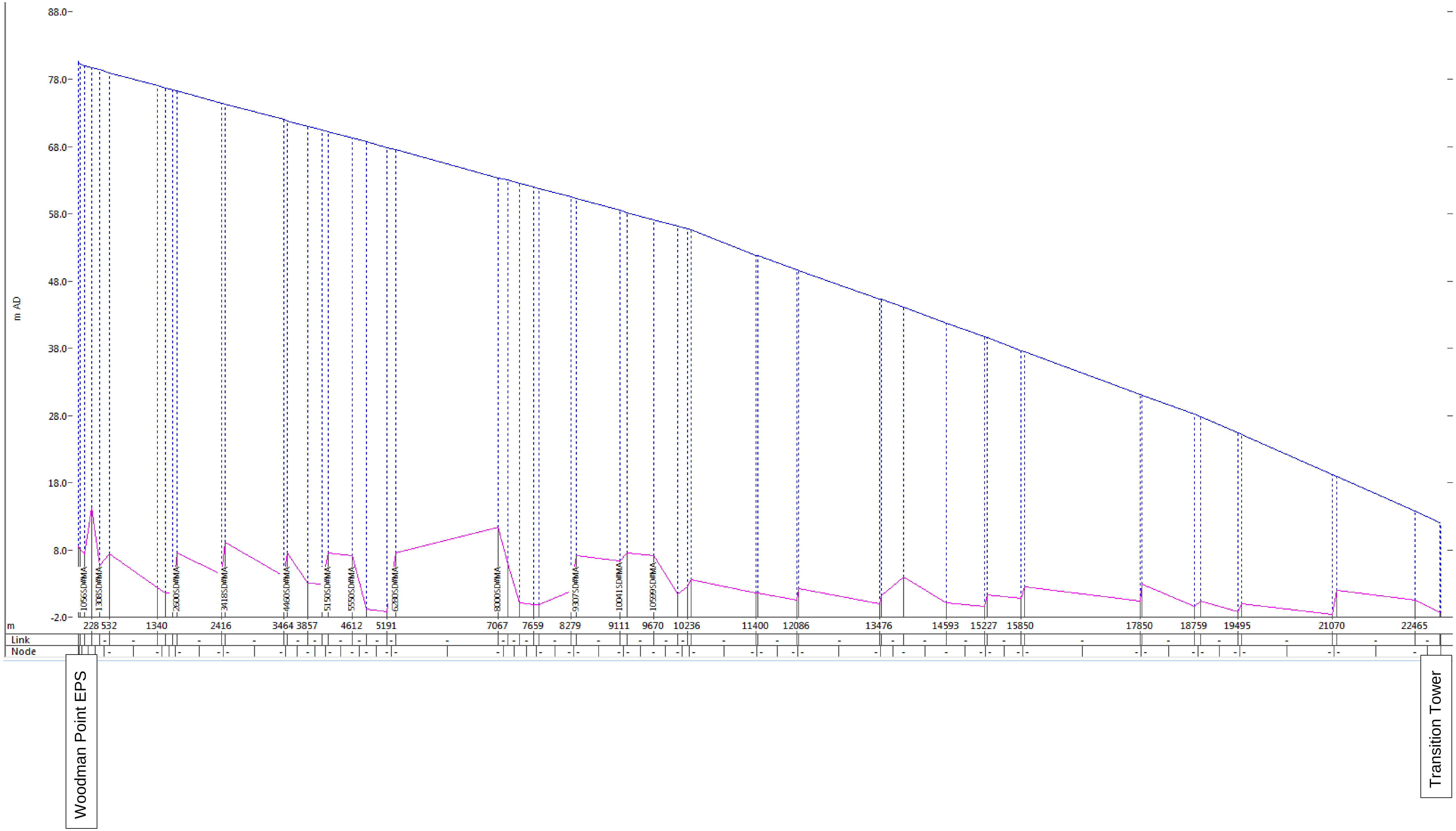
Appendix C – SDOOL hydraulic grade lines

InfoWorks Model Results – Existing SDOOL System – Longsections with HGL under various operating scenarios

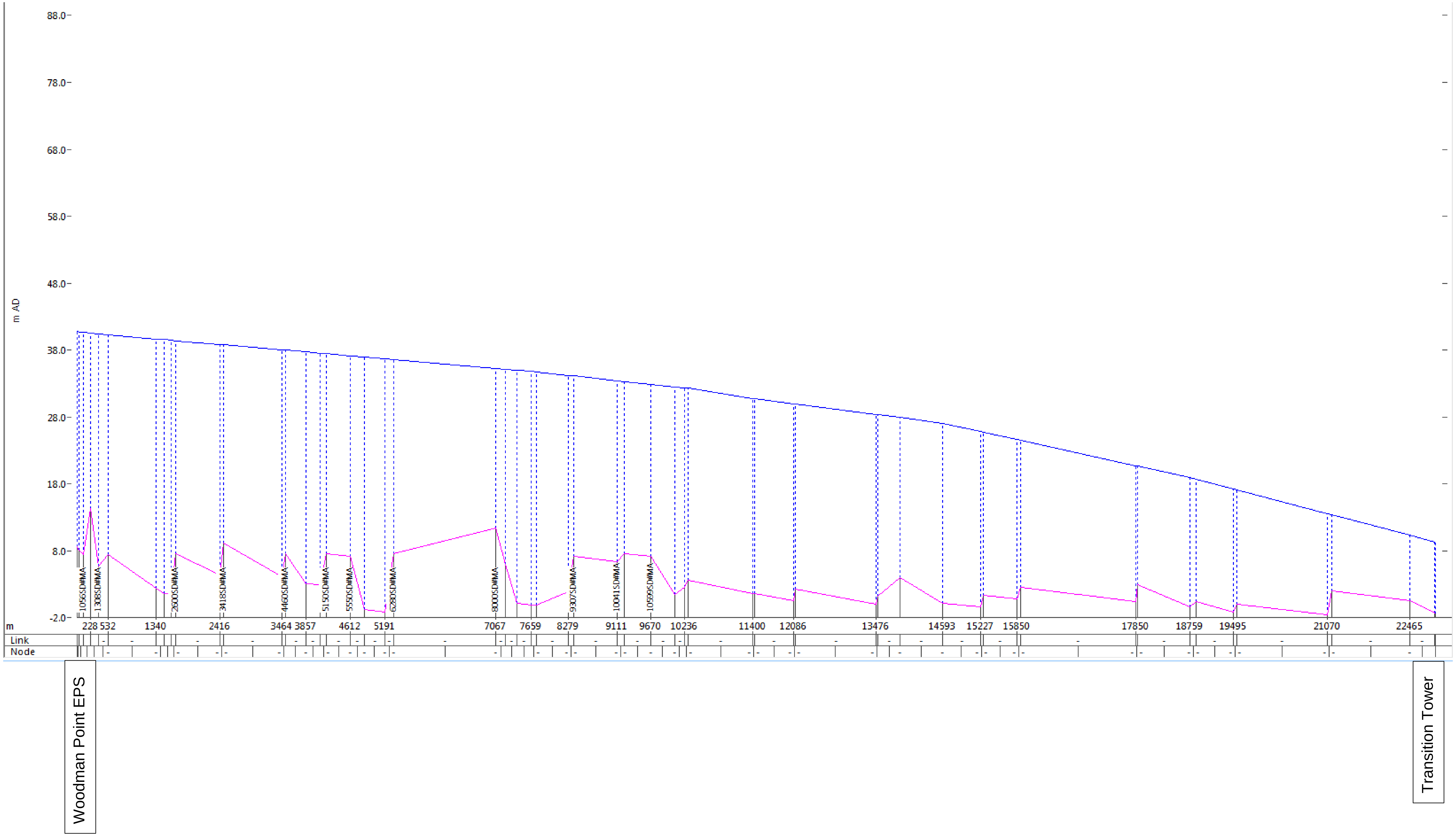
Woodman Point EPS large pump @ 2530 L/s
Kwinana EPS off
East Rockingham EPS off
Point Peron EPS pumping @ 255 L/s



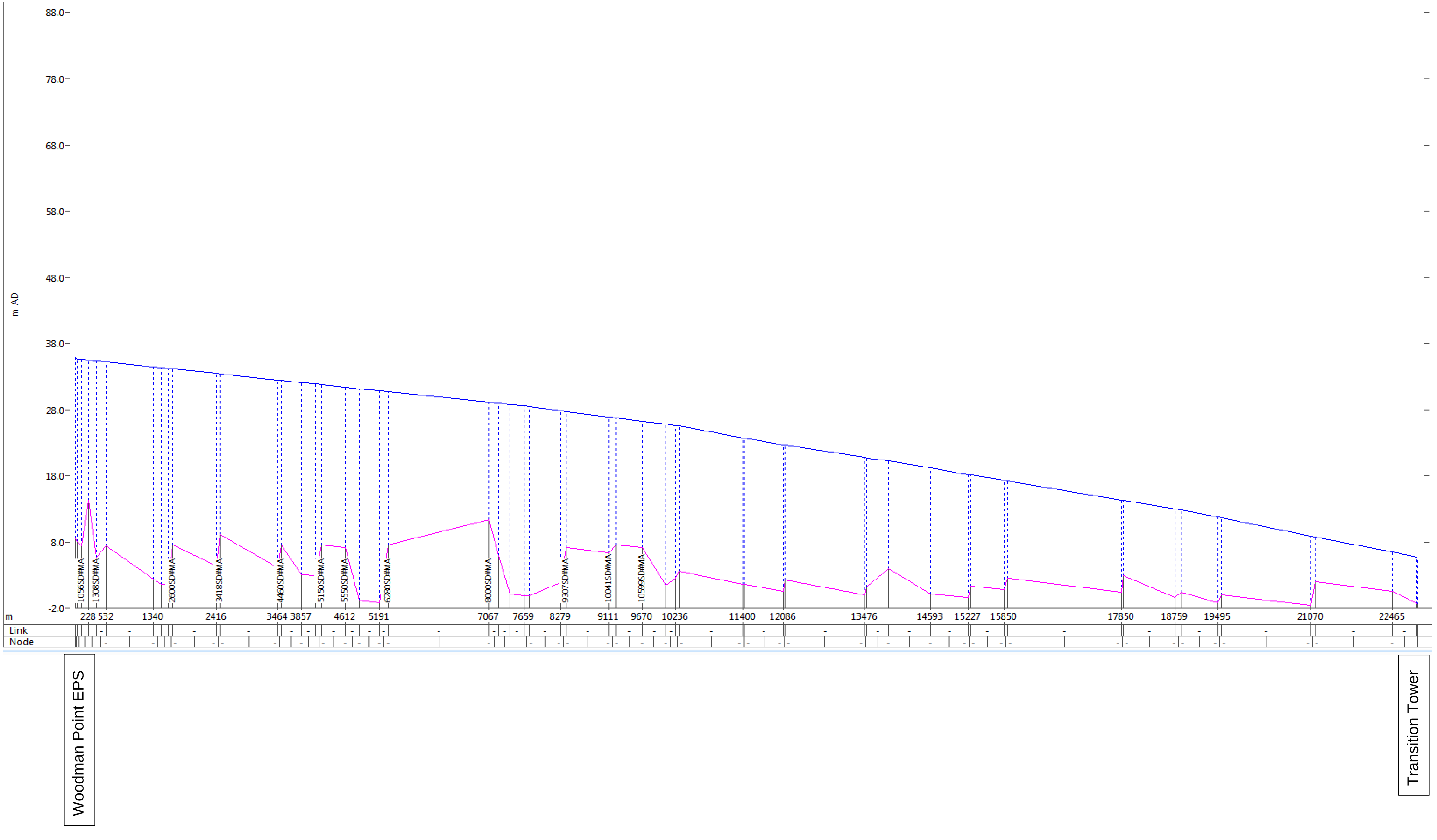
Woodman Point EPS large pump @ 2560 L/s
Kwinana EPS off
East Rockingham EPS off
Point Peron EPS off



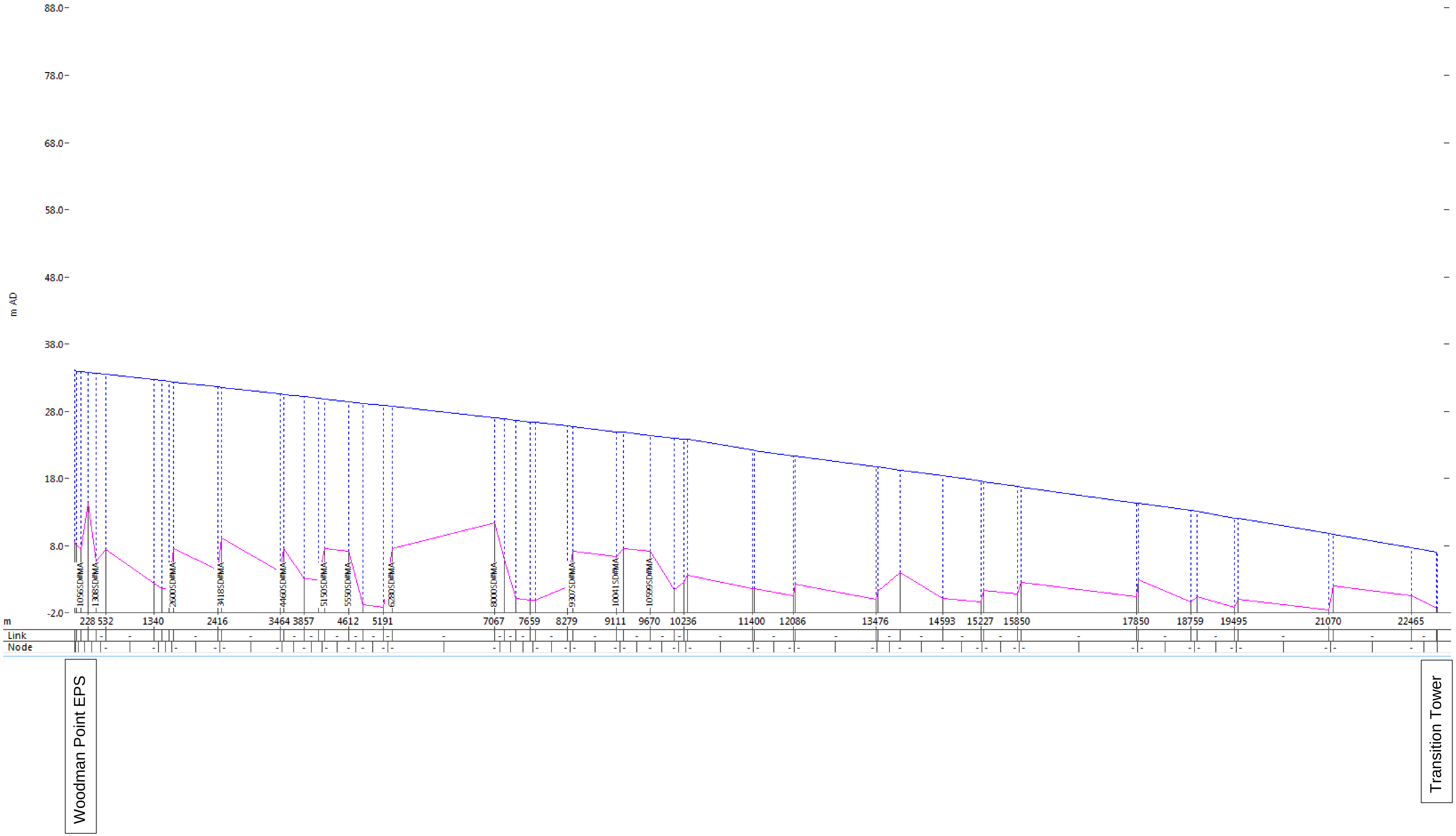
Woodman Point EPS small pump @ 1450 L/s
Kwinana EPS pumping @ 170 L/s
East Rockingham EPS pumping @ 395 L/s
Point Peron EPS pumping @ 250 L/s



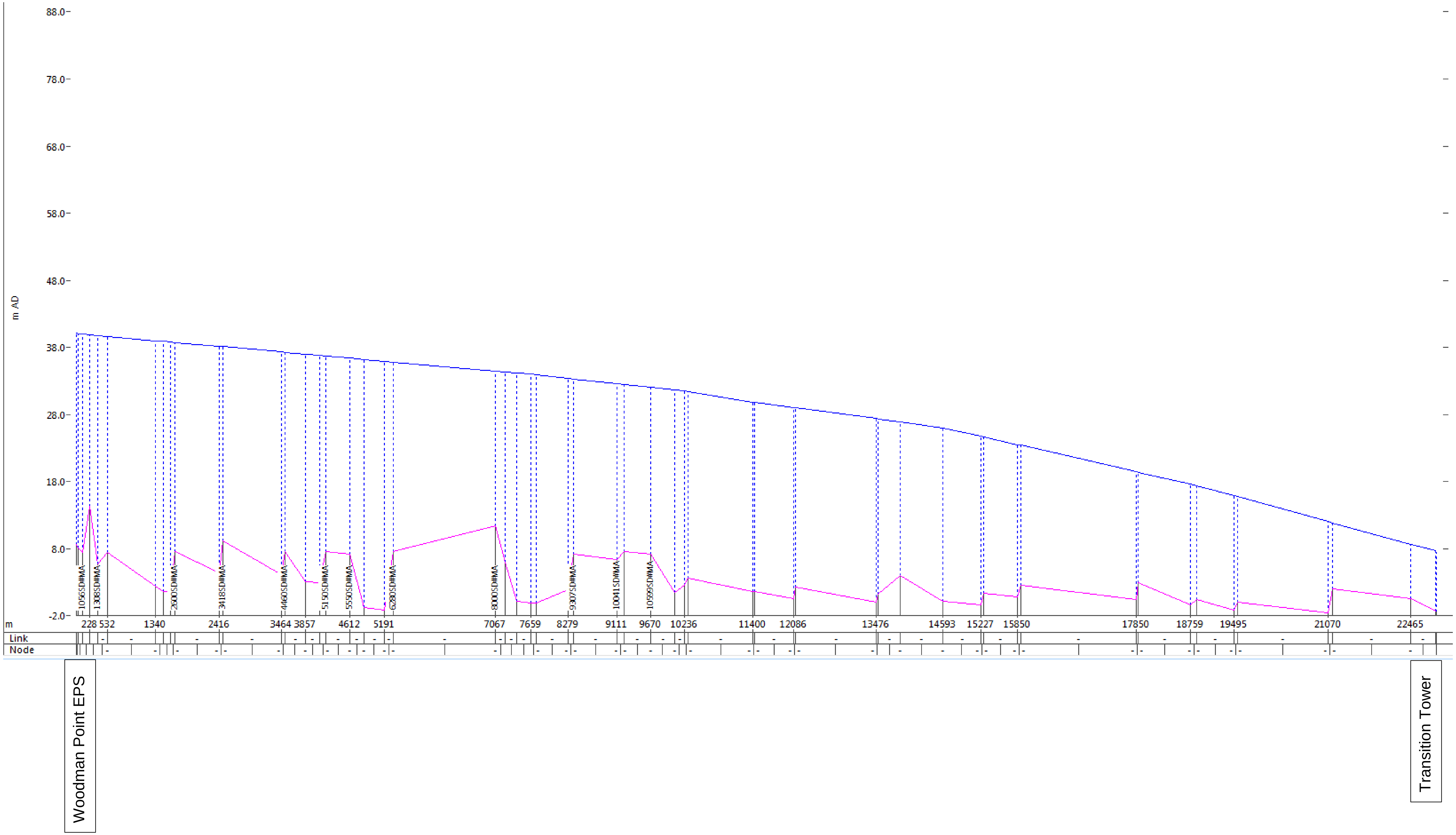
Woodman Point EPS small pump @ 1600 L/s
Kwinana EPS pumping @ 170 L/s
East Rockingham EPS off
Point Peron EPS off



Woodman Point EPS small pump @ 1640 L/s
Kwinana EPS off
East Rockingham EPS off
Point Peron EPS pumping @ 330 L/s



Woodman Point EPS small pump @ 1475 L/s
Kwinana EPS pumping @ 170 L/s
East Rockingham EPS off pumping @ 410 L/s
Point Peron EPS off



Appendix D – Functional control descriptions

Department of Jobs Tourism Science and Innovation

WTC MAR Scheme - Engineering Design & Costing Study

Functional Control Descriptions

March 2018

Table of contents

1. Introduction....1
2. Key Definitions....1
   2.1 Compliant Water....1
3. Site 1 Pre- Treatment Facility Stage 1....2
   3.1 Inflow Isolation Valve....2
   3.2 Inflow Flowmeter....2
   3.3 Process Isolation Valve....3
   3.4 Denitrifying Filters....4
   3.5 Backwash Pumps....5
   3.6 RO Unit....5
   3.7 Wastewater Return Pumps....6
   3.8 Outflow Isolation Valve....7
   3.9 Infiltration Flowmeter....7
   3.10 Open Infiltration Basins....8
4. Site 2 Pre-Treatment Facility....9
   4.1 TWW Feed Isolation Valve....9
   4.2 TWW Feed Pump Station....9
   4.3 TWW Feed Flowmeter....10
   4.4 Denitrifying Filters....10
   4.5 Backwash Pumps....11
   4.6 Backwash Return Pumps....12
   4.7 Recycle Water Pumps....13
   4.8 Infiltration Flowmeter....13
   4.9 Infiltration Galleries....14

Table index

Table 2-1 Glossary of Abbreviations and Acronyms....1

1. Introduction

The WTC Heavy Industry Local Water Supply Strategy (2016) from the DWER focuses on the development of water supplies for industry. This has led to the study on managed aquifer recharge (MAR) in the City of Kwinana. There are two sites that are the focus of the current study.

Site 1 is located near the northern end of the City of Kwinana, and lies on the western side of the Kwinana freight railway line. The northern end of the site is approximately 200 m east of Water Corporation's Sepia Depression Ocean Outlet Landline (SDOOL). The total area of the site is approximately 7.4 ha.

Site 2 is located west of the Kwinana Golf Course and adjacent to Gentle Road. The site is approximately 3 km north east of the Water Corporation's East Rockingham wastewater treatment plant (WWTP). It has a total area of approximately 6.0 ha.

2. Key Definitions

2.1 Compliant Water

This document uses the term 'compliant TWW'. Compliant TWW refers to water that meets the water quality parameters required of the inlet water.

This document also uses the term 'compliant water'. Compliant water refers to water that meets the water quality parameters required of the stream to the Infiltration Galleries or Infiltration Basins.

Table 2-1 Glossary of Abbreviations and Acronyms

HMI	Human Machine Interface
SCADA	Supervisory Control and Data Acquisition
SP	Setpoint
RTU	Remote Terminal Unit
ERWWTP	East Rockingham Wastewater Treatment Plant
WWTP	Wastewater Treatment Plant
TWW	Treated Wastewater
SDOOL	Sepia Depression Ocean Outlet Landline

3. Site 1 Pre- Treatment Facility Stage 1

3.1 Inflow Isolation Valve

3.1.1 Process Description

The Inflow isolation valve is located just after the offtake from the SDOOL bypass. It will prevent non-compliant water from being drawn into the process.

3.1.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Ammonia Analyser
- Turbidity Analyser
- Inflow Isolation valve
- Suction Non-Return Valve
- Pressure Sustaining Valve
- Flushing / Drainage Point Isolation
- Balance Tank(s)
- Wastewater Storage Tank Level Indicator
- Wastewater Storage Tanks

3.1.3 P&ID References

Please refer to P&ID 61-35557-J001.

3.1.4 Control Philosophy

The Isolation valve will open when the Balance tanks are at low level, or if the Wastewater Storage Tanks level is high. The Isolation valve will be closed when the Balance tank level is high.

The Isolation valve will close or remain shut when the ammonia analyser reads higher than the SP of 2mg/L, and when the Turbidity analyser reads higher than the SP.

3.2 Inflow Flowmeter

3.2.1 Process Description

The Inlet Flowmeter is installed downstream of the Inflow isolation valve and upstream of the Balance tanks. The flowmeter will provide instantaneous flow and daily totalized flow.

3.2.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Manual Inlet Flowmeter Inlet Isolation
- Inflow Flowmeter
- Manual Inlet Flowmeter Outlet Isolation

3.2.3 P&ID References

Please refer to P&ID 61-35557-J001

3.2.4 Control Philosophy

The flowmeter will run at all times and be connected to both the Water Corporation and MAR site SCADA.

3.3 Process Isolation Valve

3.3.1 Process Description

The Process isolation valve is located just after the balance tanks and before the TWW Feed pumps.

3.3.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Balance Tank
- Recycled Water Storage Tank
- Denitrifying Filters
- RO membranes

3.3.3 P&ID References

Please refer to P&ID 61-35557-J001

3.3.4 Control Philosophy

The Process Isolation valve is automated, it will normally be open. The Isolation valve will close when;

- The Wastewater Storage Tanks are at high high level,
- The combined Denitrifying Filters turbidity analyser has a reading above the high high SP for 5 minutes

Once the future works are complete the Process Isolation valve will also close if there is a fault signal from the RO membranes. TWW Feed Pump Station

3.3.5 Process Description

The TWW Feed pump station consists of two (2) pumps in a Duty/Standby arrangement. The pump withdraw from the Balance Tanks and transfer to the denitrification filters.

The pump is variable speed.

3.3.6 Instrumentation and Equipment

Equipment relevant to this section includes:

- Manual inlet isolation valve
- Upstream Pressure Indicator Block and Bleed Manifold
- TWW Feed Pump Duty
- Manual outlet isolation valve

- Downstream Pressure Indicator Block and Bleed Manifold
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

3.3.7 P&ID References

Please refer to P&ID 61-35557-J001.

3.3.8 Control Philosophy

The TWW Feed pump will be running continuously when the plant is in operation. It will start up when an operator turns it on via the MAR SCADA. As the pumps are variable speed the speed can also be controlled via the MAR SCADA.

The pump is interlocked with the Process Isolation Valve. If the process isolation valve is closed or there is a valve fault signal, the TWW Feed pump will not start and if it is running it will turn off.

3.4 Denitrifying Filters

3.4.1 Process Description

There will be five (5) Denitrifying filters in a 4 Duty / 1 Assist arrangement. The filters will remove the particulate matter and nitrogen from the TWW drawn from the Balance tanks. The filtrate flows to the Recycled Water Storage tank and then overflows to the Infiltration Basins.

The filters are backwashed once a day for 20 minutes each. The backwash water is drawn off of the filtrate in the Recycled Water Storage tanks. The backwash water goes to the Wastewater Storage tanks. The filters are backwashed consecutively.

The nitrogen compounds are removed via a biological process. The filter media supports the growth of microorganisms which remove the nitrogen compounds from the TWW. Sucrose is also dosed into the filters as food for the microorganisms.

3.4.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Sucrose Storage
- Balance Tanks
- Recycled Water Tanks
- Backwash Pumps

3.4.3 P&ID References

Please refer to P&ID 61-35557-J001.

3.4.4 Control Philosophy

The Denitrification filters will operate in parallel. When a filter is in normal operation the valves on the backwash streams should be closed and the sucrose and TWW stream valves should be open.

Each filter is to be backwashed at least once a day. The filters are backwashed one at a time. The controller will be set with the times of day at which each filter will be backwashed. When a

filter is due to be backwashed the valves on the sucrose and TWW streams should be closed and the valves on the backwash streams should be open.

If the turbidity on the outlet of a filter is above the high SP a backwash of that filter will be triggered.

If the turbidity on the outlet of the combined flow is above the high high SP for 5 minutes a signal will be sent to close the process isolation valve.

3.5 Backwash Pumps

3.5.1 Process Description

There are two (2) Backwash pumps consisting of a duty/ standby arrangement. The pump withdraws from the Recycled Water Storage tanks and transfers it to the denitrifying filters.

The pump is fixed speed. The expected output is 6 L/s. The backwash pump will run for 20 minutes per backwash.

3.5.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Recycled Water Storage Tanks
- Denitrifying Filters
- Manual inlet isolation valve
- Upstream Pressure Gauge
- Backwash Pump Duty
- Downstream Pressure Gauge
- Manual outlet isolation valve
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

3.5.3 P&ID References

Please refer to P&ID 61-35557-J001.

3.5.4 Control Philosophy

The Backwash pumps are interlocked with the Denitrification Filter control. The filter control will call the duty pump to run when;

- A filter backwash timer resets
- The turbidity of a filter filtrate is higher than the high SP

After the pump has received the call to run it will run for 20 minutes then turn off.

3.6 RO Unit

3.6.1 Process Description

Once the future works have been completed the RO unit will be in operation. The RO unit contains the cartridge filters and high pressure pump followed by the RO membranes. The unit accepts filtrate from the denitrification filter outflow. Permeate is blended back in with the filtrate in the Recycled Water Storage tanks. The reject water goes to the Wastewater Storage tanks.

3.6.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Denitrifying Filters
- Cartridge Filters
- RO Inflow Meter
- Pressure Indicator Prior RO Feed Pumps
- RO Feed Pumps
- Pressure Indicator Post RO Feed Pumps
- RO membranes
- Conductivity meter
- Turbidity meter
- Open Infiltration Basins

3.6.3 P&ID References

Please refer to P&ID 61-35557-J003.

3.6.4 Control Philosophy

When in normal operation the RO membranes will operate in parallel. A fault signal will be sent to the Process Isolation valve if

- the differential pressure on a membrane is below low low SP or above high high SP
- the outlet turbidity meter reads above the high high SP for 5 minutes
- the outlet conductivity on outlet higher than high high SP for 5 minutes

When the plant is offline the RO membranes can be chemically cleaned in place. First the permeate tank is filled. The membrane being cleaned should be manually isolated from the main process, by closing the membrane isolation valves. The chemicals will then be mixed in the CIP tank using water from the permeate tank for dilution. The clean in place system isolation valves can then be opened to allow for the CIP pump to fill the membrane with cleaning chemicals. The drain valves can be opened to drain the chemicals from the membrane.

3.7 Wastewater Return Pumps

3.7.1 Process Description

There are two (2) Wastewater Return pumps consisting of a duty/ standby arrangement. The pump withdraws from the Wastewater Storage tanks and transfers it to the SDOOL.

The pump is fixed speed.

3.7.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Backwash Storage Tank
- Manual inlet isolation valve
- Upstream Pressure Indicator Block and Bleed Manifold
- Backwash Return Pump Duty/ Standby

- Downstream Pressure Indicator Block and Bleed Manifold
- Manual outlet isolation valve
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

3.7.3 P&ID References

Please refer to P&ID 61-35557-J002.

3.7.4 Control Philosophy

The Wastewater Return pumps are interlocked with the Wastewater Storage tank, inflow and outflow isolation valves. The pump starts when the Inflow Isolation Valve and the Outflow isolation valve are open. It does not pump if the Wastewater Tank is at low level.

3.8 Outflow Isolation Valve

3.8.1 Process Description

The Outflow isolation valve is located just after the Backwash Return Pumps and upstream, of the SDOOL bypass.

3.8.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Inflow Isolation Valve
- Wastewater pumps

3.8.3 P&ID References

Please refer to P&ID 61-35557-J002.

3.8.4 Control Philosophy

The Isolation valve is automated and interlocked with the Inflow Isolation valve and the Wastewater pumps. The isolation valve will be open when the inflow isolation valve is open and the Wastewater pump is running. The TWW Feed Isolation valve will close when the Inflow Isolation Valve closes and the Wastewater pumps turn off.

3.9 Infiltration Flowmeter

3.9.1 Process Description

The Infiltration Flowmeter is installed downstream of the Recycled Water Storage tanks and upstream of the infiltration basins. The flowmeter will provide instantaneous flow and daily totalized flow.

3.9.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Manual Infiltration Flowmeter Inlet Isolation
- Infiltration Flowmeter
- Manual Infiltration Flowmeter Outlet Isolation

3.9.3 P&ID References

Please refer to P&ID 61-35557-J002.

3.9.4 Control Philosophy

The flowmeter will run at all times and be connected to the MAR site SCADA.

3.10 Open Infiltration Basins

3.10.1 Process Description

The Infiltration Basins accept the filtrate from the Recycled Water Storage tanks overflow. The water is cascaded down an aeration weir to the infiltration Basins.

3.10.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Recycled Water Storage tanks

3.10.3 P&ID References

Please refer to P&ID 61-35557-J002.

3.10.4 Control Philosophy

The TWW flows from the Recycled water tanks over an aeration weir and to the open infiltration basins.

4. Site 2 Pre-Treatment Facility

4.1 TWW Feed Isolation Valve

4.1.1 Process Description

The TWW Feed isolation valve is located upstream of the TWW Feed pumps. It will prevent non-compliant water from being drawn into the process.

4.1.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Ammonia analyser
- Turbidity Analyser
- Suction Non-Return Valve
- Flushing / Drainage Point
- TWW Feed Isolation valve
- Backwash Pump Duty
- Backwash Storage Tank

4.1.3 P&ID References

Please refer to P&ID 61-35557-J006.

4.1.4 Control Philosophy

The Isolation valve is automated and interlocked with the turbidity and ammonia analysers. The isolation valve will be open when the TWW Feed pump is running .The TWW Feed Isolation valve will close when;

- The turbidity analyser reading is greater than the high SP,
- The ammonia analyser reading is greater than the SP of 2 mg/L
- The Backwash Storage Tank level is at the High High SP

4.2 TWW Feed Pump Station

4.2.1 Process Description

The TWW Feed pump station consists of two (2) pumps in a Duty/Standby arrangement. The pump withdraws from the East Rockingham TWW storage tanks and transfers to the MAR Pre-treatment facility located adjacent to the ERWWTP. The TWW goes straight to the Denitrifying Filters.

The pump is fixed speed.

4.2.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Upstream Pressure Indicator Block and Bleed Manifold
- Manual inlet isolation valve
- TWW Feed Pump Duty

- Manual outlet isolation valve
- Downstream Pressure Indicator Block and Bleed Manifold
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

4.2.3 P&ID References

Please refer to P&ID 61-35557-J006.

4.2.4 Control Philosophy

The TWW Feed pump will be running continuously when the plant is in operation. It will start up when an operator turns it on. The pump is interlocked with the Feed Isolation Valve and the denitrification filters. If the isolation valve fault signal is active the TWW Feed pump will not start. If the denitrifying filters combined outflow reads above the high high SP the TWW Feed pump will turn off. The TWW feed pump will also not start and if running will turn off if the ERWWTP Storage tank level is low.

If the TWW Feed Isolation valve closes the TWW Feed pump will turn off.

4.3 TWW Feed Flowmeter

4.3.1 Process Description

The TWW Feed Flowmeter is installed downstream of the TWW Feed pump and upstream of the Denitrifying Filters. The flowmeter will provide instantaneous flow and daily totalized flow.

4.3.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Flowmeter Inlet Isolation
- TWW Feed Flowmeter
- Flowmeter Outlet Isolation

4.3.3 P&ID References

Please refer to P&ID 61-35557-J006.

4.3.4 Control Philosophy

The flowmeter will run at all times and be connected to both the Water Corporation and MAR site SCADA.

4.4 Denitrifying Filters

4.4.1 Process Description

Five (5) x denitrifying filters remove the particulate matter and nitrogen compounds from the TWW drawn from the ERTWW Balance Tanks. They will operate in a 5 Duty / 1 assist arrangement. The filtrate flows to the Washwater tank and overflows to the Infiltration Galleries.

The filters are backwashed once a day for 20 minutes each. The backwash water is drawn off of the filtrate in the wash water tanks. The backwash water is injected into the ERWWTP final disposal.

The nitrogen compounds are removed via a biological process. The filter media supports the growth of microorganisms which remove the nitrogen compounds from the TWW. Sucrose is also dosed into the filters as food for the microorganisms.

4.4.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Washwater Tank
- Backwash Pumps
- Turbidity analysers

4.4.3 P&ID References

Please refer to P&ID 61-35557-J006.

4.4.4 Control Philosophy

The Denitrification filters will operate in parallel. When a filter is in normal operation the valves on the backwash streams should be closed and the sucrose and TWW stream valves should be open.

Each filter is to be backwashed at least once a day. The filters are backwashed one at a time. The controller will be set with the times of day at which each filter will be backwashed. When a filter is due to be backwashed the valves on the sucrose and TWW streams should be closed and the valves on the backwash streams should be open.

If the turbidity on the outlet of a filter is above the high SP a backwash of that filter will be triggered.

If the turbidity on the outlet of a filter is above the high high SP for 5 minutes a filter fault signal will be sent to the TWW Feed Pumps.

4.5 Backwash Pumps

4.5.1 Process Description

There are two (2) Backwash pumps consisting of a duty/ Standby arrangement. The pumps withdraw from the Washwater tank and transfer it to the denitrifying filters.

The pump is fixed speed. The expected output is 128 L/s. The backwash pump will run for 20 minutes per backwash.

4.5.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Washwater Tank
- Denitrifying Filters
- TWW Feed Isolation valve
- Manual Isolation Upstream Backwash Pump Duty
- Upstream Pressure Gauge
- Backwash Pump Duty
- Downstream Pressure Gauge
- Manual Isolation Downstream Backwash Pump Duty

- Discharge Air Relief Isolation
- Discharge Pump Air Relief

4.5.3 P&ID References

Please refer to P&ID 61-35557-J006.

4.5.4 Control Philosophy

The Backwash pump is interlocked with the Denitrification Filter control. The Filter control will call the pump to run when;

- A filter is set to be backwashed
- The turbidity of a filter filtrate is above the high SP

After the pump has received the call to run it will run for 20 minutes then turn off.

4.6 Backwash Return Pumps

4.6.1 Process Description

There are two (2) Backwash Return pumps consisting of a duty/ Standby arrangement. The pump withdraws from the Backwash Storage tank and transfers it to the ERWWTP site through to the TWW Main to SDOOL.

The pump is fixed speed.

4.6.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Backwash Storage Tanks
- Backwash Storage Tank Level Indicator
- Upstream Pressure Indicator Block and Bleed Manifold
- Manual Isolation Upstream Backwash Return Pump Duty
- Manual Isolation Downstream Backwash Return Pump Duty
- Downstream Pressure Indicator Block and Bleed Manifold
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

4.6.3 P&ID References

Please refer to P&ID 61-35557-J007.

4.6.4 Control Philosophy

The Backwash Return pump starts when the available signal from the ERWWTP injection via TWW Main to SDOOL is being received and the Backwash Storage Tank Level Indicator is at the high SP.

It does not pump if the Backwash Storage Tank is at low level.

4.7 Recycle Water Pumps

4.7.1 Process Description

There are two (2) Recycle Water pumps consisting of a duty/ Standby arrangement. The pump withdraws from the Washwater Tank and transfers it to the Infiltration Galleries.

The pump is fixed speed. The expected output is 128 L/s.

4.7.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Washwater Tanks
- Upstream Pressure Indicator Block and Bleed Manifold
- Manual Isolation Upstream Recycle Water Pump Duty
- Recycle Water Pumps
- Manual Isolation Downstream Recycle Water Pump Duty
- Downstream Pressure Indicator Block and Bleed Manifold
- Discharge Air Relief Isolation
- Discharge Pump Air Relief

4.7.3 P&ID References

Please refer to P&ID 61-35557-J007.

4.7.4 Control Philosophy

The recycle water pump are interlocked with the Wash water tank level. The Recycle Water pump starts when the Wash water tank level is at the high SP. The Recycle water pumps turn off when the Wash water tank level is at the low SP.

4.8 Infiltration Flowmeter

4.8.1 Process Description

The Infiltration Flowmeter is installed downstream of the denitrifying filters and upstream of the Infiltration Galleries. The flowmeter will provide instantaneous flow and daily totalized flow.

4.8.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Infiltration Flowmeter Manual Inlet Isolation
- Infiltration Flowmeter
- Infiltration Flowmeter Manual Outlet Isolation

4.8.3 P&ID References

Please refer to P&ID 61-35557-J007.

4.8.4 Control Philosophy

The flowmeter will run at all times and be connected to the MAR site SCADA.

4.9 Infiltration Galleries

4.9.1 Process Description

The Infiltration Galleries accepts the filtrate from the Wash water tank overflow. The water is cascaded down an aeration weir to the infiltration galleries.

4.9.2 Instrumentation and Equipment

Equipment relevant to this section includes:

- Wash water tank
- Infiltration Flowmeter

4.9.3 P&ID References

Please refer to P&ID 61-35557-J007.

4.9.4 Control Philosophy

The TWW flows from the Recycled water tanks over an aeration weir and to the open infiltration basins.

GHD

Level 10
999 Hay Street
T: 61 8 6222 8222   F: 61 8 6222 8555   E: permail@ghd.com

6135557-99660/https://projects.ghd.com/oc/WesternAustralia/westerntradecoastmar/Delivery/Documents/Functional Control System.docx

Document Status

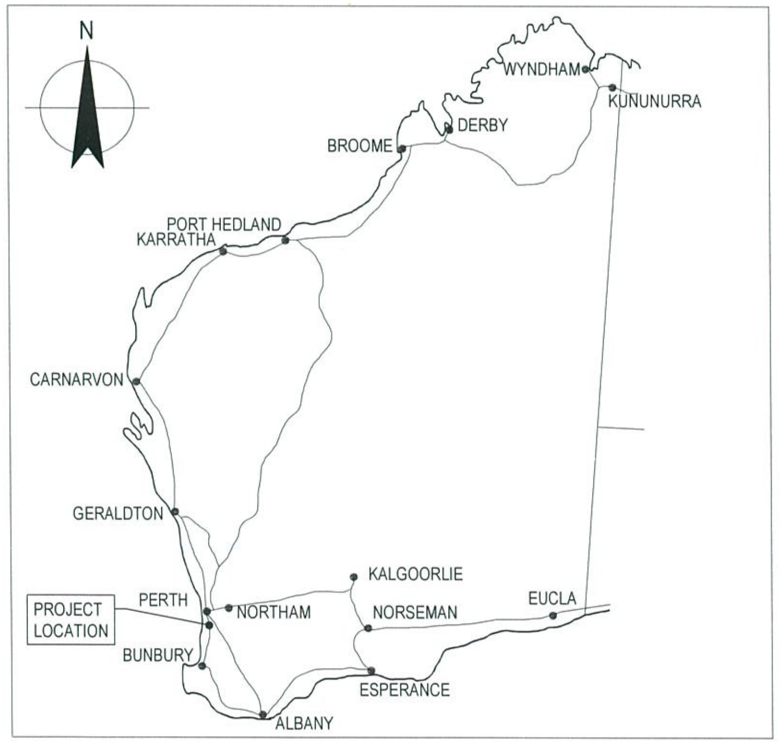
Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date

www.ghd.com

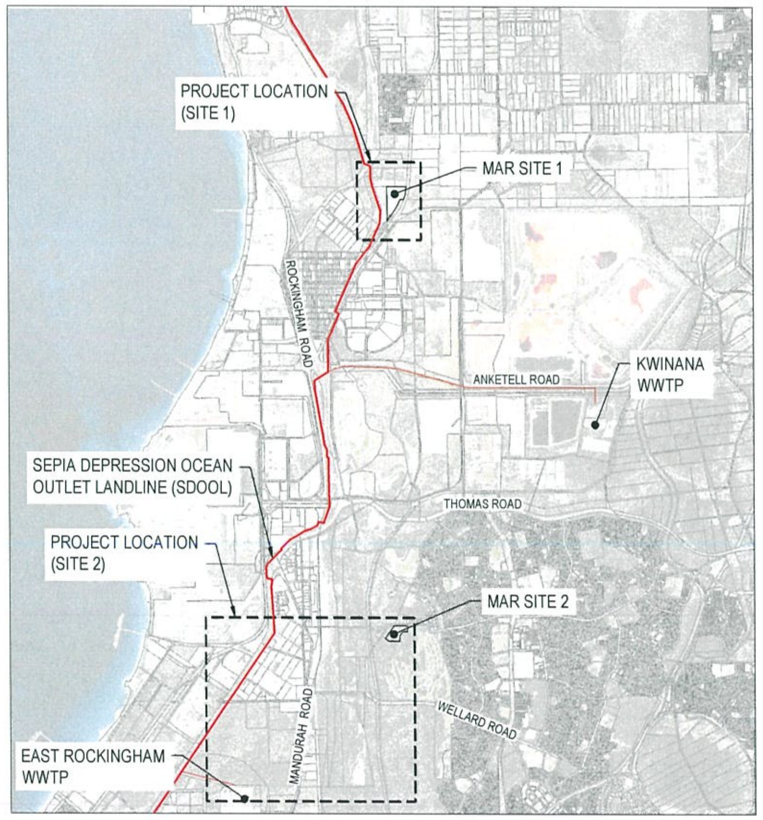
Appendix E – Engineering design drawings

DEPARTMENT OF JOBS, TOURISM SCIENCE AND INNOVATION (DJTSI) WESTERN TRADE COAST (WTC) MANAGED AQUIFER RECHARGE (MAR) SCHEME

61-35557



LOCALITY PLAN
NTS



LOCALITY PLAN
SCALE: 1:50000

DRAWING INDEX

DRAWING No.	DRAWING TITLE
GENERAL	
61-35557-G001	COVER SHEET AND DRAWING INDEX
MAR SITE 1	
61-35557-C001	CONVEYANCE PIPELINE - PIPELINES FROM SDOOL TO MAR SITE 1
61-35557-C002	SITE 1 - SDOOL OFFTAKE - GENERAL ARRANGEMENT
61-35557-C004	SITE 1 - INFILTRATION SYSTEM - GENERAL ARRANGEMENT
61-35557-C005	SITE 1 - INFILTRATION SYSTEM - INFILTRATION BASIN DETAILS
61-35557-C008	SITE 1 - PRE-TREATMENT FACILITY - GENERAL ARRANGEMENT
61-35557-J001	SITE 1 - INLET & DENITRIFICATION FILTER - P&ID
61-35557-J002	SITE 1 - OUTLET WASTE & INFILTRATION - P&ID
61-35557-J003	SITE 1 - REVERSE OSMOSIS UNIT - P&ID
MAR SITE 2	
61-35557-C003	CONVEYANCE PIPELINE - TWW, WASTEWATER AND RECYCLED WATER PIPELINES
61-35557-C006	SITE 2 - INFILTRATION SYSTEM - GENERAL ARRANGEMENT
61-35557-C007	SITE 2 - INFILTRATION SYSTEM - INFILTRATION GALLERIES DETAILS
61-35557-C009	SITE 2 - PRE-TREATMENT FACILITY - GENERAL ARRANGEMENT
61-35557-J004	SITE 2 - INLET & DENITRIFICATION FILTER - P&ID
61-35557-J005	SITE 2 - WASTE DISPOSAL & INFILTRATION - P&ID

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 500 1000 1500 2000 2500m
SCALE 1:50,000 AT ORIGINAL SIZE

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

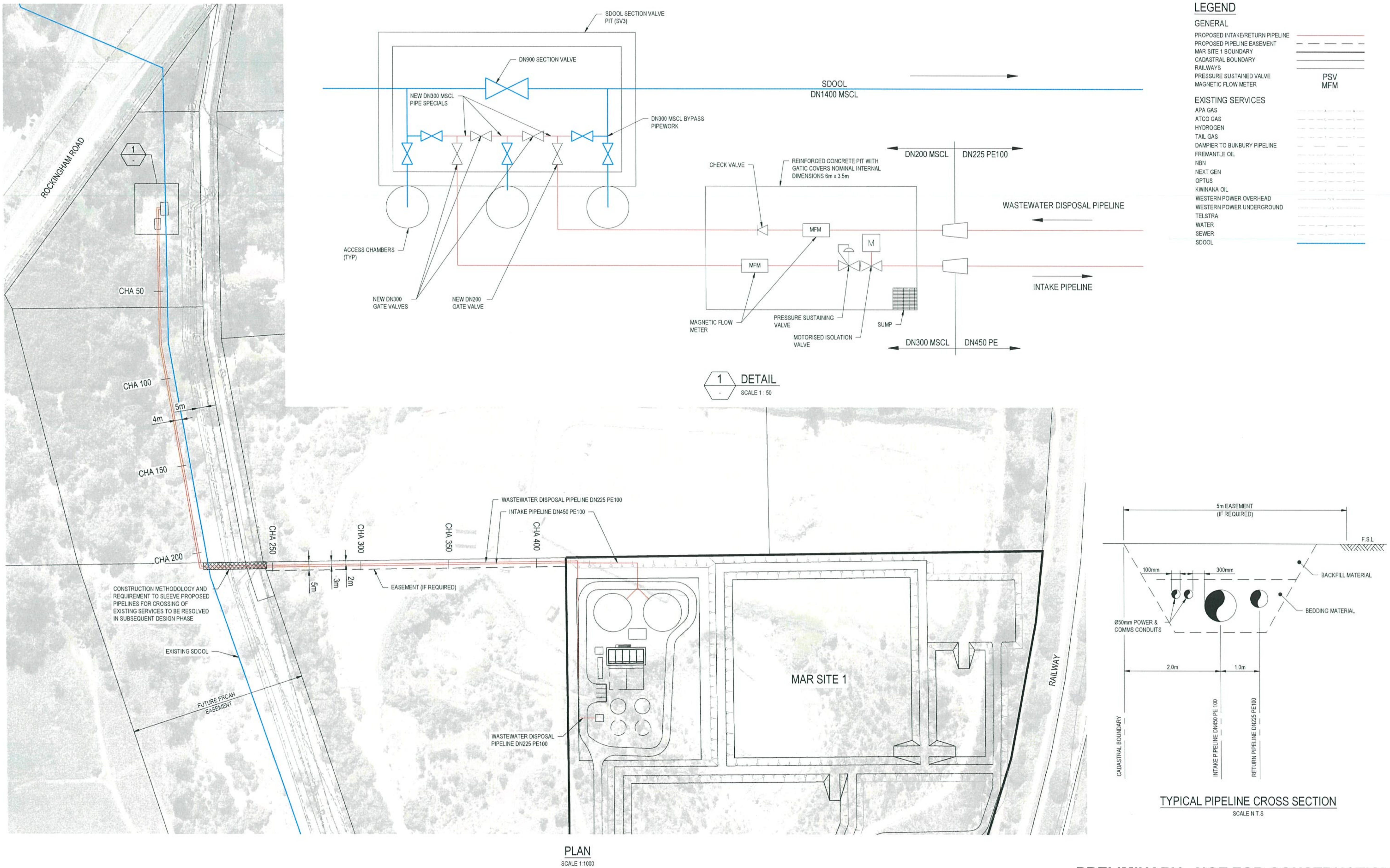
DO NOT SCALE

Drawn	B.SHAW	Designer	D.EDGAR
Drafting Check		Design Check	
Approved (Project Director)			
Date			
Scale	1:50,000	This Drawing must not be used for Construction unless signed as Approved	

Client: DJTSI
Project: WTC MAR SCHEME
Title: COVER SHEET & DRAWING INDEX

Original Size: A1 — Drawing No: **61-35557-G001** — Rev: B

Plot Date: 22 May 2018 - 4:15 PM   Plotted by: Brendan Gaunson   Cad File No: G:\61\35557\CADD\Drawings\61-35557-G001.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS			24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 0.5 1.0 1.5 2.0 2.5m — SCALE 1:50 AT ORIGINAL SIZE

0 10 20 30 40 50m — SCALE 1:1000 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

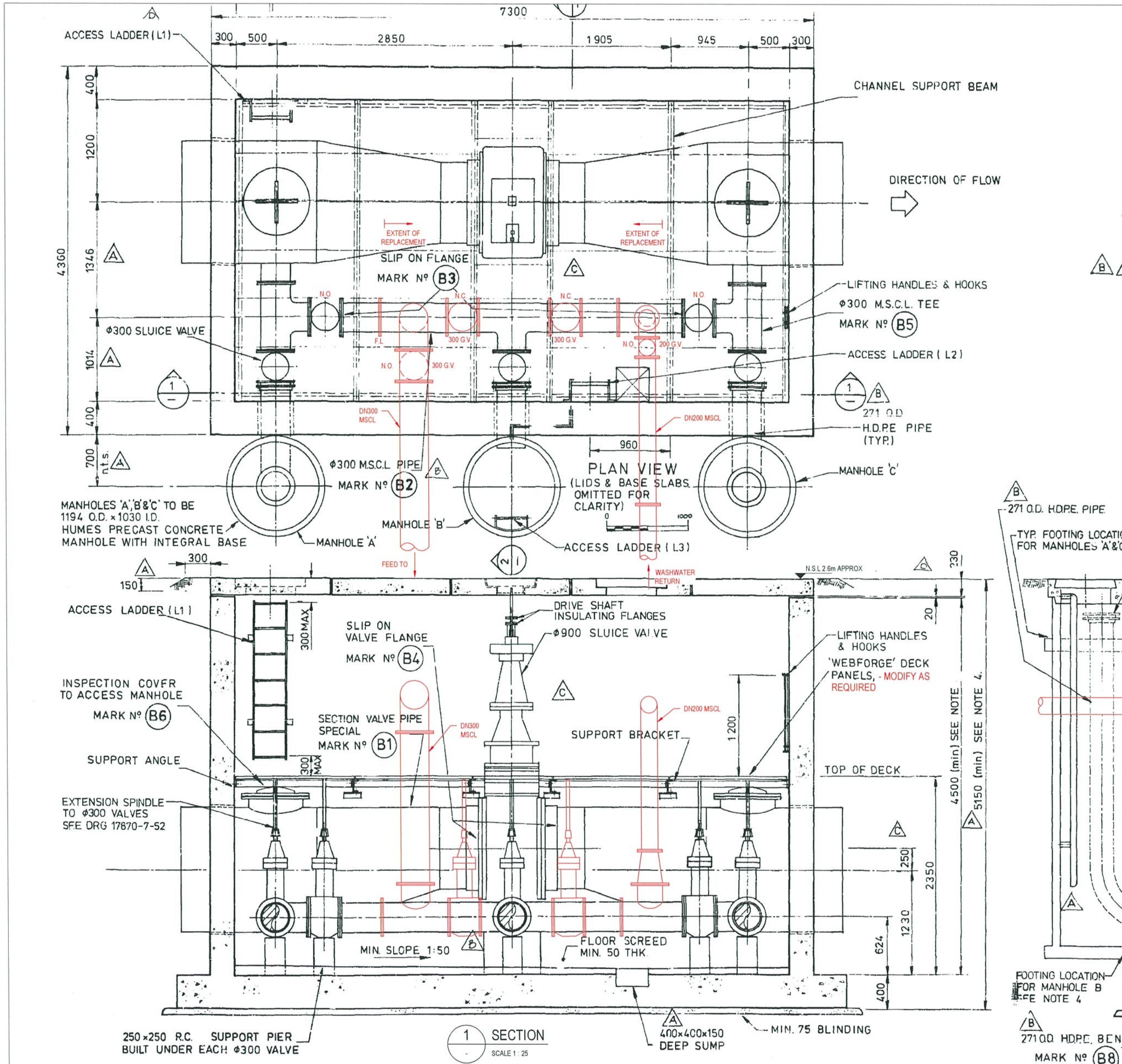
Conditions of Use.
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose

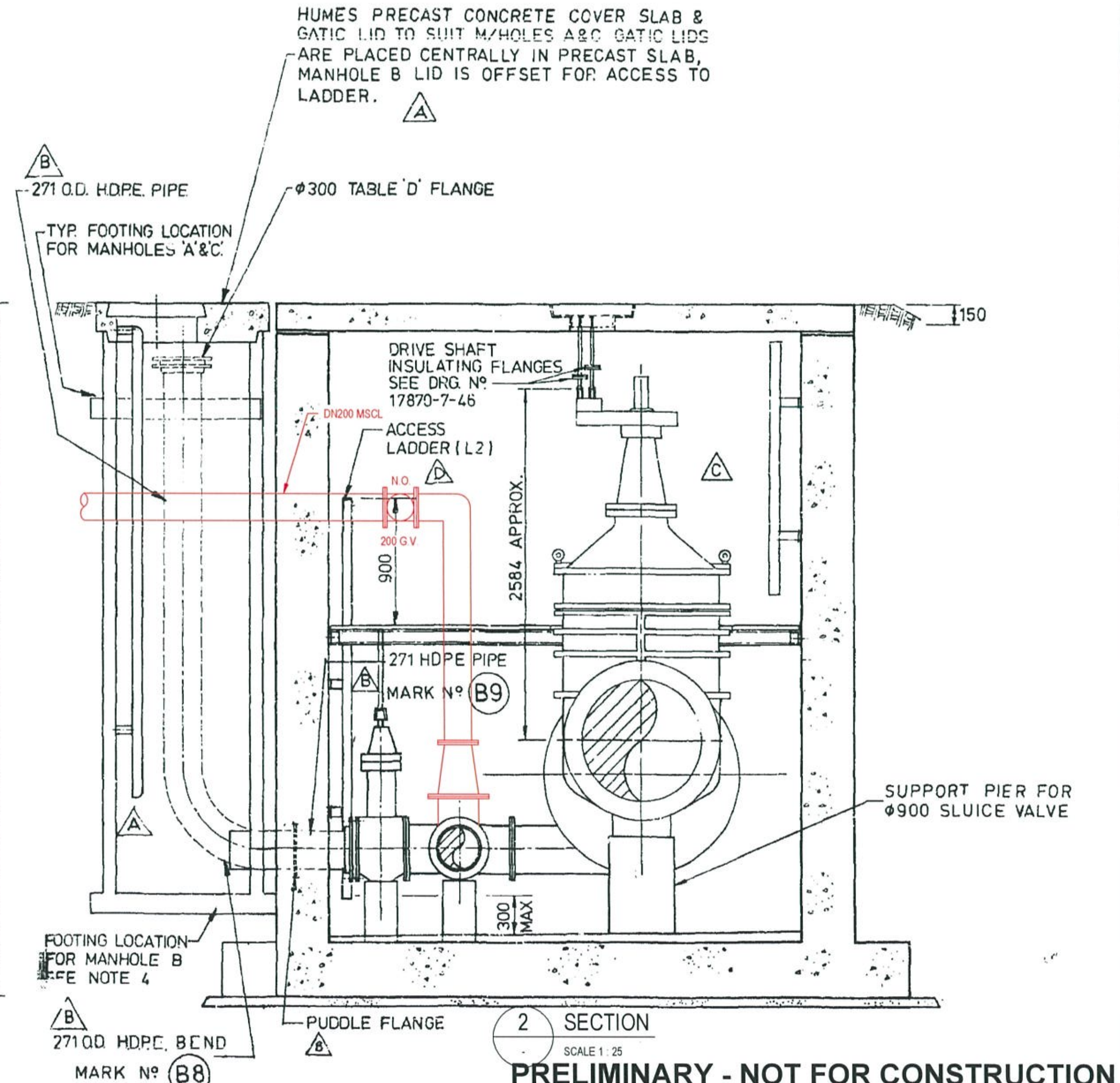
Drawn B.SHAW | Designer D.EDGAR
Drafting Check | Design Check
Approved (Project Director)
Date
Scale AS SHOWN
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **CONVEYANCE PIPELINE PIPELINES FROM SDOOL TO MAR SITE 1**

Original Size A1
Drawing No: **61-35557-C001**
Rev: **B**

Plot Date: 22 May 2018 - 4:11 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C001.dwg





NOTES

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN
2. FOR LOCATIONS OF SECTION VALVES SEE LONGITUDINAL SECTIONS.
3. FOR DETAILS OF — SEE DRG Nº
   - CONCRETE DETAILS — 17870-5-51
   - PIT REINFORCEMENT — 17870-6-53, 54, 55, 56 & 57
   - LID REINFORCEMENT — 17870-6-58
   - REINFORCEMENT SCHEDULE — 17870-6-110, 111, 112, 113, 114 & 115
   - METALWORK — 17870-7-52
   - PIPE SPECIALS — 17870-7-34 & 36
   - FIELD INSTALLATION OF PIPEWORK — 17870-7-31
   - ROOF BOX — 17870-7-43 & 44
4. DEPTH OF PIT DEPENDS ON LOCATION. FOR DETAILS SEE TABLE 1 ON DRG Nº 17870-5-51
5. ALL EXPOSED STEEL PIPEWORK AND FITTINGS IN MANHOLES TO BE FINALLY WRAPPED WITH DENSO TAPE AS SPECIFIED
6. TO ENSURE CORRECT ALIGNMENT - H.D.P.E. PIPE FLANGES MUST BE BOLTED TO VALVE FLANGES BEFORE PIT WALLS ARE CAST AROUND THEM

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 0.25 0.5 0.75 1.0 1.25m
SCALE 1:25 AT ORIGINAL SIZE

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

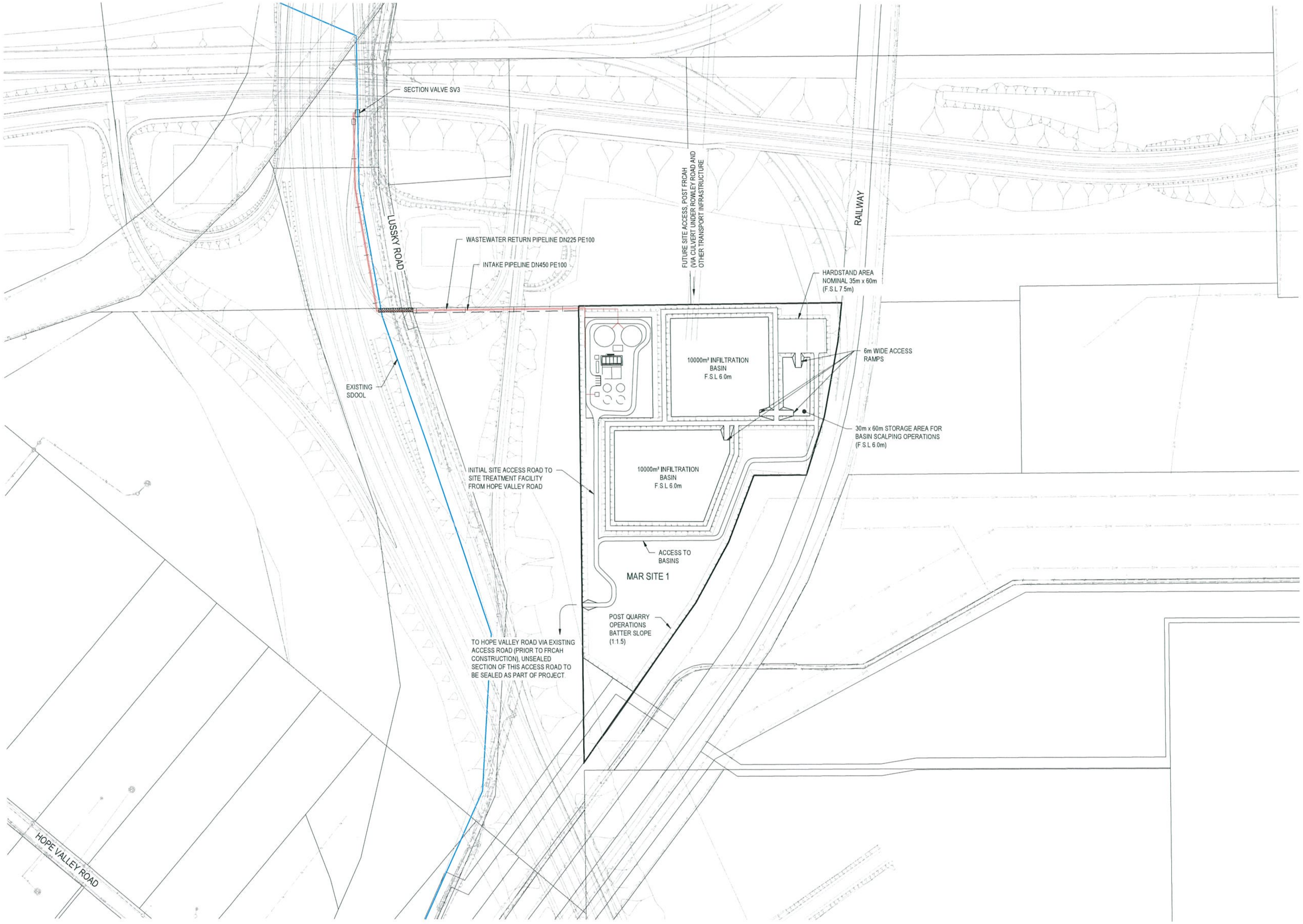
Conditions of Use.
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn	B.SHAW	Designer	D.EDGAR
Drafting Check		Design Check	
Approved (Project Director)			
Date			
Scale	1:25	This Drawing must not be used for Construction unless signed as Approved	

Client: DJTSI
Project: WTC MAR SCHEME
Title: SITE 1 - SDOOL OFFTAKE GENERAL ARRANGEMENT

Original Size: A1 Drawing No: 61-35557-C002 Rev: B

Plot Date: 22 May 2018 - 4:18 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C002.dwg



PLAN
SCALE 1:2000

LEGEND

GENERAL

- PROPOSED INTAKE/RETURN PIPELINE
- PROPOSED PIPELINE EASEMENT
- MAR SITE 1 BOUNDARY
- CADASTRAL BOUNDARY
- RAILWAYS

EXISTING SERVICES

- APA GAS
- ATCO GAS
- HYDROGEN
- TAIL GAS
- DAMPIER TO BUNBURY PIPELINE
- FREMANTLE OIL
- NBN
- NEXT GEN
- OPTUS
- KWINANA OIL
- WESTERN POWER OVERHEAD
- WESTERN POWER UNDERGROUND
- TELSTRA
- WATER
- SEWER
- SDOOL

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 20 40 60 80 100m
SCALE 1:2000 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

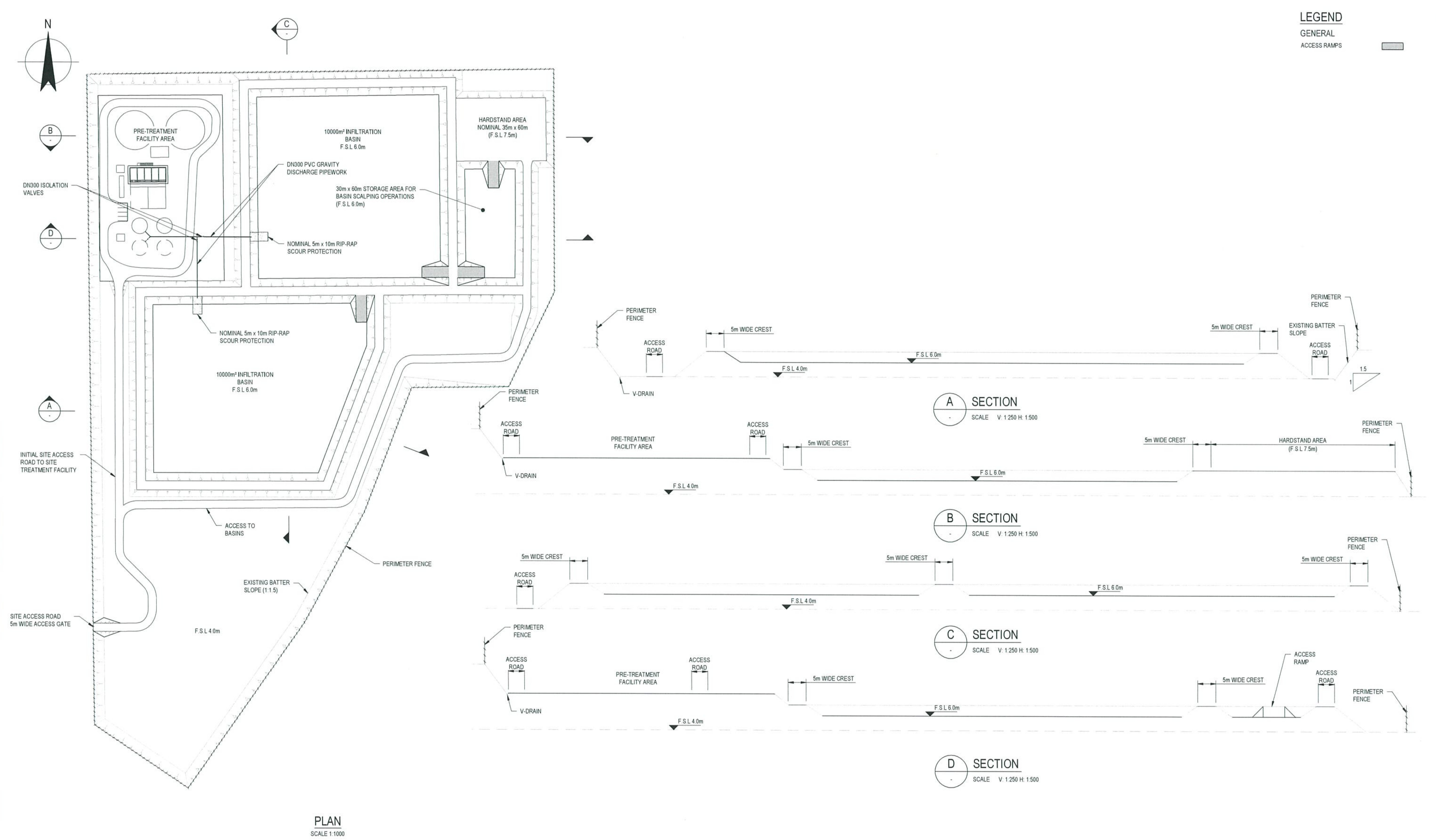
Conditions of Use.
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn B.SHAW | Designer D.EDGAR
Drafting Check | Design Check
Approved (Project Director)
Date
Scale 1:1000
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - INFILTRATION SYSTEM GENERAL ARRANGEMENT**

Original Size A1 | Drawing No: **61-35557-C004** | Rev: **B**

Plot Date: 22 May 2018 - 4:13 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C004.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 10 20 30 40 50m SCALE 1:1000 AT ORIGINAL SIZE

VERTICAL 1:250 AT ORIGINAL SIZE 0 2.5 5 7.5 10 12.5m

HORIZONTAL 1:500 AT ORIGINAL SIZE 0 5 10 15 20 25m

GHD

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

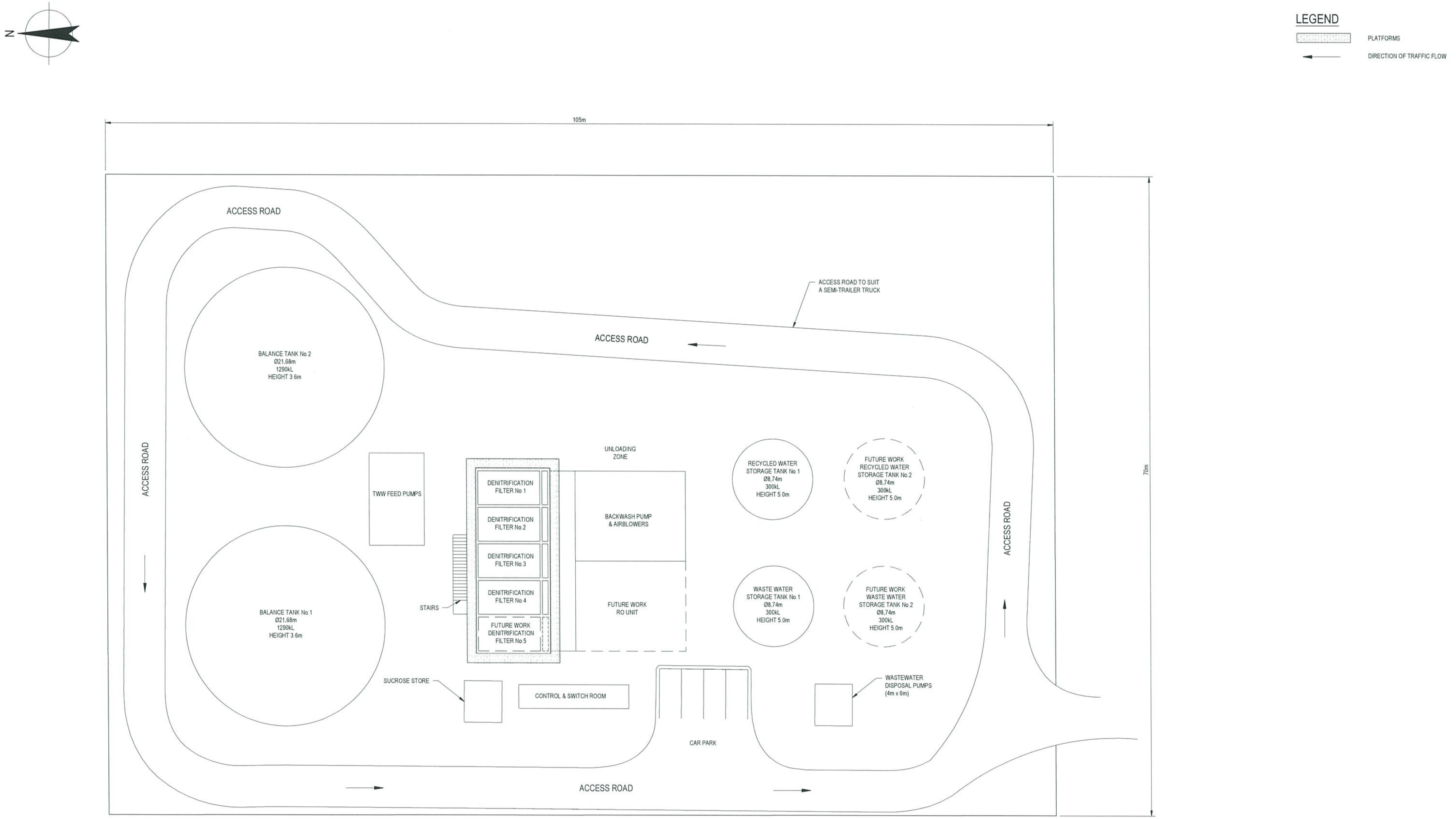
DO NOT SCALE

Drawn B.SHAW | Designer D.EDGAR
Drafting Check | Design Check
Approved (Project Director)
Date
Scale AS SHOWN
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - INFILTRATION SYSTEM INFILTRATION BASIN DETAILS**

Original Size **A1** Drawing No: **61-35557-C005** Rev: **B**

Plot Date: 22 May 2018 - 4:13 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C005.dwg



SITE 1 - PRE-TREATMENT FACILITY
SCALE 1:200

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 2 4 6 8 10m
SCALE 1:200 AT ORIGINAL SIZE

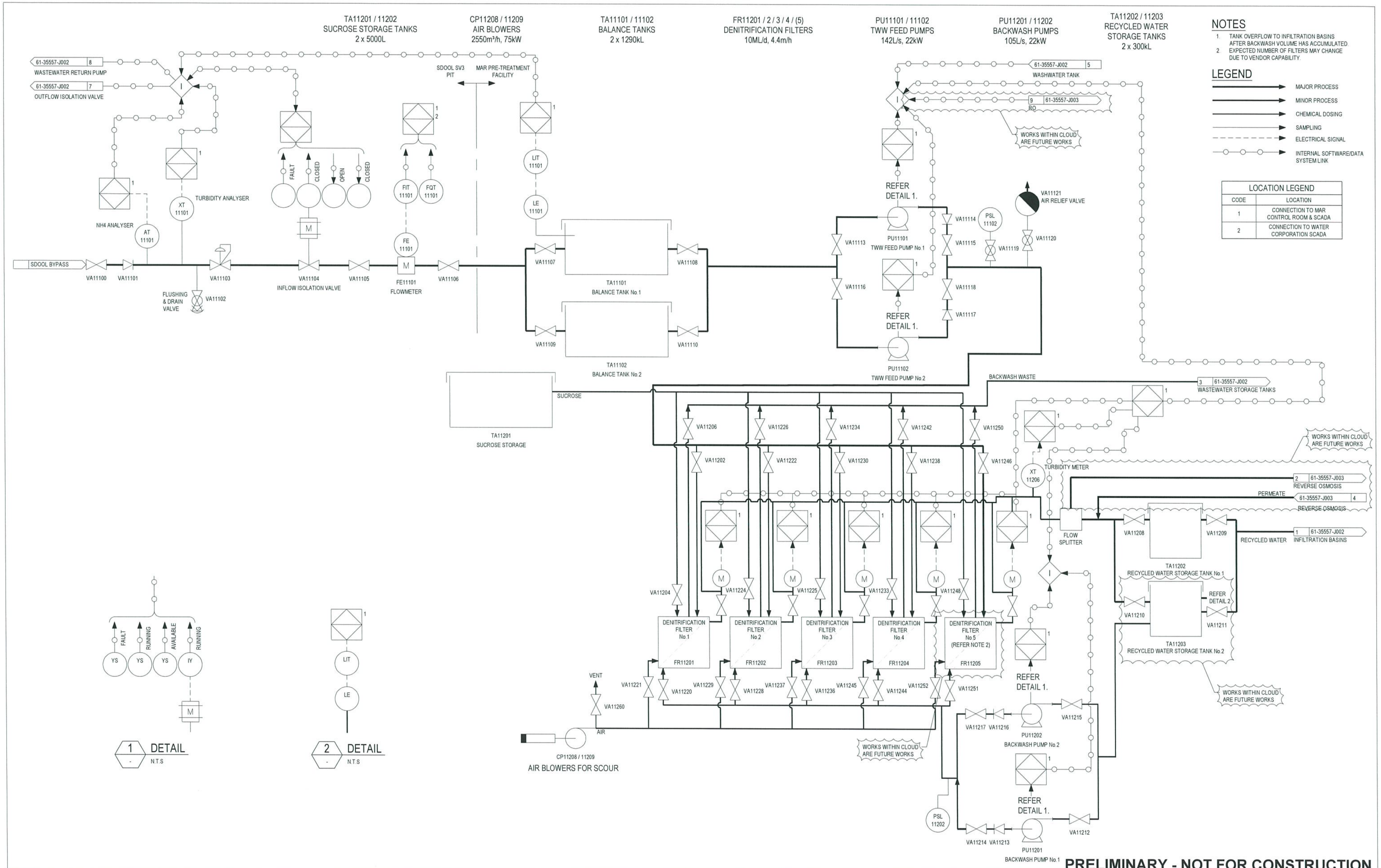
GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Drawn B.SHAW	Designer D.EDGAR
Drafting Check	Design Check
Approved (Project Director) Date	
Scale 1:200	This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - PRE-TREATMENT FACILITY GENERAL ARRANGEMENT**
Original Size **A1** Drawing No: **61-35557-C008** Rev: **B**

Plot Date: 22 May 2018 - 4:14 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C008.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

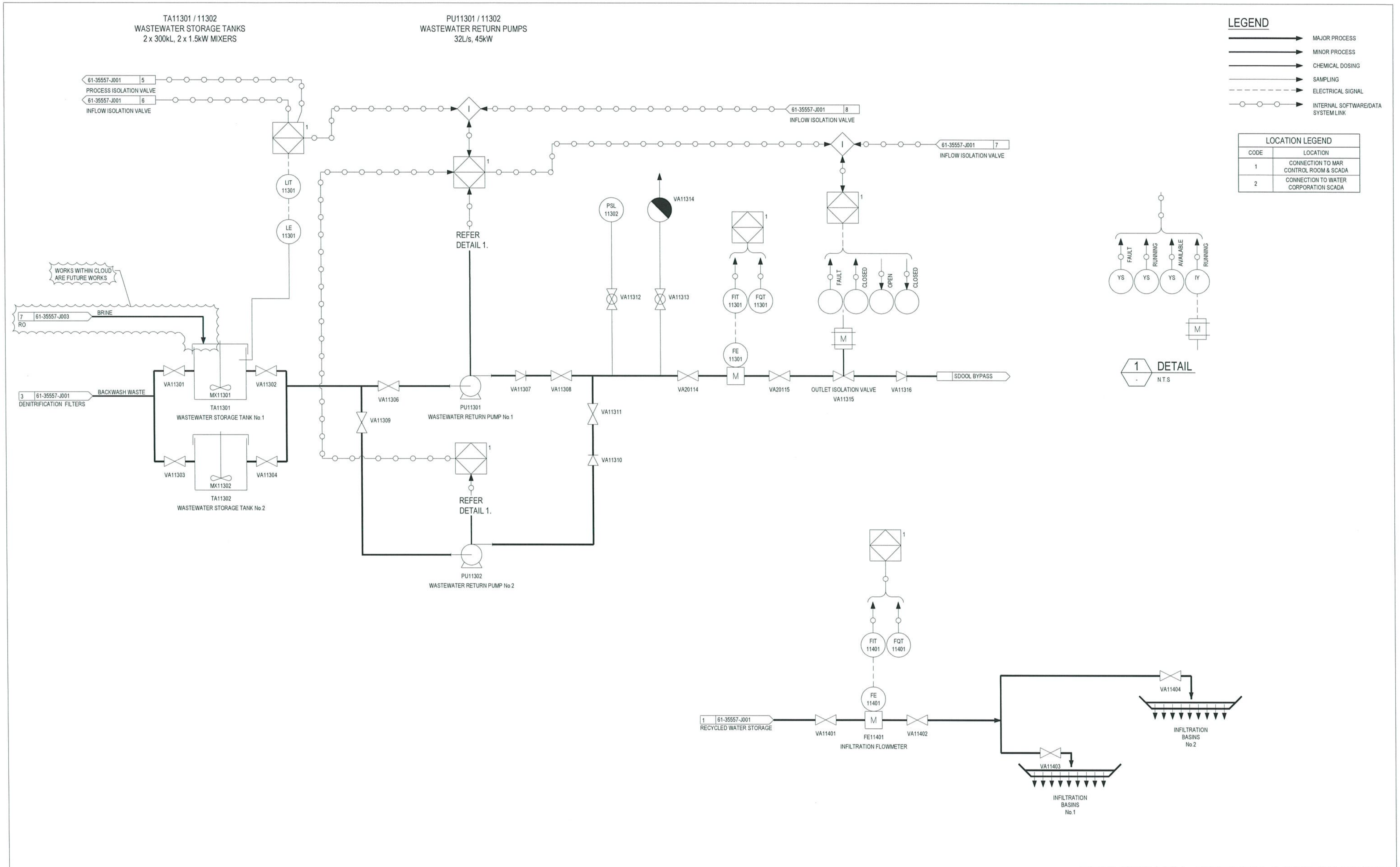
Conditions of Use
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn B.SHAW | Designer P.WALKER
Drafting Check | Design Check
Approved (Project Director)
Date
Scale N.T.S
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - INLET & DENITRIFICATION FILTER P&ID**

Original Size A1 | Drawing No: **61-35557-J001** | Rev: B

Plot Date: 22 May 2018 - 4:15 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-J001.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Drawn B.SHAW | Designer P.WALKER
Drafting Check | Design Check
Approved (Project Director)
Date
Scale N.T.S

This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - OUTLET WASTE & INFILTRATION P&ID**

Original Size **A1**
Drawing No: **61-35557-J002**
Rev: **B**

Plot Date: 22 May 2018 - 4:16 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-J002.dwg

FR12301 / 12302
CARTRIDGE FILTERS
2 No. DUTY

PU12301 / 12302
RO FEED PUMPS
110kW

RO12301
STAGE 1 REVERSE OSMOSIS
30 PRESSURE VESSELS

RO12302
STAGE 2 REVERSE OSMOSIS
15 PRESSURE VESSELS

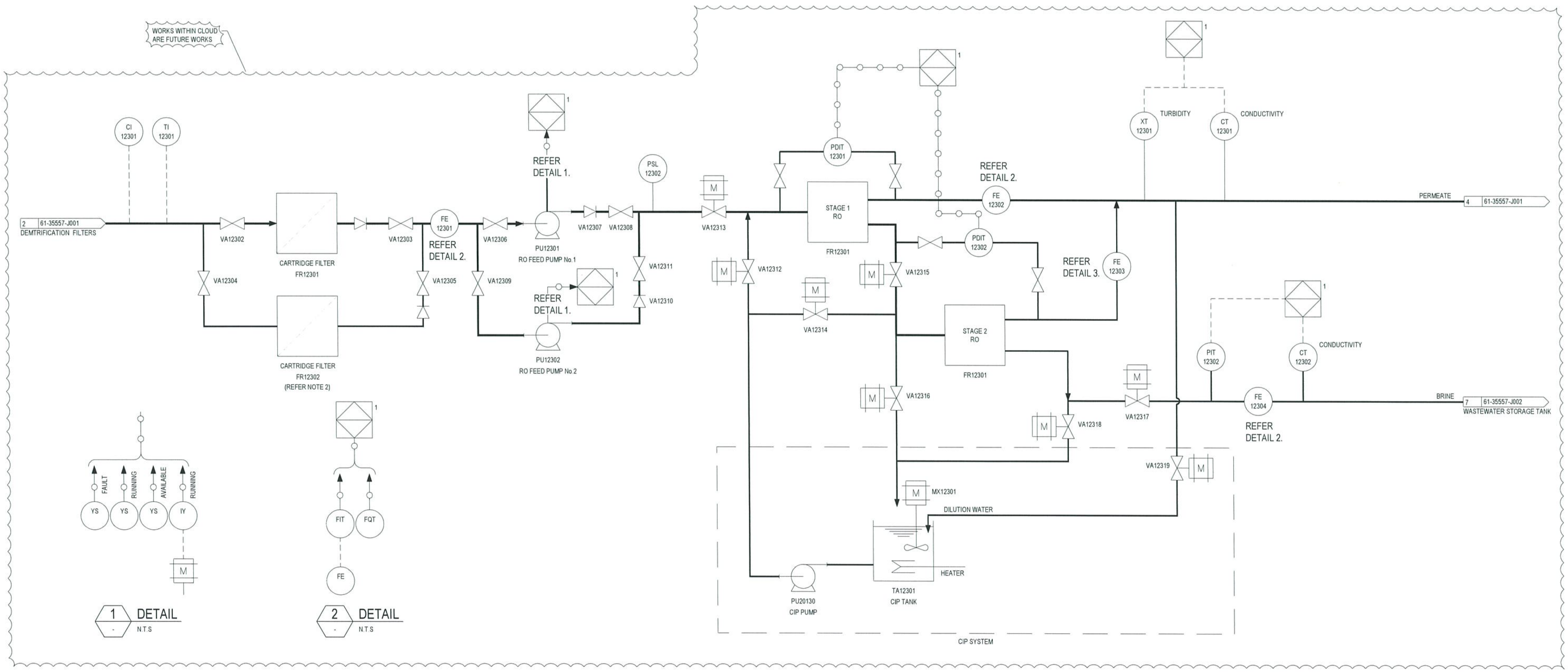
NOTES

1. NUMBER OF FILTERS REQUIRED TO BE CONFIRMED.

LEGEND

- MAJOR PROCESS
- MINOR PROCESS
- CHEMICAL DOSING
- SAMPLING
- ELECTRICAL SIGNAL
- INTERNAL SOFTWARE/DATA SYSTEM LINK

LOCATION LEGEND	
CODE	LOCATION
1	CONNECTION TO MAR CONTROL ROOM & SCADA
2	CONNECTION TO WATER CORPORATION SCADA



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD

Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Drawn B.SHAW | Designer P.WALKER
Drafting Check | Design Check
Approved (Project Director)
Date
Scale N.T.S
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 1 - REVERSE OSMOSIS UNIT P&ID**

Original Size **A1** Drawing No: **61-35557-J003** Rev: **B**

Plot Date: 22 May 2018 - 4:16 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-J003.dwg

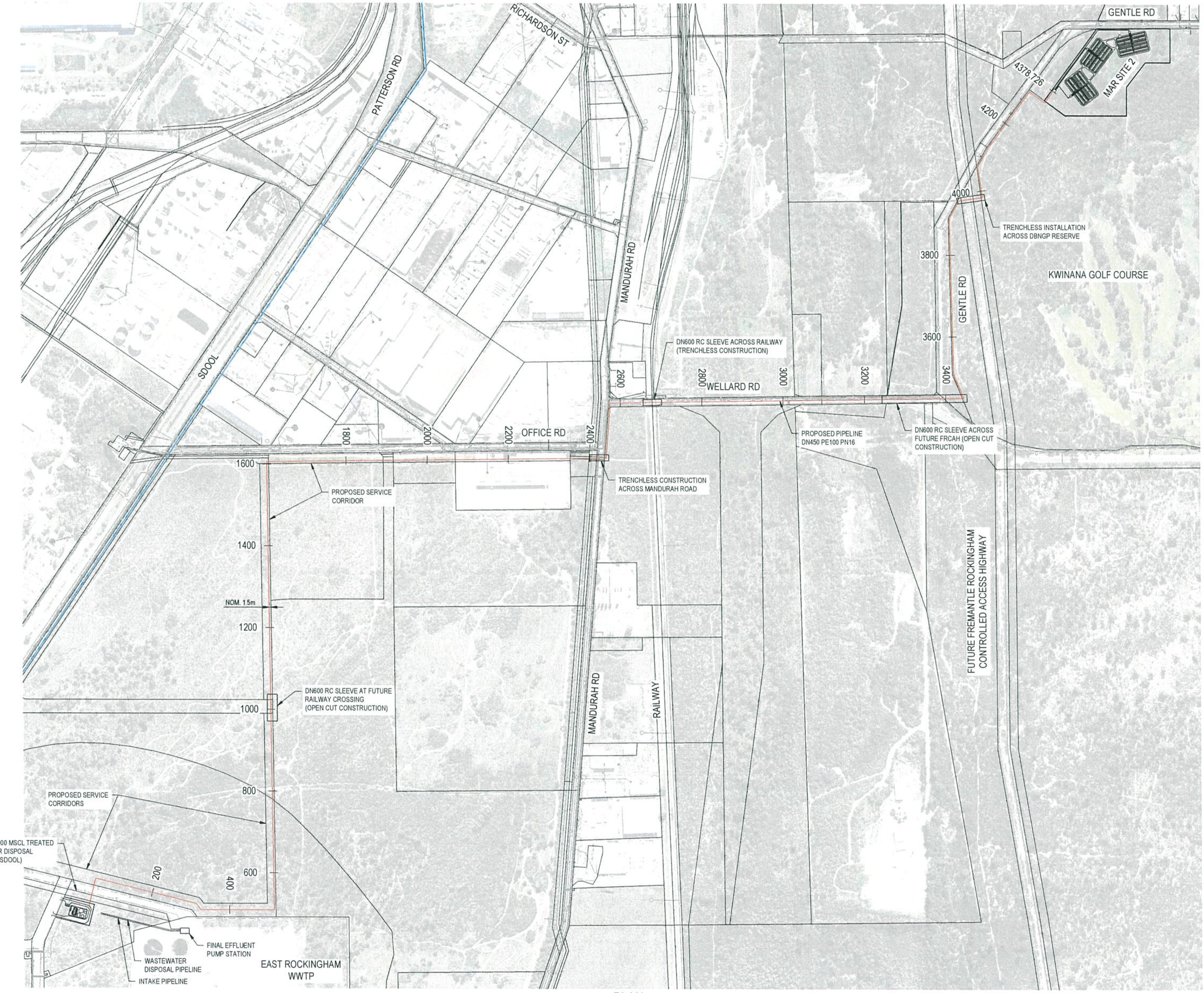
LEGEND

GENERAL

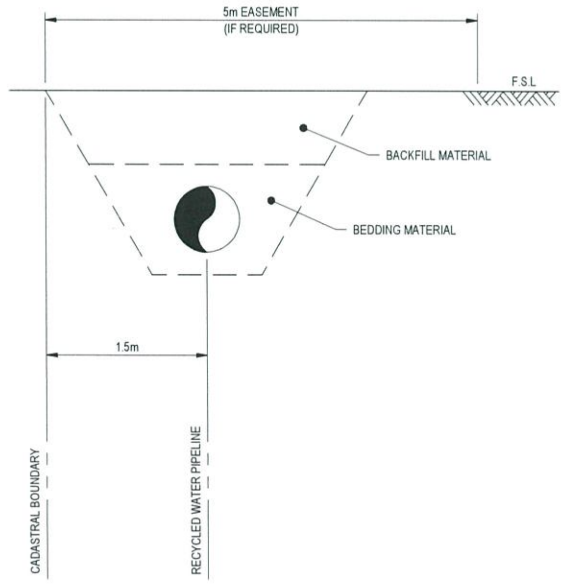
- PROPOSED RECYCLED WATER PIPELINE
- MAR SITE 2 BOUNDARY
- CADASTRAL BOUNDARY
- RAILWAYS
- SLEEVED CONSTRUCTION REQUIRED

EXISTING SERVICES

- APA GAS
- ATCO GAS
- HYDROGEN
- TAIL GAS
- DAMPIER TO BUNBURY PIPELINE
- FREMANTLE OIL
- NBN
- NEXT GEN
- OPTUS
- KWINANA OIL
- WESTERN POWER OVERHEAD
- WESTERN POWER UNDERGROUND
- TELSTRA
- WATER
- SEWER
- SDOOL



PLAN
SCALE 1:5000



TYPICAL TRENCH CROSS SECTION DETAIL
SCALE N.T.S

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 50 100 150 200 250m
SCALE 1:5000 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

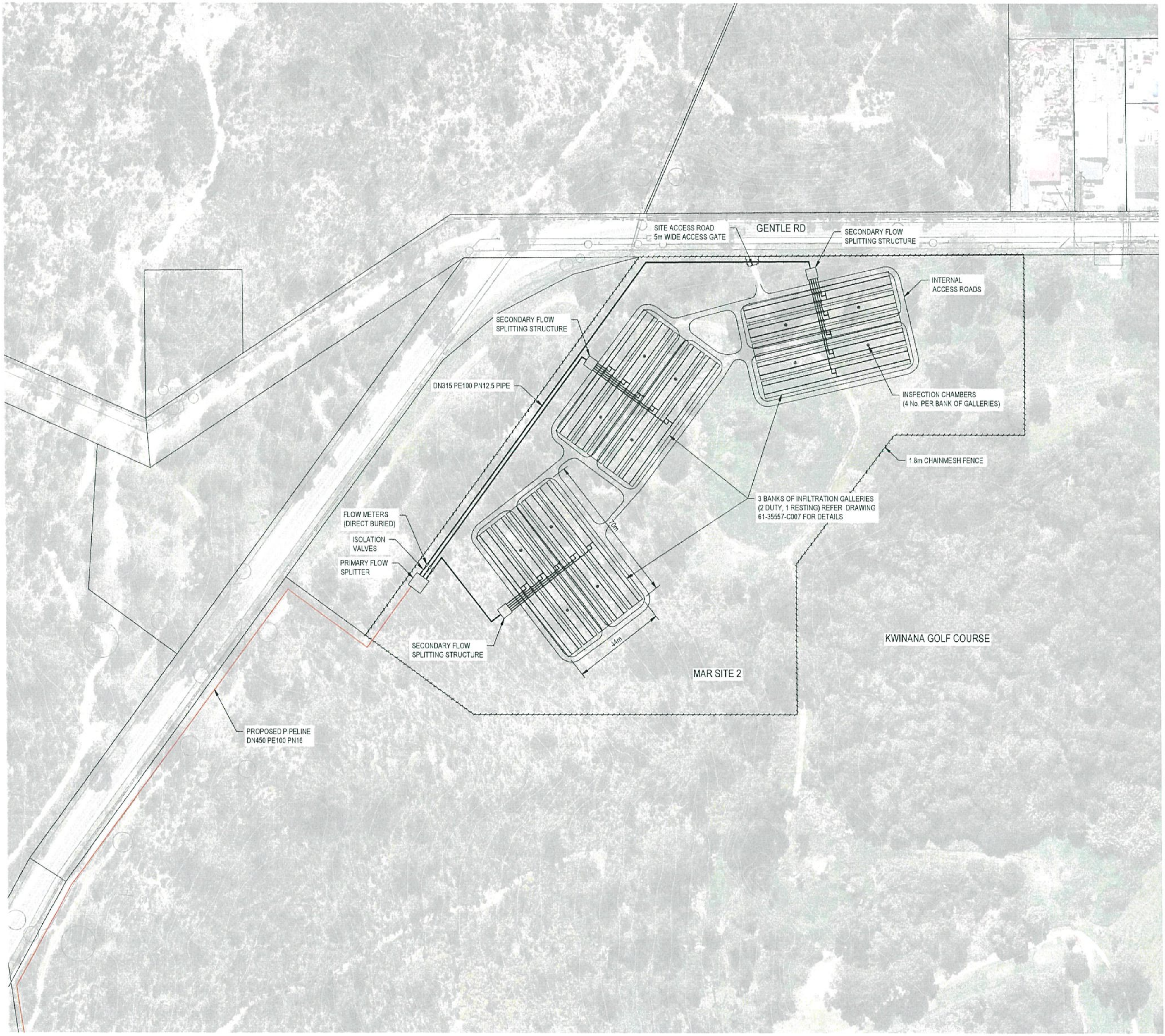
Conditions of Use
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn	B.SHAW	Designer	D.EDGAR
Drafting Check		Design Check	
Approved (Project Director)			
Date			
Scale	1:5000	This Drawing must not be used for Construction unless signed as Approved	

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **CONVEYANCE PIPELINE**
TWW, WASTEWATER AND RECYCLED WATER PIPELINES

Original Size A1 Drawing No: **61-35557-C003** Rev: **B**

Plot Date: 22 May 2018 - 4:12 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C003.dwg



PLAN

SCALE 1:1000

LEGEND

GENERAL

- PROPOSED RECYCLED WATER PIPELINE
- MAR SITE 2 BOUNDARY
- CADASTRAL BOUNDARY
- RAILWAYS
- SLEEVED CONSTRUCTION REQUIRED

EXISTING SERVICES

- APA GAS
- ATCO GAS
- HYDROGEN
- TAIL GAS
- DAMPIER TO BUNBURY PIPELINE
- FREMANTLE OIL
- NBN
- NEXT GEN
- OPTUS
- KWINANA OIL
- WESTERN POWER OVERHEAD
- WESTERN POWER UNDERGROUND
- TELSTRA
- WATER
- SEWER
- SDOOL

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS	[signature]	[signature]	24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 10 20 30 40 50m

SCALE 1:1000 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Drawn	B.SHAW	Designer	D.EDGAR
Drafting Check		Design Check	
Approved (Project Director)			
Date			
Scale	1:1000	This Drawing must not be used for Construction unless signed as Approved	

Client **DJTSI**

Project **WTC MAR SCHEME**

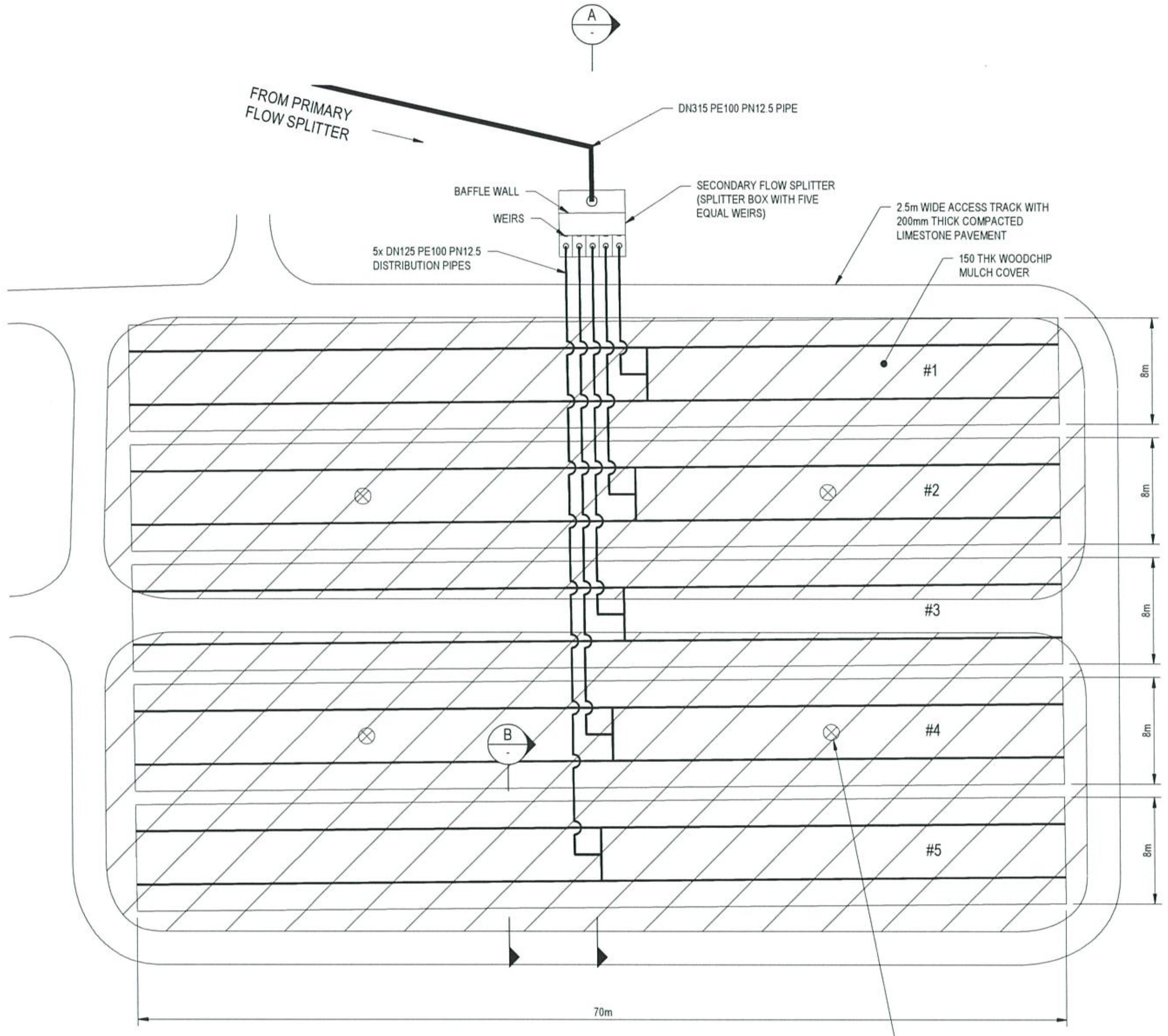
Title **SITE 2 - INFILTRATION SYSTEM GENERAL ARRANGEMENT**

Original Size **A1** Drawing No: **61-35557-C006** Rev: **B**

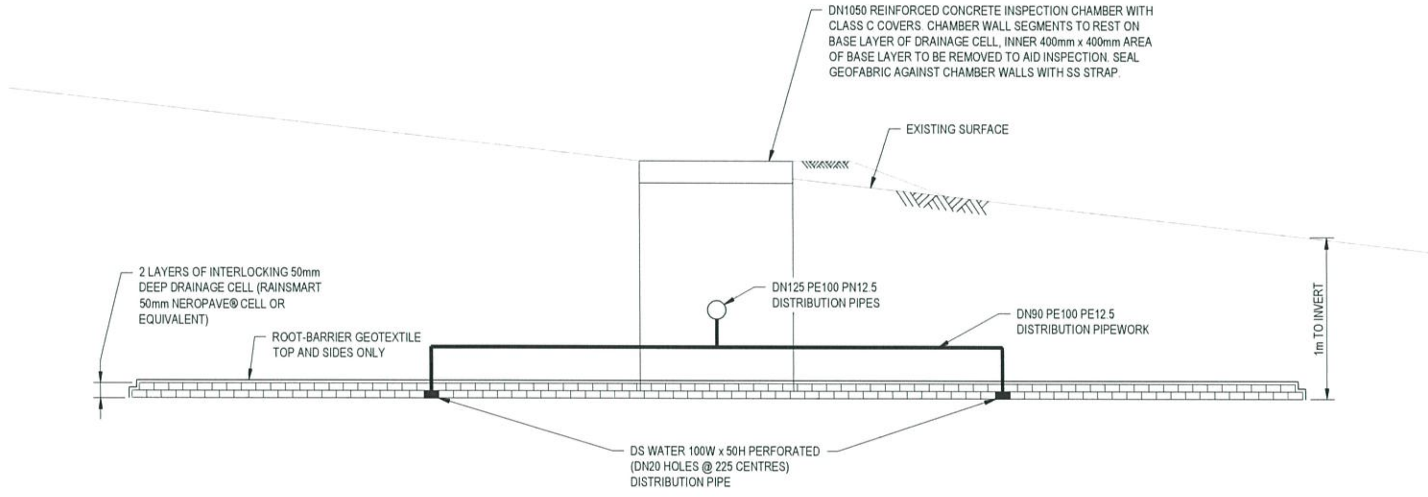
Plot Date: 22 May 2018 - 4:14 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C006.dwg

NOTES

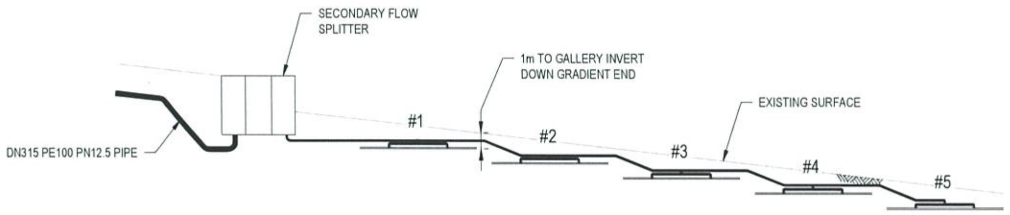
1. DRAINAGE CELL TO BE PLACED HORIZONTAL.
2. IF ROCK ENCOUNTERED AT DRAINAGE CELL FOUNDATION LEVEL OVER EXCAVATE TO DEPTH OF 500mm AND REPLACE WITH COMPACTED CLEAN SAND.
3. GALLERIES TO BE BACKFILLED WITH EXCAVATED MATERIAL DEVOID OF ROCK.



PLAN
SCALE 1:250



B SECTION
SCALE 1 : 25



A SECTION
SCALE 1 : 250

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS			24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 0.25 0.5 0.75 1.0 1.25m
SCALE 1:25 AT ORIGINAL SIZE

0 2.5 5 7.5 10 12.5m
SCALE 1:250 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Conditions of Use.
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn B.SHAW | Designer D.EDGAR
Drafting Check | Design Check
Approved (Project Director)
Date
Scale AS SHOWN
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 2 - INFILTRATION SYSTEM INFILTRATION GALLERIES DETAILS**
Original Size **A1**
Drawing No: **61-35557-C007**
Rev: **B**

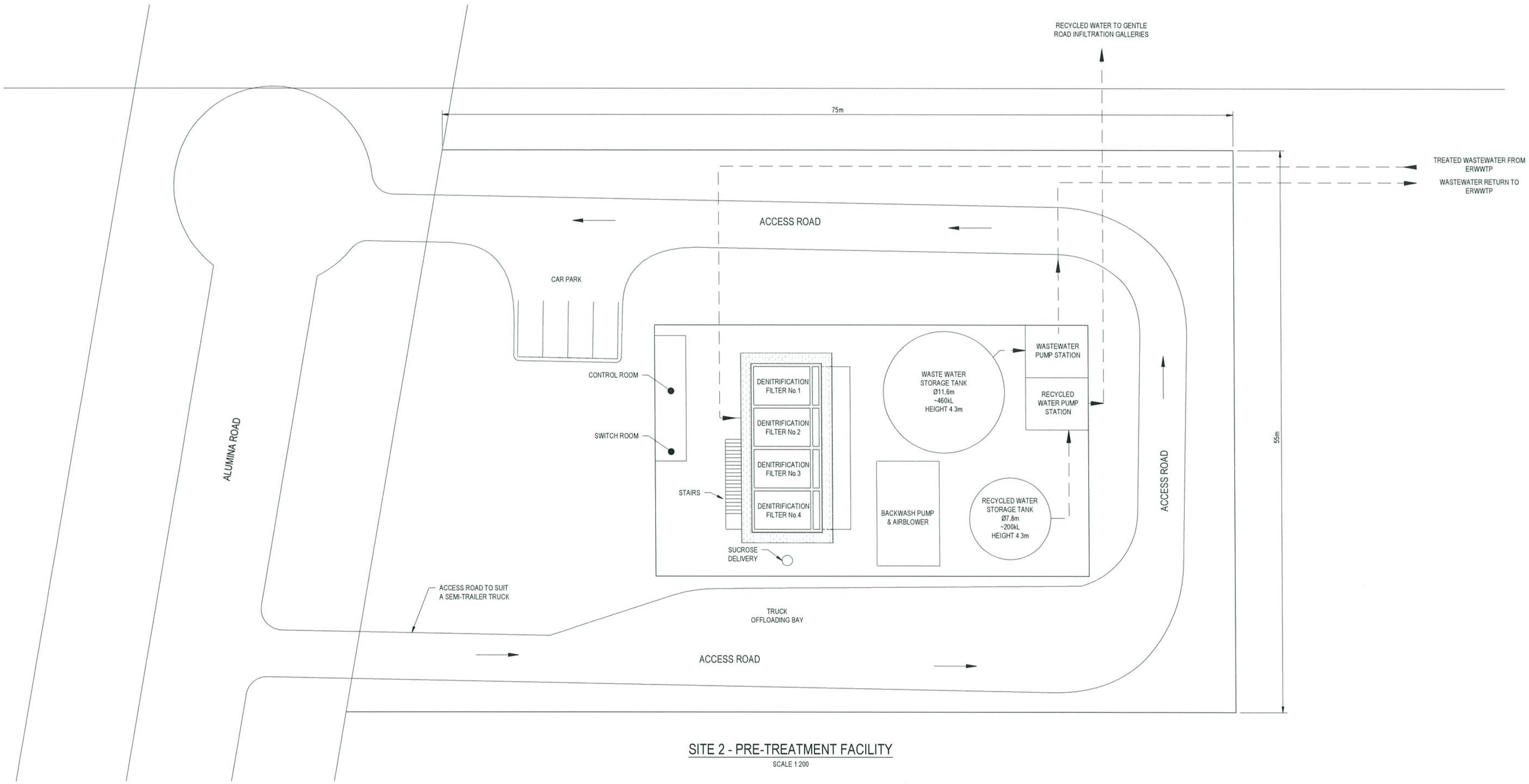
Plot Date: 22 May 2018 - 4:14 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C007.dwg

NOTES

1. TANK SIZES REFER TO GROSS CAPACITY, NOT OPERATIONAL STORAGE VOLUMES

LEGEND

PLATFORMS



SITE 2 - PRE-TREATMENT FACILITY

SCALE 1:200

PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS			24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

0 2 4 6 8 10m
SCALE 1:200 AT ORIGINAL SIZE

N

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

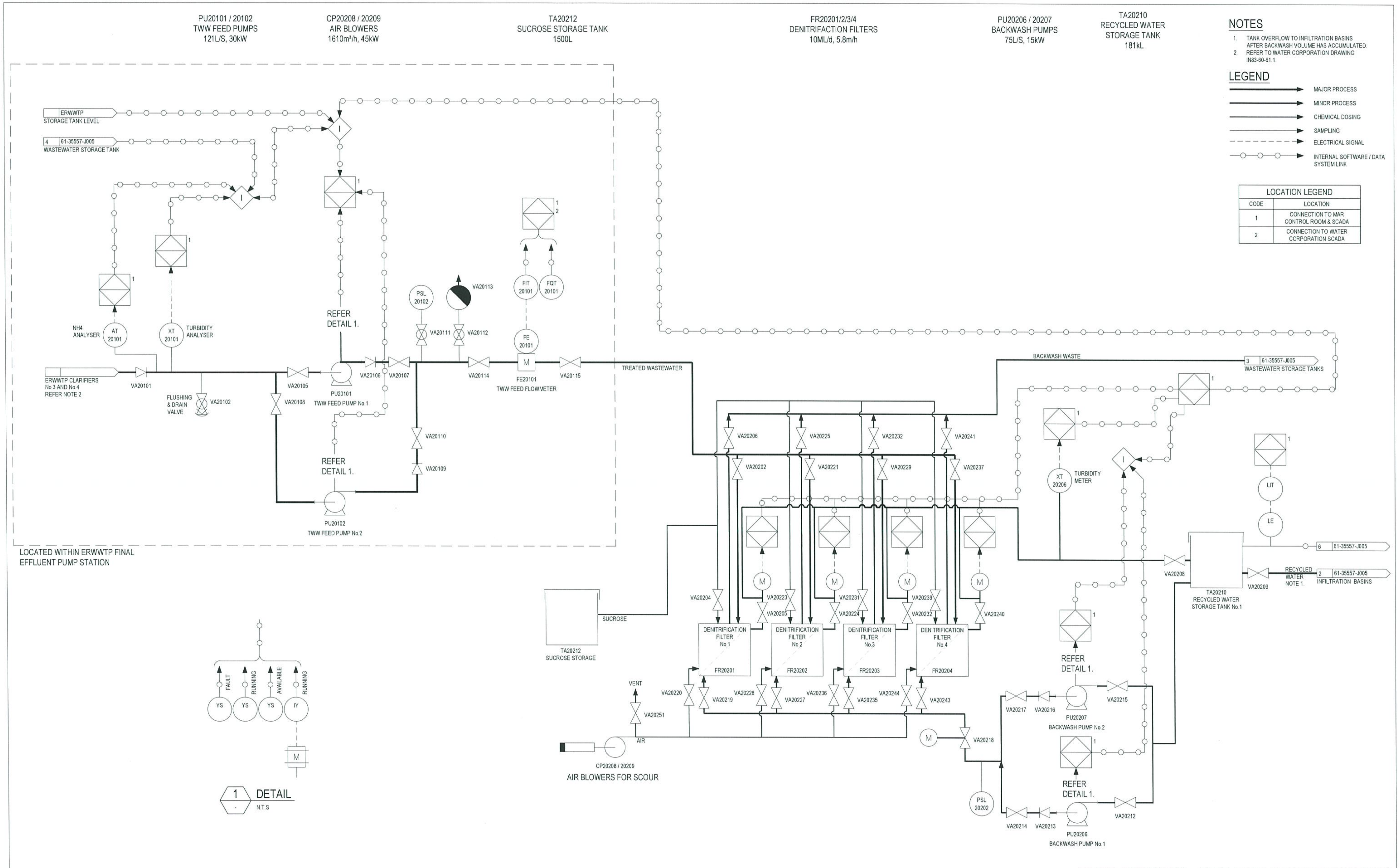
Conditions of Use.
This document may only be used by GHD's client (and any other person who GHD has agreed can use this document) for the purpose for which it was prepared and must not be used by any other person or for any other purpose.

Drawn B.SHAW | Designer J.FOLEY
Drafting Check | Design Check
Approved (Project Director)
Date
Scale 1:200
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 2 - PRE-TREATMENT FACILITY GENERAL ARRANGEMENT**

Original Size A1 Drawing No: **61-35557-C009** Rev: **B**

Plot Date: 22 May 2018 - 4:15 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-C009.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS			24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

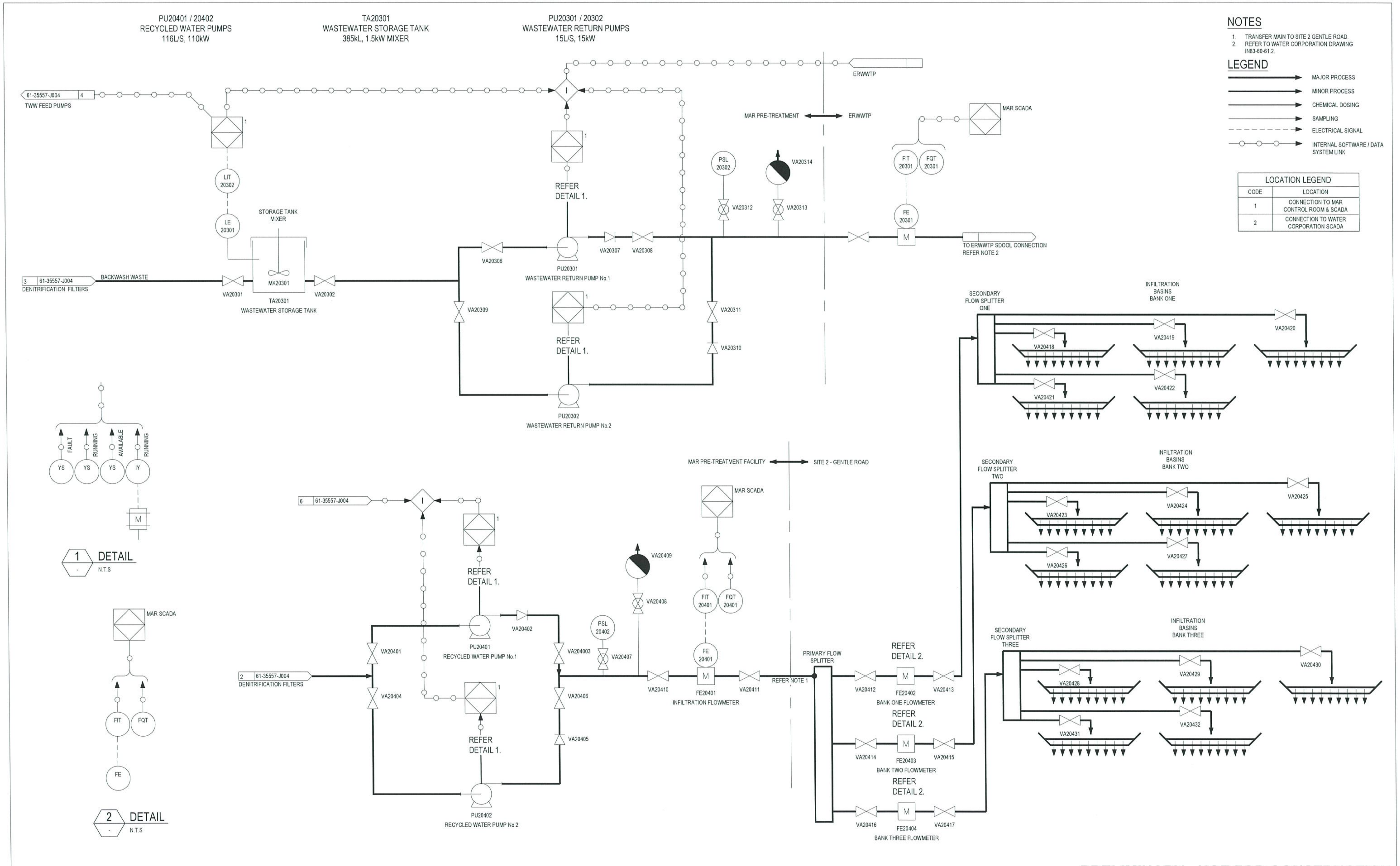
DO NOT SCALE

Drawn B.SHAW
Designer P.WALKER
Drafting Check
Design Check
Approved (Project Director)
Date
Scale N.T.S
This Drawing must not be used for Construction unless signed as Approved

Client DJTSI
Project WTC MAR SCHEME
Title SITE 2 - INLET & DENITRIFICATION FILTER P&ID

Original Size A1
Drawing No: 61-35557-J004
Rev: B

Plot Date: 22 May 2018 - 4:16 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-J004.dwg



PRELIMINARY - NOT FOR CONSTRUCTION

No	Revision	Drawn	Job Manager	Project Director	Date
B	ISSUED FOR FINAL REPORT REV 0	BAS			24/05/18
A	ISSUED FOR CLIENT REVIEW	BAS			

Note: * indicates signatures on original issue of drawing or last revision of drawing

GHD
Level 10, 999 Hay Street Perth WA 6000
PO Box Y3106 Perth WA 6832 Australia
T 61 8 6222 8222 F 61 8 6222 8555
E permail@ghd.com.au W www.ghd.com

DO NOT SCALE

Drawn B.SHAW | Designer P.WALKER
Drafting Check | Design Check
Approved (Project Director)
Date
Scale N.T.S
This Drawing must not be used for Construction unless signed as Approved

Client **DJTSI**
Project **WTC MAR SCHEME**
Title **SITE 2 - WASTE DISPOSAL & INFILTRATION P&ID**

Original Size A1 | Drawing No: **61-35557-J005** | Rev: **B**

Plot Date: 22 May 2018 - 4:11 PM Plotted by: Brendan Gaunson Cad File No: G:\61\35557\CADD\Drawings\61-35557-J005.dwg

Appendix F – Treatment technologies

Denitrifying filters

Whilst the filtration and denitrification processes can be conducted in separate vessels, it is possible to combine them in so-called ‘denitrifying filters’ as a single process step. Deep bed media filters are well suited to this combination, as the filtration media also provides significant surface area for growth of the denitrifying biomass.

There are several vendors and process configurations available in the market. For the purposes of design development in this study, GHD engaged with Leopold / Xylem and their elimi•NITE® technology. However, GHD has confirmed that the general design principles behind the elimi•NITE® technology are consistent with widely published general design parameters for denitrifying filters (Tchobanoglous, Stensel, Tsuchihashi, & Burton, 2014).

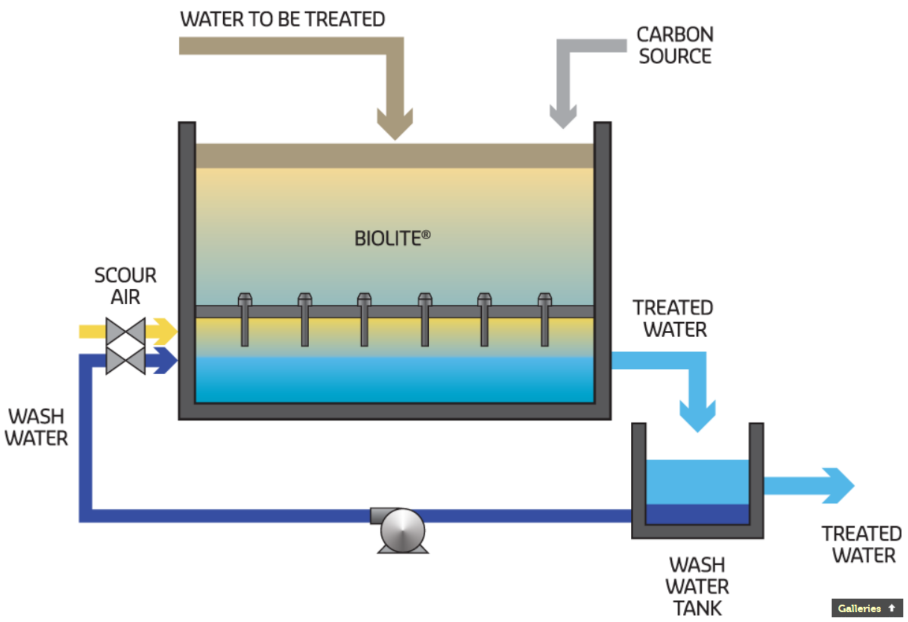
Process description

The denitrifying filter system is an attached growth, microbiological process. In the case of elimi•NITE®, this is implemented as a gravity-fed, deep-bed down flow sand filter. Denitrifying microorganisms attach to the filter media, which provides the support system for their growth. A carbon source (e.g. D.Nitro sucrose solution) is added upstream of the packed-bed filter and a nitrified influent is filtered through the media. The packed-bed filter system is well suited for denitrification because it provides the necessary hydraulic detention time for the biological reaction to take place. The filter media is composed of a coarse, hard, predominately siliceous material. This media can filter out solids and serve as a support system for the denitrifying microorganisms.

As denitrification occurs, nitrogen gas accumulates in the filter media, which increases the head loss across the media. The nitrogen gas bubbles are periodically released from the media by taking the filter off line and applying backwash water for a few minutes. This process is called the nitrogen release cycle or filter ‘bumping’. The frequency of the nitrogen release cycle is a function of both nitrate removal and the storage capacity of the media. Usually a filter needs to be bumped once every four to eight hours, again depending on the nitrogen loading rate. After a bump the head loss in the filter is reduced. However, when the hydraulic level in the filter reaches a designated high level, signifying that the bumps are not effective in reducing head loss, a full backwash is performed on the filter.

The full backwash consists of the following sequence:

- Drawdown – The influent valve is closed, and the water level in the filter cell is drawn down until it reaches a height approximately 150 mm above the media. The effluent valve is closed and the backwash waste valve is opened.
- Air only wash – The backwash blower is started, the air isolation valve is opened, and the vent valve is closed. Air only continues for approximately 1-2 minutes.
- Concurrent wash – The backwash pump is started and the backwash isolation valve is opened. A concurrent air and water backwash continues for approximately 15-20 minutes.
- Rinse – The air isolation valve is closed, the vent valve is opened, and the blower is stopped. Water only backwash continues for approximately 5-8 minutes to wash solids from the filter bed.
- Back in service – The backwash isolation valve is closed and the backwash pump is stopped. The waste valve is closed, the influent and effluent valves are opened, and the filter is placed back into service.



(ref: Suez Denifor™)

(ref: Leopold elimi•NITE®)

Figure E-1 Example schematics of denitrifying filter

Desalination

Whilst there are generally several technologies available for brackish water desalination, reverse osmosis has become the most effective, widespread and readily accepted. For the scale and application of this study, brackish water reverse osmosis (BWRO) is ideally suited. General design parameters for reverse osmosis are widely published and extensive information is also available from vendors. An example process schematic and image of the MAK Water BWRO technology [23] is shown below.

[23] https://www.makwater.com.au/products/brackish-water-reverse-osmosis-bwro/ , accessed 26/9/2017

Figure E-2 Example schematic and image of BWRO (ref: MAK Water)

In these MAR pre-treatment facilities, the reverse osmosis membranes would be installed downstream of the denitrifying filter. Hence, these filters would also serve as protection for the RO membranes. In addition, cartridge filters (or similar) would be installed upstream of the reverse osmosis membranes to provide further protection and removal of residual particulates.

Given the relatively low salinities of the source TWW, it is likely that only a portion (approx. 50 – 60%) of the flow would need to be subjected to reverse osmosis to achieve the target TDS prior to recharge.

Appendix G – Cost estimates

Project: Western Trade Coast MAR Project - Engineering Design & Costing Study
GHD Job Number - 6135557

Revision Status

Rev No	Date	Issue
0	28/03/2018	Issue to DJTSI, Draft for Review
1	15/04/2018	Issue to Synergies, Alternative Estimate Breakdown
2	24/05/2018	Issue for Final Report Rev 0

Cost Estimate Summary

SITE 1 - Northern Site

	CAPEX ($M)	OPEX ($M/year)
Stage 1 Scheme	21.5	0.89
Stage 2 MAR Pre-Treatment Facilities	6.6	1.5 (1)
Total	28.1	

1. Total OPEX post Stage 2 upgrade

Unit Water Cost ($/kL)

Discount Rate %pa	MAR "Recovery Efficiency"[(1)]	
	80%	100%
4.0%	$1.00/kL	$0.80/kL
6.0%	$1.12/kL	$0.89/kL
8.0%	$1.24/kL	$0.99/kL
10.0%	$1.37/kL	$1.10/kL
12.0%	$1.50/kL	$1.20/kL

1. Proportion of recharge water volume that creates additional allocation available to industry.
2. No allowance included for TWW supply charges or wastewater disposal charges.
3. Average annual recharge volume = 3,550 ML/year (355 day operation at 10 ML/d).
4. Scheme operational at full capacity from time it is commissioned, being start Q4 Year 2.
5. Stage 2 upgrade commissioned at end Year 8 (nominal only).

SITE 2 - Southern Site

	CAPEX ($M)	OPEX ($M/year)	PERIODIC OPEX[(1)] ($M)
Stage 1 Scheme	17.3	0.85	0.83

1. Cost to renovate/reconstruct infiltration galleries, to restore their infiltration capacity

Unit Water Cost ($/kL) - Gallery Renovation Required 10-Yearly

Discount Rate %pa	MAR "Recovery Efficiency"[(1)]	
	80%	100%
4.0%	$0.63/kL	$0.50/kL
6.0%	$0.73/kL	$0.58/kL
8.0%	$0.83/kL	$0.66/kL
10.0%	$0.93/kL	$0.75/kL
12.0%	$1.04/kL	$0.84/kL

Unit Water Cost ($/kL) - Gallery Renovation Required 5-Yearly (Sensitivity Check)

Discount Rate %pa	80% MAR Recovery Efficiency[(1)]
4.0%	$0.66/kL
6.0%	$0.75/kL
8.0%	$0.86/kL
10.0%	$0.96/kL
12.0%	$1.07/kL

1. Proportion of recharge water volume that creates additional allocation available to industry
2. No allowance included for Water Corporation TWW supply charges or wastewater disposal charges.
3. Average annual recharge volume = 3,550 ML/year (355 day operation at 10 ML/d).
4. Scheme operational at full capacity from time it is commissioned, being start Q4 Year 2.

Project	Title		Date:	Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study			Graeme Harris / Cheyne Sear
Site	**Stage**		**Date:**	**Checked**
1	1 - Initial construction		24/05/2018	Doug Edgar and Jeff Foley

CAPEX Estimate - Stage 1 Plant

	Location/Description	Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
Direct Costs							
SDOOL Connection Works (SV3)							
1	**SDOOL Connection Works - Procurement**					**$ 117,553**	
1.1	DN300 MSCL pipe specials	Refer drawing 61-35557-C002	6	No	$ 2,000	$ 12,000	GHD estimate
1.2	DN300 gate valves		3	No	$ 5,000	$ 15,000	GHD estimate
1.3	DN150 gate valve		1	No	$ 2,050	$ 2,050	Rawlinsons 2017
1.4	DN300 MSCL pipe		20	m	$ 300	$ 6,000	GHD estimate
1.5	DN200 MSCL pipe		20	No	$ 200	$ 4,000	GHD estimate
1.6	Check valve		1	No	$ 1,775	$ 1,775	Rawlinsons 2017
1.7	Magnetic flow meter (DN300)		1	No	$ 5,000	$ 5,000	GHD estimate
1.8	Magnetic flow meter (DN150)		1	No	$ 3,000	$ 3,000	GHD estimate
1.9	Ammonia analyser		1	No	$ 2,500	$ 2,500	GHD estimate
1.10	Turbidity analyser		1	No	$ 2,500	$ 2,500	GHD estimate
1.11	PLC Control Cubicle (including comms) including programming & testing		1	item	$ 15,000	$ 15,000	GHD estimate
1.12	Pressure sustaining valve	Model number: WW08-720-ES-00-Y-C-ASTE-EB-NN-VFI	1	No	$ 6,800	$ 6,800	Budget estimate Bermad
1.13	Motorised isolation valve (DN300)	AVK make valve, 520 Nm, IQ40, 3 phase on/off	1	No	$ 14,800	$ 14,800	Budget estimate Rotork
1.14	Contractors indirects	30% x direct costs above	1	item	$ 27,128	$ 27,128	
2	**SCOOL Connection Works - Construction/Installation**					**$ 201,359**	
2.1	Excavation and backfill for pipework around valve pit	Footprint 10×5m, depth 5m, batter 1:1	450	cum	$ 22	$ 10,035	Rawlinsons 2017, sand
2.2	Coring and repair of existing valve pit walls	2 holes for DN150 and DN300 MSCL pipework penetrations	2	No	$ 5,000	$ 10,000	Nominal allowance
2.3	Replacement of expanded mesh platform decking	Area 7m x 4m, assume structural steel OK as-is.	28	sqm	$ 303	$ 8,484	Rawlinsoins 2017, 28kg/m2 galv steel
2.4	Reinforced concrete pit for flowmeters and isolation valve	6m x 3.5m internal dimensions, RC cover slab with gatic covers	21	sqm	$ 3,700	$ 77,700	Rawlinsons 2017, based on cost of insitu RC pit
2.5	Installation of pipework, valves, instrumentation	Costed at 50% x supply cost	1	No	$ 45,213	$ 45,213	GHD estimate
2.6	MEIC testing/commissioning	10% x MEIC supply costs	1	item	$ 3,460	$ 3,460	GHD estimate
2.7	Contractors indirects	30% x direct costs above	1	item	$ 46,467	$ 46,467	
Pipelines/Conduits from SDOOL to Tertiary Treatment Facilities							
3	**Open-cut service installation**					**$ 586,993**	
3.1	Clearing of vegetation - light vegetation	200m of chainage x (4.5m wide trench + 10m work corridor)	3,000	sqm	$ 0	$ 1,140	Rawlinsons 2017 rate
3.2	Tree removal	5 trees (500mm girth) require removal: cut down, grubbing of stump and roots and cart away	5	No	$ 211	$ 1,055	Rawlinsons 2017 rate
3.3	Common services trench - excavation and backfill	2.4m base width, 1.5m deep, 1:1 batters, sand	425	m	$ 200	$ 85,000	Rawlinsons 2017 rate, sand, $34/cum
3.4	Common services trench - extra-over for rock excavation and disposal	25% x trench volume, extra-over of $126/m3 for rock excavation plus $21/m3 for refill with clean sand	650	cum	$ 150	$ 97,500	Rawlinsons 2017 rate, avg soft/hard rock rate plus rate for backfill with clean sand
3.5	Trench for intake pipeline only - excavation and backfill	Assume nil rock as within engineered sand fill	65	m	$ 100	$ 6,500	Rawlinsons 2017 rate, sand
3.6	Trench for wastewater disposal pipeline only - excavation and backfill	Assume nil rock as within engineered sand fill	110	m	$ 100	$ 11,000	Rawlinsons 2017 rate, sand
3.7	Trench for power/comms conduits only - excavation and backfill	Assume nil rock as within engineered sand fill	75	m	$ 30	$ 2,250	Rawlinsons 2017 rate, sand
3.8	DN450 PE100 PN16 - Intake pipeline supply/weld/lay	$5.50/kg, mass 52.08 kg/m	440	m	$ 286	$ 125,840	GHD estimate from previous study (6136560)
3.9	DN225 PE100 PN16 - Wastewater disposal pipeline supply/weld/lay	$5.50/kg, mass 13.07 kg/m	440	m	$ 72	$ 31,680	GHD estimate from previous study (6136560)
3.10	Intake and wastewater disposal pipeline DN100 air valves - complete	2 air valves on each pipeline	4	No	$ 7,500	$ 30,000	GHD estimate from previous study (6133010)
3.11	Intake and wastewater disposal pipeline DN100 scour valves - complete	2 scour valves on each pipeline	4	No	$ 8,000	$ 32,000	GHD estimate from previous study (6133010)
3.12	Instrument power and signal cable	1x2C +E 2.5mm2 power, 1 pair instrolex instrument cable. 440m x 2 power cable + 440m x 4 signal cable.	3,520	m	$ 3	$ 10,208	Rawlinsons 2018
3.13	Instrument power and comms conduit, supply and install	50mm installed with pipework trenching. 440m distance x (1 power + 1 signal conduit	880	m	$ 10	$ 8,360	Rawlinsons 2018

Project	Title		Date:	Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study			Graeme Harris / Cheyne Sear
Site	**Stage**		**Date:**	**Checked**
1	1 - Initial construction		24/05/2018	Doug Edgar and Jeff Foley

CAPEX Estimate - Stage 1 Plant

Location/Description		Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
3.14	Cable pits, supply and install	One every 50m, type 5 with extension riser and cover	18	m	$ 500	$ 9,000	Rawlinsons 2018
3.15	Contractors indirects	30% x direct costs above	1	item	$ 135,460	$ 135,460	
4	**Trenchless crossing of service corridor & future FRCAH ramp**					**$ 177,450**	
4.1	Mobilisation and demobilisation		2	No	$ 5,000	$ 10,000	GHD estimate for previous study (6131100)
4.2	Drilling and receival pits		4	No	$ 8,000	$ 32,000	GHD estimate for previous study (6131100)
4.3	Supply and install DN600 RC sleeve by thrust boring		35	m	$ 700	$ 24,500	GHD estimate for previous study (6131100)
4.4	Supply and install DN450 PE intake pipeline in sleeve with spacers & grout ends of sleeve		35	m	$ 300	$ 10,500	GHD estimate for previous study (6131100)
4.5	Supply and install DN400 RC sleeve by thrust boring		35	m	$ 700	$ 24,500	GHD estimate for previous study (6131100)
4.6	Supply and install DN225 PE wastewater disposal pipe in sleeve with spacers & grout ends of sleeve		35	m	$ 300	$ 10,500	GHD estimate for previous study (6131100)
4.7	Supply and install 2 x DN63PE conduits by directional drilling techniques		70	No	$ 350	$ 24,500	GHD estimate from previous study (6133010)
4.8	Contractors indirects	30% x direct costs above	1	item	$ 40,950	$ 40,950	
MAR Pre-treatment/Infiltration Basin Site							
5	**General Site/Civil Works and Access Roads**					**$ 7,225,537**	
5.1	Imported fill required to increase levels (over sites of MAR pre-treatment facilities and infiltration basins) and to form infiltration basins - supply/place/compact inclusive of testing	Import/place/compact fill	128,000	cum	$ 40	$ 5,120,000	GHD estimate, based on rates for land development projects
5.2	Compacted limestone for hardstand areas, embankment crests, basin access ramps - supply/place/compact, 300mm thick		9,000	sqm	$ 15	$ 133,200	Rawlinsons 2017
5.3	Rip-rap for recycled water outfall pipelines in infiltration basins	200mm thick limestone pitching, embedded in mortar	100	sqm	$ 92	$ 9,200	Rawlinsons 2017
5.4	Wood chip treatment of new batters (excluding internal basin batters)	100mm thick wood chips	4,100	sqm	$ 9	$ 37,720	Rawlinsons 2017
5.5	On-site access roads - sub-base (300mm crushed limestone)		2,500	sqm	$ 15	$ 37,000	Rawlinsons 2017
5.6	On-site access roads - hot bituminous concrete including tack coat (50mm thick)		2,500	sqm	$ 23	$ 57,000	Rawlinsons 2017
5.7	Drainage - DN1800 soak wells		6	No	$ 1,800	$ 10,800	Rawlinsons 2017
5.8	Drainage - Pipework to Convey Tank Scour/Overflow to Basins - DN450 RC Pipework		120	m	$ 310	$ 37,200	Rawlinsons 2017, 230 for Class 2 DN450 RC plus $80/m excavation/backill in sand
5.9	Off-site access road to Hope Valley Road - hot bituminous concrete including tack coat (50mm thick) to unsealed portion of existing road	350m x 4m wide	1,400	sqm	$ 23	$ 31,920	Rawlinsons 2017
5.1	Security fencing - 2.1m galv steel chainmesh, 3 rows barbed wire		1,200	m	$ 69	$ 82,800	Rawlinsons 2017
5.11	Site access gate - 5m wide double date		1	No	$ 1,265	$ 1,265	Rawlinsons 2017
5.12	Contractors indirects	30% x direct costs above	1	item	$ 1,667,432	$ 1,667,432	
6	**MAR Pre-Treatment Facilities - Denitrifying Gravity Filters and Desalination Packages**					**$ 4,433,000**	
6.1	Filtration system equipment and components - supply only		1	Item	$ 1,210,000	$ 1,210,000	Budget price from Xylem
6.2	Filtration system structures, connecting pipework, EIC - supply/install/commission		1	Item	$ 2,200,000	$ 2,200,000	Budget price from Xylem, plus 10% for Site 1 as larger filters
6.3	Contractors indirects	30% x direct costs above	1	item	$ 1,023,000	$ 1,023,000	
7	**MAR Pre-Treatment Facilities - Balance of Plant**					**$ 1,843,220**	
7.1	Storage tanks - Treated Wastewater (feed) Balance Tanks, foundation ring beam		140	m	$ 226	$ 31,640	Rawlinsons 2017, foundation beam 450Wx600D
7.2	Storage tanks - Treated Wastewater (feed) Balance Tanks, supply/install	Kingspan Rhino RCT 790-36	2	No	$ 168,000	$ 336,000	Budget price from Kingspan
7.3	Storage tank - Wastewater Storage Tank No. 1, foundation ring beam		35	m	$ 226	$ 7,910	Rawlinsons 2017, foundation beam 450Wx600D
7.4	Storage tank - Wastewater Storage Tank No. 1, supply/install	Kingspan Rhino RCT 200-36	1	No	$ 45,000	$ 45,000	Budget price from Kingspan
7.5	Storage tank - Recycled Water Storage Tank No. 1, foundation ring beam		28	m	$ 226	$ 6,328	Rawlinsons 2017, foundation beam 450Wx600D
7.6	Storage tank - Recycled Water Storage Tank No. 1, supply/install	Kingspan Rhino RCT 130-43	1	No	$ 37,000	$ 37,000	GHD estimate
7.7	Pump station - TWW Feed Pump Station, supply	2 × CL10131 22kW 6P 304SS	1	No	$ 187,951	$ 187,951	Budget price from Grundfos
7.8	Pump station - TWW Feed Pump Station, transport plus install complete with ground slab and shade structure	$30k for slab/shelter plus 20% x supply cost to install/connect/commission	1	No	$ 67,590	$ 67,590	GHD estimate
7.9	Pump station - Wastewater Disposal Pump Station, supply	2 × CL40101 110kW 2P 316SS	1	No	$ 111,111	$ 111,111	Budget price from Grundfos
7.10	Pump station - Wastewater Disposal Pump Station, transport plus install complete with ground slab and shade structure	$30k for slab/shelter plus 20% x supply cost to install/connect/commission			$ 52,222	$ -	GHD estimate
7.11	Sucrose storage and dosing system	Moulded poly tank 2 × 5kL integrated with dosing package	1	No	$ 30,000	$ 30,000	GHD estimate

Project	Title
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study

Site	Stage
1	1 - Initial construction

Date:	Created	Checked
24/05/2018	Graeme Harris / Cheyne Sear	Doug Edgar and Jeff Foley

CAPEX Estimate - Stage 1 Plant

Location/Description		Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
7.12	Motorised isolation valve (DN300)	AVK make valve, 520 Nm, IQ40, 3 phase on/off	1	No	$ 14,800	$ 14,800	Budget price Rotork
7.13	Western Power supply	500kVA sole use transformer	1	No	$ 100,000	$ 100,000	GHD estimate
7.14	Main Switchboard	800 A Switchboard with SPD and metering	1	No	$ 50,000	$ 50,000	GHD estimate
7.15	Motor Control Centre (MCC)	Form 4 Indoor Switchboard	1	No	$ 100,000	$ 100,000	GHD estimate
7.16	Lighting and general power distribution board		1	No	$ 5,000	$ 5,000	GHD estimate
7.17	Consumer mains cable	4 x 1C 500mm2 XLPE/PVC	400	m	$ 140	$ 56,000	Rawlinsons 2018
7.18	Power/communications cabling, instrumentation, conduits and cable pits		1	item	$ 53,678	$ 53,678	Rawlinsons 2018
7.19	PLC Control Cubicle (including comms) including programming & testing		1	No	$ 30,000	$ 30,000	GHD estimate
7.20	Earthing System and bonding		1	No	$ 20,000	$ 20,000	GHD estimate
7.21	Building services	Lighting, general purpose outlet, security treatments (reed switches, motion detector, alarm panel)	1	Item	$ 50,000	$ 50,000	GHD estimate
7.22	MEIC testing/commissioning	10% x MEIC supply costs	1	item	$ 77,854	$ 77,854	GHD estimate
7.23	Contractors indirects	30% x direct costs above	1	item	$ 425,359	$ 425,359	
Other							
8	**Monitoring Bores**					**$ 141,450**	
8.1	Site reconnaissance, approval and clearances		1	item	$ 10,750	$ 10,750	GHD estimate
8.2	Monitoring bore installation		1	item	$ 102,750	$ 102,750	GHD estimate
8.3	Baseline groundwater quality monitoring		1	item	$ 27,950	$ 27,950	GHD estimate
Total Directs						**$ 14,726,561**	
Indirect Costs							
9	**Investigations and Approvals**					**$ 230,000**	
9.1	Geotechnical investigation	Drilling/CPT investigation at SV3, TTP site, pipeline route including site of trenchless service crossings	1	item	$ 150,000	$ 150,000	GHD estimate
9.2	Survey investigation and underground service location	Full feature survey for proposed works plus underground service location along pipeline route	1	item	$ 30,000	$ 30,000	GHD estimate
9.3	Environmental impact assessment and approvals documentation	Environmental investigations, impact assessment and preparation of documentation for DWER and DoH approvals. With respect to environmental approvals it is assumed informal assessment under Part V of EPAct1986 required only.	1	item	$ 50,000	$ 50,000	GHD estimate
10	**Design and Project Management**	estimated at 15% x direct costs	1	item	$ 2,208,984	**$ 2,208,984**	
11	**Contingency**	estimated at 25% x (direct costs + indirect costs)	1	item	$ 4,291,386	**$ 4,291,386**	
Total Indirects						**$ 6,730,371**	
Total Cost						**$ 21,460,000**	

Exclusions

1. Future cost to construct new access to site from north, under Rowley Road etc, after FRCAH constructed.
2. Land acquisition and easement costs.
3. Service/pipeline/valve relocation costs required prior to construction of FRCAH and associated road/rail works etc.
4. Removal or rock prior to placement of fill at site of MAR pre-treatment facilities and infiltration basins
5. Filling of excavations prior to placement of fill at site of MAR pre-treatment facilities and infiltration basins
6. Additional groundwater modelling studies (assuming CSIRO studies satisfy regulatory agencies and adequate to inform EIA).

Project	Title		Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Graeme Harris / Cheyne Sear
Site	**Stage**	**Date:**	**Checked**
1	2 - Prior to construction of Woodman Point Advanced Water Treatment Plant (2030)	24/05/2018	Doug Edgar and Jeff Foley

CAPEX Estimate - Stage 2 Facilities

Location/Description		Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
Direct Costs							
1	**Tertiary Treatment Facilities - Denitrifying Gravity Filters and Desalination Packages**					**$ 3,850,600**	
1.1	Construct additional filter (future)	Estimated at 20% x cost of initial Stage 1 plant (4 filters)	1	Item	$ 682,000	$ 682,000	GHD estimate based on Xylem costing advice
1.2	RO Unit - supply/install/commission (future)		6	No	$ 380,000	$ 2,280,000	Budget price fron Novatron
1.3	Contractors indirects	30% x direct costs above	1	item	$ 888,600	$ 888,600	
2	**Tertiary Treatment Facilities - Balance of Plant**					**$ 737,333**	
2.1	Storage tank - Wastewater Storage Tank No. 2, foundation ring beam (future)		35	m	$ 226	$ 7,910	Rawlinsons 2017, foundation beam 450Wx600D
2.2	Storage tank - Wastewater Storage Tank No. 2, supply/install (future)	Kingspan Rhino RCT 200-36	1	No	$ 45,000	$ 45,000	Budget price from Kingspan
2.3	Storage tank - Recycled Water Storage Tank No. 2, foundation ring beam (future)		28	m	$ 226	$ 6,328	Rawlinsons 2017, foundation beam 450Wx600D
2.4	Storage tank - Recycled Water Storage Tank No. 2, supply/install (future)	Kingspan Rhino RCT 130-43	1	No	$ 38,000	$ 38,000	GHD estimate
2.5	Pump station - RO Pretreatment Feed Pump Station, supply		1	No	$ 187,951	$ 187,951	GHD estimate - assume similar to cost of TWW feed pump station
2.6	Pump station - RO Pretreatment Feed Pump Station, transport plus install complete with ground slab and shade structure		1	No	$ 67,590	$ 67,590	GHD estimate - assume similar to cost of TWW feed pump station
2.7	Building for RO plant	12m x 18m, steel framed/clad building	216	sqm	$ 900	$ 194,400	Rawlinsons 2017, high bay warehouse with metal rook, brick external walls
2.8	PLC Control Cubicle (including comms) including programming & testing		1	item	$ 20,000	$ 20,000	GHD estimate
2.9	Contractors indirects	30% x direct costs above	1	item	$ 170,154	$ 170,154	
Total Directs						**$ 4,587,933**	
Indirect Costs							
3	**Investigations and Approvals**					**$ 20,000**	
3.1	Environmental impact assessment and approvals documentation	GHD estimate	1	item	$ 20,000	$ 20,000	GHD estimate
4	**Design and Project Management**	estimated at 15% x direct costs	1	item	$ 688,190	**$ 688,190**	
5	**Contingency**	estimated at 25% x (direct costs + indirect costs)	1	item	$ 1,324,031	**$ 1,324,031**	
Total Indirects						**$ 2,032,221**	
Total Cost						**$ 6,620,000**	

Exclusions

1. Future cost to construct new access to site from north, under Rowley Road etc, after FRCAH constructed.
2. Land acquisition and easement costs.
3. Service/pipeline/valve relocation costs required prior to construction of FRCAH and associated road/rail works etc.
4. Additional groundwater modelling studies (it is assumed that CSIRO studies will satisfy regulatory agencies and adequately the inform EIA).

Project	Title		Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Doug Edgar
Site	**Stage**	**Date:**	**Checked**
1	1 - Initial construction	24/05/2018	Jeff Foley

OPEX Estimate - Stage 1 Plant

Item	Facility/Description	Assumptions	Quantity	UoM	Unit Rate	Amount pa	Estimate Note
1	**SDOOL Offtake, Pipelines, Mar Pre-Treatment Facilities**					**$ 549,249**	
1.1	Operator (with responsibility for routine maintetance of instrumentation/pumpsets)	30 hours (3 x 10 hour days) per week	1,560	hr	$ 100	$ 156,000	GHD estimate
1.2	Vehicle for operator (2WD utility vehicle)		12	month	$ 1,200	$ 14,400	Hertz multi-month car hire rates 2018
1.3	Vehicle fuel costs	250km travel per week	13,000	km	$ 0.17	$ 2,165	Assumed mileage of 11.1L/100km (2.7Litre Petrol Toyota Hilux), fuel price of $1.50/L
1.4	Power - supply charge		365	days	$ 2.10	$ 767	Synergy rate for Business Time of Use (R1) tariff, April 2017
1.5	Power - consumption charge		508,126	kWhr	$ 0.26	$ 133,078	Synergy rate for Business Time of Use (R1) tariff, April 2018
1.6	Chemicals - Sucrose	Dose of 815L/day	297	kL	$ 720	$ 213,840	Based on advice from Water Corp (max $950/WT) and assumed density of 1.32 tonnes/kL
1.7	Onsite laboratory analysis consumables		1	No	$ 1,000	$ 1,000	Nominal allowance
1.8	NATA laboratory analysis (operational plus license compliance testing)	Monthly testing, BOD, TDS, nutrients, e.coli - influent and recycled water	24	No	$ 250	$ 6,000	ALS price list 2016
1.9	Mechanical plant - major planned maintetance	1 week (50 hours) per year, 2-man crew	100	No	$ 100	$ 10,000	GHD estimate
1.10	Unplanned maintenance	6 events per year, 1 day per event, 2-man crew with truck at $2k/day	6	No	$ 2,000	$ 12,000	GHD estimate
2	**Infiltration basins**					**$ 40,740**	
2.1	Operator (with responsibility for routine maintetance tasks)	included above	0	hr	$ 100	$ -	
2.2	Basin weed control	Herbicide applied to weeds/emergent vegetation in basins in advance of scaling operations (as per practice at Gordon Road WWTP)	6	No	$ 1,000	$ 6,000	GHD estimate (nominal allowance)
2.3	Basin weed control/scralping operations (cut to stockpile)	Each scalping operation yields 40 tonnes of organic contaminated sand (max of typical range for Gordon Road WWTP basin scalping operations)	6	No	$ 2,000	$ 12,000	Budget price from VMS Contractors, includes mobilisation/demobilisation, based on actual cost of operations at Gordon Rd WWTP
2.4	Analysis/grading of stockpiled material	Pathogen and contaminant grading, 7 samples required for statistical robustness as per Biosolids Guidelines, assume stockpiled material removed every 2 years hence allow for 3.5 tests per annum	3.5	No	$ 1,240	$ 4,340	ALS price list 2016
2.5	Disposal of stockpiled material	40 WT/scalping operation, 6 basin scalping operations every year	240	WT	$ 50	$ 12,000	Budget price from VMS Contractors, includes mobilisation/demobilisation, based on actual cost of operations at Gordon Rd WWTP
2.6	Replacement of removed basin floor material with clean sand		160	cum	$ 40	$ 6,400	GHD estimate
3	**Groundwater monitoring program**					**$ 53,200**	
3.1	Professional fees, sampling and reporting	52 hours per quarterly sampling round, includes 12 hours for summary reporting	208	hr	$ 175	$ 36,400	GHD estimate
3.2	Consumables	Hydrasleeves	1	item	$ 7,200	$ 7,200	GHD estimate
3.3	Laboratory costs	Basic analysis suite, all bores, 2 depths per bore	1	item	$ 9,600	$ 9,600	GHD estimate
Sub-Total						**$ 643,189**	
4	**Contingency**	Estimated at 20% x sub-total	1	item	$ 128,638	**$ 128,638**	
5	**Licensed service provider profit margin**	Estimated at 15% x (sub-total+contingency)	1	item	$ 115,774	**$ 115,774**	
Total Cost						**$ 890,000**	per year

Exclusions

1. Capital replacement costs
2. TWW supply charges
3. Wastewater (filter backwash) disposal charges

Project	Title		Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Doug Edgar

Site	Stage	Date:	Checked
1	2 - Post installation of 5th filter and RO facilities	24/05/2018	Jeff Foley

OPEX Estimate - Stage 1+2 Plant

Item	Facility/Description	Assumptions	Quantity	UoM	Unit Rate	Amount pa	Estimate Note
1	**SDOOL Offtake, Pipelines, Mar Pre-Treatment Facilities**					**$ 1,017,891**	
1.1	Operator (with responsibility for routine maintetance tasks)	40 hours (4 x 10 hour days) per week	2,080	hr	$ 100	$ 208,000	
1.2	Vehicle for operator (2WD utility vehicle)		12	month	$ 1,200	$ 14,400	Hertz multi-month car hire rates 2018
1.3	Vehicle fuel costs	330km travel per week	17,160	km	$ 0.17	$ 2,857	Assumed mileage of 11.1L/100km (2.7Litre Petrol Toyota Hilux), fuel price of $1.50/L
1.4	Power - supply charge		365	days	$ 2.10	$ 767	Synergy rate for Business Time of Use (R1) tariff, April 2017
1.5	Power - consumption charge	Extra demand atributable to RO estimated at 111kW	1,425,840	kWhr	$ 0.26	$ 373,427	Synergy rate for Business Time of Use (R1) tariff, April 2018
1.6	Chemicals - Sucrose	Dose of 1,170L/day	427	kL	$ 720	$ 307,440	Based on advice from Water Corp (max $950/WT) and assumed density of 1.32 tonnes/kL
1.7	Membrane pre-treatment and CIP system - consumable and chemical costs	Assume media filters plus 5micron cartridge filters used as pre-treatment, CIP waste neutralised and returned to SDOOL, intermittent dosing of DBNPA (non-oxiding biocide) required to prevent biofouling, daily dose of 10 kg/d	1	item	$ 60,000	$ 60,000	GHD estimate: DBNPA cost estimated at $10/kg assumed, $50/day assumed for cartridge filter replacement, approximately $5,000/year allowed for CIP chemicals
1.8	Onsite laboratory analysis consumables		1	No	$ 1,000	$ 1,000	Nominal allowance
1.9	NATA laboratory analysis (operational plus license compliance testing)	Monthly testing, BOD, TDS, nutrients, e.coli - influent and recycled water	24	No	$ 250	$ 6,000	ALS price list 2016
1.10	Mechanical plant - major planned maintenance	2 weeks (2x50 hours) per year, 2-man crew	200	No	$ 100	$ 20,000	GHD estimate
1.11	Unplanned maintenance	12 events, 1 day per event, 2-man crew with truck at $2k/day	12	No	$ 2,000	$ 24,000	GHD estimate
2	**Infiltration basins**					**$ 40,740**	
2.1	Operator (with responsibility for routine maintetance tasks)	included above	0	hr	$ 100	$ -	
2.2	Basin weed control	Herbicide applied to weeds/emergent vegetation in basins in advance of scaling operations (as per practice at Gordon Road WWTP)	6	No	$ 1,000	$ 6,000	GHD estimate (nominal allowance)
2.3	Basin weed control/scralping operations (cut to stockpile)	Each scalping operation yields 40 tonnes of organic contaminated sand (max of typical range for Gordon Road WWTP basin scalping operations)	6	No	$ 2,000	$ 12,000	Budget price from VMS Contractors, includes mobilisation/demobilisation, based on actual cost of operations at Gordon Rd WWTP
2.4	Analysis/grading of stockpiled material	Pathogen and contaminant grading, 7 samples required for statistical robustness as per Biosolids Guidelines, assume stockpiled material removed every 2 years hence allow for 3.5 tests per annum	3.5	No	$ 1,240	$ 4,340	ALS price list 2016
2.5	Disposal of stockpiled material	40 WT/scalping operation, 6 basin scalping operations every year	240	WT	$ 50	$ 12,000	Budget price from VMS Contractors, includes mobilisation/demobilisation, based on actual cost of operations at Gordon Rd WWTP
2.6	Replacement of removed basin floor material with clean sand		160	cum	$ 40	$ 6,400	GHD estimate
3	**Groundwater monitoring program**					**$ 53,200**	
3.1	Professional fees, sampling and reporting	52 hours per quarterly sampling round, includes 12 hours for summary reporting	208	hr	$ 175	$ 36,400	GHD estimate
3.2	Consumables	Hydrasleeves	1	item	$ 7,200	$ 7,200	GHD estimate
3.3	Laboratory costs	Basic analysis suite, all bores, 2 depths per bore	1	item	$ 9,600	$ 9,600	GHD estimate
Sub-Total						**$ 1,111,831.14**	
4	**Contingency**	Estimated at 20% x sub-total	1	item	$ 222,366	**$ 222,366**	
5	**Licensed service provider profit margin**	Estimated at 15% x (sub-total+contingency)	1	item	$ 200,130	**$ 200,130**	
Total Cost						**$ 1,530,000**	per year

Exclusions
1. Capital replacement costs
2. TWW supply charges
3. Wastewater (filter backwash/brine/neutralised CIP waste) disposal charges

Project	Title		Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Doug Edgar
Site		**Date:**	**Checked**
2	Draft Estimate for Review	24/05/2018	Jeff Foley

CAPEX Estimate

Location/Description		Assumptions	Quantity	UoM	Unit Rate		Amount		Estimate Note
Direct Costs									
East Rockingham WWTP Final Effluent Pump Station									
1	**Treated Wastewater Pump Station**						**$**	**375,369**	
1.1	Pump station - TWW Feed Pump Station, supply	2 × CL10131 22kW 6P 304SS	1	No	$	176,200	$	176,200	Budget price from Grundfos
1.2	Pump station - TWW Feed Pump Station, transport plus install complete with ground slab/plinth, shade structure and connections to FEPS Bay 4 suction/delivery manifolds	$30k for slab/shelter plus 20% x supply cost to install/connect/commission plus $20k for connections to FEPS suction/delivery manifolds	1	No	$	85,240	$	85,240	GHD estimate
1.3	TWW feed pump power cable	3 x 1C +E 6mm2 XLPE/PVC	50	m	$	13	$	638	Rawlinsons 2018
1.4	Instrument power and signal cable	1x2C +E 2.5mm2 power, 1 pair instrolex instrument cable.	50	m	$	3	$	145	Rawlinsons 2018
1.5	Conduit	50mm PVC conduit	50	m	$	10	$	523	Rawlinsons 2018
1.6	Cable pits	type 5 with extension riser and cover	2	m	$	500	$	1,000	Rawlinsons 2018
1.7	PLC & data communications programming mods		1	item	$	10,000	$	10,000	GHD estimate
1.8	Magnetic flow meter		1	No	$	5,000	$	5,000	GHD estimate
1.9	Pressure indicator		2	No	$	2,500	$	5,000	GHD estimate
1.1	Ammonia analyser		1	No	$	2,500	$	2,500	GHD estimate
1.11	Turbidity analyser		1	No	$	2,500	$	2,500	GHD estimate
1.12	Contractors indirects	30% x direct costs above	1	item	$	86,624	$	86,624	
Pipelines									
2	**Pipelines between East Rockingham WWTP FEPS and Tertiary Treatment Plant**						**$**	**348,570**	
2.1	Shared pipe trench - excavation and backfill	2.4m base width, 1.5m deep, 1:1 batters, sand	250	m	$	200	$	50,000	Rawlinsons 2017 rate, sand, $34/cum
2.2	Shared pipe trench - extra-over for rock excavation and disposal	25% x trench volume, extra-over of $126/m3 for rock excavation plus $21/m3 for refill with clean sand	370	cum	$	150	$	55,500	Rawlinsons 2017 rate, avg soft/hard rock rate plus rate for backfill with clean sand
2.3	DN450 PE100 - Intake Pipeline supply/weld/lay	Assumed PN16, $5.50/kg, mass 52.08 kg/m	250	m	$	286	$	87,288	GHD estimate from previous study (6136560)
2.4	DN160 PE100 - Reject Water Disposal Pipeline suppply/weld/lay	Assumed PN16, $5.50/kg, mass 6.63 kg/m	250	m	$	37	$	37,293	GHD estimate from previous study (6136560)
2.5	Intake and wastewater disposal pipeline DN100 air valves - complete	1 air valve on each pipeline	2	No	$	7,500	$	15,000	GHD estimate from previous study (6133010)
2.6	Intake and wastewater disposal pipeline DN100 scour valves - complete	1 scour valve on each pipeline	2	No	$	8,000	$	16,000	GHD estimate from previous study (6133010)
2.7	Instrument signal cable	1 pair instrolex instrument cable. 250m x 3 signal cable.	750	m	$	3	$	2,175	Rawlinsons 2018
2.8	Instrument signal conduit, supply and install	50mm installed with pipework trenching. 440m distance x (1 power + 1 signal conduit	250	m	$	10	$	2,375	Rawlinsons 2018
2.9	Cable pits, supply and install	One every 50m, type 5 with extension riser and cover	5	m	$	500	$	2,500	Rawlinsons 2018
2.10	Contractors indirects	30% x direct costs above	1	item	$	80,439	$	80,439	
3	**Recycled Water Pipeline from Tertiary Treatment Plant and Gentle Road (Infiltration Gallery) Site**						**$**	**3,524,209**	
3.1	Pipe trench - excavation and backfill	0.8m base width, 1.5m deep, 1:1 batters, sand	4,380	m	$	120	$	525,600	Rawlinsons 2017 rate, sand, $34/cum
3.2	Pipe trench extra-over for rock excavation and disposal	25% x trench volume, extra-over of $126/m3 for rock excavation plus $21/m3 for refill with clean sand	3,121	cum	$	150	$	468,150	Rawlinsons 2017 rate, avg soft/hard rock rate plus rate for backfill with clean sand
3.3	DN450 PE100 PN16 - Recycled Water Pipeline supply/weld/lay	$5.50/kg, mass 52.08 kg/m; total quantity includes sleeved areas	4,380	m	$	286	$	1,252,680	GHD estimate from previous study (6136560)
3.4	DN600 RC Sleeve - open cut construction (future rail/major road crossings)	Future RIZ railway crossing + future FRCAH	220	m	$	400	$	88,000	Rawlinsons 2017 Class 4 RC pipe
	DN600 RC Sleeve - trenchless construction	Mandurah Road + existing railway crossing + DBNGP Reserve					$	-	
3.5	Drilling and receival pits		6	No	$	8,000	$	48,000	GHD estimate for previous study (6131100)
3.6	Supply and install DN600 RC jacking pipe sleeve by thrust boring		120	m	$	1,000	$	120,000	GHD estimate for previous study (6131100)
3.7	Supply and install DN450 PE pipe in sleeve with spacers & grout ends of sleeve		120	m	$	300	$	36,000	GHD estimate for previous study (6131100)
3.8	Restoration		6	No	$	3,000	$	18,000	GHD estimate for previous study (6131100)
3.9	Mobilisation and demobilisation		3	No	$	5,000	$	15,000	GHD estimate for previous study (6131100)
3.1	Recycled water pipeline DN100 scour valves - complete	2 air valves per km (nominal)	9	No	$	7,500	$	67,500	GHD estimate from previous study (6133010)
3.11	Recycled water pipeline DN100 air valves - complete	2 scour valves per km (nominal)	9	No	$	8,000	$	72,000	GHD estimate from previous study (6133010)
3.12	Contractors indirects	30% x direct costs above	1	item	$	813,279.00	$	813,279	
MAR Pre-Treatment Facilities									

Project	Title		Date:	Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study			Doug Edgar
Site				**Checked**
2	Draft Estimate for Review		24/05/2018	Jeff Foley

CAPEX Estimate

	Location/Description	Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
4	**General Site/Civil Works and Access Roads**					$ 158,412	
4.1	Compacted limestone for hardstand areas, embankment crests, basin access ramps - supply/place/compact, 300mm thick		1,600	sqm	$ 15	$ 23,680	Rawlinsons 2017
4.2	On-site access roads - sub-base (300mm crushed limestone)		1,300	sqm	$ 15	$ 19,240	Rawlinsons 2017
4.3	On-site access roads - hot bituminous concrete including tack coat (50mm thick)		1,300	sqm	$ 23	$ 29,640	Rawlinsons 2017
4.4	Drainage - DN1800 soak wells		6	No	$ 1,800	$ 10,800	Rawlinsons 2017
4.5	Drainage - Pipework to Convey Tank Scour/Overflow to Basins - DN450 RC Pipework		60	m	$ 310	$ 18,600	Rawlinsons 2017, 230 for Class 2 DN450 RC plus $80/m excavation/backill in sand
4.6	Security fencing - 2.1m galv steel chainmesh, 3 rows barbed wire		270	m	$ 69	$ 18,630	Rawlinsons 2017
4.7	Site access gate - 5m wide double date		1	No	$ 1,265	$ 1,265	Rawlinsons 2017
4.8	Contractors indirects	30% x direct costs above	1	item	$ 36,557	$ 36,557	
5	**MAR Pre-Treatment Facilities - Denitrifying Gravity Filter Package**					$ 4,043,000	
5.1	Filtration system equipment and components - supply only		1	Item	$ 1,110,000	$ 1,110,000	Budget price from Xylem
5.2	Filtration system structures, connecting pipework, EIC - supply/install/commission		1	Item	$ 2,000,000	$ 2,000,000	Budget price from Xylem
5.3	Contractors indirects	30% x direct costs above	1	item	$ 933,000	$ 933,000	
6	**MAR Pre-Treatment Facilities - Balance of Plant**					$ 1,250,574	
6.1	Storage tank - Wastewater Storage Tank, foundation ring beam		37	m	$ 226	$ 8,362	Rawlinsons 2017, foundation beam 450Wx600D
6.2	Storage tank - Wastewater Storage Tank, supply/install	Kingspan Rhino RCT 230-43	1	No	$ 62,000	$ 62,000	Budget price from Kingspan
6.3	Storage tank - Recycled Water Storage Tank, foundation ring beam		25	m	$ 226	$ 5,650	Rawlinsons 2017, foundation beam 450Wx600D
6.4	Storage tank - Recycled Water Storage Tank, supply/install	Kingspan Rhino RCT 100-43	1	No	$ 46,000	$ 46,000	GHD estimate
6.5	Pump station - Recycled Water Pump Station, supply	2 × CL80201 110kW 4P 304SS	1	No	$ 212,166	$ 212,166	Budget price from Grundfos
6.6	Pump station - Recycled Water Pump Station, transport plus install complete with ground slab and shade structure	$30k for slab/shelter plus 20% x supply cost to install/connect/commission	1	No	$ 67,590	$ 67,590	GHD estimate
6.7	Pump station - Wastewater Disposal Pump Station, supply	2 × CRNE45-2	1	No	$ 23,562	$ 23,562	Budget price from Grundfos
6.8	Pump station - Wastewater Disposal Pump Station, transport plus install complete with ground slab and shade structure	$30k for slab/shelter plus 20% x supply cost to install/connect/commission	1	No	$ 52,222	$ 52,222	GHD estimate
6.9	Sucrose storage and dosing system	Moulded poly tank 2 × 5kL integrated with dosing package	1	No	$ 30,000	$ 30,000	GHD estimate
6.10	Motorised isolation valve (DN300)	AVK make valve, 520 Nm, IQ40, 3 phase on/off	1	No	$ 14,800	$ 14,800	Budget price Rotork
6.11	Western Power supply	315kVA sole use transformer	1	Item	$ 60,000	$ 60,000	GHD estimate
6.12	Main Switchboard	500 A SPD and metering	1	No	$ 50,000	$ 50,000	GHD estimate
6.13	Motor Control Centre (MCC)	Form 4 Indoor	1	No	$ 75,000	$ 75,000	GHD estimate
6.14	Lighting and general power distribution board		1	No	$ 5,000	$ 5,000	GHD estimate
6.15	Consumer mains cable	4 x 1C 400mm2 XLPE/PVC	400	m	$ 112	$ 44,800	Rawlinsons 2018
6.16	Power/communications cabling, instrumentation, conduits and cable pits		1	item	$ 51,178	$ 51,178	Rawlinsons 2018
6.17	PLC Control Cubicle & programming		1	Item	$ 20,000	$ 20,000	GHD estimate
6.18	Earthing System and bonding		1	Item	$ 20,000	$ 20,000	GHD estimate
6.19	Building services	Lighting, general purpose outlet, security treatments (reed switches, motion detector, alarm panel)	1	Item	$ 50,000	$ 50,000	GHD estimate
6.20	MEIC testing/commissioning	10% x MEIC supply costs	1	item	$ 63,650	$ 63,650	GHD estimate
6.21	Contractors indirects	30% x direct costs above	1	item	$ 288,594	$ 288,594	
Infiltration Gallery Site (Gentle Road)							
7	**General Site/Civil Works and Access Roads**					$ 749,514	
7.1	Clear site of vegetation and cart away	"Medium vegetation" cleared from area of 17,000m^2 (includes allowance for stockpile and laydown areas)	17,000	sqm	$ 0.6	$ 9,690	Rawlinsons 2017
7.2	Tree removal	500mm girth (rough estimate of 50 trees)	50	No	$ 185	$ 9,250	Rawlinsons 2017
7.3	Strip topsoil to stockpile, respread after galleries constructed	Strip over area of 11,550m^2, to depth 150mm	1,750	cum	$ 10	$ 17,325	Rawlinsons 2017
7.4	Earthworks - cut to adjacent stockpile, place and compact after galleries constructed	Bulk earthworks rates apply	15,000	cum	$ 14	$ 208,500	Rawlinsons 2017
7.5	Earthworks - extra-over for rock (limestone) excavation and disposal	Rock comprises 20% of sub-topsoil excavation volume, able to be removed by ripping and can be spread on site. Rate allows for import of clean sand.	3,000	cum	$ 45	$ 135,000	Rawlinsons 2017 for rock ripping/removal ($20/cum), plus $25/cum for imported sand (GHD estimate)
7.6	Compacted limestone for hardstand areas, embankment crests, basin access ramps - supply/place/compact, 300mm thick		2,738	sqm	$ 15	$ 40,522	Rawlinsons 2017
7.7	Wood chip treatment of new batters (excluding internal basin batters)	100mm thick wood chips	10,000	sqm	$ 9	$ 92,000	Rawlinsons 2017
7.8	Security fencing - 2.1m galv steel chainmesh, 3 rows barbed wire		913	m	$ 69	$ 62,997	Rawlinsons 2017

Project	Title		Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Doug Edgar
Site		**Date:**	**Checked**
2	Draft Estimate for Review	24/05/2018	Jeff Foley

CAPEX Estimate

Location/Description		Assumptions	Quantity	UoM	Unit Rate	Amount	Estimate Note
7.9	Site access gate - 5m wide double date		1	No	$ 1,265	$ 1,265	Rawlinsons 2017
7.10	Contractors indirects	30% x direct costs above	1	item	$ 172,965	$ 172,965	
8	**Infiltration Galleries (excluding bulk earthworks) and Pipework**					**$ 1,098,014**	
8.1	Primary flow splitter	RC structure, 2.2m W x 3.0m L, hinged chequer plate cover	6.6		$ 7,400	$ 48,840	Rawlinsons 2017, based on cost of insitu RC pit, factored to account for internal walls, pipe penetrations, weirs, access stairs/platforms
8.2	Secondary flow splitters	2 x RC structures, 2.8m W x 1.8m L each, hinged chequer plate cover.	10.2	sqm	$ 7,400	$ 75,480	Rawlinsons 2017, based on cost of insitu RC pit, factored to account for internal walls, pipe penetrations, weirs, access stairs/platforms
8.3	DN315PE Pipework - Shared pipe trench excavation and backfill	1.4m base width, 1.5m deep, 1:1 batters, sand	130	m	$ 150	$ 19,500	Rawlinsons 2017 rate, sand, $34/cum
8.4	DN315PE Pipework - Shared pipe trench extra-over for rock excavation and disposal	25% x trench volume, extra-over of $126/m3 for rock excavation plus $21/m3 for refill with clean sand	140	cum	$ 150	$ 21,000	Rawlinsons 2017 rate, avg soft/hard rock rate plus rate for backfill with clean sand
8.5	DN315PE Pipework - Individual pipe trench excavation and backfill	0.8m base width, 1.5m deep, 1:1 batters, sand	125	m	$ 120	$ 15,000	Rawlinsons 2017 rate, sand, $34/cum
8.6	DN315PE Pipework - Shared pipe trench extra-over for rock excavation and disposal	25% x trench volume, extra-over of $126/m3 for rock excavation plus $21/m3 for refill with clean sand	110	cum	$ 150	$ 16,500	Rawlinsons 2017 rate, avg soft/hard rock rate plus rate for backfill with clean sand
8.7	DN315 PE100 PN12.5 - Distribution pipe supply/weld/lay	$5.50/kg, mass 21.14 kg/m	450	m	$ 116	$ 52,322	GHD estimate from previous study (6136560)
8.8	DN125 PE100 PN12.5 - Distribution pipe supply/weld/lay	$5.50/kg, mass 3.34 kg/m	500	m	$ 18	$ 9,185	GHD estimate from previous study (6136560)
8.9	Inspection chamber - DN1050 Class C cover	Manhole 1000 to 1100mm dia. w/ conc base & precast conc wall sections: 2m deep	12	No	$ 1,900	$ 22,800	Rawlinsons 2017
8.10	Supply/intall galleries - 2 layers of RainSmart® Nero Pave® complete with geofabric cover and perforated 100mmx50mm distribution pipe		8,400	sqm	$ 60	$ 504,000	Budget price from DS Agencies
8.11	DN300 gate valves - supply and install		3	No	$ 5,000	$ 15,000	GHD estimate
8.12	DN300 magnetic flowmeters		3	No	$ 5,000	$ 15,000	GHD estimate
8.13	Flowmeter Control Cubicle		1	Item	$ 10,000	$ 10,000	GHD estimate
8.14	Solar Power System (for flowmeters)	No allowance for batteries	1	Item	$ 20,000	$ 20,000	GHD estimate
8.15	Contractors indirects	30% x direct costs above	1	item	$ 253,388	$ 253,388	
9	**Monitoring Bores**					**$ 113,950**	
9.1	Site reconnaissance, approval and clearances		1	item	$ 9,000	$ 9,000	GHD estimate
9.2	Monitoring bore installation		1	item	$ 82,500	$ 82,500	GHD estimate
9.3	Baseline groundwater quality monitoring		1	item	$ 22,450	$ 22,450	GHD estimate
Total Directs						**$ 11,661,611.83**	
Indirect Costs							
10	**Investigations and Approvals**					**$ 400,000**	
10.1	Geotechnical investigation	Drilling/CPT investigation at TTP site, Gentle Road site and pipeline route including sites of trenchless service crossings	1	item	$ 250,000	$ 250,000	GHD estimate
10.2	Survey investigation and underground service location	Full feature survey for proposed works plus underground service location along pipeline route	1	item	$ 60,000	$ 60,000	GHD estimate
10.3	Environmental impact assessment and approvals documentation	Environmental investigations, impact assessment and preparation of documentation for DWER and DoH approvals. With respect to environmental approvals it is assumed informal assessment under Part V of EPAct1986 required only.	1	item	$ 90,000	$ 90,000	GHD estimate. Allowance of $40,000 included for fauna/flora surveys in Bush Forever areas (section of recycled water pipeline route and Gentle Road infiltration gallery site).
11	**Design and Project Management**	estimated at 15% x direct costs	1	item	$ 1,749,242	**$ 1,749,242**	
12	**Contingency**	estimated at 25% x (direct costs + indirect costs)	1	item	$ 3,452,713	**$ 3,452,713**	
Total Indirects						**$ 5,601,955**	
Total Cost						**$ 17,260,000**	

Exclusions

1. Land acquisition, easement and (if applicable) Bushforever offset costs.

Project	Title	Date:	Created
6135557	Western Trade Coast MAR Project - Engineering Design and Costing Study		Doug Edgar
Site		**Date:**	**Checked**
2	Draft Estimate for Review	24/05/2018	Jeff Foley

OPEX Estimate

Item	Facility/Description	Assumptions	Quantity	UoM	Unit Rate	Amount pa	Estimate Note
ANNUAL COSTS							
1	**SDOOL Offtake, Pipelines, MAR Pre-Treatment Facilities**					**$ 567,467**	
1.1	Operator (with responsibility for routine maintenance of instrumentation/pumpsets)	30 hours (3 x 10 hour days) per week	1,560	hr	$ 100	$ 156,000	GHD estimate
1.2	Vehicle for operator (2WD utility vehicle)		12	month	$ 1,200	$ 14,400	Hertz multi-month car hire rates 2018
1.3	Vehicle fuel costs	250km travel per week	13,000	km	$ 0.17	$ 2,165	Assumed mileage of 11.1L/100km (2.7Litre Petrol Toyota Hilux), fuel price of $1.50/L
1.4	Power - supply charge		365	days	$ 2.10	$ 767	Synergy rate for Business Time of Use (R1) tariff, April 2017
1.5	Power - consumption charge		1,178,220	kWhr	$ 0.26	$ 308,576	Synergy rate for Business Time of Use (R1) tariff, April 2018
1.6	Chemicals - Sucrose	Dose of 815L/day	73	kL	$ 720	$ 52,560	Based on advice from Water Corp (max $950/WT) and assumed density of 1.32 tonnes/kL
1.7	Onsite laboratory analysis consumables		1	No	$ 1,000	$ 1,000	Nominal allowance
1.8	NATA laboratory analysis (operational plus license compliance testing)	Monthly testing, BOD, TDS, nutrients, e.coli - influent and recycled water	24	No	$ 250	$ 6,000	ALS price list 2016
1.9	Mechanical plant - major planned maintetance	1 week (50 hours) per year, 2-man crew	100	No	$ 100	$ 10,000	GHD estimate
1.10	Unplanned maintenance	8 events per year, 1 day per event, 2-man crew with truck at $2k/day	8	No	$ 2,000	$ 16,000	GHD estimate
2	**Infiltration galleries**					**$ 6,000**	
2.1	Operator (with responsibility for routine maintetance tasks)	included above	0	hr	$ 100	$ -	
2.2	Weed control	Herbicide spraying of gallery area	6	No	$ 1,000	$ 6,000	GHD estimate (nominal allowance)
3	**Groundwater monitoring program**					**$ 39,200**	
3.1	Professional fees, sampling and reporting	38 hours per quarterly sampling round, includes 8 hours for summary reporting	152	hr	$ 175	$ 26,600	GHD estimate
3.2	Consumables	Hydrasleeves	1	item	$ 5,400	$ 5,400	GHD estimate
3.3	Laboratory costs	Basic analysis suite, all bores, 2 depths per bore	1	item	$ 7,200	$ 7,200	GHD estimate
Sub-Total						**$ 612,667**	
4	**Contingency**	Estimated at 20% x sub-total	1	item	$ 122,533	$ 122,533	
5	**Licensed service provider profit margin**	Estimated at 15% x (sub-total+contingency)	1	item	$ 110,280	**$ 110,280**	
Total Cost						**$ 850,000**	per year

Exclusions

1. Capital replacement costs
2. TWW supply charges
3. Wastewater disposal charges

Item	Facility/Description	Assumptions	Quantity	UoM	Unit Rate	Amount/event	Estimate Note
PERIODIC GALLERY RENOVATION/RECONSTRUCTION COSTS							
1	Cut woodchips to stockpile, respread after gallery renovation complete	Woodchips can be reused as cover material	1,500	cum	$ 18	$ 27,075	Rawlinsons 2017, excavation plus fill rates
2	Cut limestone to stockpile, respread after gallery renovation complete	Limestone can be reused to rebuild light vehicle access roads	821	cum	$ 18	$ 14,826	Rawlinsons 2017, excavation plus fill rates
3	Earthworks - cut to adjacent stockpile, place and compact after galleries constructed	Bulk earthworks rates apply	15,000	cum	$ 14	$ 208,500	Rawlinsons 2017
4	Remove access chambers, replace during gallery reconstruction		12	No	$ 1,000	$ 12,000	
5	Remove DN125 gallery distribution pipework, replace during gallery reconstruction	Assume cost similar to supply/install of new pipework	1	item	$ 9,185	$ 9,185	GHD estimate
6	Remove/clean/reinstall gallery and perforated distribution pipe - 2 layers of RainSmart® Nero Pave® complete with new geofabric cover	Dose of 815L/day	16	No	$ 7,000	$ 112,000	Budget price from DS Agencies (upper end of range provided ($5,000-7,000/gallery])
7	Excavate 100mm depth of sand from below infiltration surface, cart to stockpile		840	cum	$ 12	$ 10,080	Nominal allowance
8	Analysis/grading of stockpiled "contaminated" sand	Pathogen and contaminant grading, 7 samples required for statistical robustness as per Biosolids Guidelines, assume stockpiled material removed every 2 years hence allow for 3.5 tests per annum	7.0	No	$ 1,240	$ 8,680	ALS price list 2016
9	Disposal of stockpiled "contaminated" sand	Landfill disposal required	840	cum	$ 50	$ 42,000	Budget price from VMS Contractors, includes mobilisation/demobilisation, based on actual cost of operations at Gordon Rd WWTP
10	Import and place clean sand over gallery floors		8	cum	$ 2,000	$ 16,000	GHD estimate, based on rates for land development projects
11	Contractors indirects	30% x direct costs above	1	item	$ 138,104	$ 138,104	
Sub-Total						**$ 598,450**	
12	**Contingency**	Estimated at 20% x sub-total	1	item	$ 119,690	**$ 119,690**	
13	**Licensed service provider profit margin**	Estimated at 15% x (sub-total+contingency)	1	item	$ 107,721	**$ 107,721**	
Total Cost						**$ 830,000**	per renovation event

Appendix H – Review of potential to source TWW from East Rockingham WWTP for multiple MAR sites

H1 - Scope of Review

The designs and cost estimates presented in this study assume that TWW for Site 1 will be sourced from the SDOOL, and that TWW for Site 2 will be sourced from the East Rockingham WWTP. One reason for this is that it will be some time (2027 based on current flow projections) before flows to East Rockingham WWTP will be sufficient to supply TWW to two or more 10 ML/d recharge sites operating at capacity. If the supply-demand balance for industry is such that the MAR scheme could be augmented over time as flows to East Rockingham WWTP increase, it would be possible to supply TWW from East Rockingham WWTP to multiple 10 ML/d capacity recharge sites. It is this possibility that is explored in this review.

The scope of this review involved:

- Developing high level (order of magnitude) CAPEX and OPEX estimates for supply of TWW from the East Rockingham WWTP to both Site 1 and Site 2, with these estimates based on those developed in the study.
- Completing a net present value analysis to compare (on a whole of life basis) these costs with the cost to source TWW (for Site 1) from the SDOOL.
- Completing a sensitivity analysis to compare the costs for the scenario where desalination of TWW at Site 1 is not necessary, as would be the case if the Water Corporation do not proceed with their plans to develop an AWRP at Woodman Point WWTP.

In completing this review it was assumed that:

- TWW from the East Rockingham WWTP supplied to both sites will be further treated in MAR pre-treatment facilities (denitrifying filters) located on industrial land near the East Rockingham WWTP.
- The initial scheme (operational end Year 2) will supply recycled water to Site 2 only.
- The scheme will be augmented to also supply Site 2 from the end of Year 7.
- The recycled water pump station and pipeline from East Rockingham WWTP will be sized to convey 20 ML/d of recycled water to Site 2.
- The recycled water pipeline from Site 2 to Site 1 (10 ML/d capacity) will follow the notional route developed in an earlier stage of this study (refer to Figure H-1 below). Whilst there are numerous significant constraints associated with this route, highlighted in Figure H-1, it is assumed that none are ”fatal flaws”.

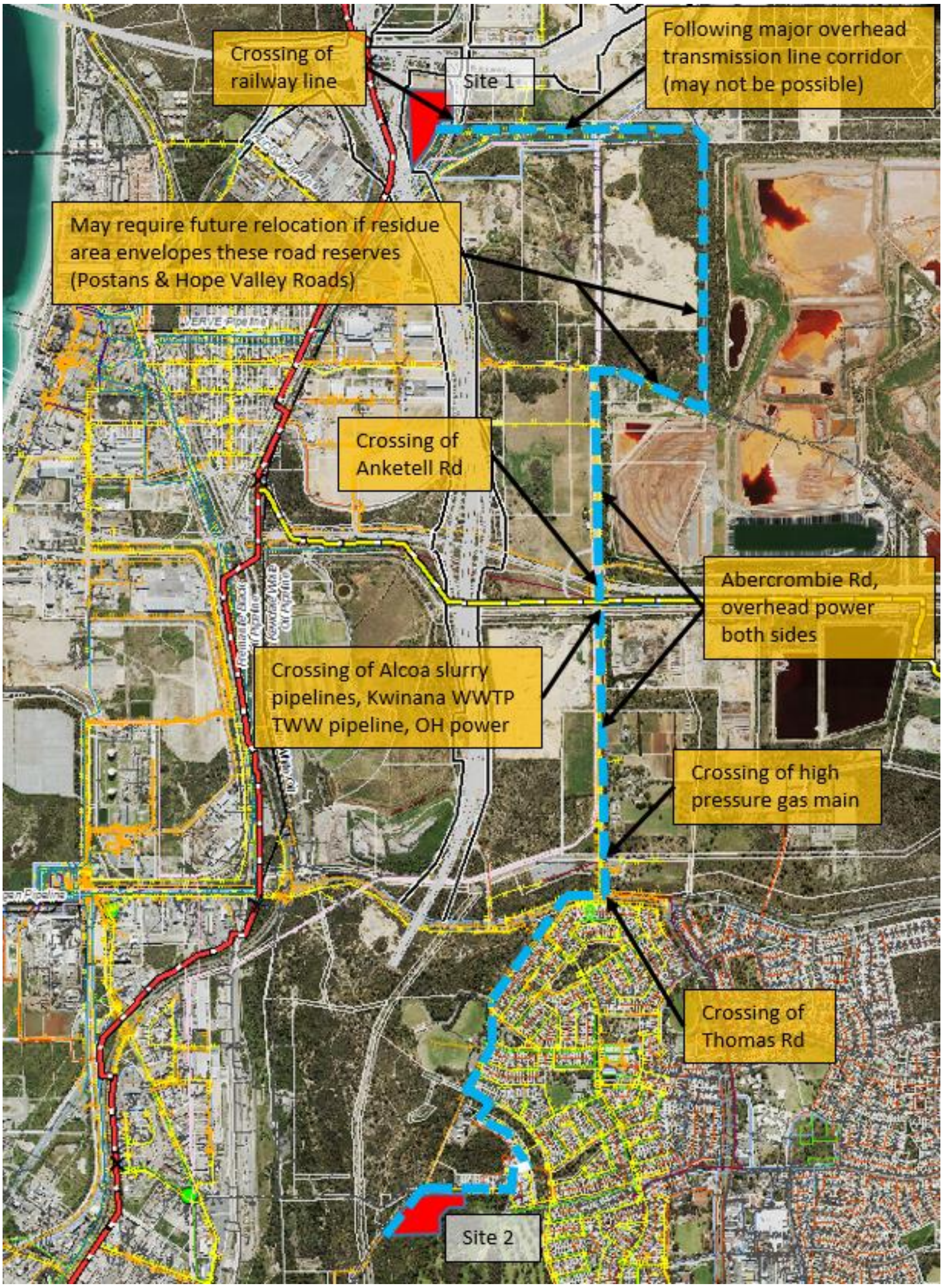


Figure H-1 Notional route for North-South recycled water pipeline between Site 2 and Site 1

H2 – Findings

The findings from the net present value analysis indicate that the unit water cost for this alternative scheme would be slightly lower (in the order of 5 to 10% lower) than the average unit water cost applicable to the schemes designed and costed in this study (Site 1 supplied with recycled water sourced from SDOOL, Site 2 supplied with recycled water sourced from East Rockingham WWTP). If however desalination of TWW sourced from the SDOOL was not required, the unit water cost for this scheme would be slightly lower (in the order of 5% lower) than the average unit water cost applicable to the schemes designed and costed in this study.

H3 - Limitations

It must be noted that the cost estimates developed in this review are order of magnitude estimates only. If this alternative scheme is considered to have merit, further work will need to completed in the next stage of the study to confirm the validity of the findings drawn from this high level review.

A significant risk for this alternative scheme is that the notional north-south route assumed in this study could prove to be non-viable, necessitating an alternative and potentially significantly longer (and thus higher cost) route for this pipeline.

GHD

Level 10
999 Hay Street
T: 61 8 6222 8222 F: 61 8 6222 8555 E: permail@ghd.com

6135557-69627/https://projects.ghd.com/oc/WesternAustralia/westerntradecoastmar/Delivery/Documents/6135557-REP-0_WTC MAR Scheme Final Report.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Draft A	A. Gilfoyle J. Foley D. Edgar G. Harris A.Osbaldeston	D. Edgar	DME	J. Foley	JMF	28.03.18
0	A. Gilfoyle D. Edgar	D. Edgar	DME	J. Foley	JMF	24.05.18
1	A. Gilfoyle D. Edgar	D. Edgar		J. Foley		25.06.18

www.ghd.com

Appendix B – Stage 2 Risk Assessment

LAND AND WATER
www.csiro.au

Western Trade Coast Managed Aquifer Recharge – Risk Assessment

Michael J Donn, Joanne L Vanderzalm and Tao Cui

March 2019

CSIRO Land and Water

Citation

Donn MJ, Vanderzalm JL and Cui T (2019) Western Trade Coast Managed Aquifer Recharge – Risk Assessment. CSIRO, Australia.

Copyright

Important disclaimer

Contents

Acknowledgments v

Executive summary vi

1 Introduction 8

2 Background 10

2.1 Superficial aquifer 10

2.2 Treated wastewater sources 10

2.3 Prospective sites assessed 12

2.4 Receiving environments / receptors 14

2.5 Risk assessment / MAR Guidelines 15

3 Stage 2 Risk assessment 17

3.1 Hazard identification and fate 17

3.2 Maximal and pre-commissioning residual risk assessment 41

4 Conclusions 50

References 52

Appendix A Treated wastewater saturation indices 56

Figures

Figure 1 Overview of Western Trade Coast (WTC) study area showing the proposed MAR sites, wastewater treatment plant (WWTP) locations, treated wastewater (TWW) pipelines and environmental assets (wetlands and Cockburn Sound). Insert (a) Site 1 and immediate surrounds, insert (b) Site 2 and immediate surrounds (a and b are at the same scale). DWER = Department of Water and Environmental Regulation, WC = Water Corporation 11

Figure 2 Modelled travel time for treated wastewater infiltrated at Site 1 (a and b) and Site 2 (c and d). The longer term travel times (a and c) indicate the extent of the treated wastewater plume expected and while shorter term travel times (b and d) are more relevant to pathogen removal. Licenced abstraction bore are also shown as they were implemented in the groundwater model. Details of modelling provided in Cui and Donn (2018).......... 21

Figure 3 Range of major ion concentrations at industry groundwater monitoring locations, boxes represent the interquartile (25th to 75th) range, the horizontal line the 50th percentile error bars the 10th and 90th percentiles an the points (black circles) the 5th and 95th percentiles. Average treated wastewater (TWW) concentrations for the three WWTP in the catchment (Table 6) are shown for reference. Industry data represents latest data provided (mostly 2013), seawater impacted samples removed. Note not all ions are measured at all industry monitoring locations. 22

Figure 4 Heavy metal/metalloid concentrations in secondary treated wastewater. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles. Trigger values are for slightly-moderately disturbed freshwater systems at 95% protection level except for Hg and Se (99% protection level) and Co (marine 95% protection level) (ANZECC-ARMCANZ, 2000). Water quality data provided by Water Corporation 24

Figure 5 Salinity of treated wastewater sources, groundwater (DWER Water Information Reporting and industry) and important wetlands (Thomsons Lake and The Spectacles Swamp). Treated wastewater data provided by Water Corporation (April 2009 to present). Groundwater and wetland data obtained from Water Information Reporting (Department of Water and Environmental Regulation, 2018b). Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles 27

Figure 6 Seasonal variability in salinity for Thomsons Lake and The Spectacles Swamp, data obtained from Water Information Reporting (Department of Water and Environmental Regulation, 2018b). Note this data is only indicative as the number of samples and their date range varies both between locations and between months 28

Figure 7 Total phosphorus concentrations in treated wastewater sources (data provided by Water Corporation, April 2009 until present). Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles 29

Figure 8 Concentration of nitrogen species in treated wastewater sources (data provided by Water Corporation, April 2009 until present). Regional groundwater total nitrogen (GW – WIR, source: Department of Water and Environmental Regulation (2018b)) and groundwater abstracted for industrial uses (GW – Industry) shown for reference. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles 31

Figure 9 Total suspended solid concentration in treated wastewater sources. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles. Data provided by Water Corporation (April 2009 to present). The proposed TSS concentration criteria for gallery infiltration (5 mg/L) is shown for reference 34

Figure 10 Median inundation extent across all models for Site 1 (north, a and b) and Site 2 (south, c and d) for the no MAR scenario (a and c) and the MAR no recovery scenario (b and d) under the DWER dry climate scenario (2030). End of model (2045) results shown 37

Figure 11 Median maximum mound height across all models determined from the relative change in modelled groundwater level between the MAR and no MAR scenarios at the proposed MAR sites, Site 1 (a and b) and Site 2 (c and d). The response to MAR is greater with no additional groundwater abstraction (a and c) than with 100% or 10 ML/d of additional abstraction (b and d) at locations down gradient of the infiltration location 38

Figure 12 Treated wastewater pH. Boxes represent the interquartile range, the whiskers the 10^{th} and 90^{th} percentiles and the points the 5^{th} and 95^{th} percentiles. Data provided by Water Corporation (April 2009 to present). 40

Tables

Table 1 Component of the managed aquifer recharge systems proposed for the two sites assessed. After Table 2.1 MAR guidelines (NRMMC-EPHC-NHMRC, 2009) 12

Table 2 Microbial indicators in source wastewater and default pathogen numbers for recycled water .. 18

Table 3 Potential uses, associated exposures and performance targets for groundwater downstream or recycles water MAR 19

Table 4 Exposure reduction provided by on-site preventative measures relevant to potential uses of groundwater (after NRMMC-EPHC-NHMRC, 2006) 19

Table 5 Removal time for a 90% loss (T_{90}) of pathogen (after Sidhu et al., 2015) determined in the Superficial aquifer at Floreat Infiltration Gallery 19

Table 6 Major ion chemistry, saturation index (SI) of calcite and amorphous iron hydroxide (Fe(OH)3(a)) and sodium adsorption ratio (SAR) of treated wastewater (TWW) sources within the study area and Beenyup TWW for comparison 23

Table 7 Range of heavy metal/metalloid concentrations in groundwater (µg/L) surrounding the Kwinana WWTP infiltration basins. Trigger values as per Figure 4. Bold value indicate exceedance of trigger values 25

Table 8 Salinity of potential and reference treated wastewater sources for managed aquifer recharge. Beenyup provided as a reference site. Salinity shown as electrical conductivity (mS/m) and total dissolved solids (mg/L, in brackets) 27

Table 9 Detections (and percentage of samples with detections) of a range of trace organic chemical in treated wastewater, groundwater and surface water 33

Table 10 Life cycle greenhouse gas (GHG) emissions for the proposed MAR sites and literature equivalents for desalination based on 182.5 GL over 50 years 41

Table 11 Risk assessment categorisation and ranking method adapted from Phase 1 Australia Guidelines for Water Recycling 43

Table 12 Maximal and pre-commissioning residual risk assessment for proposed managed aquifer recharge location - Site 1 (north) 44

Table 13 Maximal risk assessment for proposed managed aquifer recharge location - Site 2 (south) where different to Site 1 (Table 13) 48

Acknowledgments

CSIRO would like to acknowledge the financial assistance of the Australian Government through the National Water Infrastructure Development Fund delivered through the Western Australian Department of Water and Environmental Regulation and Department of Job, Tourism, Science and Innovation. The Western Trade Coast – Managed Aquifer Recharge (WTC-MAR) project was also co-funded by CSIRO Land and Water and the Kwinana Industry Council (KIC).

CSIRO would like to acknowledge the support of the Water Corporation of Western Australia for their provision of data for treated wastewater and groundwater, and for their and the Aroona Alliances assistance in providing access to their sites for the collection of treated wastewater and groundwater samples.

The authors would also like to acknowledge the contributions that both internal and external review made to the report.

Executive summary

The Western Trade Coast (WTC) located ~30 km southwest of Perth is one of Western Australia's major industrial precincts. Water is critical for many industries located there however the major industrial water source, groundwater, is already fully allocated (Department of Water and Environmental Regulation, 2018a) hampering future productivity of the region. Thus alternative water supplies are urgently required to meet the future growth in water demand of the WTC. Through the National Water Infrastructure Development Fund and with support from CSIRO Land and Water and the Kwinana Industry Council (KIC) the Western Trade Coast Managed Aquifer Recharge (WTC-MAR) project was established to determine the feasibility of Managed Aquifer Recharge of treated wastewater (TWW) as an alternative water supply source.

This report outlines the risk assessment undertaken at two sites in accordance with the Stage 2 assessment under Phase 2 of the *Australian guidelines for water recycling: Managing health and environmental risks (MAR).* These sites were selected based on previous investigations undertaken in the pre-feasibility study (McFarlane et al., 2015) and the findings of the Stage 1 entry level assessment (Department of Water, 2016). The risk assessment methodology involved an initial maximal risk assessment being undertaken for the infiltration of secondary TWW into the Superficial Aquifer at the two sites where TWW source was either the Woodman Point wastewater treatment plant (WWTP, Site 1) (via the Sepia Depression Sepia Depression Ocean Outlet Landline) and from the East Rockingham WWTP (Site 2). The risk assessments were undertaken based on the end use being non-potable industrial water use with current groundwater quality a surrogate for this as MAR is proposed to supplement this existing water source and due to the undetermined end user requirements. Subsequent to this a pre-commissioning risk assessment was conducted in which engineering controls and the aquifers natural attenuation potential were employed to reduce the risks (to human health and the environment).

The maximal risk assessment identified that there was moderate, high or very high risk associated with pathogens, nutrients (phosphorus and nitrogen), turbidity and particulates, inundation due to groundwater level rise (Site 1 only), contaminant migration through the limestone aquifer and impacts on groundwater dependent ecosystems, especially wetlands. These risks were largely associated with the high pathogen, nutrient and particulate concentrations associated with the TWW. Groundwater modelling also indicated that there was uncertainty associated with the predicted groundwater levels at Site 1 and subsequent inundation and the risks to infrastructure (e.g. rail and roads) at this site. Data gaps also make the assessment of conduit flow in the Tamala Limestone uncertain and the impact to ecological health and water quality in wetlands, the dominant GDE likely to be impacted. However despite these concerns with regard to current and future groundwater use by industry the risk is expected to be low due to the similarity of TWW quality to local groundwater used by industry.

The residual risk assessment identified a number of risks associated with the TWW that could be mitigated through the pre-treatment options proposed, as part of the engineering assessment (GHD, 2018), prior to infiltration and the potential of the aquifer to attenuate pathogens and phosphorus resulting in low residual risks. Nitrogen removal via denitrification still remains uncertain due to the unknown capacity of the aquifer, though the risk is reduced due to interception of the MAR plume through abstraction for industrial use. Additional validation of the groundwater model at Site 1 is required to assess existing groundwater levels and the potential for inundation arising from MAR. A regional assessment of the hydrogeology of the Tamala Limestone aquifer indicates that conduit flow is unlikely resulting in a low residual risk, however validation is required to confirm this. Due to uncertainty related to the impact of pathogens, nutrients and salinity, further baseline ecological and water quality assessments are required

for wetlands to confirm the low residual risk for Site 1 and especially at Site 2 where a moderate residual risk remains.

Due to the uncertainties remaining it is recommended that further investigations (including local scale modelling, aquifer characterisation (in particular metals/metalloids), impacts on contaminated sites and seawater intrusion) be undertaken to determine whether the risks are low before proceeding to Stage 3 of the MAR guidelines (construction and commissioning) at both sites. Infiltration galleries for recycled wastewater MAR are yet to be trialled within an operational scheme and a risk management plan developed. It will be important to establish influent (TWW/pre-treated TWW) water quality targets to minimise clogging processes (removal of TSS and nutrients) as remediation of clogging in a buried infiltration gallery will be more difficult than for an open infiltration basin. As part of the MAR trials it is expected that validation monitoring take place and further risk assessments take place as per Stage 3 of the MAR guidelines.

1 Introduction

The Western Trade Coast Managed Aquifer Recharge (WTC-MAR) project seeks to undertake a feasibility study of the potential for managed aquifer recharge (MAR) in the Superficial Aquifer as a means of storage and delivery of bulk, affordable recycled wastewater for heavy industry. The project builds on a pre-feasibility study undertaken by CSIRO (McFarlane et al., 2015) which identified that MAR appeared to be a cost-effective source of future non-potable water supply for heavy industry. A parallel assessment of the local water supply strategy for the Western Trade Coast (WTC) undertaken by the Department of Water (Department of Water, 2016) identified increasing demand from heavy industry at the same time as decreasing availability of groundwater supply from the Superficial Aquifer. Recycling treated wastewater via MAR was identified as a potential new water source that could fill the gap between projected demand and supply. The recently updated *Cockburn Groundwater Allocation Plan* (Department of Water and Environmental Regulation, 2018a) identified that Superficial groundwater resources are fully or over-allocated and as a result revised groundwater allocations to current levels of use and identifies the need to recover water entitlements to address the over-allocated Superficial groundwater resources. This reinforces the need to find alternative water supplies to support current and future industry in the WTC.

The WTC-MAR project focuses on the two most prospective sites previously identified in the pre-feasibility study (McFarlane et al., 2015) and is made up of five components:

1. Local groundwater flow and solute transport modelling.
2. Stage 2 assessment under Phase 2 of the *Australian guidelines for water recycling: Managing health and environmental risks (MAR)* (referred to as 'MAR guidelines') (NRMMC-EPHC-NHMRC, 2009); including field investigations and water quality monitoring.
3. Engineering design and costing of the MAR scheme (GHD, 2018).
4. Commercial feasibility assessment of service provision options (Synergies Economic Consulting, 2018).
5. Assessment of regulatory and licensing requirements.

This report addresses component 2, and outlines the Stage 2 assessment under Phase 2 of the *Australian guidelines for water recycling: Managing health and environmental risks (MAR).* It incorporates results from the groundwater flow in the assessment of the risks. Additional technical information can be found in the associated groundwater modelling reports (Castilla et al., 2018; Cui and Donn, 2018). The assessment has been undertaken considering the following assumptions:

- The treated wastewater will be recovered for non-potable industrial water supply. As MAR is considered to be a substitute for groundwater use, the quality of existing groundwater is assumed to be adequate for industrial purposes. Therefore in the absence of water quality guidelines for industrial use, the current groundwater quality is adopted as the target water quality for industrial use as different industries have different end use water quality requirements and management.
- The source water for MAR is secondary treated wastewater from one of two wastewater treatment plants (WWTPs); (i) Woodman Point (via the Sepia Depression Ocean Outlet Landline) and (ii) East Rockingham. The Kwinana WWTP is also in the WTC catchment area however the majority of treated wastewater (TWW) from this WWTP is already infiltrated as part of the disposal licence (DER, 2014). Treated wastewater is to be supplied as is by the Water Corporation. However to

ensure the TWW is suitable for infiltration, pre-MAR treatment options have been outlined by GHD (2018) for both sites.

- Recharge of the aquifer will be via infiltration basins or galleries depending on the location.

The maximal risk assessment is an assessment of the risks in the absence of preventative measures whereas the subsequent pre-commissioning residual risk assessment assesses the risk in the presence of preventative measures (NRMMC-EPHC-NHMRC, 2009). The objective of this report is to outline the maximal and residual risks associated with the infiltration of treated wastewater into the Superficial Aquifer at two sites identified in the pre-feasibility study (McFarlane et al., 2015) as potential sites for MAR. The maximal risk assessment is largely based on the source water quality from the two TWW sources being considered, the Superficial Aquifer sediment properties and interaction with TWW, ambient groundwater quality, and the hydrogeological responses of the aquifer to infiltration as determined by groundwater modelling. The residual risk assessment takes into account the engineering controls outlined by GHD (2018) and the natural treatment capacity of the aquifer, incorporating modelling assessments of residence time. The risk assessments are conducted using the qualitative framework outlined in Phase 1 of the *Australian guidelines for water recycling: Managing health and environmental risk* (NRMMC-EPHC-NHMRC, 2006). Where possible the risks are also assessed in a quantitative manner as outlined by the MAR guidelines (NRMMC-EPHC-NHMRC, 2009), however this is not possible for all risks as there is either a lack of local data or suitable guidelines with which to make the assessment.

The report represents a pre-commissioning residual risk assessment in accordance with the MAR guidelines (NRMMC-EPHC-NHMRC, 2009). As outlined above, this level of risk assessment uses existing information and investigations to identify preventative measures that will ensure acceptable risks to human health and the environment. This step is necessary prior to progressing to construction and commissioning the project. However, from a risk assessment perspective, commissioning trials are essential to verify the efficacy of these preventative measures and to revise them as necessary to ensure the scheme has acceptably low risks during ongoing operation.

The pre-commissioning residual risk assessment (this report) informs on hazards that require validation monitoring during commissioning trials. For potential hazards introduced with the treated wastewater that require removal or treatment in the subsurface (e.g. phosphorus), monitoring will verify the efficacy of such removal. Commissioning trial monitoring is also used to validate our understanding of risks associated with aquifer sediments (e.g. metal/metalloid mobilisation). This will be validated with monitoring of an appropriately designed monitoring network during commissioning. In the event that the preventative measures outlined in the pre-commissioning residual risk assessment are inadequate, additional investigations (sediment analysis, laboratory column studies, modelling) are then necessary to firstly understand the underlying mechanism and then identify strategies to manage the hazard.

2 Background

2.1 Superficial aquifer

The two proposed sites (Site 1 (north) and 2 (south) in Figure 1) are situated on the Tamala Limestone aquifer to the east of the Safety Bay Sand occurrence. The Tamala Limestone is a highly transmissive calcareous eolianite with variable proportions of quartz sand, fine- to medium-grained shell fragments and minor clay lenses (Davidson and Yu, 2008). It is approximately 30 m thick at Site 1 and approximately 25 m thick at Site 2. At both sites, samples taken using a sonic drilling rig during bore installation and based on observations by CSIRO the upper 9 m at Site 1 and 12 m at Site 2 of the profile contains sandy material with limestone fragments/gravel with the remainder more consolidated limestone material.

Further detail on the Superficial Aquifer properties can be found in McFarlane et al. (2015) and (Donn et al., 2019).

2.2 Treated wastewater sources

There are three wastewater treatment plants (WWTPs) that could potentially supply treated wastewater for MAR in the broader Western Trade Coast (WTC) area, Woodman Point, Kwinana and East Rockingham (Figure 1). The most likely sources for the Site1 is from Woodman Point and East Rockingham for Site 2 as outlined below (Section 2.3). The Woodman Point wastewater treatment plant lies in the northern section of the WTC with treated wastewater disposed of through the Sepia Depression Ocean Outlet Landline (SDOOL) which runs from north to south through the Kwinana industrial area to Point Peron and then 4 km offshore to the ocean outlet in the Sepia Depression. This is the main source of treated wastewater with > 50 GL/yr currently going to marine discharge. Part of the TWW in the SDOOL is tertiary treated at the Kwinana Water Reclamation Plant (KWRP) to produce up to 6 GL/yr of reverse osmosis treated wastewater in its current configuration (Department of Water, 2016; McFarlane et al., 2015). Future uses of TWW from the Woodman Point WWTP include increasing capacity at KWRP to 9.6 GL/yr (Synergies Economic Consulting, 2018) and the expansion of Groundwater Replenishment by Water Corporation (up to 32 GL/yr, GHD, 2018). Despite the other uses for TWW from Woodman Point WWTP there remains sufficient quantity of TWW to supply water for the MAR schemes of the size proposed as part of this project (10 ML/d or 3.65 GL/yr herein and in GHD, 2018).

The smaller Kwinana and East Rockingham WWTPs are also connected to the SDOOL. However the majority of the TWW (~80% of 2.0 GL/yr) is already infiltrated at the Kwinana WWTP, the remaining TWW is not sufficient to supply the MAR schemes proposed. Currently the remainder of the TWW at Kwinana and all at East Rockingham (0.86 GL/yr) is disposed of to the SDOOL. Currently East Rockingham cannot supply the full proposed 10 ML/d (3.65 GL/yr) MAR scheme, though forecasting indicates that East Rockingham will reach this level of production by 2027 (Synergies Economic Consulting, 2018). Therefore East Rockingham WWTP represents a future source of TWW for MAR, whereas the Kwinana WWTP is unlikely to have sufficient TWW available for an additional 10 ML/d scheme.

The TWW quality in general is poorer at the Woodman Point WWTP with higher suspended solids (Section 3.1.6) and nutrient (Section 3.1.4) concentrations than observed currently at the Kwinana and East Rockingham WWTPs. These differences arise from the different treatment processes used, the capacity and current operation of the treatment plants and will be discussed below. Further detail is provided in the risk

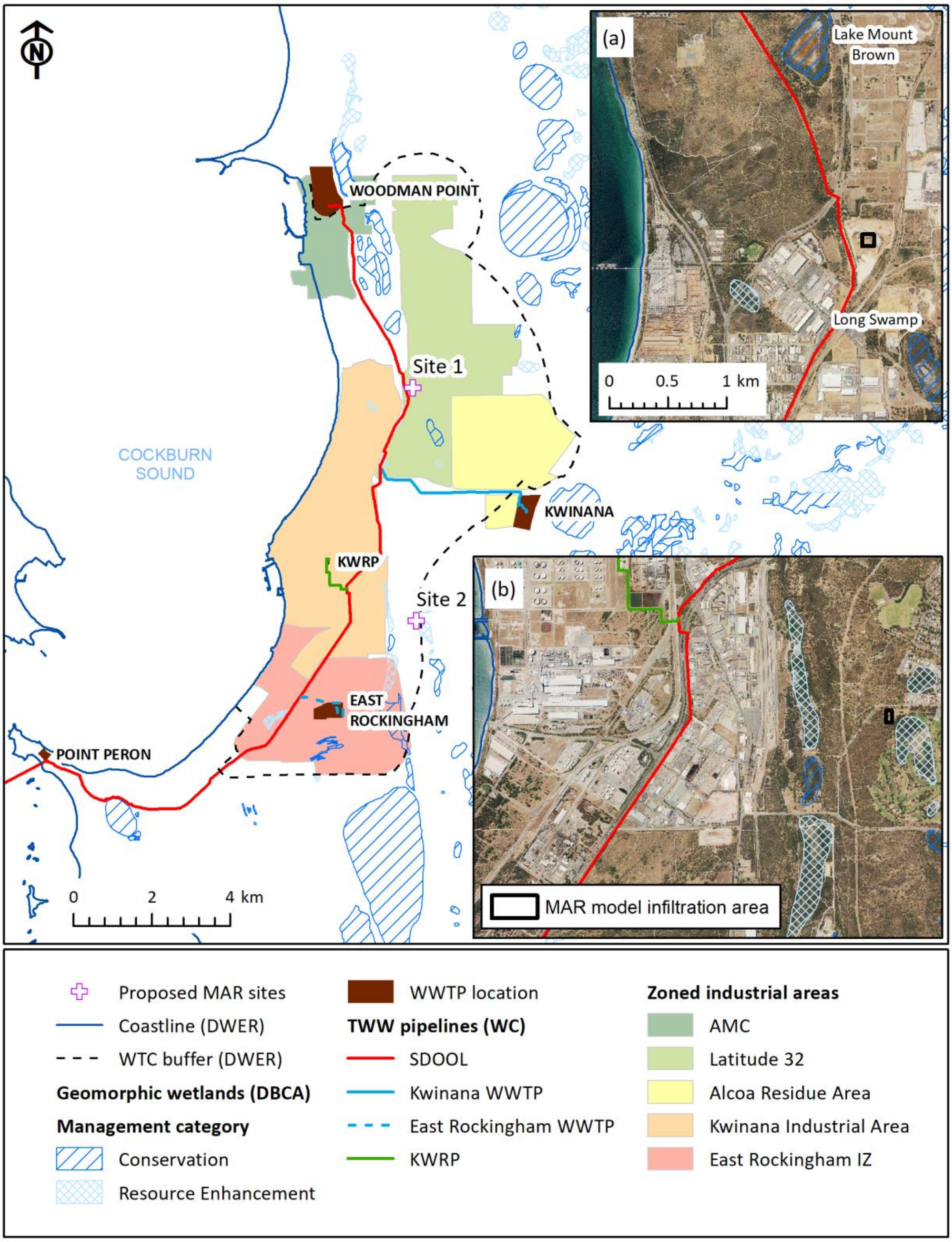


Figure 1 Overview of Western Trade Coast (WTC) study area showing the proposed MAR sites, wastewater treatment plant (WWTP) locations, treated wastewater (TWW) pipelines and environmental assets (wetlands and Cockburn Sound). Insert (a) Site 1 and immediate surrounds, insert (b) Site 2 and immediate surrounds (a and b are at the same scale). DWER = Department of Water and Environmental Regulation, WC = Water Corporation

assessment below on TWW quality, however it is expected that greater pre-treatment will be required prior to infiltration for any site supplied from the SDOOL as opposed to direct supply from East Rockingham (GHD, 2018). TWW quality data for East Rockingham WWTP is limited, therefore TWW quality from Kwinana is used at times in this report to represent the quality of TWW that may be available from East Rockingham, while Beenyup represents longer term quality expected from Woodman Point.

2.3 Prospective sites assessed

The MAR sites chosen for the feasibility study were based on the most favourable locations arising from the pre-feasibility study where sites were selected following as staged approach whereby the aquifer response to MAR and the constraints, including environmental, infrastructure, MAR water source, land availability and potential end users were considered (McFarlane et al., 2015). For both prospective MAR sites a TWW infiltration rate of 10 ML per day based on previous investigations by CSIRO (McFarlane et al., 2015) has been used for the engineering design, economic assessment and groundwater modelling. The components of the proposed MAR systems are outlined in Table 1 with more detail provided below.

Table 1 Component of the managed aquifer recharge systems proposed for the two sites assessed. After Table 2.1 MAR guidelines (NRMMC-EPHC-NHMRC, 2009)

Component	Site 1 (north)	Site 2 (south)
Capture zone (water source)	Woodman Point WWTP	East Rockingham WWTP
Pre-treatment [a]	Denitrification filter	Denitrification filter
Recharge (method)	Infiltration basin	Infiltration gallery
Subsurface storage	Superficial Aquifer	Superficial Aquifer
Recovery	Existing or new recovery wells located down-gradient at the point of use (industrial water user)	Existing or new recovery wells located down-gradient at the point of use (industrial water user)
Post-treatment	Dependent on water use Likely to be similar to current practices of industrial groundwater users	Dependent on water use Likely to be similar to current practices of industrial groundwater users
End use	Non-potable industrial water supply	Non-potable industrial water supply

[a] proposed pre-treatment method

2.3.1 Site 1 (north)

Site 1 is located to the north of the Kwinana Industrial Area within the footprint of the Latitude 32 development (Figure 1). The site is bounded by the Kwinana freight railway to the east and existing industrial/commercial land use to the south-east. The site is currently under lease for the commercial extraction of sand and limestone, though mining is currently not occurring. Several constraints to MAR were noted by GHD (2018) including above and below ground services in close proximity and potentially most critical the impact of rising groundwater levels resulting from MAR on existing (rail and road) and proposed (Fremantle Rockingham Controlled Access Highway) infrastructure.

Treated wastewater for Site 1 will be sourced from the SDOOL which is in close proximity to the proposed MAR infiltration area (Figure 1a). This TWW will originate from Woodman Point WWTP. Based on the Woodman Point TWW quality, denitrifying filters are proposed to remove suspended solids and nitrogen from the TWW before infiltration (GHD, 2018). Following expansion of Groundwater Replenishment, treatment by reverse osmosis (RO) will also be required to decrease the salt loads arising from disposal of brines to the SDOOL upstream (GHD, 2018). Backwash water from the filters and RO brine disposal through

return to the SDOOL is proposed. GHD (2018) has proposed that the TWW be recharged through a pair of open infiltration basins into the Superficial Aquifer (1 ha infiltration area with a 1 m/d infiltration rate assumed) with one basin active at any one time. Maintenance of the infiltration rate is the main objective of this two basin system with redundancy enabling rejuvenation of the non-operating basin either naturally through drying or mechanically through removal of the clogging layer. Further detail and costings are provided in GHD (2018).

2.3.2 Site 2 (south)

Site 2 is located to the east of the Kwinana Industrial Area adjacent to the Kwinana Golf Course in Medina (Figure 1b). The site is situated on a Crown Reserve vested to the City of Kwinana with the native vegetation having 'Bush Forever' status. Aside the clearing required to establish the infiltration locations the other main physical constraint for this site is the slope of the land (significant proportion at 10%) (GHD, 2018).

Treated wastewater for Site 2 will be sourced directly from the East Rockingham WWTP and conveyed to the site through a new pipeline constructed for this purpose (GHD, 2018). Although the East Rockingham TWW quality is substantially better than that observed for the SDOOL a denitrifying filter pre-treatment system located at or close to the East Rockingham WWTP is also proposed for Site 2 (GHD, 2018). Pre-treatment is proposed based on increased TSS concentrations expected in the future as the inflows to the WWTP increase (personal communication, Water Corporation). Backwash water from the filters is proposed to be discharged to the pipeline which delivers TWW from East Rockingham to the SDOOL.

Buried infiltration galleries have been proposed to infiltrate the TWW at Site 2 into the Superficial Aquifer due to the close proximity to the golf course, businesses to the north and residential areas to the east of the site as well as the topographical constraints of the site. Three infiltration galleries are proposed for Site 2 with two active gallery modules and one resting module at any one time. The designed infiltration rate for the galleries is 2 m/d over the two active modules. Clogging is proposed to be controlled through the pre-treatment of the TWW, rotation of the galleries receiving the TWW and in the longer term periodic (decadal) 'renovation' of the galleries (excavation of the galleries and removal of the clogging layer). Further detail and costings are provided in GHD (2018).

2.3.3 MAR water recovery

The major beneficiaries of increased water availability as a result of a MAR scheme in the WTC is intended to be industry. In practice recovery by industry of MAR water will occur through either existing or new recovery well located down gradient of the infiltration galleries. As part of the groundwater modelling investigations recovery of MAR water was simulated from 20 'new' recovery wells (Cui et al., 2019). The location of these recovery wells was based on the delineation of a 'MAR zone' based on particle tracking and groundwater level responses resulting from modelled TWW infiltration under current groundwater abstraction rates. This is consistent with the methodology discussed with the Department of Water and Environmental Regulation during the project development, however the methodology needs to be tested during MAR implementation. With regard to the proportion of the 10 ML/d of MAR water that could be recovered, modelling indicated that there was little difference between the abstraction of 80% or 100% of the MAR water (Cui et al., 2019).

The 20 recovery wells were distributed spatially over the 'MAR zone' to avoid excessive drawdown (not explicitly modelled) and placed in locations such that they did not impact existing infrastructure (e.g. buildings, roads, etc.). It is assumed that all recovered water will be utilised by industry and lost from the groundwater balance since the 'customers' of a MAR scheme and hence uses of the recovered water have

yet to be identified. The positioning of the recovery wells and 'use' of the MAR water also has the potential benefit of intercepting a proportion of the MAR water before it reaches Cockburn Sound.

2.4 Receiving environments / receptors

As indicated above the main purpose of the proposed MAR sites is to provide an alternative water source for non-potable industrial uses. Non-potable water is used for industrial processing, cooling towers, wash down, cogeneration heat and power, dust suppression and slurry transport within the wider WTC area (Department of Water, 2016). These end uses are not specific to the proposed MAR schemes and as users have not been identified at present only generalisations with regard to the uses of MAR water can be made. Groundwater accounts for a high proportion of current water use (57%, Department of Water, 2016), however under increasing pressure from the drying climate in south-west Australia, current abstraction rates from natural groundwater resources are unsustainable in the Cockburn Groundwater Area, in which the WTC lies (Department of Water and Environmental Regulation, 2018a). The recharge of TWW to the Superficial Aquifer is proposed as an alternative to groundwater water supply, thus impacts for the risk assessment process undertaken herein are related to groundwater users and receptors. For example infiltration of TWW may impact on existing groundwater users (industrial and other users) as well as environmental receptors such as groundwater dependent wetlands and Cockburn Sound.

The requirements for industrial non-potable water supply will depend on the purpose to which the water is being used. Considering the recovered water from the MAR schemes is intended as a replacement or a supplement for existing groundwater use and the lack of available information on end use quality it is assumed that existing groundwater quality is sufficient for industry requirements and similarly for other non-potable water uses (e.g. irrigation). That is if groundwater is current fit-for-purpose then the MAR water should meet this standard as a minimum.

The main environmental receptors in the study area are wetlands, both fresh and brackish/saline and the marine environment of Cockburn Sound (McFarlane et al., 2015). There is also native vegetation associated with the bush forever classification of Site 2, however large areas of this have a depth to groundwater greater than 10 m (Donn et al., 2015) which is not considered to be groundwater dependent for terrestrial vegetation (Barron et al., 2012; Froend and Sommer, 2010). The wetland management categories with Geomorphic Wetlands dataset (DPaW, 2013) are used to as a guide for wetland importance. Conservation wetlands support a high level of attributes and functions while Resource Enhancement wetlands have been modified or degraded but still support substantial attributes and functions (Department of Biodiversity Conservation and Attractions, 2017). At Site 1 there are three wetlands (sumpland) classified as either conservation or resource enhancement in the Geomorphic Wetlands dataset (DPaW, 2013); Lake Mount Brown to the north (conservation), Long Swamp to the south (conservation) and an unnamed wetland to the west (resource enhancement) (Figure 1a). Long Swamp is closest to the infiltration site at 900 m, Lake Mount Brown is 1400 m and the unnamed resource enhancement wetland is 1000 m from the infiltration site. Both Long Swamp and Lake Mount Brown are ecological monitoring sites for the Cockburn Groundwater Area management plan (Department of Water and Environmental Regulation, 2018a), though they are only assessed through trends in groundwater or surface water level and not water quality.

There are four unnamed wetlands (sumpland) in the vicinity of Site 2; two resource enhancement category wetlands up-gradient of the infiltration site, and one resource enhancement and one conservation category wetland down-gradient of the infiltration site (Figure 1b). The up-gradient wetlands are in close proximity to the infiltration site (100 m and 280 m) while the down-gradient wetlands are between 600 m (resource enhancement) and 710 m (conservation) from the infiltration site.

Site 1 and Site 2 are situated approximately 1900 m and 2300 m from Cockburn Sound, respectively. Due to the embayment formed between the mainland and Garden Island, Cockburn Sound is particularly sensitive

to nutrient additions including from groundwater (McFarlane et al., 2015). Currently the majority (>70%) of the nitrogen balance for Cockburn Sound is supplied through internal cycling (i.e. sediment release) however additional nitrogen discharge through groundwater as a result of MAR may alter the nitrogen balance (Greenwood et al., 2016). Further detail on wetlands and Cockburn Sound can be found in McFarlane et al. (2015).

2.5 Risk assessment / MAR Guidelines

The MAR guidelines (NRMMC-EPHC-NHMRC, 2009) outline a staged approach to risk assessment and development of MAR projects to allow decision points for investment in a MAR scheme based on an informed understanding of the next required level of investigation. These stages are

(i) ***Stage 1 Desktop study***: Entry-level assessment comprising a) viability assessment and b) degree-of-difficulty assessment (complete prior to this study, Department of Water, 2016).

(ii) ***Stage 2 Investigations and assessment***: Maximal risk assessment and pre-commissioning residual risk assessment (completed in this report).

(iii) ***Stage 3 Construction and commissioning:*** Operational residual risk assessment, refinement of the pre-commissioning residual risk assessment during a commissioning trial (to be completed).

(iv) ***Stage 4 Operation***: Risk management plan (to be completed).

An entry-level assessment was conducted as part of the WTC local water supply strategy (Department of Water, 2016). It was identified that the following areas had a moderate to high level of difficulty and required additional information and assessment:

- Site-specific information relating to the chemical and physical properties of the source water and groundwater for MAR
  - required to assess the source water quality with respect to both groundwater and end use environmental values; the potential for reactions between the source water and the aquifer (groundwater and sediments); and the potential for clogging processes to reduce infiltration rates.
- Groundwater modelling and assessment of how infiltrated water affects groundwater-dependent ecosystems, in particular Cockburn Sound
  - required to assess the impact of MAR on other groundwater users and downstream ecosystems, and to define appropriate buffer zones around infiltration points
- How experienced a proponent is to design, construct and operate a recycled wastewater MAR scheme, including the management of appropriate buffer zones around infiltration points.

This report considers aspects for the first two points and provides the Stage 2 Maximal risk assessment and pre-commissioning residual risk assessment. Maximal risk is risk in the absence of preventative measures, while residual risk is risk after consideration of preventative measures. The risk assessment process assesses twelve key human and environmental health hazards that are relevant to MAR schemes (NRMMC-EPHC-NHMRC, 2009). Therefore the Stage 2 assessment identifies preventative measures to ensure that the residual risk is acceptable (or low) for all of these hazards.

In this assessment the maximal risk assessment is based on treated wastewater (TWW) quality, potential interactions between TWW and the sediments of the Superficial Aquifer, groundwater quality (as surrogate for end user quality requirements) and predictions of groundwater flow. Ambient groundwater quality is assumed to be low risk as it is currently being used for industrial water supply; the exception is where site specific ambient groundwater may pose a risk, e.g. in areas of seawater intrusion.

The pre-commissioning residual risk assessment for water quality hazards considers preventative measures such pre-treatment or natural treatment in the aquifer, based on previous experience with MAR or TWW infiltration in the Superficial Aquifer, predictions of groundwater flow and solute transport for the prospective sites and engineering controls provided by GHD (2018).

The qualitative framework for the assessment of the maximal and residual risks outlined in Phase 1 of the *Australian guidelines for water recycling: Managing health and environmental risks* (NRMMC-EPHC-NHMRC, 2006). This process involves the identification of the hazards or hazard events that may occur as the result of MAR. Twelve hazard categories are identified in the MAR guidelines, these are

- Pathogens
- Inorganic chemicals
- Salinity and sodicity
- Nutrients
- Organic chemicals
- Turbidity and particulates
- Radionuclides
- Pressure, flow rates, volumes and levels
- Contaminant migration in fractured rock and karstic aquifers
- Aquifer dissolution and stability of well and aquitard
- Impacts on groundwater dependent ecosystems
- Greenhouse gases

The hazards are identified in the Section 3.1. Once the hazards have been identified a likelihood of the particular hazard occurring is evaluated along with the impact or consequence of the hazard occurring. Based on this likelihood-impact matrix a level of risk is assigned. These tables are outlined at the beginning of the risk assessment (Section 3.2).

The next step would be to assess these preventative measures in operation within the Stage 3 construction and commissioning phase. The Stage 3 construction and commission phase allows the residual risk assessment to be refined, prior to implementation of an operational risk management plan.

3 Stage 2 Risk assessment

3.1 Hazard identification and fate

3.1.1 Pathogens

As little is known about the microbial impact of MAR on the environment (NRMMC-EPHC-NHMRC, 2009) this section focuses on the human health impact of pathogens only. Since the source water proposed for MAR is wastewater there is the potential for a wide range of enteric pathogens (bacteria, viruses and protozoa) to be present. In unconfined aquifers, there can be other sources of pathogens, such as from sewer spills or manure spreading; this assessment focuses only on the risk associated with the use of recycled water via MAR.

Given the large number of pathogenic hazards in source waters for MAR, three reference pathogens have been identified to represent bacterial, viral and protozoan risks; *Camplylobacter*, rotavirus and *Cryptosporidium* (NRMMC–EPHC–AHMC, 2006).

However specific pathogen numbers are not routinely determined for the WWTPs of interest (Table 2). *Escherichia coli* and *Enterococci* are the only routinely monitored microbial indicators in source wastewater (Donn et al., 2017). Concentrations for the Woodman Point, Kwinana and East Rockingham WWTPs are shown in Table 2 and are typical of secondary treated wastewater in Perth (Bekele et al., 2011). *Escherichia coli* and *Enterococci* cannot be used to assess microbial pathogen risks, but instead can be used in validation or operational monitoring.

Performance targets for pathogenic hazards in MAR represent the reductions required to achieve a residual risk that complies with the tolerable level (10^{-6} Disability adjusted life years (DALYs), per person per year) (NRMMC-EPHC-NHMRC (2006). Table 2 indicates a lack of pathogen data for the source treated wastewater and therefore the default values for recycled water were used to determine the performance targets shown in Table 3.

Industrial process water supply is the main use for recovered MAR water within the WTC area and the majority of abstraction occurs after a long residence times (Site 1: >2 years and Site 2 >5 years based on the residence time to the closest current industrial land use, Figure 2 a and c) down-gradient of both proposed MAR sites. Current uses for groundwater include cooling towers, wash down water, process water and dust suppression/slurry transport (Department of Health, 2009; Department of Water, 2016). Due to the more restricted access to MAR water and the ability of industry to implement controls on recycled water the potential for human contact is lower than in the general public. The exposure frequency and volume associated with industrial use of recycled water, requires a project-by-project assessment (Department of Health, 2011). For this assessment, frequent (daily) exposure was assumed.

Modelled residence times suggest that greater than 1 year's travel time occurs before a licenced pumping bore intercepts the model particles (Figure 2). For Site 2 a greater concern might be the discharge of impacted groundwater to the wetlands within the golf course, however as this wetland is represented by a 'drain' in the groundwater model (i.e. a sink for groundwater discharge) it represents the worst case scenario (Cui et al., 2019). Further investigation of these wetlands should be undertaken in the future with a revised representation within the model reflecting the groundwater-surface water interaction. Licenced abstraction bores within the golf course are beyond the MAR impact area, thus the risk is considered to be low (pending confirmation through monitoring). However as exempt use or non-licenced bore locations are not recorded there still remains a higher risk associated with groundwater abstraction near the MAR sites.

Additional surveys of businesses and residences near the MAR sites need to confirm the presence or absence of these bores, the residence time from the MAR site and nature of groundwater use.

$\log_{10}$ reduction calculations were calculated using the following formula:

$$\log_{10}\text{ reductions}=\log_{10}\left(\frac{\text{no. of organisms in TWW }(n/\text{L})\times\text{exposure volume (L)}\times\text{frequency (/yr)}}{\text{dose equivalent to }10^{-6}\text{ DALY }(n/\text{yr})}\right)$$

where the dose equivalent to 10^{-6} DALY is 2.5×10^{-3} n/yr Rotavirus, 1.6×10^{-2} n/yr *Cryptosporidium,* 3.7×10^{-2} n/yr *Campylobacter* (NRMMC-EPHC-NHMRC, 2006).

The Australian Guidelines for Water Recycling (NRMMC-EPHC-NHMRC, 2006) specifies indicative $\log_{10}$ reductions of treatment processes and preventative measures for enteric pathogens. Preventative measures to reduce the risk of pathogenic hazards in recycled water include removing pathogens using treatment processes (natural treatment in the subsurface, or engineered treatment prior to recharge) and reducing exposure to the recycled water.

This assessment focuses on natural treatment after recharge, in combination with preventative measures such as on-site exposure controls. Bacteria, protozoa and virus removal during MAR is affected by physical, chemical and biological processes with removal primarily related to residence time of the recharge water, activity of indigenous microorganisms, the aquifer redox state and the temperature (NRMMC-EPHC-NHMRC, 2009).

Table 4 summarises relevant exposure controls while Table 5 details pathogen inactivation rates determined in the Superficial aquifer at the Floreat Infiltration Gallery site (Sidhu *et al.*, 2015) and the corresponding log removals after 1 year residence time in the subsurface. While Table 4 specifies ‘no public access during irrigation’ as a preventative measure, presumably no public access in an industrial setting can be demonstrated to have a similar log reduction value (LRV) (2 log).

Table 4 and Table 5 show natural treatment processes in the subsurface can be used in combination with on-site preventive measures to meet the minimum health-based $\log_{10}$ reduction targets. As aquifer residence time less than 6 months is unlikely to provide sufficient treatment for viral hazards, residence time to exempt use bores remains to be assessed. The required $\log_{10}$ reductions can be accumulated over sequential treatments and control measures. It is to be noted that a single treatment process (barrier) cannot be attributed a pathogen log reduction value (LRV) greater than 4 log. This is because validation of treatment barriers becomes problematic at > 4 log due to a lack of available surrogates for monitoring.

Table 2 Microbial indicators in source wastewater and default pathogen numbers for recycled water

	Default values *	Woodman Point WWTP			Kwinana WWTP			East Rockingham WWTP		
	95th percentile	n	median	95th percentile	n	median	95th percentile	n	median	95th percentile
Rotavirus (n/L)	8000		*nd*			*nd*			*nd*	
***Cryptosporidium* (n/L)**	2000		*nd*			*nd*			*nd*	
***Camplylobacter* (n/L)**	7000		*nd*			*nd*			*nd*	
***Escherichia coli* (n/100 mL)**	***na***	76	43,000	695,000	68	>24,000	>24,000	10	18,000	>24,000
***Enterococci* (MPN/100 mL)**	***na***	67	9,200	>24,000	32	6,500	>24,000		*nd*	

* default values for reference pathogens in recycled water (NRMMC-EPHC-NHMRC, 2006); *nd*=not detrmined; *na*=not applicable

Table 3 Potential uses, associated exposures and performance targets for groundwater downstream or recycles water MAR

Activity	Route of exposure	Volume (mL)	Frequency/person/year	log10 reduction targets		
				Rotavirus	*Cryptosporidium*	*Camplylobacter*
Industrial use – dust suppression	Ingestion of sprays	0.1 *	365 †	5.1	3.	3.8
Industrial use – cooling towers	Ingestion of sprays	0.1 *	365 †	5.1	3.7	3.8
Bore interception – municipal irrigation	Ingestion of sprays	1 *	50 *	5.2	3.8	4.0

* taken from NRMMC-EPHC-NHMRC (2006); † frequency unknown, daily industrial use and associated exposure assumed

Table 4 Exposure reduction provided by on-site preventative measures relevant to potential uses of groundwater (after NRMMC-EPHC-NHMRC, 2006)

Control measure	Reduction in exposure to pathogens
Spray drift control	1 log
Drip irrigation of plants/shrubs	4 log
Subsurface irrigation of plants/shrubs or grassed areas	5-6 logs
No public access during irrigation	2 log
No public access during irrigation and limited contact after (non-grassed areas)	3 log
Buffer zones (25-30 m)	1 log

Table 5 Removal time for a 90% loss (T_{90}) of pathogen (after Sidhu et al., 2015) determined in the Superficial aquifer at Floreat Infiltration Gallery

Pathogen	T_{90} (days)	Potential log removal after days 1 year travel time in the aquifer
Rotavirus	34	10.7
***Cryptosporidium* (n/L)**	39	9.4
***Camplylobacter* (n/L)**	2	>10

Based on data provided by the Water Corporation (Donn et al., 2017) and collected as part of this study (Kwinana WWTP, *E. coli* is not detectable in groundwater within 15 m from the infiltration basin, <1 *n*/100 mL) removal of *E. coli* occurs quickly once TWW is infiltrated. This reflects the relatively short inactivation rates for bacteria in aquifers, e.g. a generally value of 3 days for 1-log reduction (90% loss) (NRMMC-EPHC-NHMRC, 2009). Under conditions similar to those expected at the two potential MAR sites, bacterial 1-log reduction times of less than 2 days were observed in *in-situ* diffusion chamber studies undertaken in groundwater wells located in the Tamala Limestone aquifer (Table 5) (Sidhu and Toze, 2012; Sidhu et al., 2015).

The protozoa *Clostridium perfringens* was measured in TWW (KWRP influent, and Kwinana and East Rockingham WWTP effluent) and groundwater at the Kwinana WWTP as part of this study. *Clostridium*

perfringens is a spore-forming pathogenic bacteria that has been used as a surrogate for protozoa *Cryptosporidium* (Brookes et al., 2005). The *Clostridium perfringens* concentrations in TWW varied from 160 spores/100 mL to greater than the detection limit (1000 spores/100 mL) with replicate samples also showing similar variability. However, *Clostridium perfringens* was not detected in groundwater within 15 m of the infiltration basin at a detection limit of 10 spores/100 mL. This suggests the protozoa risks associated with TWW use for industrial purposes can be mitigated by MAR, though validation would be required to substantiate this at the proposed MAR sites.

Viruses in Australian aquifer typically have longer removal rates than bacteria and protozoa (NRMMC-EPHC-NHMRC, 2009). *In-situ* diffusion chamber studies have identified that 1-log reduction time for viruses may be up to 50 days depending on the virus (Table 5) (Sidhu and Toze, 2012; Sidhu et al., 2015). At the same site used for the diffusion chamber studies it was observed that the aerobic carbonate aquifer provided at least a 3-log removal of thermotolerant coliforms over 50 m, and substantial removal of all coliphage and selected enteric viruses within 10 m of the infiltration site (Bekele et al., 2011). At other MAR sites in the United States (Arizona, Colorado and California), Betancourt et al. (2014) observed approximately 2 log removal of viruses in ~15 days travel time in the aquifer. A static quantitative microbial risk assessment (QMRA) undertaken for the infiltration of TWW into an unconfined carbonate aquifer (Floreat WA) found that virus numbers were the single most important factor in determining the mean residual health risk of pathogens in recovered water (Toze et al., 2010). Depending on the exposure pathway the static QMRA indicated that up to 150 days residence time is required before the rotavirus was considered acceptable.

Generally, a compliance or operational monitoring level of <10 MPN or cfu/100 mL is suggested for *E. coli* concentration in the end-product water for industrial use (Department of Health, 2011). This is the only local guideline available to provide quantitative comparison. The source TWW would therefore fail this criteria, while the median quality of groundwater abstracted from the proposed MAR sites is likely to meet this criteria given evidence from TWW infiltration sites (Donn et al., 2017). Furthermore, groundwater at the Kwinana WWTP showed *E. coli* concentrations less than 1 cfu/100 mL for samples collected at 16 locations approximately 5 to 500 m from the infiltration basins during this study. Given the above evidence groundwater abstracted from the proposed MAR sites is expected to meet the Department of Health compliance monitoring guidelines for *E. coli* in water for industrial uses. However the rapid removal of *E. coli* in groundwater is not representative of the fate of more persistent viruses and protozoa (Table 5). Therefore validation monitoring should include appropriate surrogates for each of the pathogen types (bacteria, viruses, protozoa), which can subsequently be used in operational monitoring.

While quantification of performance targets for pathogenic hazards during MAR and microbial indicator monitoring data suggests that microbial hazards can be reduced to an acceptable level, this remains to be demonstrated at the sites under consideration. It is necessary to quantify reference pathogen numbers in TWW and groundwater, to validate removal rates locally prior to MAR implementation, and to establish appropriate operational monitoring for pathogen hazards as part of the MAR water quality management plan.

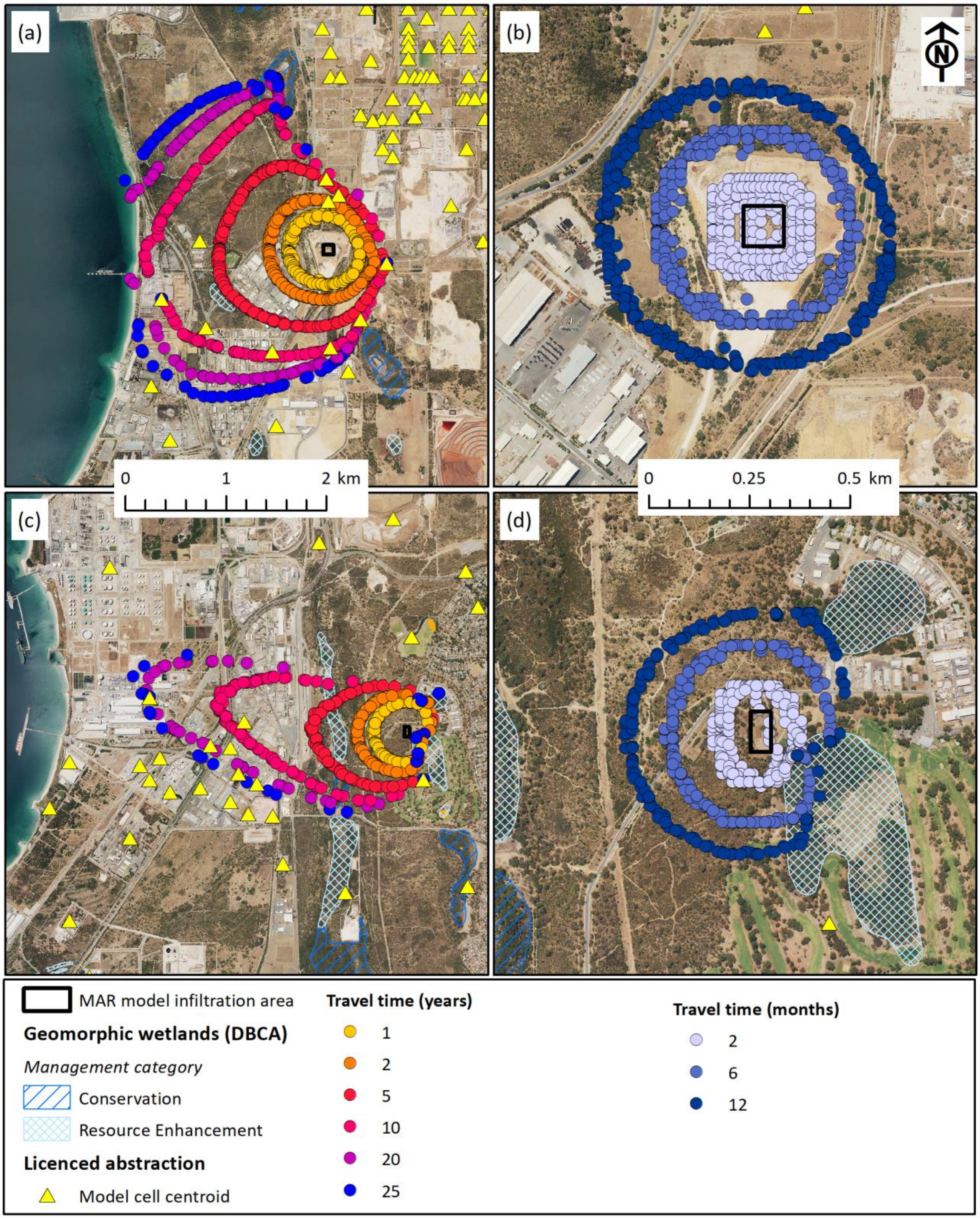


Figure 2 Modelled travel time for treated wastewater infiltrated at Site 1 (a and b) and Site 2 (c and d). The longer term travel times (a and c) indicate the extent of the treated wastewater plume expected and while shorter term travel times (b and d) are more relevant to pathogen removal. Licenced abstraction bore are also shown as they were implemented in the groundwater model. Details of modelling provided in Cui and Donn (2018).

3.1.2 Inorganic chemicals

This section identifies the hazards related to inorganic chemicals, e.g. major ions and trace metals in the TWW and resulting from interaction between the TWW and the aquifer material.

The overall impact of major ions (sodium, calcium, magnesium, potassium, chloride, sulfate and carbonate/bicarbonate) is discussed in the following section on salinity and sodicity.

Historical groundwater major ion data was provided by industry however comprehensive analysis was not possible as one or more ions were missing. Based on this incomplete data as summarised in Figure 3, groundwater major ion chemistry in the WTC varies spatially and is influenced by a number of factors including seawater intrusion and industrial contamination (e.g. sulfate, Trefry et al., 2006). Despite the variability in major ion chemistry, groundwater from the Superficial Aquifer is currently being utilised by industry. Whether ambient groundwater is currently used untreated or following treatment, with respect to major ion chemistry, MAR would be considered low risk to current groundwater use practices provided that additional pumping does not induce saltwater intrusion.

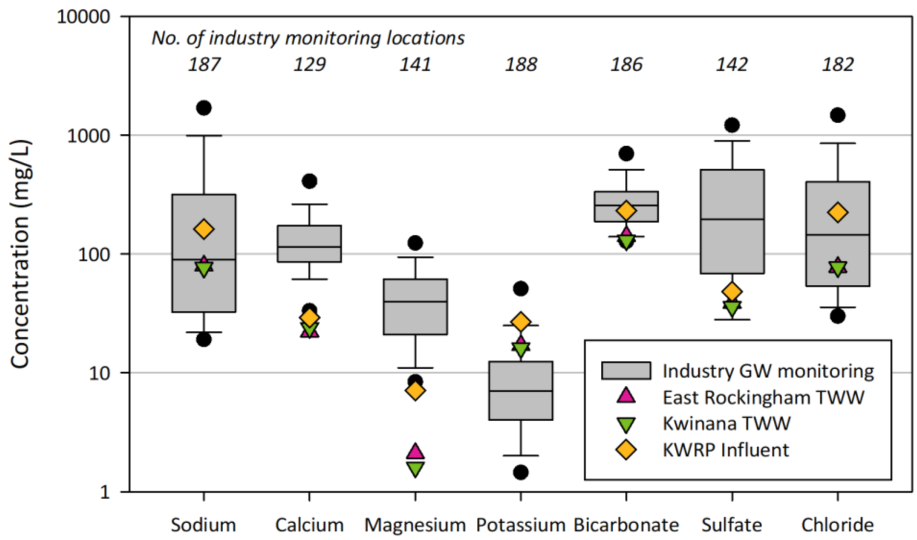


Figure 3 Range of major ion concentrations at industry groundwater monitoring locations, boxes represent the interquartile (25th to 75th) range, the horizontal line the 50th percentile error bars the 10th and 90th percentiles an the points (black circles) the 5th and 95th percentiles. Average treated wastewater (TWW) concentrations for the three WWTP in the catchment (Table 6) are shown for reference. Industry data represents latest data provided (mostly 2013), seawater impacted samples removed. Note not all ions are measured at all industry monitoring locations.

Major ion concentrations in TWW show similar chemistry between the different TWW sources (Table 6). To determine whether reaction between TWW and aquifer minerals could alter groundwater quality or aquifer permeability, aquifer mineral equilibrium saturation indices for a range of minerals were calculated (Appelo and Postma, 2005; Parkhurst and Appelo, 1999). To calculate the saturation indices the major ion compositions were input into the geochemical equilibrium model, PHREEQC (Parkhurst and Appelo, 1999). A saturation index equal to zero indicates equilibrium, while a saturation index <0 indicates subsaturation and >0 supersaturation (Appelo and Postma, 2005). Solutions subsaturation with respect to a mineral phase indicate a tendency for mineral dissolution (can impact on water quality), while supersaturation indicates a tendency toward precipitation (clogging risk).

The TWW composition indicates that the TWW sources (Woodman Point/SDOOL and East Rockingham) being considered for MAR are close to equilibrium with calcite (Table 6 and Table 7). After quartz, calcite is one of the major mineral in the aquifer (12 to 40% Bekele et al., 2009; Patterson et al., 2011), therefore

there is unlikely to be substantial changes in the major ion composition as a result of the infiltration of the TWW. The TWW is supersaturated with respect to iron oxides (Table 6, Appendix A) this may represent a potential risk for clogging through the precipitation of iron oxyhydroxides during infiltration, though due to low concentrations of iron in TWW (Table 6) the risk is low.

Table 6 Major ion chemistry, saturation index (SI) of calcite and amorphous iron hydroxide (Fe(OH)3(a)) and sodium adsorption ratio (SAR) of treated wastewater (TWW) sources within the study area and Beenyup TWW for comparison

	Ca	K	Mg	Na	Cl	SO_4	HCO_3	Fe	SI (calcite)	SI ($Fe(OH)_3(a)$)	SAR
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	-	-	-
East Rockingham TWW (this study)											
Mean	22	17	2.1	80	78	38.8	142	0.13	-0.30	1.27	4.3
Std Dev	2	2	0.4	8	3	0.5	6	0.05	0.09	0.05	0.3
n	4	4	4	4	4	4	4	4	4	4	4
Kwinana TWW (this study)											
Mean	24	16	1.6	77	78	36.0	130	0.03	-0.29	1.17	4.1
Std Dev	1	1	0.9	3	2	0.8	2	0.004	0.03	0.08	0.3
n	4	4	4	4	4	4	4	4	4	4	4
Kwinana Water Reclamation Plant (KWRP) Influent (this study; equivalent to Woodman Point TWW)											
Mean	29.3	27	7.1	162	220	48	230	0.02	-0.23	1.79	7.0
Std Dev	0.6	2	0.8	5	25	2	35	0.004	0.15	0.21	0.1
n	4	4	4	4	4	4	4	4	4	4	4
Beenyup Secondary TWW (Department of Health, 2009)											
Mean	37	23	12	180	220	101	130	0.04[b]	nd[c]	nd	6.8*
Std Dev	4	2	1	21	27	63	59				
n	12	12	12	12	12	12	12	356			
Woodman Point TWW (Department of Health, 2009)											
Mean	27	24	8	153	180	64	160	0.08[b]	nd	nd	6.7*
Std Dev	1	2	1	3	16	4	35				
n	3	3	9	3	3	3	163	281			

[a] median values, [b] calculated from mean values, c nd – not determined data not sufficient

The main environmental risk posed for the infiltration of TWW is the input of metals with the TWW or release due to interactions between the TWW and the aquifer. Comparison of the metal concentrations in TWW to the trigger values for ecosystem protection (ANZECC-ARMCANZ, 2000), indicates that chromium (Cr), copper (Cu) and zinc (Zn) consistently exceed the trigger values of 1.0 µg/L, 1.4 µg/L and 8.0 µg/L, respectively (Figure 4) suggesting that these metals may pose a threat to the freshwater ecosystems. Groundwater sampled at the Kwinana WWTP also indicates that these metals are elevated relative to the trigger values (Table 7). However it should be noted that the trigger values for Cr and Zn were also exceeded in background groundwater (up-gradient of the Spectacles wetland; Cr 1.5 to 2.6 mg/L, Zn 6 to 22 mg/L) and Cu concentrations exceed the trigger values in the November 2017 sampling (1.8 to 2.1 mg/L). In a study of Superficial groundwater between Gingin and Mandurah, Zn and Cu concentrations at 51 locations were observed to exceed the trigger values at greater than 90% and 95% of sites, respectively (Department of Water, 2010), indicating the likelihood of naturally high groundwater concentrations of these metals.

The site-specific background groundwater metal concentrations may be a more appropriate trigger value for ecosystem value, than the generic trigger values given in ANZECC-ARMCANZ (2000). Pending

background groundwater metal concentrations at the two proposed MAR sites, investigation of metal fate is likely to be required following initiation of MAR at the proposed sites.

One difference between the proposed MAR sites and the Kwinana WWTP is the presence of calcium carbonate in the soil and aquifer materials compared to a largely quartz dominated aquifer in the vicinity of the Kwinana WWTP. Carbonate minerals are known to remove metals through sorption (Shaheen et al., 2013), thus may potentially limit the impacts of metals in the TWW. The sorption capacity of the soils and aquifer materials however would need to be confirmed at the proposed sites and modelled should the sorption capacity prove insufficient.

Limited information is available for metals in groundwater used for industrial supply. The available data indicates that concentrations of metals are below a detection limit of 25 µg/L. Thus the only potential impact is likely to be from zinc given the concentrations observed in TWW (median ~45 µg/L) exceed the 25 µg/L detection limit in the industrial data. The impact of metal concentrations in groundwater on industrial groundwater users is unknown, thus further consultation is required with industry to determine whether there are any impacts to industrial use pertaining from of existing groundwater and potential groundwater metal concentrations arising from MAR.

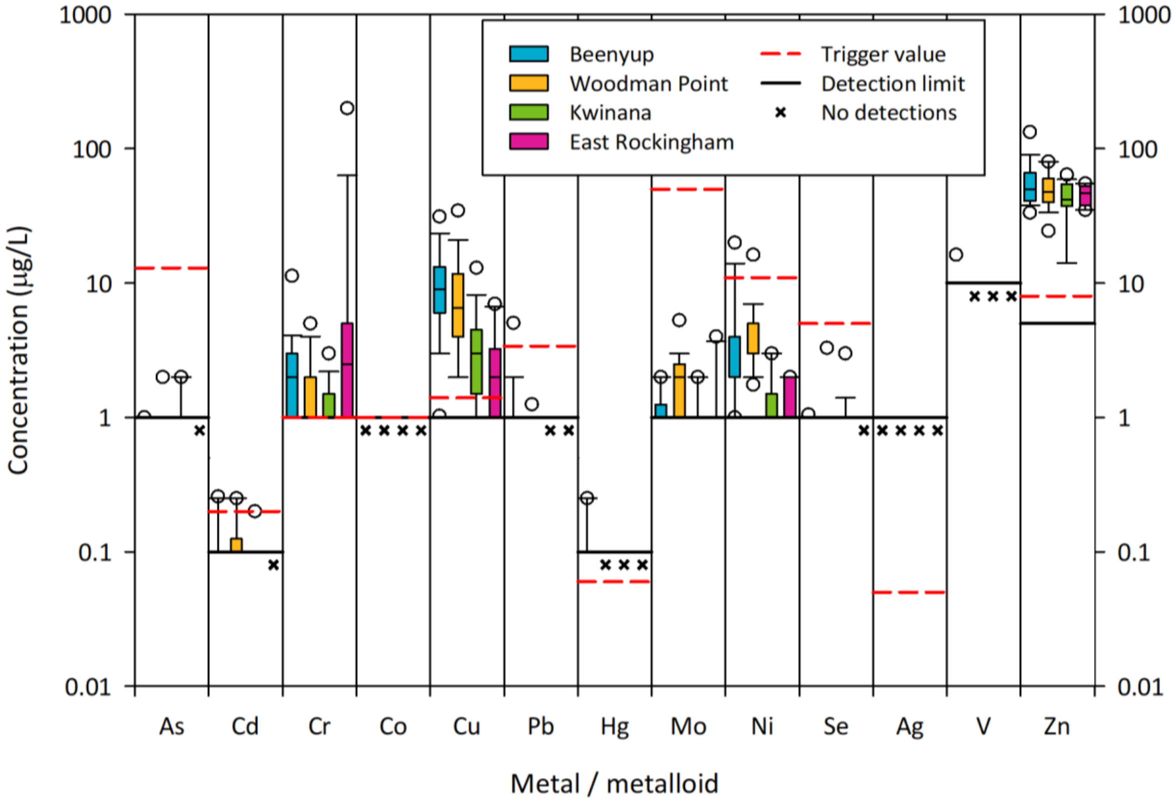


Figure 4 Heavy metal/metalloid concentrations in secondary treated wastewater. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles. Trigger values are for slightly-moderately disturbed freshwater systems at 95% protection level except for Hg and Se (99% protection level) and Co (marine 95% protection level) (ANZECC-ARMCANZ, 2000). Water quality data provided by Water Corporation

Table 7 Range of heavy metal/metalloid concentrations in groundwater (µg/L) surrounding the Kwinana WWTP infiltration basins. Trigger values as per Figure 4. Bold value indicate exceedance of trigger values

	As	Cd	Cr	Co	Cu	Pb	Hg	Ni	Se	Ag	V	Zn
Trigger value	*13*	*0.2*	*1.0*	*1.0*	*1.4*	*3.4*	*0.06*	*11*	*5.0*	*0.05*	*-*	*8.0*
Min	<1	<0.1	<0.5	<0.1	<0.1	<0.1	<0.1	<1	<0.1	<0.1	0.6	<1
Max	**22**	<0.1	**6.5**	0.3	**2.4**	2.2	<0.1	2	2	**0.2**	34	**37**

Metals and metalloids may also be associated with the aquifer matrix and the infiltration of TWW may result in the mobilisation via dissolution and ion exchange reactions. For example the release of adsorbed metals/metalloids upon the reductive dissolution of iron oxyhydroxides has been shown to occur associated with wastewater plumes (e.g. Kent and Fox, 2004). This process relies on the bioavailability of organic carbon either introduced with the TWW or from sediment organic matter. The dissolved organic carbon (DOC) concentrations measured in the treated wastewater sources ranged from 7.4 to 16 mg/L (this study). Analysis of groundwater associated with TWW infiltration sites in Western Australia indicates that the attenuation of nitrate through denitrification is typically incomplete within a few hundred metres of the infiltration basins (Donn et al., 2017). This suggests that there is insufficient bioavailable organic carbon to drive denitrification in these systems. As nitrate is a more energetically favourable electron acceptor relative to iron oxides metal release associated with reductive dissolution is likely to be of low risk.

Should metal/metalloid mobilisation occur from alteration of the aquifer matrix the impact is likely to be only localised as a result of adsorption onto minerals such as calcite. Sorption of metals and metalloids both cationic and anionic is well documented in the literature (e.g. Davis et al., 1987; Romero et al., 2004; Sdiri and Higashi, 2013; Yokoyama et al., 2012). The pH buffering effect of calcite and the strong sorption capacity for phosphate would also limit desorption of metals as a result of pH changes and resulting from ion exchange with phosphate (e.g. arsenate). This further reduces the risk of metal mobilisation.

Confirmation of aquifer sediment mineralogy and metal/metalloid content (e.g. through analysis by X-ray fluorescence or acid extractable metals) would be suggested for the MAR sites. The potential for metal/metalloid mobilisation is deemed to be acceptably low, based on available data and understanding gained through existing TWW infiltration operations. However, it is recommended that this is validated by monitoring during the commissioning phase (commissioning trials).

3.1.3 Salinity and sodicity

As recycled water from the potential MAR schemes is proposed as a fit-for-purpose replacement for decreasing groundwater supplies in the WTC, the salinity and sodicity hazards proposed by MAR are assessed relative to the existing groundwater. Existing groundwater salinity in general within the study area, salinity of groundwater utilised for industrial abstraction and salinity in two important wetlands are compared to different treated wastewater sources to assess this potential risk posed by this hazard.

The salinity, as typically measured as the electrical conductivity, of the TWW sources varies within the study area (Table 8 and Figure 5) with 40% lower salinity observed at East Rockingham and Kwinana than at Woodman Point. However the salinity of all TWW sources are within the bounds of the ANZECC wetland trigger values (180 to 900 mg/L; 30 to 150 mS/m, south-west Australia) (ANZECC-ARMCANZ, 2000). Increases in salinity as the result of brine returns to the SDOOL related to future groundwater replenishment (GWR) are predicted to increase median wastewater salinities from 620 mg/L (103 mS/m) to 760 mg/L (127 mS/m) and 890 mg/L (148 mS/m) in 2030 and 2050, respectively (GHD, 2018).

In general the salinity of TWW sources is lower and less variable (smaller interquartile range) than that of groundwater and wetland salinities in the study area (Figure 5). Salinity of groundwater abstracted by industry has a narrower interquartile range (270 mg/L; 45 mS/m) than groundwater (1010 mg/L; 1690 mS/m) in general. However the median salinity of industrial groundwater abstraction (736 mg/L; 122.7 mS/m) still exceeds TWW median values (Woodman Point 600 mg/L, 100 mS/m; East Rockingham 366 mg/L, 61 mS/m) prior to the impacts of GWR (Table 8). As a result recycled water delivered through MAR utilising current TWW sources would provide a comparable or lower salinity to that currently being used by industry within the WTC. Utilising TWW from the SDOOL following brine disposal would marginally increase salinities in 2030 with greater impacts in 2050 as TWW salinity increases.

Impacts of MAR on groundwater salinities in general would similarly be low with the potential to freshen the aquifer locally. Initial groundwater electrical conductivity measurements at the two proposed MAR sites varies with depth and ranged from 96 to 140 mS/m at the northern site (Site 1) and 58 to 108 mS/m at the southern site (Site 2) (CSIRO this study). The infiltration of TWW would therefore potentially freshen groundwater at both these sites. Sufficient data is available for two larger wetlands (Thomsons Lake and The Spectacles Swamp) in the study area to provide an indication of the seasonality of wetland salinity (Figure 6). Salinity in the wetlands exceeds the ANZECC trigger values event during winter months (Figure 6) and depending on the time of the year the MAR water (which is within the salinity trigger values) that enters wetlands is likely to be fresher than water within the wetlands (especially in summer as evaporation concentrates salts in the wetlands). As outlined in McFarlane et al. (2015) the impact will depend on the wetlands that may potentially intercept the infiltrated TWW and at present there is no surface water salinity information for the wetlands within the golf course at Site 2 to make an assessment on these wetlands. Lake Mt Brown has the potential to be impacted at Site 1 (Figure 2), however Davis et al. (1993) indicates that this wetland is brackish with a TDS of 4765 mg/L (794 mS/m; winter 1990). Strehlow et al. (2005) also observed similar brackish to saline regime (5000 to 33000 mg/L; 833 to 5500 mS/m) for Lake Mt Brown (Sept 2002 to Feb 2004). Thus impacts are unlikely to differ from natural groundwater inputs to this wetland.

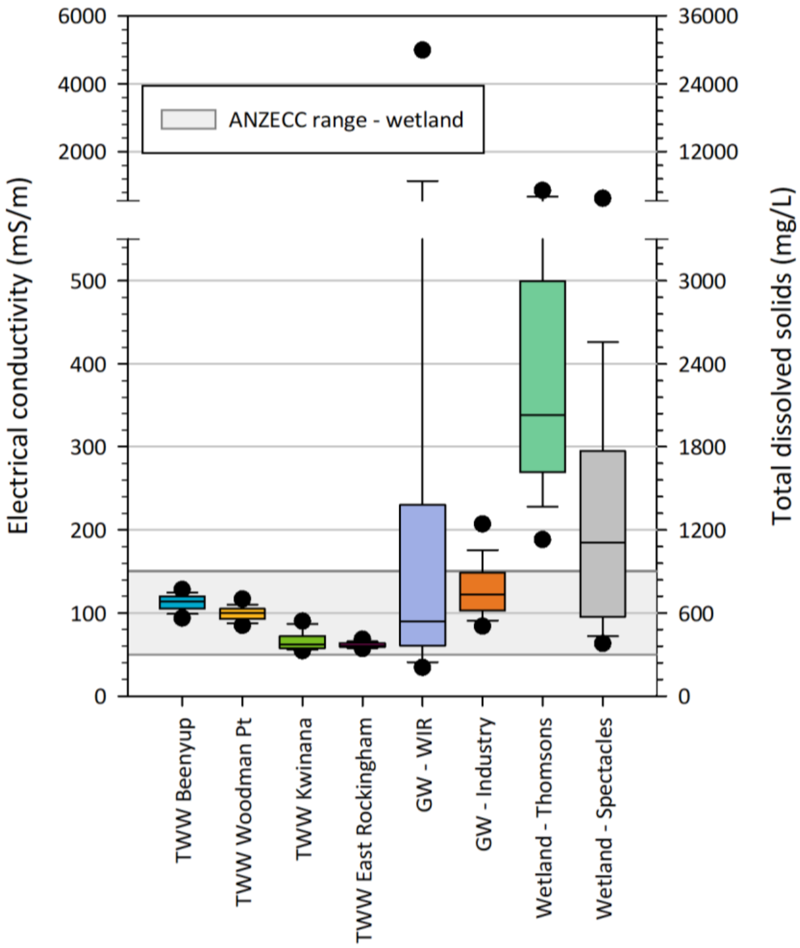


Figure 5 Salinity of treated wastewater sources, groundwater (DWER Water Information Reporting and industry) and important wetlands (Thomsons Lake and The Spectacles Swamp). Treated wastewater data provided by Water Corporation (April 2009 to present). Groundwater and wetland data obtained from Water Information Reporting (Department of Water and Environmental Regulation, 2018b). Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles

Table 8 Salinity of potential and reference treated wastewater sources for managed aquifer recharge. Beenyup provided as a reference site. Salinity shown as electrical conductivity (mS/m) and total dissolved solids (mg/L, in brackets)

Percentile	Wastewater treatment plant				Industry abstraction (current)
	East Rockingham	Kwinana	Woodman Point	Beenyup	
	n = 31	n = 114	n = 93	n = 46	n = 4385
0.05	57.5 (345)	54.0 (324)	85.0 (510)	95.3 (572)	84 (504)
0.25	59.0 (354)	57.3 (344)	93.0 (558)	105 (630)	103 (618)
0.5	61.0 (366)	60.0 (360)	100 (600)	114 (681)	123 (736)
0.75	63.5 (381)	63.0 (378)	105 (630)	120 (720)	148 (890)
0.95	67.0 (402)	69.4 (416)	115 (690)	125 (750)	207 (1241)

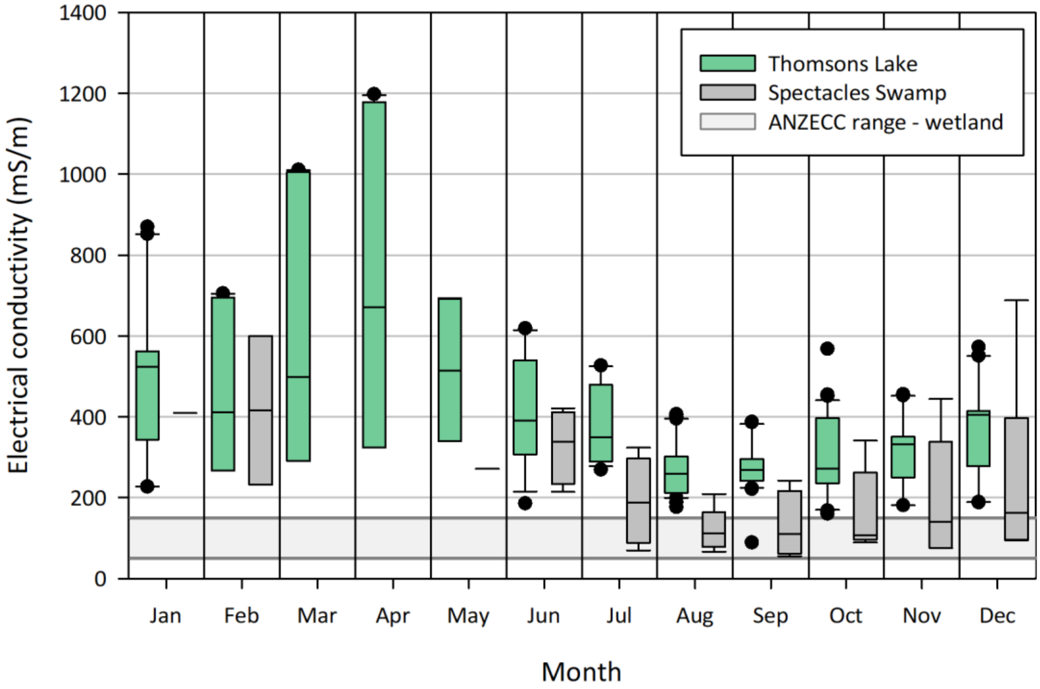


Figure 6 Seasonal variability in salinity for Thomsons Lake and The Spectacles Swamp, data obtained from Water Information Reporting (Department of Water and Environmental Regulation, 2018b). Note this data is only indicative as the number of samples and their date range varies both between locations and between months

Sodicity is related to the proportion of sodium to that of calcium and magnesium in irrigation water and its impact on soil structure especially in clay soils where high sodium results in dispersal of clay particles that result in clogging of infiltration basins and aquifer pores. Sodicity impacts are determined based on the sodium adsorption ratio (SAR) of the irrigation water which is defined by

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where Na, Ca and Mg are the sodium, calcium and magnesium concentrations in milliequivalents per litre. Values less than 10 are considered to not impact on soil structure (Rayment and Higginson, 1992). SAR values for TWW from the SDOOL at KWRP and the Kwinana and East Rockingham WWTPs range from 4.3 to 7.0 (Table 6). Thus sodicity is unlikely to present a risk.

3.1.4 Nutrients

The MAR guidelines identify phosphorus and nitrogen as major environmental hazards due to their potential impacts on receiving water bodies and to induce biological growth and clogging (NRMMC-EPHC-NHMRC, 2009). The impact on receiving water bodies is especially relevant for the infiltration of TWW into the Superficial Aquifer due to the potential to alter the nutrient balances for wetlands and Cockburn Sound. This was identified in the pre-feasibility study (McFarlane et al., 2015) where nitrogen loads to Cockburn Sound was determined to be the main hazard arising from MAR of TWW. TWW contains sufficient nutrients to stimulate biological growth, which is expected to contribute to biological clogging and a reduction in infiltration rate. Clogging management options include pre-treatment of TWW to minimise the clogging risk

and periodical removal of the clogging layer, which is currently done for TWW infiltration basins in Western Australia. Removal of the clogging layer will be easier in an open infiltration basin (Site 1) than for a buried infiltration gallery (Site 2). Therefore it will be more important to focus on management of the clogging risk by pre-treatment of TWW at Site 2. A site-specific clogging evaluation may be required to assess water quality targets suited to the MAR scheme.

Phosphorus

The total phosphorus concentration in TWW varies between the wastewater treatment plants with lower median concentrations observed at Woodman Point (4.6 mg/L) and Kwinana (3.5 mg/L) than at East Rockingham (7.0 mg/L) (Figure 7). The majority (>80%) of the total P is present in the form of inorganic phosphate (as measured as soluble reactive phosphorus, CSIRO this study) with the remainder mainly as particulate P.

Due to the carbonate minerals present in the vadose zone and aquifer phosphorus is likely to be attenuated through either precipitation as highly insoluble calcium phosphate or by adsorption to the aquifer matrix. This has been observed in previous infiltration trials using TWW (Bekele et al., 2011; Bekele et al., 2015). Although these trials were only relatively short (at most 39 months) water quality data collected at other TWW infiltration sites suggest that the capacity of the limestone aquifer to attenuate phosphorus is high (Donn et al., 2017). Given that phosphorus is likely to be precipitated as calcium phosphate or adsorbed to calcite (the main mineral in the aquifer) then substantial changes to the TWW acidity (see Sections 3.1.2 and 3.1.10 for discussion) would be needed to either dissolved the calcium phosphate or dissolved calcite thus releasing phosphate.

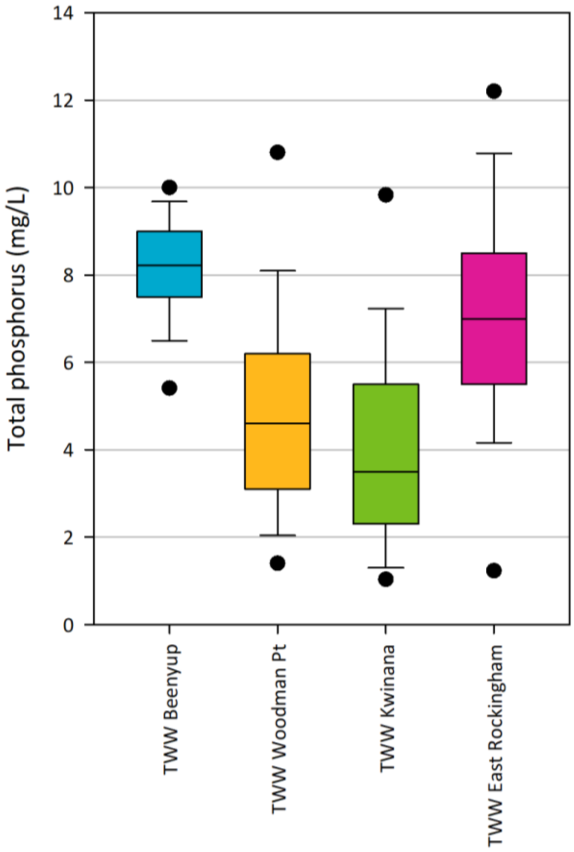


Figure 7 Total phosphorus concentrations in treated wastewater sources (data provided by Water Corporation, April 2009 until present). Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles

Nitrogen

Nitrogen may be present in TWW as a number of species; nitrate, nitrite, ammonium or organic nitrogen. Nitrogen concentrations vary between the different TWW sources with effluent from the larger Beenyup and Woodman Point WWTPs (median > 15 mg/L) having higher total nitrogen concentrations than the smaller Kwinana and East Rockingham WWTPs (median < 5 mg/L) (Figure 8). Depending on the WWTP different nitrogen species dominate, however inorganic forms (nitrate, nitrite and ammonium) dominate generally. Median groundwater total nitrogen concentrations are lower (0.93 mg/L) than TWW with groundwater abstracted by industry with approximately double that of regional groundwater (median 2.0 mg/L) (Figure 8). Limited nitrogen concentration data is available for wetlands potentially impacted by the proposed MAR with surface water in Lake Mt Brown having total nitrogen concentrations between 1 and 4 mg/L (Davis et al., 1993). Given the potential for native groundwater and wetland total nitrogen concentrations to exceed the ANZECC wetland trigger value (1.5 mg/L in south-west Australia) a better understanding of local conditions prior to MAR is required.

The capacity of the aquifer to attenuate nitrogen depends on the species present in the source water and the redox conditions in the aquifer. Based on the TWW nitrogen speciation and analysis at other similar sites (Donn et al., 2017) nitrate will be the dominant species in groundwater immediately adjacent to the infiltration locations. While it is still uncertain as to the capacity of the aquifer to provide nitrogen removal through denitrification, the interception of the MAR plume through additional abstraction is expected to reduce the loads to Cockburn Sound to a greater extent than determined by McFarlane et al. (2015), thus posing a decreased risk.

The pre-treatment of TWW before infiltration especially at Site 1 will reduce the impact of nitrogen on both wetlands and Cockburn Sound. However for the wetlands at Site 2 the impact of TWW infiltration is uncertain due to the lack of water quality data and the close proximity to the golf course which is likely to influence groundwater and consequentially wetland nitrogen concentrations due to fertiliser application.

Total nitrogen greater than 10 mg/L poses a high risk of clogging (NRMMC-EPHC-NHMRC, 2009), thus indicating pre-treatment would be required for TWW from Woodman Point. Approximately 4.7 ML/d of TWW is successfully infiltrated at the Kwinana WWTP indicating that nitrogen may not strongly contribute to clogging. However due to the gallery design proposed for Site 2 verification of the impact of nitrogen on clogging is required.

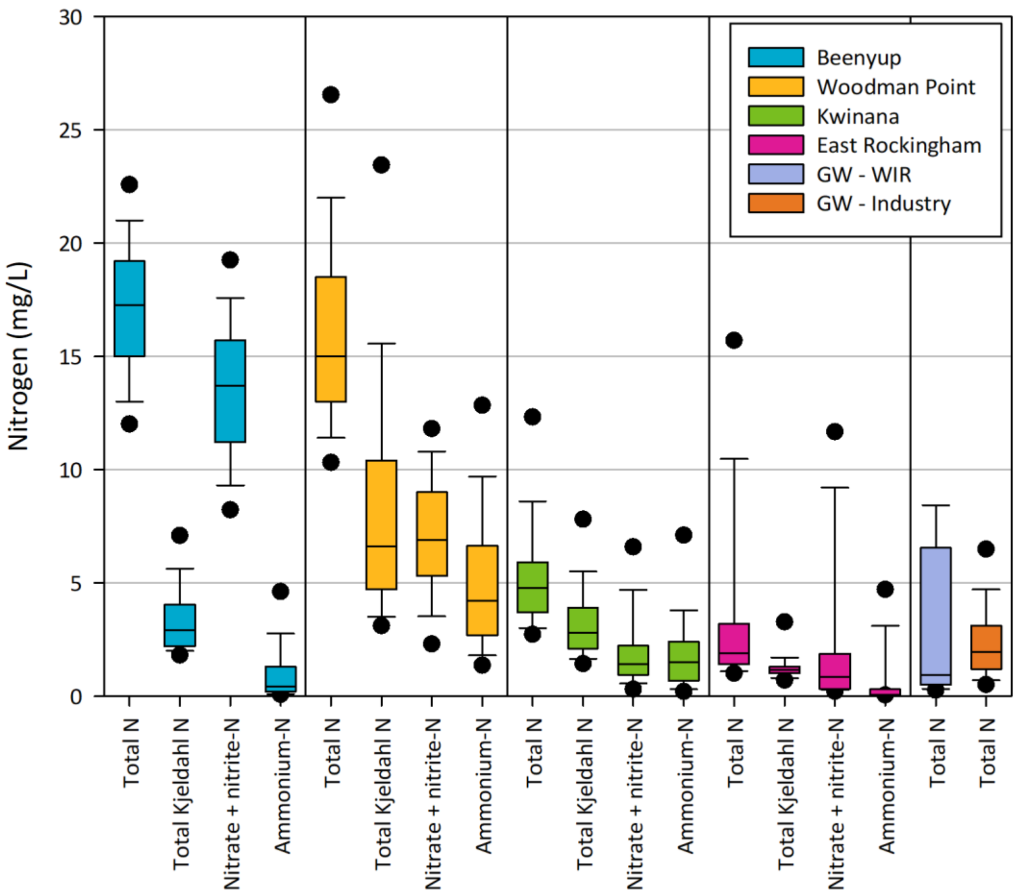


Figure 8 Concentration of nitrogen species in treated wastewater sources (data provided by Water Corporation, April 2009 until present). Regional groundwater total nitrogen (GW – WIR, source: Department of Water and Environmental Regulation (2018b)) and groundwater abstracted for industrial uses (GW – Industry) shown for reference. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles

3.1.5 Organic chemicals

Due to the nature of the source TWW for the proposed MAR locations, trace organic chemicals ranging from pharmaceuticals, personal care products, endocrine disrupting chemicals and pesticides are likely to be present. A wide range of trace organic chemicals (pesticides, disinfection by-products, nitrosamines, volatile organic compounds, phenols, polyaromatic hydrocarbons, dioxins, pharmaceuticals, estrogen hormones, aminopolycarboxylate chelating agents and other miscellaneous organic chemicals) have been detected in secondary TWW in the Perth metropolitan area (Department of Health, 2009). Due to the low concentrations of trace organic chemicals in the Department of Health (2009a) study, the number of detections varied from a few percent to 100 percent of the samples depending on the compound, with additional seasonal and wastewater source variability influencing median concentrations. In screening for health risks, most organic chemicals detected in TWW had low to very low risk to human health. Some pesticides, disinfection by-products, N-nitrosamines had median concentrations that were potentially harmful to human health.

There were very few (12) compounds that were detected in the Department of Health (2009) study that had ANZECC trigger values for environmental toxicity (ANZECC-ARMCANZ, 2000) and only one of these, Chlorpyrifos, had a median concentration (0.05 μg/L) exceeding the trigger value (0.01 μg/L).

In addition to the above, CSIRO undertook two rounds of sampling to determine the trace organic chemical concentrations in TWW from three sources within the study area (KWRP influent, Kwinana WWTP and East Rockingham WWTP) and groundwater associated with TWW infiltration at the Kwinana WWTP. Due to the challenging groundwater matrix containing high concentrations of dissolved organic carbon and dissolved solutes (salts) the pre-concentration step prior to analysis produced poor reproducibility. Therefore the results are only presented qualitatively in Table 9 which shows the number of detections in TWW, groundwater, the Spectacles wetland and background groundwater for each compound. The compounds are split into four categories; artificial sweeteners, used as tracers for wastewater; pharmaceuticals; pesticides and endocrine disruptors (although some pharmaceuticals can have endocrine disrupting effects also).

The removal of trace organic chemicals often depends on the redox conditions of the aquifer with some trace organic chemicals degrading under aerobic conditions and others under anaerobic. It should also be noted that the groundwater at the Kwinana WWTP is naturally anoxic, while groundwater in the Tamala Limestone may be oxic as observed at the Floreat Infiltration Galleries (Bekele et al., 2009), thus care should be taken when transferring the Kwinana results to other MAR sites. Patterson et al. (2011) observed that bisphenol A (plastics), 17β-estradiol (hormone), iohexol (X-ray contrast media) degrade rapidly under aerobic conditions while iodipamide (X-ray contrast media) only degraded when anaerobic conditions were imposed in simulated MAR using columns. In the same study carbamazepine was persistent under both aerobic and anaerobic conditions. While 17B-estradiol was not recorded in wastewater or groundwater at the Kwinana WWTP carbamazepine was present in all TWW and TWW impacted groundwater samples (Table 9). Other compounds found in groundwater at the Kwinana WWTP include acesulfame, diclofenac, caffeine, DEET, benzotriazole, imidacloprid, simazine, diuron, 2,4-D and triclosan. Some of these compounds, e.g. caffeine, imidacloprid and simazine appear to be attenuated within the aquifer as they are only detected in bores closer to the infiltration location, however degradation rates differ for different compounds. Other compounds, e.g. acesulfame, diclofenac, benzotriazole, diuron and triclosan like carbamazepine appear to be more persistent under the anoxic conditions encountered at the Kwinana site. Lastly DEET is ubiquitous being also found in the background groundwater which corresponds with findings elsewhere (Sui et al., 2015).

Further characterisation of TWW is required to provide a more robust assessment of the source water for MAR. Analysis of groundwater associated with wastewater infiltration into aerobic, Tamala Limestone aquifer may provide a better understanding of the fate of trace organic chemicals and inform the assessment of the hazard for the two proposed MAR sites in this study.

Table 9 Detections (and percentage of samples with detections) of a range of trace organic chemical in treated wastewater, groundwater and surface water

		LOR[a] (ng/L)	Treated wastewater		Groundwater		Spectacles Wetland		Background groundwater	
Sampling campaign			Jun-17	Nov-17	Jun-17	Nov-17	Jun-17	Nov-17	Jun-17	Nov-17
Number of sampling locations			*3*	*3*	*16*	*16*	*1*	*1*	*2*	*2*
Artificial sweeteners	Acesulfame	*1*	**3 (100)**	**3 (100)**	**16 (100)**	**16 (100)**	**1 (100)**	**1 (100)**	0	0
	Saccharin	*5*	**2 (67)**	**2 (67)**	**1 (6)**	**2 (13)**	0	0	0	0
	Cyclamate	*1*	**3 (100)**	**2 (67)**	**8 (50)**	**4 (25)**	0	0	0	0
Pharmaceuticals	Acetylsalicylic acid (Aspirin metabolite)	*1*	**3 (100)**	**2 (67)**	**2 (13)**	**1 (6)**	0	0	0	0
	Diclofenac	*1*	**3 (100)**	**3 (100)**	**14 (88)**	**16 (100)**	0	0	0	0
	Caffeine	*1*	**3 (100)**	**3 (100)**	**8 (50)**	**13 (81)**	**1 (100)**	0	**1 (50)**	0
	Ketoprofen	*5*	0	**1 (33)**	0	**5 (31)**	0	0	0	0
	Paracetemol	*1*	0	**1 (33)**	**1 (6)**	0	0	0	0	0
	Carbamazepine	*0.5*	**3 (100)**	**3 (100)**	**16 (100)**	**16 (100)**	0	0	0	0
	Venlafaxine	*1*	**3 (100)**	**3 (100)**	**5 (31)**	**6 (38)**	0	0	0	0
	Ibuprofen	*5*	**3 (100)**	**1 (33)**	**3 (19)**	**3 (19)**	0	0	0	0
	DEET	*1*	**3 (100)**	**3 (100)**	**16 (100)**	**16 (100)**	**1 (100)**	0	**2 (100)**	**2 (100)**
	Benzotriazole	*2*	**3 (100)**	**3 (100)**	**13 (81)**	**14 (88)**	0	0	0	0
	Sulfamethoxazole	*5*	**2 (67)**	**3 (100)**	0	**5 (31)**	0	0	0	0
	Trimethoprim	*1*	**2 (67)**	0	0	0	0	0	0	0
Pesticide	Imidacloprid	*0.5*	**3 (100)**	**3 (100)**	**7 (44)**	**8 (50)**	0	0	0	0
	Simazine	*2*	**3 (100)**	**2 (67)**	**5 (31)**	**3 (19)**	0	0	0	0
	Atrazine	*2*	0	**1 (33)**	0	**1 (6)**	0	0	0	0
	Myclobutanil	*1*	0	0	0	0	0	0	0	0
	Metolachlor	*1*	**1 (33)**	**1 (33)**	0	0	0	0	0	0
	Diuron	*1*	**3 (100)**	**3 (100)**	**15 (94)**	**15 (94)**	0	0	0	0
	MCPA	*1*	**3 (100)**	**3 (100)**	0	**2 (13)**	0	0	0	0
	2,4-D	*2*	**3 (100)**	**1 (33)**	0	**11(69)**	0	0	0	**1 (50)**
	Prochloraz	*1*	0	0	0	0	0	0	0	0
	Carbary	*1*	**1 (33)**	0	**3 (19)**	0	0	0	0	0
	Pyrimethanil	*1*	0	0	0	0	0	0	0	0
	Pyraclostrobin	*1*	0	0	0	0	0	0	0	0
	Pirimicarb	*2*	0	0	0	0	0	0	0	0
	Metalaxyl	*1*	0	0	0	0	0	0	0	0
Endocrine disruptors	17α-Ethynylestradiol EE2	*1*	0	0	0	0	0	0	0	0
	17β-Estradiol E2	*1*	0	0	0	0	0	0	0	0
	Estrone E1	*1*	**3 (100)**	0	**3 (19)**	0	0	0	**2 (100)**	0
	Estriol E3	*0.5*	0	0	0	0	0	0	0	0
	Trichlosan	*1*	**3 (100)**	**3 (100)**	**11 (69)**	**15 (94)**	0	0	0	**1 (50)**

[a] LOR = limit of reporting

3.1.6 Turbidity and particulates

The turbidity or particulate load of the source water is mainly an operational hazard for infiltration systems where by the infiltrating surface of a basin or gallery can become clogged over time. This filtration prevents the mobilisation of particles into the aquifer therefore there is low risk associated with increased groundwater turbidity as a result of MAR. The total suspended solid (TSS) concentration provides a measure of the particulates in TWW. Woodman Point TWW shows a higher median TSS concentration (8.4 mg/L) than the other proposed MAR source water (East Rockingham, 5.0 mg/L) as well as higher variability (Figure 9). While the median concentration of TSS for Woodman Point is below the MAR guidelines value of 10 mg/L suggesting a high risk of clogging, 38% of samples exceed it with a maximum of 630 mg/L. A more stringent TSS criteria of <5 mg/L is required for the southern site (Site 2) supplied by the East Rockingham TWW since infiltration galleries are proposed for this site (GHD, 2018). Clogging issues impact on the majority of MAR schemes and can be managed through pre-treatment of source water or mitigation after infiltration rates have declined (Martin, 2013). For infiltration basins, mitigation includes drying and rejuvenation of the infiltration source. However this type of mitigation may be more challenging for buried infiltration galleries, and therefore management through pre-treatment is a high priority.

To maintain efficient infiltration at both proposed MAR sites pre-treatment was proposed (denitrifying filter, TSS < 5 mg/L) with on-line turbidity screening to monitor for poor influent water quality (GHD, 2018). This will reduce the risk of clogging and provide for extended operation between maintenance to remove the clogging layer from the infiltration basins (Site 1, North) or infiltration galleries (Site 2, South).

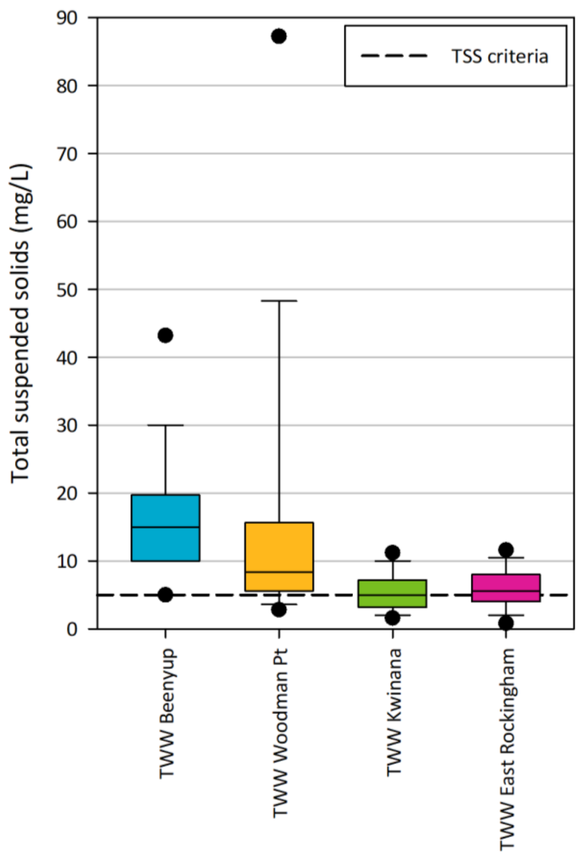


Figure 9 Total suspended solid concentration in treated wastewater sources. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles. Data provided by Water Corporation (April 2009 to present). The proposed TSS concentration criteria for gallery infiltration (5 mg/L) is shown for reference

3.1.7 Radionuclides

According to the MAR guidelines *"The main radionuclide concern is recovery of water posing a risk to human health by ingestion of drinking water or foods via crop irrigation, stock watering, or food chain accumulation (radium and radon), or inhalation of gas released from the water supply (radon)"* (NRMMC-EPHC-NHMRC, 2009). In the absence of specific criteria for the end uses, the Australian Drinking Water guidelines have been used as a conservative approach.

The Australian Drinking Water Guidelines recommend an initial screening of the total radioactivity present in the form of alpha and beta radiation to determine whether further analysis is required to determine dose-based values (NHMRC and NRMMC, 2011). The screening level for gross alpha and beta activity is 0.5 Bq/L. As part of the assessments undertaken for groundwater replenishment using recycled wastewater, the Department of Health (2009) determined the gross alpha and beta particle activities in three secondary treated wastewaters (influent to the Kwinana Water Reclamation Plant (KWRP), Subiaco and Beenyup). The maximum gross alpha particle activity was 0.11 Bq/L and the maximum gross beta particle activity was 0.05 Bq/L. It should be noted that the KWRP influent represents one of the sources, Woodman Point/SDOOL considered for MAR in the current project. Thus the risk related to radionuclides in the MAR source water is considered to be low.

Groundwater from the Wanneroo Water Treatment Plant, a drinking water source was also tested in the Department of Health (2009) study with the maximum gross particle activity alpha and gross particle activity beta, 0.062 Bq/L and 0.057 Bq/L, below the drinking water screening level. Although this groundwater is from the north of Perth is also suggests that the hazard related to radionuclides in groundwater is also low.

3.1.8 Pressure, flow rates, volumes and levels

Infiltration of TWW into the shallow unconfined Superficial Aquifer poses a threat should mounding of groundwater beneath the infiltration basins/galleries be sufficient to lead to waterlogging or impact on infrastructure such as roads, rail and buildings. The impacts from waterlogging was assessed using the groundwater model. The extent of inundation of the land surface by groundwater was determined by subtracting the land surface from the modelled groundwater level with and without the addition of MAR water (Figure 10). More details can be found in the groundwater modelling report (Cui et al., 2019).

The groundwater model poorly represents the area of inundation at Site 1 (north; Figure 10a) with the predicted inundation greater than the current extent of waterlogging experienced surrounding this site. For example the predicted inundation area in the vicinity of Long Swamp (lower left of image) is approximately double that of the extent mapped in the Geomorphic Wetlands dataset, with areas not waterlogged showing inundation. This may be related to the limited number of bores available to use for calibration in the area with the closest 1.2 km from Site 1. Infiltration of TWW at Site 1 results in an increased area of inundation (Figure 10b).

The relative changes in groundwater level in response to TWW infiltration provides a better estimate of the impact of MAR at Site 1. Close to the infiltration location the median groundwater levels rise by ~5 m relative to the no infiltration scenario (Figure 11a and b). Preliminary groundwater levels measured at newly installed bore close to Site 1 indicate that the groundwater level is approximately 9 m below ground surface. This suggests that despite modelled groundwater levels there may be sufficient capacity to accept 10 ML/d of TWW infiltration. Further collation of groundwater level data from industry and new measurements may improve model accuracy at Site 1.

Generally the infiltration of TWW at Site 2 does not cause any increase the extent of inundation in the vicinity of the infiltration site (Figure 10c and d). The reasoning for no impact on inundation area at Site 2 is

related to smaller mounding of groundwater (Figure 11c and d) with approximately a 2 m rise in groundwater levels at this site.

Another consequence to altering groundwater levels through the infiltration of TWW is the change in groundwater fluxes towards Cockburn Sound. Due to the industrial land use in the WTC, groundwater contamination is present between the infiltration sites and the Sound (McFarlane et al., 2015; Trefry et al., 2006). Alteration of groundwater flow regimes has the potential to modify the groundwater plumes associated with these contaminant sources through shifting their current position through displacement or increasing the rate of travel towards the coastline. Reuse of the infiltrated MAR water for industrial water supply would potentially negate these impacts as fluxes to the Sound would be effectively reduced (provided that reuse is equal to MAR infiltration). Modelling also suggests that changes to groundwater level are likely to be limited to areas to the east of currently contaminated sites and are reduced due to groundwater reuse (Figure 11).

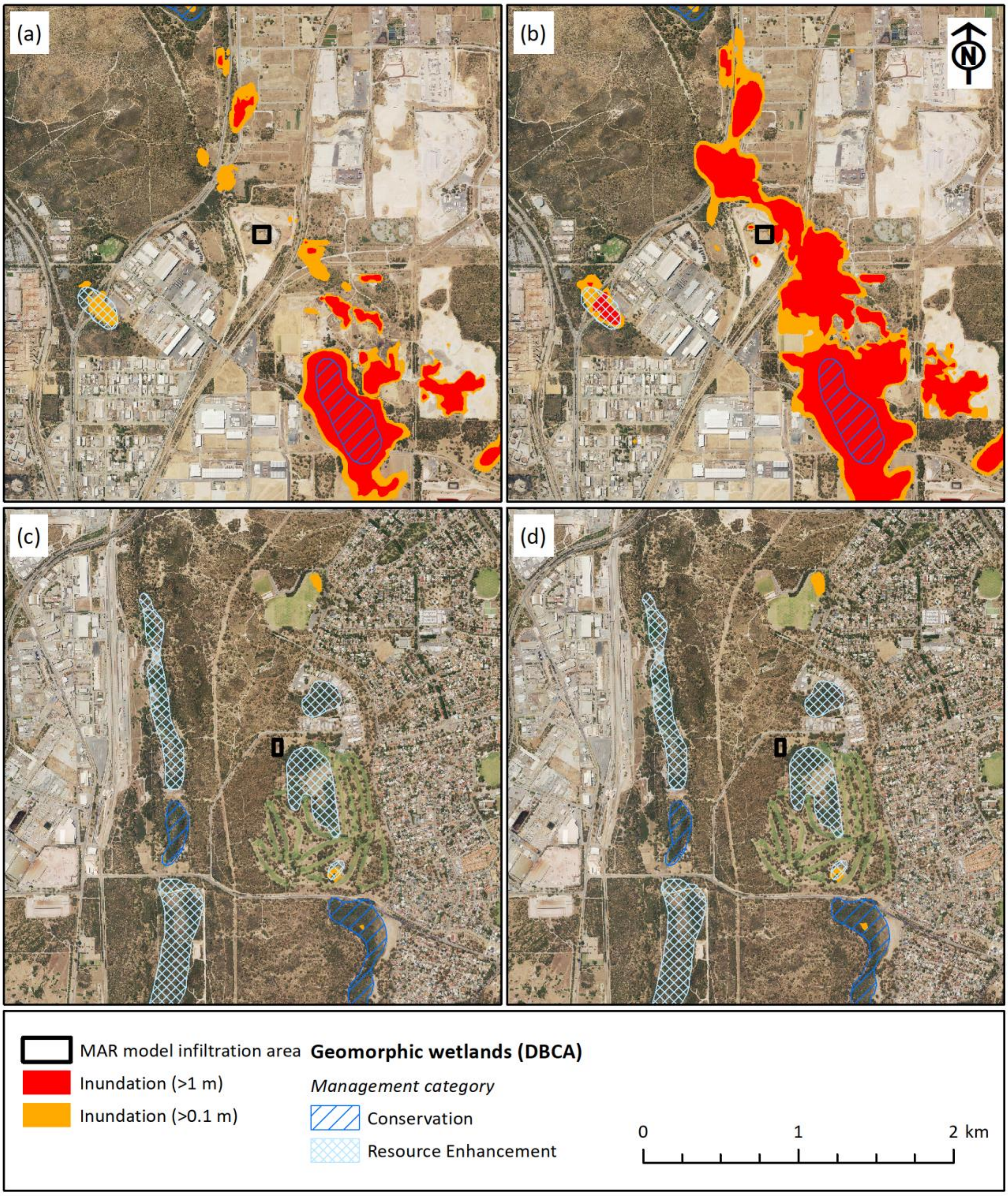


Figure 10 Median inundation extent across all models for Site 1 (north, a and b) and Site 2 (south, c and d) for the no MAR scenario (a and c) and the MAR no recovery scenario (b and d) under the DWER dry climate scenario (2030). End of model (2045) results shown

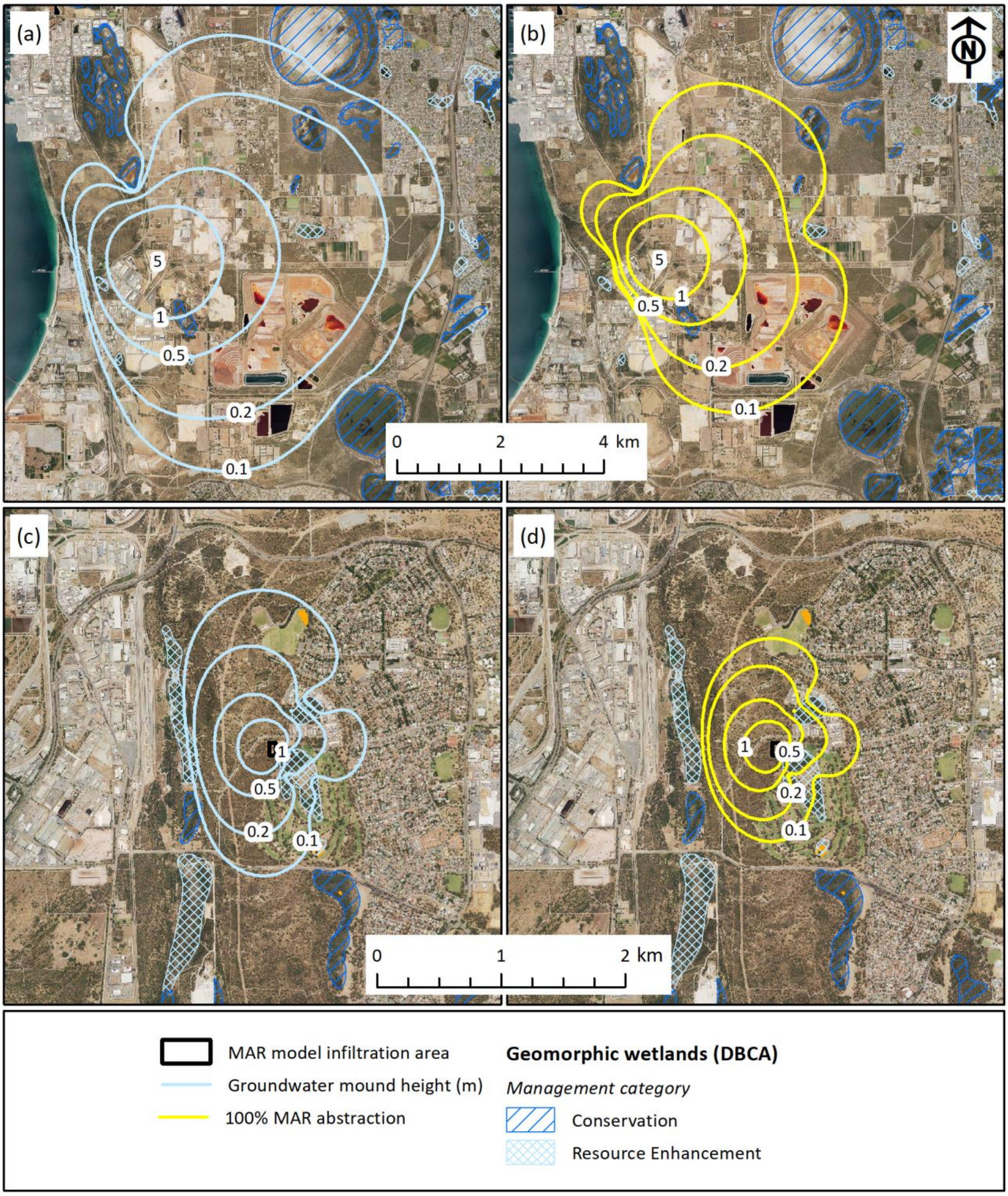


Figure 11 Median maximum mound height across all models determined from the relative change in modelled groundwater level between the MAR and no MAR scenarios at the proposed MAR sites, Site 1 (a and b) and Site 2 (c and d). The response to MAR is greater with no additional groundwater abstraction (a and c) than with 100% or 10 ML/d of additional abstraction (b and d) at locations down gradient of the infiltration location

3.1.9 Contaminant migration in fractured rock and karstic aquifers

Both proposed MAR sites are located within the occurrence of the Tamala Limestone and between 1.8 km and 3.3 km of the coastline of Cockburn Sound. Investigations by Smith et al. (2011) characterised the Tamala Limestone (a carbonate eolianite) as an eogenetic karst of early- to mid-development. Eogenetic karst is characterised by dual porosity that consists of may connected channels within a matrix of interparticle porosity. The evolution of eogenetic karst with large primary porosity leads to a diffuse-flow aquifer rather than on dominated by conduit flow (Smith et al., 2011; Vacher and Mylroie, 2002).

In the context of contaminant migration resulting from MAR due to this diffuse-flow nature of the Tamala Limestone it is unlikely that contaminants be transported rapidly through conduits to discharge locations such as Cockburn Sound. This does not mean that transport through the diffuse-flow is slow especially considering the large to very large transmissivity (Smith et al., 2011) of the aquifer. The residence time of groundwater under this dispersive flow paradigm is longer than would be expected due to conduit flow. Therefore while the attenuation zone is likely to be larger than expected for a homogeneous porous media removal of contaminants such as pathogens and nutrients is still likely to occur relatively close to the infiltration point.

It should also be noted that at the two proposed MAR sites the upper 9 to 12 m of aquifer contains sandy material with limestone fragments/gravel (CSIRO drilling observations) suggesting that the upper part of the aquifer may be more homogeneous. Secondary porosity features were however observed deeper in more consolidated sections of limestone, though these were relatively small <15 mm diameter.

Based on the available knowledge the aquifer is not considered to have significant conduit flow, however the monitoring of TWW tracers and groundwater levels along with solute/reactive transport modelling is required to verify this within an operational MAR scheme.

3.1.10 Aquifer dissolution and stability of well and aquitard

Since the mode of recharge is through infiltration into the unconfined Superficial Aquifer at both the proposed sites injection well and aquitard stability are not considered hazards thus not discussed in this section.

Since the vadose zone and aquifer contain calcite (calcium carbonate) there exists the potential to dissolve the aquifer material. Dissolution of carbonates may occur through the recharge of acidic water (low pH), aerobic recharge water oxidising sulfide minerals, or recharge water under-saturated with respect to the carbonate minerals present. The pH of the TWW is neutral to slightly basic with median pH ranging from 7.2 to 7.6 (Figure 12). As indicated above the TWW source waters from Woodman Point and East Rockingham are close to being in equilibrium with calcite (saturation index ranges from -0.04 to -0.38). This along with the pH suggests that the infiltration of TWW at the proposed MAR locations is unlikely to result in significant dissolution of the aquifer.

Thus aquifer dissolution is considered an acceptable risk and does not require preventative measures. Major ion concentrations in groundwater can be used to verify this within an operational MAR scheme.

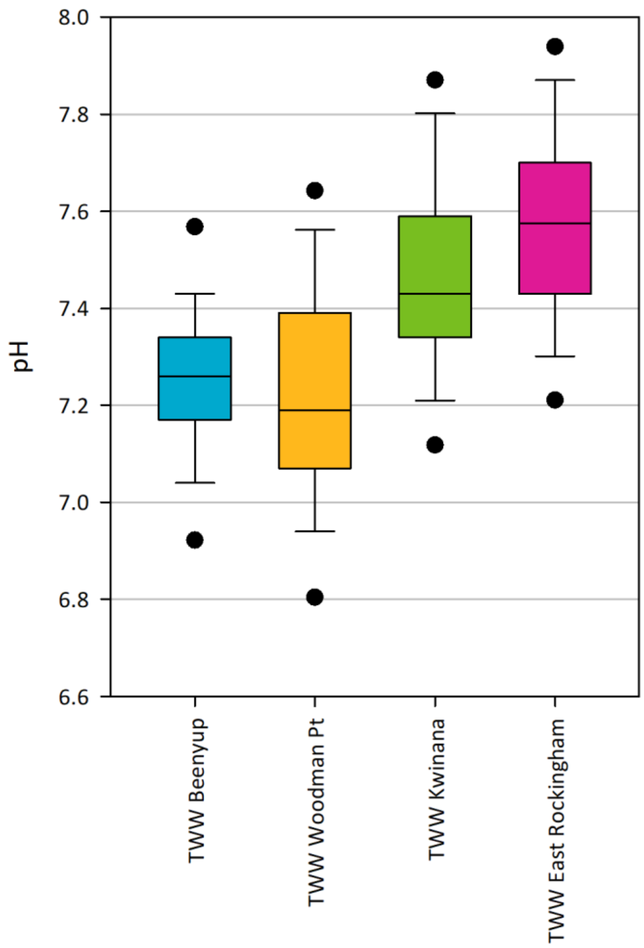


Figure 12 Treated wastewater pH. Boxes represent the interquartile range, the whiskers the 10th and 90th percentiles and the points the 5th and 95th percentiles. Data provided by Water Corporation (April 2009 to present).

3.1.11 Impacts on groundwater-dependent ecosystems

The main groundwater dependent ecosystems (GDEs) likely to be impacted by MAR are the wetlands identified in Section 2.4. While Long Swamp and Lake Mount Brown are representative GDEs (conservation category wetlands) in the Cockburn Groundwater Management Plan and as such have water level monitoring and criteria associated, there is relatively little information on the ecosystem condition or water quality within the conservation or resource enhancement wetlands identified. There appears to have been no assessment to confirm the mapping of these wetlands by Hill et al. (1996) since roads and golf course infrastructure for example are mapped within the wetland extents (Figure 1). Apart from salinity and nutrient measurements for Lake Mount Brown (Sections 3.1.3 and 3.1.4) there is no published water quality data for any of the potentially impacted wetlands. Since the 'current' natural salinity and nitrogen concentrations of Lake Mount Brown exceed the ANZECC trigger values the assessment of the risks posed to wetlands from MAR would be inappropriate. Therefore without further assessment of current wetland water quality it is difficult to assess the hazard posed by MAR on these wetlands from a water quality perspective.

Increasing groundwater levels in response to MAR may have a beneficial impact for these wetlands counteracting drying due to climate change on vegetation within and surrounding the wetlands. Water levels are likely to have been higher in the past during wetter periods.

It is clear that baseline and validation monitoring of water quality, and wetland and groundwater levels is required for the potentially impacted wetlands, especially at Site 2 where MAR water residence times in the aquifer are relatively low (60 days), to assess the impact of MAR.

3.1.12 Greenhouse gases

The other alternatives water supplies to groundwater that were identified to meet industry demands were recycled water from the Kwinana Water Reclamation Plant (KWRP) and the Integrated Water Supply Scheme (IWSS) (Synergies Economic Consulting, 2018). Both of these water sources rely at least partially on desalination. Without a life cycle assessment of the greenhouse gas emissions for these water supplies it is not possible to directly compare with the values calculated by GHD (2018) for the MAR schemes at Sites 1 and 2. However utilising the carbon dioxide equivalent values reported by Cornejo et al. (2014) for seawater reverse osmosis (RO) desalination (0.4 to 6.7 kg CO_2-e/kL) and brackish water RO desalination (0.4 to 2.5 kg CO_2-e /kL) the MAR schemes proposed by GHD are equivalent to or have less impact compared to a similar volume of water (10 ML/d) produced from a desalination plant over an assumed 50 year life cycle (Table 10). The MAR schemes also had lower greenhouse gas footprints compared to seawater and TWW plants in Western Australian. Therefore relative to other sources of water available the risk associated with greenhouse gas emissions is low.

Table 10 Life cycle greenhouse gas (GHG) emissions for the proposed MAR sites and literature equivalents for desalination based on 182.5 GL over 50 years

	Life cycle (50 years) GHG emissions t CO_2-e	Reference
Site 1 (north)	106,000	GHD (2018)
Site 2 (south)	55,000	GHD (2018)
Seawater desalination	73,000 – 1,222,750	Cornejo et al. (2014)
Brackish water desalination	73,000 – 456,250	Cornejo et al. (2014)
Southern Seawater Desalination Plant (Western Australia)	710,000	Biswas (2009)
TWW desalination Groundwater Replenishment Trial (Western Australia)	187,000	Simms et al. (2017)

3.2 Maximal and pre-commissioning residual risk assessment

Based on the hazards identified above a maximal risk assessment has been conducted based on the qualitative assessment the likelihood and consequences of the particular hazard occurring. This is assessed for health risks, environmental risks, risks associated with impacts on industrial groundwater use and risks associated with the operation of the MAR scheme at each of the two proposed sites. The measures of qualitative likelihood and consequence or impact are based on those modified from Phase 1 Australia Guidelines for Water Recycling (NRMMC-EPHC-NHMRC, 2006) and shown in Table 11.

The maximal risk assessment for Sites 1 is shown in Table 12 and for Site 2 in Table 13 where hazards show a different risk to that of Site 1.

The maximal risk assessment determined that there was moderate, high or very high risk associated with pathogens, nutrients (phosphorus and nitrogen), turbidity and particulates, inundation due to groundwater level rise, contaminant migration through the limestone aquifer and impacts on groundwater dependent ecosystems, especially wetlands. Due to the different TWW source Site 1 and 2 have different maximal risks for nitrogen and particulates, though while concentrations are lower in the East Rockingham TWW similar risks apply due to the different infiltration design and the potential to impact GDEs. The maximal risks for inorganic chemicals, salinity and sodicity, radionuclides, aquifer dissolution and greenhouse gases were deemed to be low risk for both sites.

While the residual risk assessment indicated that the risks could be reduced to low for most of the hazards there still remains concern regarding certain aspects.

Pathogens – Validation monitoring is required to determine concentrations following filtration and to ensure that groundwater residence times are sufficient to remove bacteria, protozoa and viruses.

Nutrients – Nitrogen removal potential of the aquifer (i.e. through denitrification) is still to be validated at the two potential MAR sites. However the long residence time in the aquifer suggests that should denitrification be occurring the risk to Cockburn Sound will be low especially with additional abstraction in the MAR plume zone. The impacts on wetlands at Site 2 is uncertain due to the lack of water quality data available. Given that the closed wetland is within a golf course it is likely that the wetland is already impacted by nitrogen. Pre-treatment requirements to minimise biological clogging need to be determined for each site.

Organic chemicals – There is insufficient information regarding the TWW concentrations and the environmental persistence and impact of trace organic chemicals in groundwater. Due to the wide range and large number of trace organic chemicals the potential risks may alter in the future as new information on TWW constituents arises. Additional monitoring of TWW and groundwater is required to validate both the hazard and the potential risk to the environment.

Inundation due to groundwater table rise – This needs to be assessed further with modelling at Site 1 incorporating additional groundwater level data from industry and new monitoring firstly to establish the current groundwater levels relative to ground level and secondly to determine the impact from MAR.

Contaminant migration in Tamala Limestone aquifer – Validation monitoring of TWW tracers is required to determine if assumptions of no conduit flow within the aquifer

Groundwater dependent ecosystems – Very little is known about the current ecosystem health, water regimes and water quality in wetlands potentially impacted by MAR at the proposed sites, especially for Site 2. Additional wetland assessments and monitoring is required to determine these baseline values and conditions before MAR impacts can be fully assessed.

Table 11 Risk assessment categorisation and ranking method adapted from Phase 1 Australia Guidelines for Water Recycling

LIKELIHOOD		
Level		**Example description**
1	Rare	Rare May occur only in exceptional circumstances. May occur once in 100 years
2	Unlikely	Unlikely Could occur within 20 years or in unusual circumstances
3	Possible	Possible Might occur or should be expected to occur within a 5- to 10- year period
4	Likely	Likely Will probably occur within a 1- to 5- year period
5	Almost certain	Almost certain Is expected to occur with a probability of multiple occurrences within a year

CONSEQUENCE / IMPACT		
Level		Example description
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health – Minor impact for small population Environment - Potentially harmful to local ecosystem with local impacts contained to site
3	Moderate	Health – Minor impact for large population Environment – Potentially harmful to regional ecosystem with local impacts primarily contained to on-site
4	Major	Health – Major impact for small population Environment – Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts
5	Catastrophic	Health – Major impact for large population Environmental – Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts

		CONSEQUENCES / IMPACT				
		1	2	3	4	5
LIKELIHOOD	1	Low	Low	Low	High	High
	2	Low	Low	Moderate	High	Very high
	3	Low	Moderate	High	Very high	Very high
	4	Low	Moderate	High	Very high	Very high
	5	Low	Moderate	High	Very high	Very high

Table 12 Maximal and pre-commissioning residual risk assessment for proposed managed aquifer recharge location - Site 1 (north)

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Pathogens (health risk)	Re-use for industrial water supply and incidental use for irrigation (health hazard only)	Possible MAR water to be intercepted by groundwater users	Major Industrial licenced users and exempt use (non-licenced) bores may intercept groundwater impacted by pathogens	Very high	Unlikely Predicted groundwater residence times adequate to provide sufficient time for pathogen removal.	Insignificant For industrial water supply. While ingestion of sprays is still possible the volume would be low and pathogen number are also likely to be low. Minor Exempt use bores may intercept groundwater though likely to be small due to location of infiltration site. Confirmation required.	Low
Inorganic chemicals (environmental risk)	Wetlands / Cockburn Sound Industrial water supply	Moderate TWW major ion chemistry similar to groundwater and metal concentrations are similar to groundwater. There is the potential to release metals from the aquifer sediments, though this and the aquifers potential to attenuate (sorption) metals is	Minor Impact not likely to be detectable	Moderate	Unlikely	Minor Impact not likely to be detectable outside management (attenuation) zone due to sorption.	Low

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
		not yet quantified. Other sources (industry) are likely to impact groundwater before discharge to the Sound					
Salinity and sodicity (environmental risk)	Wetlands Industrial water supply	Unlikely Current salinity of TWW sources within range of groundwater salinities associated with wetlands and industrial water supply. Predicted salinity due to GWR in 2030 also within upper bounds and initial evidence exists for higher salinity closer to Site 1. No sodicity impacts due to TWW and aquifer composition.	Insignificant Environmental receptors distant from infiltration location (Lake Mt Brown is saline already) Similar groundwater salinities to existing industrial supply	Low	Unlikely	Insignificant	Low
Nutrients – Phosphorus (environmental risk)	Wetlands / Cockburn Sound Industrial water supply	Likely	Catastrophic Widespread off-site impacts on environmental receptors and industrial water supply	Very high	Rare Attenuation of phosphorus through precipitation and/or adsorption close to infiltration location	Insignificant Environmental receptors and industrial water users distant from infiltration location	Low
Nutrients – Nitrogen (environmental and	Wetlands / Cockburn Sound	Likely Median TWW nitrogen	Catastrophic Widespread off-site impacts on environmental	Very high	Unlikely With pre-treatment options suggested and plume	Minor Local impacts contained to site	Low

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
operational risk)	Industrial water supply	concentrations over 5 mg/L target Almost certain Current TN likely to result in biological clogging	receptors and industrial water supply Moderate Impacts contained to on-site		interception by abstraction within the MAR zone will reduce the likelihood		
Organic chemicals	Wetlands / Cockburn Sound	**Unable to determine environmental risk based on existing data** • **Further assessment of TWW required to define trace organic chemicals present** • **Assessment of TWW tracer organic chemicals at analogous sites may inform risk assessment (Kwinana WWTP not suitable due to matrix effects during analysis)** **Treatment capacity of the aquifer will differ for different organic chemicals**					
Turbidity and particulates (operational risk)	Clogging of infiltration basin	Almost certain Current TWW particulate load likely to clog basins quickly	Moderate Impacts contained to on-site	High Clogging of infiltration basins will need to be managed	Unlikely Pre-treatment (filtration) and basin management (rotation, vegetation management and scraping) will minimise clogging	Minor Impacts contained to on-site	Low Clogging of infiltration basins will need to be managed
Radionuclides (health and environmental risk)	Wetlands / Cockburn Sound Industrial water supply	Rare Based on gross alpha and beta particle activity in TWW	Insignificant	Low	Rare	Insignificant	Low
Pressure, flow rates, volumes and levels (operational risk)	Inundation of land surface	Possible Based on current groundwater modelling inundation could occur near Site 1. However there are	Major Based on current modelling	Very high Further groundwater model validation and groundtruthing required pending	**Unable to assess at present additional data required to determine depth to groundwater in the vicinity of Site 1**		

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
		inconsistences between measured and modelled groundwater levels that additional data may improve		additional data being supplied			
Contaminant migration in fractured rock and karstic aquifers	Wetlands / Cockburn Sound Industrial water supply	Rare Based on geohydrology of Tamala Limestone not exhibiting conduit flow	Catastrophic Widespread on-site and off-site impacts (e.g. increased loading of nutrient to Cockburn Sound)	High	Rare	Moderate Monitoring of TWW tracers through the groundwater monitoring scheme for evidence of conduit flow	Low
Aquifer dissolution	Infiltration infrastructure	Rare Based on current TWW acidity	Minor Impacts to aquifer locally on site	Low	Rare	Minor	Low
Impacts on groundwater dependent ecosystems	Wetlands	Possible There is the potential to indirectly (positively) impact wetlands due to groundwater table rise (e.g. Long Swamp)	Minor This impact is uncertain due to the lack of information on the wetland ecological condition/health and water quality for wetlands like Long Swamp and Lake Mount Brown it is not clear what the impact of increasing water levels would be	Moderate	Unlikely Based on groundwater residence times MAR water is not likely reach the wetlands under 10 years	Insignificant Monitoring program required to validate that impacts will be insignificant	Low
Greenhouse gases	Relative to other sources of non-potable water supply,	Unlikely	Minor Energy use and greenhouse gas	Low	Unlikely	Minor	Low

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
	i.e. desalinated TWW (KWRP) or scheme water (a proportion of which is derived from desalination)		emission are likely to be equivalent to or lower than alternative sources of non-potable water				

Table 13 Maximal risk assessment for proposed managed aquifer recharge location - Site 2 (south) where different to Site 1 (Table 13)

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Nutrients – Nitrogen (environmental and operational risk)	Wetlands / Cockburn Sound Industrial water supply	Possible Median TWW nitrogen concentrations less than 5 mg/L target Likely Current TN likely to result in biological clogging	Moderate Potentially harmful to regional ecosystem and industrial water supply with local impacts Moderate Impacts contained to on-site, due to buried gallery infrastructure the impact of clogging will involve gallery renewal	High	Unlikely With pre-treatment options suggested and plume interception by abstraction within the MAR zone will reduce the likelihood	Minor Local impacts contained to site, monitoring of golf course wetland require to assess impact particular to TWW infiltration	Low Clogging of infiltration galleries will need to be managed, including provision for renewal
Turbidity and particulates (operational risk)	Clogging of infiltration basin	Likely Current TWW particulate load is not overly high however clogging is still likely to develop	Moderate Due to buried gallery infrastructure the impact of clogging will involve gallery renewal	High Clogging of infiltration galleries will need to be managed	Unlikely Pre-treatment (filtration) and gallery management (rotation and vegetation management) will minimise clogging	Minor Impacts contained to on-site (gallery renewal)	Low Clogging of infiltration galleries will need to be managed, including provision for renewal

MAR Hazard	Environmental receptor / Intended uses / infrastructure	MAXIMAL RISK ASSESSMENT			PRE-COMMISSIONING RESIDUAL RISK ASSESSMENT		
		Likelihood	Impact/consequence	Risk	Likelihood	Impact/consequence	Risk
Pressure, flow rates, volumes and levels (operational risk)	Inundation of land surface	Unlikely Water levels may increase within wetlands east of infiltration site	Minor Based on current modelling	Low	Unlikely	Minor	Low
Impacts on groundwater dependent ecosystems	Wetlands (east of infiltration site including golf course)	Likely Nitrogen (and potentially organic chemicals) from TWW is likely to impact wetlands	Major This impact is uncertain and therefore the impact is conservative as no information is available on wetland ecological condition/health and nutrient status	Very high	Likely Monitoring of groundwater and wetland required to determine the impact	Minor Impacts likely to occur at the golf course wetland but the impacts needs to be determined relative to existing wetland conditions	Moderate Verification required through monitoring

4 Conclusions

A Stage 2 risk assessment was conducted under Phase 2 of the *Australian guidelines for water recycling: Managing health and environmental risk (managed aquifer recharge)* for two potential MAR sites within the groundwater catchment of the Western Trade Coast. The purpose of MAR was to supplement the decreasing natural groundwater supply with secondary treated wastewater from one of two sources, Woodman Point WWTP and East Rockingham WWTP. A maximal and pre-commissioning risk assessment was conducted using the qualitative risk assessment process outlined in Phase 1 of the *Australian guidelines for water recycling: Managing health and environmental risks*.

The maximal risk assessment identified that there was moderate, high or very high risk associated with pathogens, nutrients (phosphorus and nitrogen), turbidity and particulates, inundation due to groundwater level rise (Site 1 only), contaminant migration through the limestone aquifer and impacts on groundwater dependent ecosystems, especially wetlands. These risks were largely associated with the high pathogen, nutrient and particulate loads associated with the TWW sources. There was also uncertainty associated with the predicted groundwater levels at Site 1 which influenced the area of inundation, the potential for conduit flow in the Tamala Limestone, and the ecological health and water quality in wetlands, the dominant GDE likely to be impacted. Considering the similarity of TWW quality to local groundwater used by industry, as an alternative to natural groundwater the risk to current and future groundwater use by industry is expected to be low.

The risks associated with the TWW were mitigated through the treatment options proposed, as part of the engineering assessment (GHD, 2018), prior to infiltration and the potential of the aquifer to attenuate pathogens and phosphorus resulting in low residual risks. Nitrogen removal via denitrification still remains uncertain though the risk is reduced due to interception of the MAR plume through abstraction for industrial use. Additional validation of the groundwater model at Site 1 is required to assess existing groundwater levels and the potential for inundation arising from MAR. A regional assessment of the hydrogeology of the Tamala Limestone aquifer indicates that conduit flow is unlikely resulting in a low residual risk, however validation is required to confirm this. Further baseline ecological and water quality assessments are required for wetlands to confirm the low residual risk for Site 1 and especially at Site 2 where a moderate residual risk remains.

Due to the uncertainties remaining the following recommendations should be considered before proceeding to full implementation of MAR.

- Additional modelling at a local scale especially with regard to interactions with wetlands and the impacts of inundation. While this will answers some of the residual risks there may not be sufficient groundwater monitoring in the vicinity of the proposed MAR sites to enable robust model calibration and there is lack of data on wetland hydrology to support modelling of groundwater-surface water interactions.
- The impact on contaminants currently present in the aquifer (i.e. contaminated sites) was not address within this assessment due to a lack of accessible data. Contaminated site mapping is not sufficient to assess the impacts of MAR as it does not provide details of the spatial extent or the temporal behaviour of contaminant plumes. Further investigation is required to first identify major contaminant plume locations/extents before modelling the impacts of MAR on them. This is a considerable task given the number of actual and potential contaminated sites in the Kwinana industrial area.
- Characterisation of the aquifer geochemistry is required to fully assess the potential risks associated with metal/metalloid release as a result of TWW infiltration. This should be a staged approach to initially determine that metal area present in environmentally significant quantities that would impact a

receptor. If the risks are found to be high then further investigation would be required to determine metal speciation and potential mechanisms for mobilisation.

- Recovery of MAR water down-gradient of the proposed MAR sites has the potential to draw in salt water and impact seawater intrusion if not managed appropriately. While abstraction was modelled using 20 abstraction wells they were not located to service a specific end-user. Therefore once actual pumping locations are proposed further modelling of the impacts on seawater intrusion should be undertaken. Industry data along with newly installed (2018) salt water interface monitoring bores would be critical in initially defining the current interface location before the impacts of MAR (positive) and abstraction (negative) are considered.
- Both MAR sites should proceed through trials initially (commissioning trials), although it is likely that the potential for inundation at Site 1 and impacts on infrastructure (e.g. rail and roads) may make this site not viable. Infiltration galleries for recycled wastewater MAR is yet to be proven within an operational scheme. It will be important to establish influent (TWW/pre-treated TWW) water quality targets to minimise clogging processes (removal of TSS and nutrients) as remediation of clogging in a buried infiltration gallery will be more difficult than for an open infiltration basin. As part of the MAR trials it is expected that validation monitoring take place and further risk assessments take place as per Stage 3 of the MAR guidelines. Commissioning trials are essential to ensure the MAR operation has acceptably low risks to human health and environment during ongoing operation. A risk management plan is then developed for the MAR operation. The monitoring program needs to be carefully considered to meet the needs of the validation monitoring and due to the changes expected in the relative groundwater levels between the shallow and deep aquifer upon MAR infiltration short screen monitoring bores should be considered.

References

ANZECC-ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Appelo CAJ and Postma D (2005) Geochemistry, Groundwater and Pollution, Second Edition. Second Edition. Taylor & Francis.

Barron O, Silberstein R, Ali R, Donohue R, McFarlane DJ, Davies P, Hodgson G, Smart N and Donn M (2012) Climate change effects on water-dependent ecosystems in south-western Australia. Journal of Hydrology 434, 95-109. DOI: 10.1016/j.jhydrol.2012.02.028.

Bekele E, Toze S, Patterson B, Devine B, Higginson S, Fegg W and Vanderzalm J (2009) Chapter 1 - Design and operation of infiltration galleries and water quality changes. Determining requirements for managed aquifer recharge in Western Australia. CSIRO: Water for a Healthy Country National Research Flagship.

Bekele E, Toze S, Patterson B and Higginson S (2011) Managed aquifer recharge of treated wastewater: Water quality changes resulting from infiltration through the vadose zone. Water Research 45(17), 5764-5772. DOI: 10.1016/j.watres.2011.08.058.

Bekele EB, Donn MJ, Barry KE, Vanderzalm JL, Kaksonen AH, Puzon GJ, Wylie J, Miolinski K, Cahill K, Walsh T, Morgan M, Mcfarlane D and Dillon PJ (2015) Managed Aquifer Recharge and Recycling Options (MARRO): Understanding clogging processes and water quality impacts. Australian Water Recycling Centre of Excellence.

Betancourt WQ, Kitajima M, Wing AD, Regnery J, Drewes JE, Pepper IL and Gerba CP (2014) Assessment of virus removal by managed aquifer recharge at three full-scale operations. Journal of Environmental Science and Health, Part A 49(14), 1685-1692. DOI: 10.1080/10934529.2014.951233.

Biswas WK (2009) Life cycle assessment of seawater desalinization in Western Australia. World Academy of Science, Engineering and Technology 56, 369-375.

Brookes JD, Hipsey MR, Burch MD, Regel RH, Linden LG, Ferguson CM and Antenucci JP (2005) Relative value of surrogate indicators for detecting pathogens in lakes and reservoirs. Environmental Science & Technology 39(22), 8614-8621. DOI: DOI 10.1021/es050821+.

Castilla JC, Donn MJ, Cui T and Charles SP (2018) Western Trade Coast Hydrological Model – conceptual model report. Western Trade Coast managed aquifer recharge of treated wastewater for industrial water supply – Feasibility study. CSIRO, Australia.

Cornejo PK, Santana MVE, Hokanson DR, Mihelcic JR and Zhang Q (2014) Carbon footprint of water reuse and desalination: a review of greenhouse gas emissions and estimation tools. Journal of Water Reuse and Desalination 4(4), 238-252. DOI: 10.2166/wrd.2014.058.

Cui T and Donn MJ (2018) Calibration and scenario modelling of the Western Trade Coast groundwater model. CSIRO, Australia.

Cui T, Donn MJ and Charles SP (2019) Calibration and scenario modelling of the WTC groundwater model. Western Trade Coast managed aquifer recharge of treated wastewater for industrial water supply – Feasibility study. CSIRO, Australia.

Davidson WA and Yu X (2008) Perth regional aquifer modelling system (PRAMS) model development: Hydrogeology and groundwater modelling. Department of Water Western Australia. <http://www.water.wa.gov.au/search-publications>.

Davis JA, Fuller CC and Cook AD (1987) A model for trace metal sorption processes at the calcite surface: Adsorption of Cd^{2+} and subsequent solid solution formation. Geochimica Et Cosmochimica Acta 51(6), 1477-1490. DOI: https://doi.org/10.1016/0016-7037(87)90330-9.

Davis JA, Rosich RS, Bradley JS, Growns JE, Schmidt LG and Cheal F (1993) Wetlands of the Swan Coastal Plain: Volume 6 - Wetland classification on the basis of water quality and invertebrate community data. Water and Rivers Commission and Department of Environmental Protection, Perth.

Department of Biodiversity Conservation and Attractions (2017) A methodology for the evaluation of wetlands on the Swan Coastal Plain. Department of Biodiversity, Conservation and Attractions, Peth, Western Australia.

Department of Health (2009) Characterising treated wastewater for drinking purposes following reverse osmosis treatment. Perth, Western Australia.

Department of Health (2011) Guidelines for the non-potable uses of recycled water in Western Australia. Perth, Western Australia. <https://ww2.health.wa.gov.au/Articles/N_R/Recycled-water-publications>.

Department of Water (2010) Hydrogeochemical assessment of the Superficial aquifer: Perth metropolitan area.

Department of Water (2016) Western Trade Coast industry local water supply strategy. Perth, Australia. <www.water.wa.gov.au/__data/assets/pdf_file/0004/8887/110703.PDF>.

Department of Water and Environmental Regulation (2018a) Cockburn groundwater allocation plan - for public comment. Water Resource Allocation and Planning Report series. Report No. 60. Department of Water and Environmental Regulation, Perth, Western Australia.

Department of Water and Environmental Regulation (2018b) Water Information Reporting (http://www.water.wa.gov.au/maps-and-data/monitoring/water-information-reporting).

DER (2014) Kwinana Wastewater Treatment Plant Licence - Environmental Protection Act 1986 (Licence Number: L6543/1991/11). Department of Environment Regulation, Perth, Western Australia. < http://www.der.wa.gov.au/our-work/licences-and-works-approvals/current-licences>.

Donn M, Bekele E, Tapsuwan S and Mcfarlane D (2015) Chapter 10. Managed aquifer recharge scenarios. In: McFarlane D (ed.) Recycled water for heavy industry and preventing sea water intrusion. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship. CSIRO, Australia, 150-204.

Donn MJ, Castilla JC, Cui T and Charles SP (2019) Western Trade Coast Hydrological Model – conceptual model report. Western Trade Coast managed aquifer recharge of treated wastewater for industrial water supply – Feasibility study. CSIRO, Australia.

Donn MJ, Page DW and Vanderzalm JL (2017) Treated wastewater disposal via infiltration environmental research project: Final report (Commercial-in-confidence). CSIRO, Australia.

DPaW (2013) Geomorphic Wetlands Swan Coastal Plain. In: DPaW (ed.). Department of Parks and Wildlife, Perth WA.

Froend R and Sommer B (2010) Phreatophytic vegetation response to climatic and abstraction-induced groundwater drawdown: Examples of long-term spatial and temporal variability in community response. Ecological Engineering 36(9), 1191-1200. DOI: https://doi.org/10.1016/j.ecoleng.2009.11.029.

GHD (2018) Western Trade Coast Managed Aquifer Recharge scheme engineering design and costing study. A report for the Department of Jobs, Tourism, Science and Innovation., Perth, Western Australia.

Greenwood J, Keesing JK, Donn MJ and McFarlane DJ (2016) Nitrogen budget for Cockburn Sound, Western Australia. Report to the Cockburn Sound Management Council and the Western Australian Department of Water. CSIRO, Australia.

Hill AL, Semeniuk CA, Semeniuk V and Del Marco A (1996) Wetlands of the Swan Coastal Plain: Volume 2 - Wetland Mapping, Classification and Evaluation. Water and Rivers Commission and Department of Environmental Protection, Perth.

Kent DB and Fox PM (2004) The influence of groundwater chemistry on arsenic concentrations and speciation in a quartz sand and gravel aquifera). Geochemical Transactions 5(1), 1. DOI: 10.1186/1467-4866-5-1.

Martin R (ed.) (2013) Clogging issues associated with managed aquifer recharge methods. IAH Commission on Managing Aquifer Recharge.

McFarlane DJ, Donn MJ, Bekele EB and Tapsuwan S (2015) Recycled water for heavy industry and preventing sea water intrusion. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship., Perth, Western Australia. <https://publications.csiro.au/rpr/download?pid=csiro:EP155284&dsid=DS2>.

NHMRC and NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Reserach Council, National Resource Management Ministerial Council, Canberra.

NRMMC-EPHC-NHMRC (2006) Australian Guidelines for Water Recycling and Environmental Risks (Phase 1): Managing Health and Environmental Risk. Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, Australian Health Ministers' Conference, Canberra. <http://www.environment.gov.au/water/publications>.

NRMMC-EPHC-NHMRC (2009) Australian Guidelines for Water Recycling and Environmental Risks (Phase 2): Managed Aquifer Recharge. Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, National Health and Medical Research Council, Canberra. <http://webarchive.nla.gov.au/gov/20130904135703/http://www.environment.gov.au/water/publications/quality/water-recycling-guidelines-mar-24.html>.

Parkhurst DL and Appelo CAJ (1999) User's guide to PHREEQC (Version 2) - A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. U.S. Department of the Interior and U.S. Geological Survey, Denver, Colorado.

Patterson BM, Shackleton M, Furness AJ, Bekele E, Pearce J, Linge KL, Busetti F, Spadek T and Toze S (2011) Behaviour and fate of nine recycled water trace organics during managed aquifer recharge in an aerobic aquifer. Journal of Contaminant Hydrology 122(1-4), 53-62. DOI: 10.1016/j.jconhyd.2010.11.003.

Rayment GE and Higginson FR (1992) Australian laboratory handbook of soil and water chemical methods. Inkata Press, Melbourne.

Romero FM, Armienta MA and Carrillo-Chavez A (2004) Arsenic Sorption by Carbonate-Rich Aquifer Material, a Control on Arsenic Mobility at Zimapán, México. Archives of Environmental Contamination and Toxicology 47(1), 1-13. DOI: 10.1007/s00244-004-3009-1.

Sdiri A and Higashi T (2013) Simultaneous removal of heavy metals from aqueous solution by natural limestones. Applied Water Science 3(1), 29-39. DOI: 10.1007/s13201-012-0054-1.

Shaheen SM, Tsadilas CD and Rinklebe J (2013) A review of the distribution coefficients of trace elements in soils: Influence of sorption system, element characteristics, and soil colloidal properties. Advances in Colloid and Interface Science 201-202, 43-56. DOI: https://doi.org/10.1016/j.cis.2013.10.005.

Sidhu JPS and Toze S (2012) Assessment of pathogen survival potential during managed aquifer recharge with diffusion chambers. Journal of Applied Microbiology 113(3), 693-700. DOI: doi:10.1111/j.1365-2672.2012.05360.x.

Sidhu JPS, Toze S, Hodgers L, Barry K, Page D, Li Y and Dillon P (2015) Pathogen decay during managed aquifer recharge at four sites with different geochemical characteristics and recharge water sources. Journal of Environmental Quality 44(5), 1402-1412. DOI: 10.2134/jeq2015.03.0118.

Simms A, Hamilton S and Biswas WK (2017) Carbon footprint assessment of Western Australian Groundwater Recycling Scheme. Environmental Management 59(4), 557-570. DOI: 10.1007/s00267-016-0816-x.

Smith AJ, Massuel S and Pollock DW (2011) Geohydrology of the Tamala Limestone Formation in the Perth region: Origin and role of secondary porosity. CSIRO Water for a Healthy Country National Reserach Flagship.

Strehlow K, Davis J, Sim L, Chambers J, Halse S, Hamilton D, Horwitz P, McComb A and Froend R (2005) Temporal changes between ecological regimes in a range of primary and secondary salinised wetlands. Hydrobiologia 552, 17-31. DOI: 10.1007/s10750-005-1502-9.

Sui Q, Cao X, Lu S, Zhao W, Qiu Z and Yu G (2015) Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: A review. Emerging Contaminants 1(1), 14-24. DOI: https://doi.org/10.1016/j.emcon.2015.07.001.

Synergies Economic Consulting (2018) Commercial feasibility assessment: Managed aquifer recharge of treated wastewater for industrial supply in the Western Trade Coast. Perth, Western Australia.

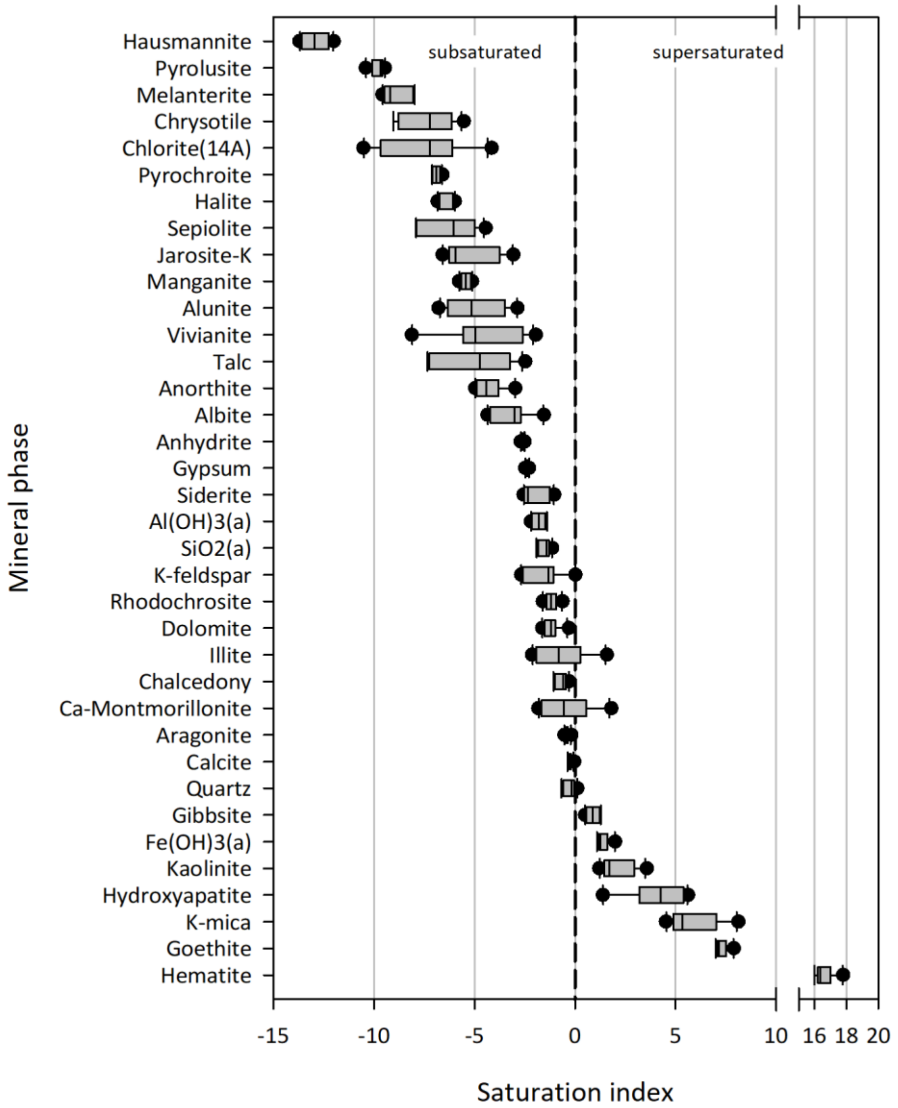
Toze S, Bekele E, Page D, Sidhu J and Shackleton M (2010) Use of static Quantitative Microbial Risk Assessment to determine pathogen risks in an unconfined carbonate aquifer used for Managed Aquifer Recharge. Water Research 44(4), 1038-1049. DOI: DOI 10.1016/j.watres.2009.08.028.

Trefry MG, Davis GB, Johnston CD, Gardiner AG, Pollock DW and Smith AJ (2006) Status of groundwater quality in the Cockburn Sound catchment. Final report to the Cockburn Sound Management Council. CSIRO, Wembley WA.

Vacher HL and Mylroie JE (2002) Eogenetic karst from the perspective of an equivalent porous medium. Carbonates and Evaporites 17(2), 182-196. DOI: 10.1007/bf03176484.

Yokoyama Y, Tanaka K and Takahashi Y (2012) Differences in the immobilization of arsenite and arsenate by calcite. Geochimica Et Cosmochimica Acta 91, 202-219. DOI: https://doi.org/10.1016/j.gca.2012.05.022.

Appendix A Treated wastewater saturation indices



Apx Figure A.1 Saturation indices for minerals potentially in equilibrium with treated wastewater. Box plot for samples from Kwinana Water Reclamation Plant, East Rockingham WWTP and Kwinana WWTP, showing the interquartile range (box bounded by 25^{th}/75^{th} percentiles), median (vertical line), 10^{th} and 90^{th} percentiles (error bars) and 5^{th} and 95^{th} percentiles (points).

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

AT CSIRO, WE DO THE
EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today – for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australia's catalyst for innovation.

CSIRO. WE IMAGINE. WE COLLABORATE.
WE INNOVATE.

FOR FURTHER INFORMATION

Land and Water
Michael Donn
t +61 8 9333 6146
e m**ichael**.donn@csiro.au
w www.csiro.au/en/Research/LWF
w research.csiro.au/mar/

Appendix C – Commercial Feasibility Assessment

Commercial Feasibility Assessment: Managed Aquifer Recharge of Treated Wastewater for Industrial Supply in the Western Trade Coast

Final Report

June 2018

Synergies Economic Consulting Pty Ltd
www.synergies.com.au

Disclaimer

Synergies Economic Consulting (Synergies) has prepared this report exclusively for the use of the party or parties specified in the report (the client) for the purposes specified in the report (Purpose). The report must not be used by any person other than the client or a person authorised by the client or for any purpose other than the Purpose for which it was prepared.

The report is supplied in good faith and reflects the knowledge, expertise and experience of the consultants involved at the time of providing the report.

The matters dealt with in this report are limited to those requested by the client and those matters considered by Synergies to be relevant for the Purpose.

The information, data, opinions, evaluations, assessments and analysis referred to in, or relied upon in the preparation of, this report have been obtained from and are based on sources believed by us to be reliable and up to date, but no responsibility will be accepted for any error of fact or opinion.

To the extent permitted by law, the opinions, recommendations, assessments and conclusions contained in this report are expressed without any warranties of any kind, express or implied.

Synergies does not accept liability for any loss or damage including without limitation, compensatory, direct, indirect or consequential damages and claims of third parties, that may be caused directly or indirectly through the use of, reliance upon or interpretation of, the contents of the report.

This report was prepared by Martin van Bueren, Simon Sagerer and Michael Reid

Synergies ECONOMIC CONSULTING

Brisbane
Level 8, 10 Felix Street
Brisbane QLD 4000
P 61 7 3227 9500
F 61 7 3221 0404

Melbourne
Level 9, 440 Collins Street
Melbourne VIC 3000
P 61 3 8692 7272
F 61 7 3221 0404

Perth
995 Hay Street
Perth WA 6000
P 61 407 348 612
F 61 7 3221 0404

Sydney
Suite 518, 377 Kent Street
Sydney NSW 2000
P 61 2 8915 6235
F 61 7 3221 0404

W www.synergies.com.au

Executive Summary

The Western Trade Coast (WTC) is a 3,900 hectare industrial region adjacent to Cockburn Sound, just south of Fremantle in Western Australia. The region comprises the Kwinana Industrial Area, Latitude 32 Industry Zone, Rockingham Industry Zone and Australian Marine Complex.

Business activities within the WTC are a major contributor to the State's economy. The region employs over 11,000 people and generates more than $15 billion per annum. Many of the business located in the region are heavy industry, which require water for their operations.

The State Government wants to continue to provide opportunities for businesses to establish and expand in the region, by providing suitable land and supporting infrastructure. Ensuring adequate and cost-effective water supplies to the region is one component of achieving this objective and replenishing groundwater aquifers with recycled wastewater (also known as Managed Aquifer Recharge, or MAR) has been proposed as a potential alternative source of water for heavy industry. MAR involves recycling wastewater to a non-potable standard then injecting the recycled water into the superficial aquifer for storage (and subsequent, future abstraction).

MAR has been shown to be technically feasible from a hydrological and engineering perspective but a full financial and economic analysis of MAR for industrial use in the WTC has not been undertaken. This study provides that analysis.

Current supply and demand situation

Industrial users currently use water from four different sources: Groundwater, potable scheme water, recycled wastewater from the Kwinana Water Recycling Plant (KWRP), and stormwater/reuse on site.

- Groundwater is an inexpensive supply source as users only incur the cost of pumping and on-site treatment (to the extent that treatment is required for their particular industrial use). Groundwater is taken from the Cockburn Groundwater Area, which is fully allocated, so there is no scope to expand supply through the granting of new licences. Current annual licenced volumes in the Cockburn Groundwater Area are around 36 GL (includes all users, not just industrial).
  - Of this total, 13.6 GL is within the two groundwater subareas of greatest relevance to this study (Valley and Wellard). A significant proportion of the

allocated volume is not used. In the case of Valley subarea, around 26% is not utilised, while in the case of Wellard subarea, about 42% remains unused[1].

- While actual use is less than the volume of licence on issue, the Department of Water and Environmental Regulation (DWER) has established that these two groundwater subareas are collectively over-allocated by 2.8 GL. This means that there is a future potential for abstractions to exceed what is considered sustainable. In order to guard against the risk of this happening, DWER has commenced recouping long-term unused water entitlements[2]. The purpose of this recouping is to restore the volumes available for use to the revised allocation limit set out in the Cockburn Allocation Plan. Once recouping is completed, it is expected that there will remain a surplus of 1.84 GL of groundwater.
- In this analysis it is assumed that the 1.84 GL will be traded into the market, thus becoming available for use. This is a conservative assumption because there may also be scope for water to shift from low value uses (e.g. agriculture) to higher value, industrial uses as groundwater in the WTC becomes scarcer.

- Potable scheme water supplied by Water Corporation through the Perth Integrated Water Supply Scheme (IWSS) is the most expensive supply source as it is treated to drinking quality and is reticulated to users through a pipe network. At present, about 4 GL of scheme water is consumed by industrial users.
- Recycled wastewater from the KWRP is a third water source. Built in 2004, the KWRP uses a reticulation network to supply customers directly with high-quality, treated water at a price below that of scheme water. The KWRP has a total capacity of 6GL (16.7 ML/day), of which 5 GL per year (14 ML/day) is currently being used. There is scope for expanding the plant by a further 3.6 GL (9.9 ML/day) with additional investment. The KWRP is owned and operated by the Water Corporation and supplies water on a fully commercial basis to five or six industrial users. The KWRP has scope to supply additional customers located within close proximity to Kwinana but is not a feasible option for supplying customers located in other areas of the WTC due to the cost and difficulty in establishing the required pipe network.
- Some businesses harness stormwater to recover water from industrial processes for internal reuse or for use by a third party. Stormwater availability varies each year as it is dependent on rainfall.

---

[1] Data from DWER based on the four year period up to 2016

[2] Department of Water and Environmental Regulation (DWER) 2018 Cockburn Groundwater Allocation Plan – for public comment

MAR is a potential, fifth supply source. This option is attractive because there is currently more than 30 GL of treated wastewater generated by existing wastewater treatment facilities in the WTC, all of which is presently discharged to the ocean through the Sepia Depression Ocean Outlet Landline (SDOOL), a pipeline that runs through the WTC.

MAR supply options

Two main MAR options are considered in this study (Site 1 and Site 2). Both are assumed to be built to inject treated wastewater into the Perth Superficial aquifer within the Cockburn Groundwater Area. It is also assumed that both sites are built to the same capacity, capable of supplying 3.55 GL per year once fully operational, but the options have some important differences:

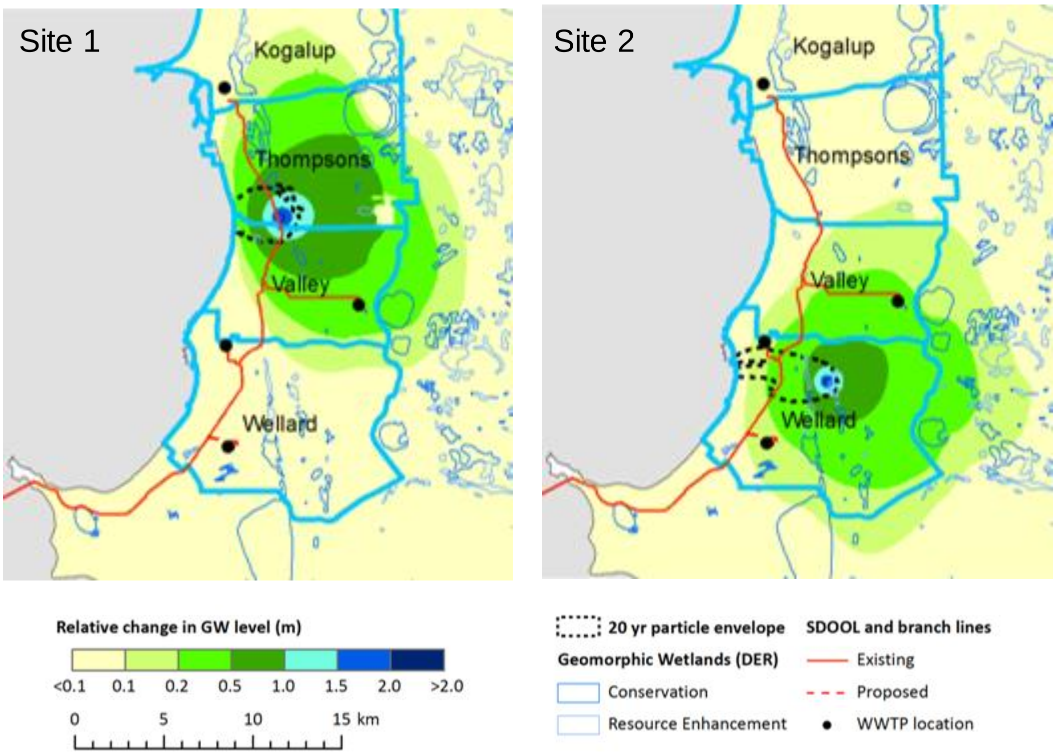
- Site 1 is located in the middle part of the WTC and based on CSIRO's groundwater modelling would be capable of supplying water to customers in two northern sub-areas[3] (Thompsons[4] and Valley). Site 2 is located in the southern part of the region, near Rockingham. Groundwater modelling suggests that Site 2 would only be capable of supplying the Valley and Wellard sub-areas. The two sites and the approximate geographic extent of aquifer recharge is shown in Figure ES1.

---

[3] McFarlane DJ (ed.) (2015). *Recycled water for heavy industry and preventing seawater intrusion*. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship, page 160

[4] As no additional demand is forecast for Thompsons sub-area, this study only focuses on the Wellard and Valley sub-areas

Figure ES1 **Recharge zones for MAR Site 1 and Site 2**



Source:. McFarlane DJ (ed.) (2015). *Recycled water for heavy industry and preventing seawater intrusion.*

- The two sites are subject to different constraints. For instance, Site 1 can be developed to its full capacity as early as 2020 because it would utilise wastewater from the SDOOL which is immediately available, whereas Site 2 would use wastewater from East Rockingham wastewater treatment plant, which will not be capable of providing enough feedstock to run the MAR scheme at full capacity until 2027.

- Differences in wastewater quality leads to significant differences in recycling costs[5], with Site 1 capable of producing MAR water for between \$0.95/kL and \$1.13/kL, while Site 2 can produce MAR water for \$0.60/kL (all estimates assume full utilisation at 3.55 GL/year).

Future demand and emerging supply shortfalls

The economic and financial viability of MAR will depend in a large part on the timing of when supply shortfalls first begin to emerge in the WTC, which in turn is governed

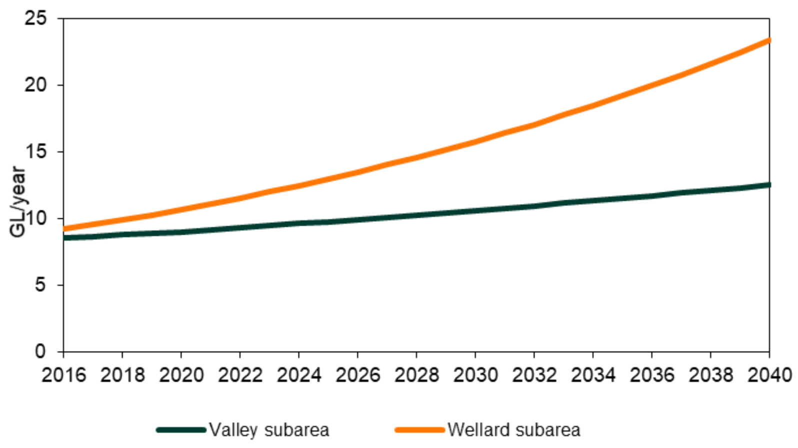
[5] Cost estimates from GHD (2018) Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study, March 2018

by the rate of demand growth and assumptions about the availability of existing water supply.

For this study we use demand forecasts previously made by the Resource Economics Unit (REU)[6] as a core set of future scenarios, but complement these forecasts with several alternative futures based on defined 'demand events' and 'supply events'. We also examine the possibility that industrial users may substitute scheme water with less expensive MAR water, subject to the MAR water being able to be treated cost-effectively on site by the customer to a 'fit for purpose' standard.

The REU demand forecasts comprise a central growth scenario ('base demand') and a lower-bound and upper-bound forecast. The central growth scenario for two sub-areas within the WTC (the Valley and Wellard) are shown in Figure ES2. These are the two sub-areas that could potentially be supplied by the MAR options under investigation. Annual cumulative growth rates average 1.7% per annum in the Valley and 4.0% for Wellard[7].

Figure ES2 Water demand forecasts of heavy industry



Source: Resource Economics Unit (2014) *Local economic growth projections for the Western Trade Coast to 2031*, a report for Department of Water

The alternative scenarios (or 'events') which could affect the timing and scale of supply shortfall, and hence the potential demand for MAR, are:

- zero growth in base demand (i.e. maintain demand at existing levels);

[6] Resource Economics Unit (2014) *Local economic growth projections for the Western Trade Coast to 2031*, a report for Department of Water.

[7] These rates are averages taken over the period 2022 to 2040

- a specified number of users switch from scheme water to MAR (a demand shift event);
- a specified number of users expand their production and utilise MAR water, subject to it being available at a price below the cost of scheme water (a demand shift event);
- a specified number of users trade their groundwater licence that is surplus to their needs (a supply shift event); and
- a decision is taken to expand the KWRP, lifting total capacity from 6GL per year to 9.6GL per year (a supply shift event).

We have introduced these scenarios into the analysis because of the considerable uncertainty around the REU demand forecasts – which was revealed through our consultations with ten of the region's largest water users. The demand and supply shifts have been incorporated into the financial and economic analysis through a probabilistic model, whereby the incidence of an event is modelled as a random draw from the suite of possible events.

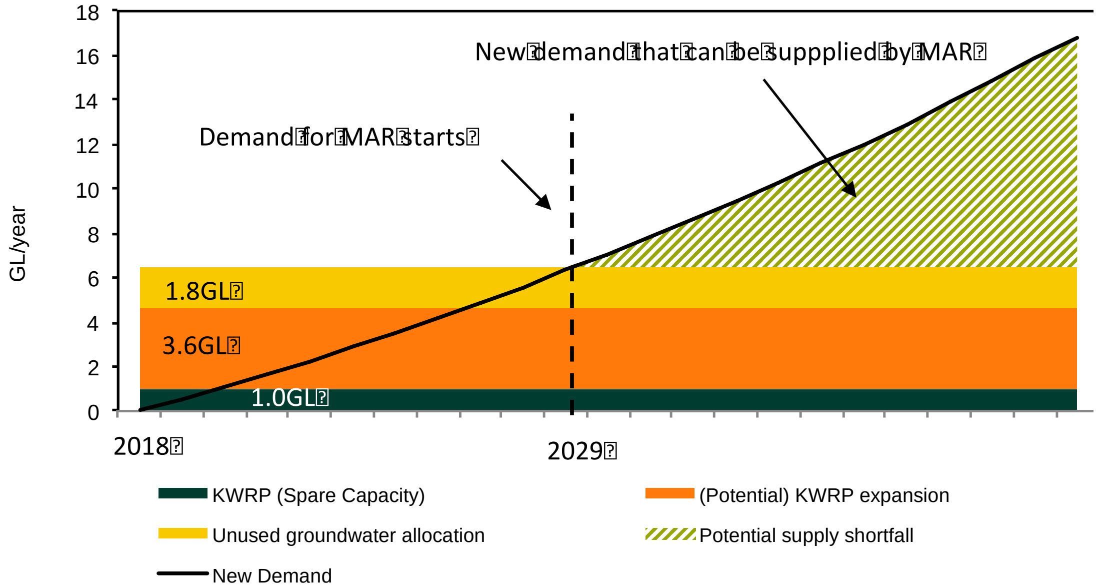
Modelling the supply shortfalls

Figure ES3 illustrates how we have modelled the emergence of a supply shortfall over time. We start with a simple example to demonstrate the process. The example assumes that

- future additional demand is first met through existing supplies of groundwater (including potential sale of unused allocation), spare KWRP capacity, and a possible expansion of the KWRP.
- any remaining unmet demand (i.e. the shortfall) is then assumed to be potentially able to be filled by MAR, subject to MAR being cost-competitive with potable scheme water on a 'like-for-like' quality basis.

Based on the mid-level REU demand forecasts, the supply shortfall is shown in Figure ES3 to first occur in 2029. This is subject to all available groundwater being used first, as well as the KWRP being expanded by 3.6GL. In practice, we have used a probabilistic approach for modelling supply and demand, which means that the timing of first shortfall differs from one model run to the next.

Figure ES3 Representation of demand for MAR and the alternative sources of supply



Financial and economic analysis

The development of a MAR scheme in the WTC would involve both costs and benefits. To be economically viable, the benefits of supplying recycled wastewater to industrial customers would need to outweigh the capital and operating cost of MAR, relative to the unit cost of a next best alternative supply source. The primary economic benefit of MAR is therefore the potential cost savings realised through substituting scheme water with a lower cost, recycled product.

There may be other, secondary benefits, including:

- any avoided wastewater treatment costs (e.g. the deferral of capital upgrades to existing wastewater infrastructure due to less volumes needing to be treated for discharge to ocean); and
- any environmental benefits of MAR (e.g. the opportunity to recharge wetlands in the WTC).

Similarly, on the cost side, there could be some indirect costs that need considering, including:

- the possible 'opportunity cost' of using wastewater as an input to MAR for industrial purposes, relative to using it instead for producing recycled water to supplement Perth's future drinking water supply; and

- any additional operating costs incurred by the Water Corporation in facilitating a MAR scheme (for example, extra risk management measures that may be needed if the MAR plant was shut down for maintenance, resulting in a sudden spike in wastewater flows having to be treated and discharged).

Synergies has examined each of the potential secondary benefits and indirect costs referred to above and concluded that none are material. Our assumptions and reasoning are summarised in Box ES1.

Box ES1 Indirect benefits and costs – key assumptions

Wastewater resource cost: It is assumed there is no economic 'opportunity cost' of using wastewater as an input to MAR for industrial purposes, relative to using it instead for producing recycled water to supplement Perth's future drinking water supply. This assumption is based on the fact that wastewater in WTC region is not a scarce resource, so diversion of around 4 GL per annum for MAR would not materially impact on future opportunities to use recycled water for other uses.

Additional wastewater treatment cost: Based on advice from the Water Corporation, it is assumed that current operating costs for wastewater treatment do not change as a result of the MAR scheme (i.e. it is assumed that there is no net cost to the Water Corporation of facilitating MAR at either Site 1 or Site 2);

Avoidable wastewater infrastructure upgrade costs: Based on advice from the Water Corporation, it is assumed that the volumes of wastewater diverted for MAR would be insufficient to have any effect on the timing of future infrastructure upgrades.

Environmental impacts: It is assumed there are no material environmental costs or benefits associated with the MAR scheme at either site. The MAR options could be designed to produce additional recycled water for environmental use – e.g. for the purpose of recharging wetlands and groundwater dependent ecosystems. However, for this analysis it is assumed that all water produced is abstracted for consumptive use.

In addition to the above economic considerations, any potential MAR scheme would also need to be financially viable. To be financially viable, a project must be capable of raising sufficient revenues to cover costs. If some of the project benefits cannot be captured through prices for MAR water, then the project may not be viable on a commercial basis. Further, project risks (e.g. demand risk, technical production risk, etc.) need to be modest and manageable.

MAR price and potential financial return

For our financial analysis, we estimate the value per unit (marginal revenue) available to a MAR supplier as equal to the price of potable scheme water, less the unit cost of wastewater input and less the cost to the customer of any on-site treatment of MAR water to bring it up to a standard for industrial use.

The logic of the calculation is that, in the absence of a MAR scheme, once existing groundwater and KWRP supply sources have become fully utilised users would have no alternative but to service their additional demand with scheme water.[8] If MAR was

[8] Scheme water is assumed to be the 'backstop' water source. Water Corporation has confirmed that all industrial customers in WTC, including future customers in greenfield developments, could be serviced through the IWSS if

available, users would be willing to pay up to price of scheme water for the MAR water, less any cost incurred themselves in having to treat the water to a suitable standard for industrial use. Further, we subtract the cost of wastewater input from the marginal revenue able to be earned by the MAR supplier, as this is a payment to Water Corporation.

The following costs and price assumptions have been adopted:

- The value for potable water is initially set to $2.40/kL, which is current long run marginal cost (LRMC), as estimated by the Economic Regulation Authority, and which is forecast to increase over the next twenty years;[9]
- A wastewater input cost of $0.50/kL, which is assumed to be the price that would be charged by the Water Corporation for access to its wastewater (in practice, this charge would be negotiated between the MAR scheme operator and the Water Corporation. The charge should reflect the cost to the Water Corporation of facilitating access to the wastewater product, less any costs avoided by the Water Corporation as a result of supplying the wastewater);
- On-site treatment costs are assumed to be no greater than $1.20/kL, which is the cost of treating MAR water with a small reverse osmosis plant (this parameter is quite uncertain, as the water quality requirements of each industrial customer vary, as does the existing capacity of customers to perform on site treatment – e.g. some would have to upgrade their treatment equipment while others would not). To reflect this uncertainty, we have conducted a sensitivity analysis using lower costs of $0.50/kL and $0.80/kL.

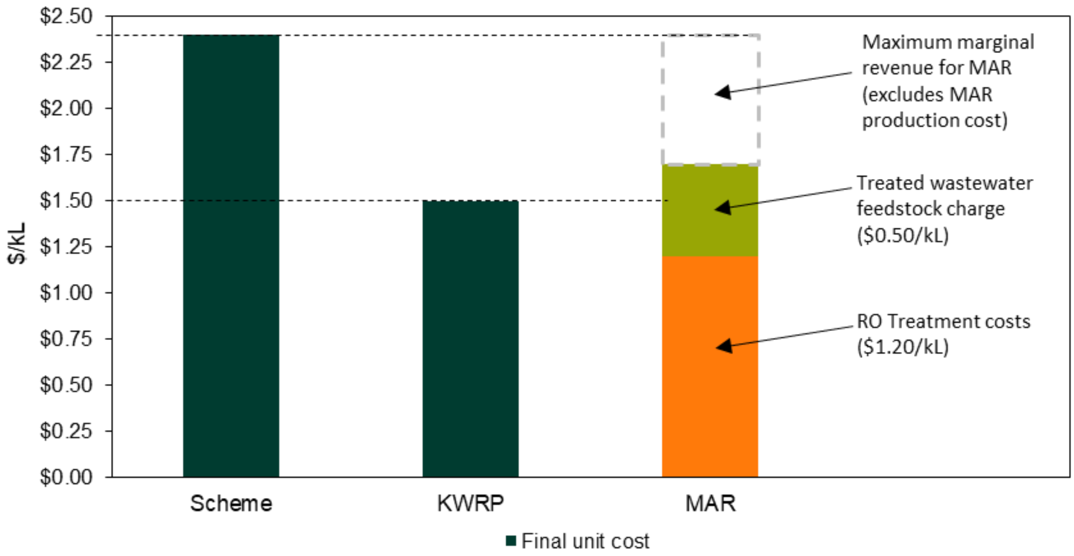
The approach is illustrated in Figure ES4. Based on the above price and cost assumptions, the marginal revenue potentially available to a MAR scheme operator is initially $0.70/kL.

---

required. In addition to the standard infrastructure contribution charge, customers would be required to pay for any distribution scheme upgrades or mains extensions to their site. Further, our assumption of an inclining LRMC for potable water captures the effect of progressive infrastructure augmentation to support increasing demand for water in Perth

[9] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105

Figure ES4 Illustration of the approach to calculating marginal revenue for MAR water



A marginal revenue of $0.70/kL also implies that total recycling costs (the operating and capital cost components) can be no more than $0.70/kL for the MAR scheme to be financially viable. This suggests that MAR water produced at Site 2 at an estimated cost of $0.60/kL would be cost-competitive with scheme water, at the current scheme water price. But not so for Site 1, where production costs range between $0.95/kL and $1.13/kL.

Looking further into the future, our modelling assumes that the price of scheme water will rise in real terms to $4.30/kL by 2040 due to increases in the LRMC of water supply as 'low cost' sources such as dams and groundwater become a smaller share of Perth's drinking water supply[10]. This means that recycling costs can be somewhat higher than $0.70/kL without jeopardising the financial viability of MAR. This may allow a scheme operator to offer a price discount to customers on MAR water to incentivise additional take up of supply contracts (we assume a 10% discount in our standard modelling runs).

Figure ES4 also shows that KWRP water, at a current price of $1.50/kL (treated and delivered to customer), is less expensive than the estimated cost of producing an equivalent quality recycled product through MAR. Therefore, our modelling assumes that all spare capacity of the KWRP will be taken up before the MAR scheme can sell water. This is a simplifying assumption, as we acknowledge that some customers may not be able to physically access KWRP water due to their geographic location within the WTC, or the cost of installing new reticulation infrastructure would be prohibitive. In

[10] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105.

practice, there could be scope for MAR to be developed ahead of all KWRP capacity being used. To the extent that this occurs, the financial returns to MAR would somewhat higher than what is estimated in this analysis.

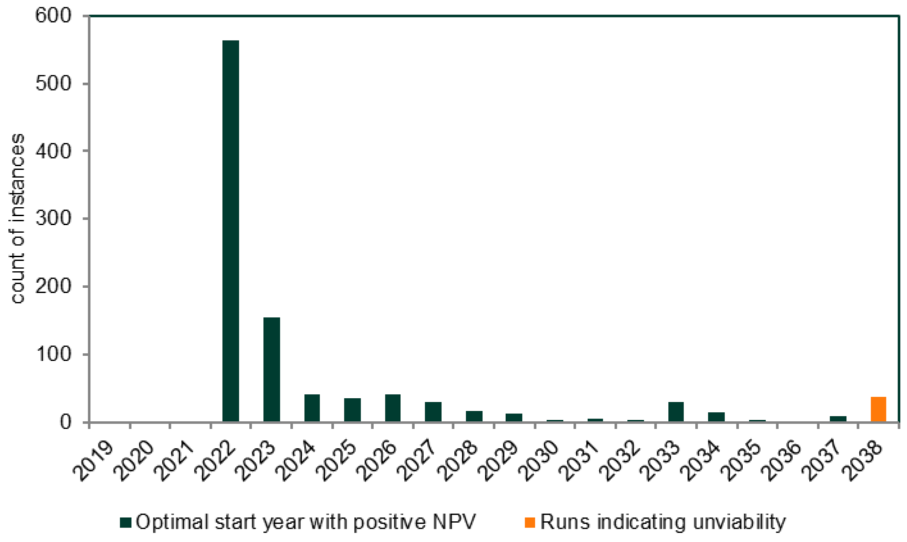
Results

Based on a number of initial modelling runs, Site 1 was found to be financially non-viable due to the slow demand growth forecast within the Valley and Thompson sub-areas (i.e. the two areas that could be supplied by Site 1). Site 1 also faces much higher capital and operating costs than Site 2. We therefore focus our attention on Site 2.

Optimal commencement timing for MAR

Instead of assuming a fixed commencement date for MAR, we examine the net financial returns (given by net present value at a 7% discount rate) from allowing the commencement date to vary according to demand and supply conditions in a given year. In this way, the model selects the start date that maximises financial net present value (NPV). Figure ES5 shows the optimal start years (i.e. corresponding to the year in which NPV is maximised) as determined for 1000 model runs, combining all demand growth scenarios and including event demand and supply.

Figure ES5 Optimal start years for all four growth scenarios



The height of the column represents the number of instances (out of the 1000 runs) for which a particular year is selected as an optimal start date. The results indicate that in about 50% of instances, the optimal start date for Site 2 is 2022. The remainder of model

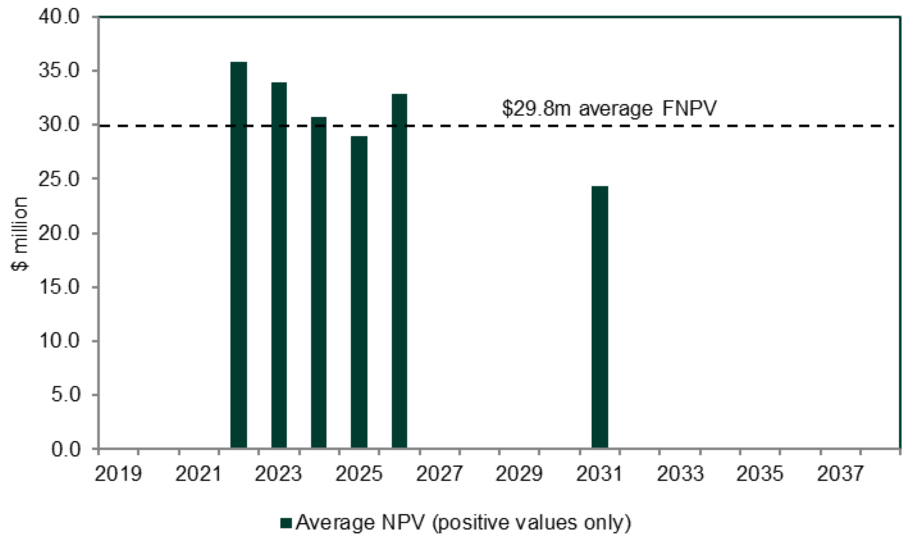
runs select start dates over a broad period that extends out to 2034, with a concentration around the period 2023 to 2027.

Expected financial returns

The average NPV for each commencement year is shown in ES6. These averages are calculated on the basis of all instances that yield a positive NPV[11]. Values in the early commencement years tend to be higher than those for later commencement dates. The result that NPVs generally decline over time partly reflects the fact that developing the project later leaves significant early revenue opportunities unexploited.

The overall average NPV, across all project commencement dates with a positive financial return, is $29.8 million (in 2018 terms). This NPV is sensitive to the assumed real rate of increase in the price of scheme water over time, and thus the potential marginal returns available for MAR supply.

Figure ES6 Average project value (NPV) by optimal commencement year



Sensitivity analysis of financial returns

These findings do vary with changes to key assumptions, as shown by the following sensitivity analysis results in Table ES1. The sensitivity tests were performed by varying just one parameter at a time, holding all others constant.

11 Model runs that produce a negative NPV have been removed because it is assumed that only those business cases yield a positive NPV would be considered for investment. .

Table ES1 Summary of sensitivity analyses

Sensitivity	Assumptions				Expected NPV
	Incentive discount	Customer treatment cost	Price of scheme water	Charge for feedstock	
Units	%	$/kL	$/kL	$/kL	
Base	10%	$1.20	$2.40 growing to $4.30	$0.50	$29.8 million
Trade of all spare groundwater[a]	10%				$27.3 million
40% incentive discount	***40%***				$15.3 million
Alternative assumptions for cost of scheme water					
Fixed at $2.40/kL	10%	$1.20	***$2.40 constant***	$0.50	N/A – never viable
Growing to $3.00/kL	10%	$1.20	***$2.40 growing to $3.00***	$0.50	$13.6 million
Growing to $3.50/kL	10%	$1.20	***$2.40 growing to $3.50***	$0.50	$21.6 million
No charge for wastewater input	10%	$1.20	$2.40 growing to $4.30	***$0.00***	$45.8 million
Customer treatment cost					
Medium RO facility	10%	***$1.20***		$0.50	$29.8 million
Large RO facility	10%	***$0.80***		$0.50	$42.0 million
Other treatment	10%	***$0.50***		$0.50	$53.5 million

Notes: Presented results are measured in 2018 terms. Bold and italicised values represent tested variables. Shaded cells show key finding. (a) Sets the probability of trade of unused allocations (after allowing for recouping of unused entitlements) at 100%.

Data source: Synergies modelling

Key results from the sensitivity analysis are follows:

- If the price of scheme water is assumed to remain constant at today's price of $2.40/kL, MAR is never financially viable (this is an unrealistic scenario, but included nevertheless for reference)
- The MAR project breaks-even, on average, at a potable scheme water price of $2.45/kL (at prices below than this, MAR water would become more expensive than scheme water)
- If the scheme water price only rises to $3.00/kL over the study timeframe, the project still returns a positive NPV of $13.6 million
- If all surplus groundwater is traded into the market, average NPV of the MAR project reduces to $27.3 million
- If the incentive discount is increased from 10% to 40%, expected NPV reduces to $15.3 million
- If the wastewater input can be acquired at no cost, the NPV becomes $45.8 million

- If the unit cost of MAR water treatment by customers can be reduced to $0.80/kL (down from $1.20/kL), expected NPV increases to $42.0 million. At a treatment cost of $0.50/kL, the NPV increases to $53.5 million.

In terms of the sensitivity of returns to future demand, we estimate that a MAR scheme at Site 2 would remain NPV positive, on average, even if the REU demand forecasts are not realised. In the scenario where only the demand and supply events are assumed to make up the demand profile, with no underlying growth, average NPV becomes $9.2 million.

Conclusions

A MAR scheme at Site 2 is assessed as being financially viable and has the potential to deliver significant financial returns if REU growth scenarios are realised (NPV of around $30 million). But based on discussions with major water users in the WTC, we have reason to doubt the validity of REU demand projections and we regard the central and high forecasts as being overly optimistic and without strong foundation.

That being said, the project can be viable even if the REU forecasts are excluded (i.e. an assumption of zero underlying growth), but the service provider would need to secure the 'event demand' before being confident of proceeding. The event demand is characterised by a decision by several major users to switch from scheme water to MAR, and several producers going ahead with expansion plans. In the course of this project, Synergies identified four potential customers who have expressed interest in substituting their current scheme water usage with an alternative source, and two that have definitive expansion plans that would trigger the demand for more water. The combined demand of these firms is about 2.7 GL by 2020, which would be sufficient to utilise up to 76% of the MAR facility's capacity and make it commercially viable.

Attempting to make these four parties the facility's foundations customers appears to be the least-risk strategy to developing this project from a commercial perspective. The operator should have scope to offer supply for these foundation customers at a significant discount to scheme water, providing them with a commercial incentive to enter into long term contracts.

In practice, Synergies expects that a proponent would likely build its business case around identified tranches of demand for which it believed it could secure foundation contracts. The proponent may then build some capacity in addition to the level required to meet the foundation demand as a calculated risk that there will be reasonably strong underlying demand growth, from which the service provider could earn additional returns. Thus, the service provider might intend to offer subsequent customers lower discounts relative to scheme water than it negotiates with its foundation customers.

Contents

Executive Summary **3**

Current supply and demand situation 3

MAR supply options 5

Future demand and emerging supply shortfalls 6

Financial and economic analysis 9

Conclusions 16

1 Introduction **20**

1.1 Background 20

1.2 Approach 22

1.3 Report structure 22

2 Current supply and demand situation **23**

2.1 Groundwater 23

2.2 Kwinana Water Reclamation Plant 24

2.3 Potable scheme water 24

2.4 Demand projections 25

2.5 What would business as usual look like? 27

3 MAR supply options **30**

3.1 MAR supply areas 30

3.2 Key features of each option 32

3.3 Treated wastewater supply for each option 33

3.4 Direct costs of each option 35

3.5 Indirect costs 36

3.6 Benefits 40

4 Evaluation approach **43**

4.1 Analytical steps 43

5 Financial and economic analysis **46**

5.1 Calculating the marginal revenue for MAR 46

5.2 Application of demand forecasts 49

5.3 Net financial value 54

5.4 Sensitivity testing and demand risk 57

5.5 Economic analysis 63

6 Commercial analysis 64

6.1 Considerations in development of MAR Scheme 64

6.2 Service Models 69

6.3 Assessment of service models 71

7 Conclusions 78

7.1 Financial viability 78

7.2 Commercial considerations 78

7.3 Service models 79

7.4 Next steps 80

A Adaption of REU demand forecasts 82

B Additional Information on MAR Facilities 84

Figures and Tables

Figure 1 Map of WTC study area and location of proposed MAR sites 21

Figure 2 Overview of study approach 22

Figure 3 REU central demand forecasts of heavy industry demand for water for Valley and Wellard subareas 26

Figure 4 Modelled groundwater mounds from infiltration at Site 1 (North) and Site 2 (South) 32

Figure 5 Treated wastewater supply compared to MAR requirement – Site 1 34

Figure 6 Treated wastewater supply compared to MAR requirement – Site 2 35

Figure 7 Illustration of the approach to calculating marginal revenue relative to the cost of scheme water 47

Figure 8 MAR marginal revenue (real), 2017 to 2080 48

Figure 9 Illustration of the combination of underlying and event growth 51

Figure 10	Representation of demand for MAR and the alternative sources of supply	52
Figure 11	Site 2: optimal start years for all four growth scenarios including event demand	55
Figure 12	Site 2: optimal start years for all four growth scenarios separate event demand	56
Figure 13	Site 2: average project value (NPV) by optimal commencement year, 2019 to 2038	57
Figure 14	Site 2: Full range of demand outcomes	59
Figure 15	Site 2: demand ranges excluding event demand	60
Figure 16	Site 2: demand ranges reflecting only REU forecasts and supply events	61
Figure 17	Site 2: Event demand with underlying growth excluded	62

Table 1	Summary of MAR Options	33
Table 2	Overview of costs assumed for Sites 1 and 2 ($2018)	36
Table 3	Demand events	50
Table 4	Supply events	51
Table 5	Summary of sensitivity analyses	58
Table 6	Summary of economic analysis findings	63
Table 7	Overview of Service Provision Options	71
Table C.1	Initial and replacement capital costs assumed for Sites 1 and 2 ($2018)	86
Table C.2	Operating costs assumed for Sites 1 and 2 ($2018)	87
Table C.3	Site 1 detailed capital, replacement and operating costs	88
Table C.4	Site 2 detailed capital, replacement and operating costs	90

1 Introduction

The WTC is a major industrial precinct in Western Australia, with growing demand for water. Supporting new industrial development in the region will require, among other things, that adequate and secure water supplies are available to new and expanding businesses. Recycled wastewater supplied through Managed Aquifer Recharge (MAR) is being investigated as a potential source of non-potable water to meet new water demand within the WTC, and possibly as a part-substitute for existing use of potable scheme water.

The Department of Jobs, Tourism, Science and Innovation (JTSI) has engaged Synergies Economic Consulting (Synergies) to:

- evaluate the net economic benefit and financial viability of options to meet WTC demand using MAR; and
- provide advice on:
  - the commercial risks and issues associated with a MAR Scheme;
  - different commercial models (service options) to deliver MAR; and
  - implementation approaches.

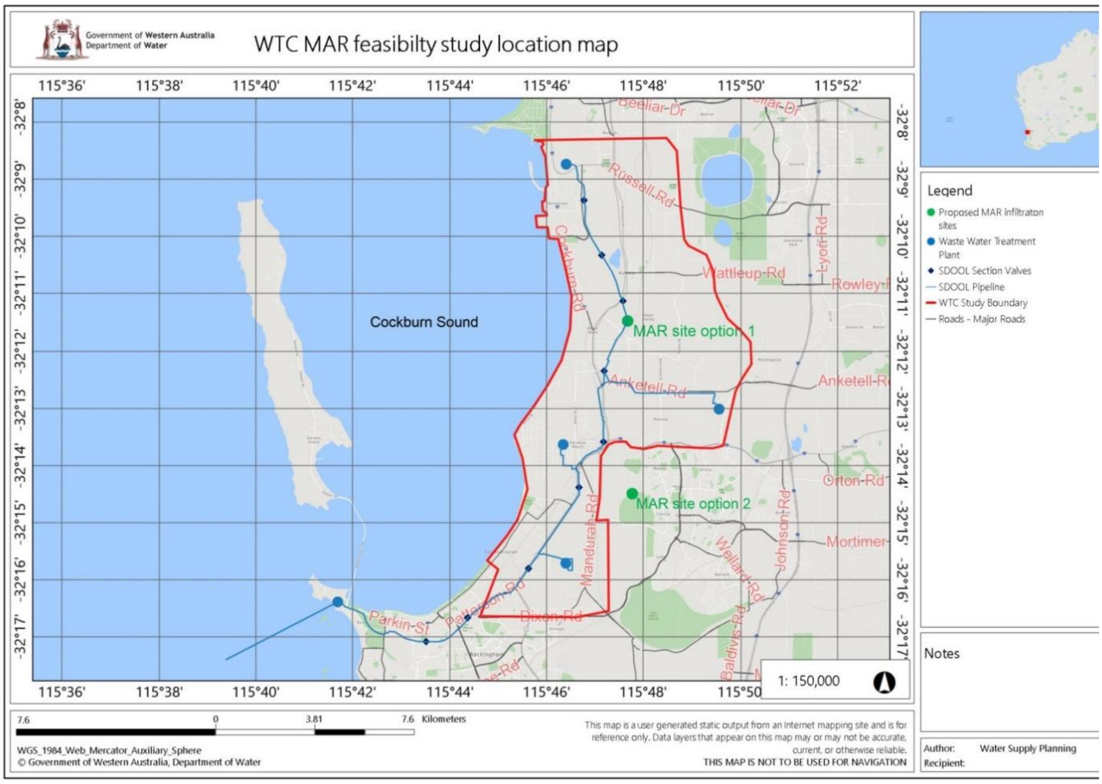
1.1 Background

The WTC is a 3,900 hectare industrial region adjacent to Cockburn Sound in Western Australia. The region comprises the Kwinana Industrial Area, Latitude 32 Industry Zone, Rockingham Industry Zone and Australian Marine Complex. Figure 1 shows the location of the study region.

Business activities within the WTC are a major contributor to the State's economy. The region employs over 11,000 people and generates more than $15 billion per annum. Many of the business located in the region are heavy industry, which require water for their operations.

The State Government wants to continue to provide opportunities for businesses to establish and expand in the region, by providing suitable land and supporting infrastructure. Ensuring adequate and cost-effective water supplies to the region is one component of achieving this objective. However, scheme water is expected to become increasingly expensive as naturally-occurring groundwater sources are exhausted. Groundwater is already fully allocated within the region and given the expectations of a drying climate and reduced rates of recharge, additional allocations are unlikely to be granted.

Figure 1 Map of WTC study area and location of proposed MAR sites



Replenishing groundwater aquifers with recycled wastewater has been proposed as a potential alternative source of water for heavy industry. This would use treated wastewater, for instance from the SDOOL which runs from north to south through the WTC. The treated wastewater would be treated to an even higher standard, then injected to the underlying aquifers to supplement natural recharge and thus sustain additional abstractions from the superficial aquifer.

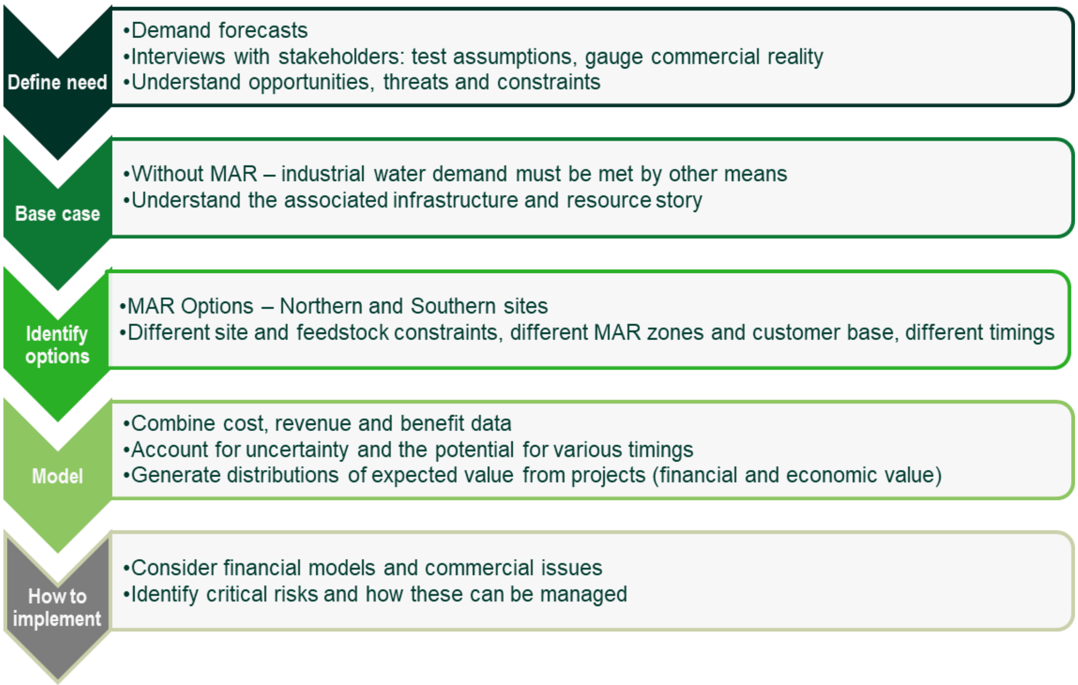
In 2015, a team of researchers led by the CSIRO prepared a report for the Australian Centre of Water Recycling into the potential use of MAR to supply heavy industry and preventing sea water intrusion[12]. This was followed by the then Department of Water's publication of a local water supply strategy for heavy industry in the WTC. These studies demonstrated that MAR is technically feasible and is likely to be environmentally sound. The studies also showed that MAR can be financially feasible under certain conditions. However, both recognised the need for further investigation of the financial and economic aspects of MAR in the WTC.

[12] McFarlane DJ (ed.) (2015). *Recycled water for heavy industry and preventing sea water intrusion*. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship.

1.2 Approach

The approach followed in this study is summarised in Figure 2.

Figure 2 Overview of study approach



1.3 Report structure

The report is organised as follows:

- Section 2 summarises the current supply and demand situation in the WTC and explores what options exist to meet future demand under 'business as usual' (also referred to as Base Case).
- Section 3 defines the two MAR supply options (Site 1 and Site 2), their respective costs, risks and geographic areas that could be serviced under each option.
- Section 4 summarises the approach taken to model the economic costs and benefits of MAR and the financial viability of each option.
- Section 5 presents the results of the financial analysis.
- Section 6 provides an assessment of commercial considerations and issues relevant to establishing a MAR scheme, including potential service options.
- Section 7 summarises the study's conclusions.

2 Current supply and demand situation

Within the WTC, demand for water from heavy industry is estimated to be approximately 28.5GL per year, of which 16GL is estimated to be met with groundwater, with the remainder met with potable scheme water (4GL), recycled water from the KWRP (5GL), and stormwater reuse.[13]

2.1 Groundwater

At present, there is about 36GL of licensed groundwater allocation in the Cockburn Groundwater Area (CGA) – which approximately corresponds to the boundaries of the WTC. This includes allocations to all users, not just industrial. Of this total, 13.6 GL is within the two groundwater subareas of greatest relevance to this study (Valley and Wellard).

A significant proportion of the allocated volume is not used. In the case of Valley subarea, around 26% is not utilised, while in the case of Wellard subarea, about 42% remains unused[14]. While actual use is less than the volume of license on issue, the Department of Water and Environmental Regulation (DWER) has established that these two groundwater subareas are collectively over-allocated by 2.8 GL. This means that there is a future potential for abstractions to exceed what is considered sustainable.

In order to guard against the risk of this happening, DWER has commenced recouping long-term unused water entitlements[15]. The purpose of this recouping is to restore the volumes available for use to the revised allocation limit set out in the Cockburn Allocation Plan. In the case of Valley and Wellard, the allocation limits are 5.50 GL and 5.38 GL respectively (a total of 10.88 GL). Over the five-year period up to 2016, average annual use has been 5.22 GL and 3.82 GL, respectively (a total of 9.04 GL). Therefore, this analysis assumes that there will remain a surplus of 1.84 GL of groundwater after the recouping process is completed (10.88 GL less 9.04 GL).

Groundwater demand in the WTC is dominated by a small number of large licensed users. For instance, in the Wellard groundwater subarea (the southern-most subarea in the CGA), eight groundwater licenses account for more than 90% of the allocated water from the Cockburn, Wellard, Perth – Superficial Swan resource.

---

13 Department of Water, 2016, Western Trade Coast heavy industry local water supply strategy.

14 Data from DWER based on the four year period up to 2016

15 Department of Water and Environmental Regulation (DWER) 2018 Cockburn Groundwater Allocation Plan – for public comment

Groundwater is an inexpensive supply source as users only incur the cost of pumping and on-site treatment (to the extent that treatment is required for their particular industrial use). Synergies' consultations reveal that most groundwater users are treating their water before use for industrial purposes (the exception being water that is used for cooling). On-site treatment would typically take the form of reverse osmosis at the users' premises. This provides users with the ability to treat water to a quality standard that is fit for their particular purposes.

2.2 Kwinana Water Reclamation Plant

Built in 2004, the KWRP uses a reticulation network to supply customers directly with high-quality, treated water at a price below that of scheme water. The KWRP has a total capacity of 6 GL per year (16.7 ML/day), of which 5 GL per year (14 ML/day) is currently being used. There is scope for expanding the plant by a further 3.6 GL (9.9 ML/day) with additional investment. The KWRP is owned and operated by the Water Corporation and supplies water on a fully commercial basis to five or six industrial users. The KWRP has scope to supply additional customers located within close proximity to Kwinana (at the southern end of the region) but is not a feasible option for supplying customers located in other areas of the WTC due to the cost and difficulty in establishing the required pipe network.

The KWRP produces recycled water of a high quality with low conductivity (salinity). Synergies was informed by several KWRP customers that they were able to use water from this source without further treatment. Others 'shandy' the KWRP water with groundwater to obtain a water product that meets their quality requirements.

2.3 Potable scheme water

Potable (drinking quality) scheme water is available to all industrial properties. It is supplied by the Water Corporation's Integrated Water Supply Scheme (IWSS).

Scheme water can thus be regarded as the 'backstop' water source to meet growing industrial demand in the WTC should other, less expensive water sources not be available.[16] The Water Corporation has confirmed that all industrial customers in WTC, including future customers in greenfield developments, could be serviced through the IWSS if required. In addition to the standard infrastructure contribution charge,

[16] In principle, other backstop sources could be feasible. For example, a consortia could construct and operate a desalination plant, if that was more cost-effective than purchasing scheme water. However, for the purpose of this analysis we have taken scheme water from the IWSS to be the 'backstop' water source. To the extent that desalination is less expensive than scheme water, this would reduce the financial competitiveness of MAR (as it would then compete with desalination not scheme)

customers would be required to pay for any distribution scheme upgrades or mains extensions to their site.

Scheme water is a ready substitute for groundwater, but owing to is generally of higher quality than industrial users actually require.

2.4 Demand projections

Consistent with the project brief, Synergies has based this analysis on demand forecasts developed in 2015 by Resource Economics Unit (REU), henceforth referred to in this report as the 'REU forecasts'.[17] The REU forecasts were prepared for the Department of Water's report titled *WTC heavy industry local water supply strategy*, published in 2016.

REU generated three sets of demand growth forecasts, each of which are based on an economic input-output model that is used to project economic growth in the WTC. Water demand is assumed to increase in proportion to three economic indicators:

- a central water demand forecast was based on value added projections,
- a lower bound forecast was based on employment projections; and
- an upper bound forecast was based on total output projections.

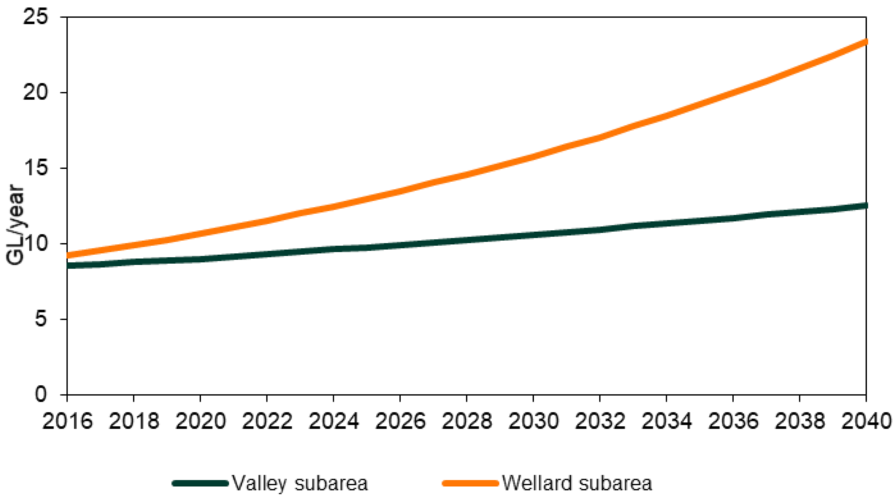
These three forecasts reflect three different assumptions about the relationship between economic growth and water demand growth, but all three forecasts are based on a single economic growth scenario.

The three demand forecasts are further disaggregated and applied to each of the four groundwater subareas within the WTC by allocating a share of projected future water demand, taking account of the characteristics of each type of industry in the subarea, availability of land and planning considerations (see Appendix A for further details).

Figure 3 shows the central forecasts made by REU for the two subareas most relevant to this study. It shows very rapid demand growth in the Wellard subarea and modest but continuous growth in the Valley subarea. By the end of the period shown, almost 1GL of new demand for water is projected to be generated each year in the Wellard subregion.

[17] Resource Economics Unit (2015) *Economic growth projections for industry in the WTC to 2031*

Figure 3 REU central demand forecasts of heavy industry demand for water for Valley and Wellard subareas



Data source: REU, 2014

2.4.1 Comparison of REU forecasts with on-the-ground developments

Since demand is critical to the economics and financial viability of MAR, Synergies explored the validity of the projections through interviews with ten of the region's largest users of groundwater. This identified several new potential projects being contemplated by existing water users in the southern regions of the WTC[18] that could generate demand for water. However, the scale of potential new demand sources identified in this process was relatively small, compared with the scale of demand growth projected by the REU.

We found that four large users are exploring options to substitute their current scheme water usage with an alternative source. Two others are considering expanding their operations, which will trigger the need for more water. The combined effect of these actions would be to increase demand by about 2.7 GL by 2020. The interviews also found that other stakeholders hold substantial unutilised groundwater allocations that they are considering selling or trading. (Our analysis includes these findings as potential future events future events that can create demand or supply tranches independent of growth associated with the REU forecasts – see section 5 for details).

The potential for new water demand from greenfield developments is more difficult to verify with reference to tangible projects. Synergies is aware of the Tianqi Lithium

[18] The southern region of the WTC forms a focus for this study because of the geographic reach of the MAR zones, discussed further in Section 3.1

Hydroxide processing facility, which is currently under construction in the Kwinana Industrial Area[19]. Another major project slated for the same area is the Lithium carbonate refinery announced by Kidman Resources and SQM[20]. In both instances, Synergies has little information regarding likely on-site water requirements.

Latitude 32 (covering an area of around 1000ha) has been presented as a possible site for significant new greenfield developments. Synergies understands that Latitude 32 is strongly connected to the outer harbour development, with suggestions that it would host freight logistics and intermodal facilities. Synergies further understands that the subdivision is currently in a holding phase until the Westport taskforce determines the site for the outer harbour and the associated logistics hub[21]. In any case, it is unclear what water requirements businesses of this type may have, but at first inspection they would seem likely to be very different (lower) to those of the chemical and mineral processing businesses concentrated in the southern regions of the WTC.

We consider demand forecasting faces unavoidable difficulties that render multi-decade forecasts necessarily imprecise. The main concern raised by the REU forecasts from Synergies perspective is the fact that the forecast range does not include any scenario under which demand for water does not grow at all. Given uncertainties about the rate of future economic growth and the nature of future changes in economic structure, this seems to us an entirely plausible future outcome, that ought to be explicitly accounted for in this analysis (see section 5 for details on our approach to incorporating such a scenario).

2.5 What would business as usual look like?

The 'business as usual' scenario, or Base Case option, provides a reference point against which to compare the costs and benefits (or revenues[22]) of any new supply options under consideration – in this case options to supply water though MAR. The Base Case is not static, but rather reflects how water supply is expected to develop in the absence of the new MAR supply options.

---

[19] The West Australian, 6 March 2018, "Lithium expansion: Tianqi's mine set to double in size as processing plant is built in Kwinana", https://thewest.com.au/news/wa/lithium-expansion-tianqis-mine-set-to-double-in-size-as-processing-plant-is-built-in-kwinana-ng-b88766174z

[20] Mining Weekly, 4 May 2018, "Kidman-SQM JV plans lithium refinery in WA's Kwinana", http://www.miningweekly.com/article/kidman-sqm-jv-plans-lithium-refinery-in-was-kwinana-2018-05-04.

[21] Pers comm, David Tomasich, LandCorp, 8 May 2018

[22] Benefits in the case of the economic analysis and revenues in the case of a financial analysis.

Under Base Case, it is assumed that all demand from new and expanding businesses in the WTC can and will be met through some combination of groundwater, recycled water from KWRP, or scheme water.

- **Utilisation of surplus groundwater**. Groundwater is an inexpensive supply source as users only incur the cost of pumping and on-site treatment (to the extent that treatment is required for their particular industrial use). It therefore makes economic sense to make best use of available groundwater resource before considering more expensive alternatives. While all groundwater is fully allocated, not all licence is fully utilised. As explained in section 2.1, there will remain a surplus of 1.84 GL of unused groundwater after the recouping process is completed, which we assume will be potentially become available for use through water trading.[23] Pricing data for water trades in this region is not available, although there is some evidence that water rarely trades much above $0.50 per kL (i.e. temporary water trade).

- **Recycled wastewater from KWRP**. The KWRP has scope to supply additional customers located within close proximity to Kwinana but is not a feasible option for supplying customers located in other areas of the WTC. Synergies understands the Water Corporation charges around $1.50/kL for KWRP water, although we could not verify this estimate as pricing information is commercial in confidence.

- **Scheme water**. Scheme water is available to all users (or a connection could be established relatively easily), but this source is expensive relative to groundwater and KWRP. The Economic Regulation Authority recently estimated that the Water Corporation's long run cost of supplying bulk potable water is around $2.40/kL and will increase over time[24].

The choice made by water users between these potential sources will reflect their access to the supply source, the cost of use and the suitability of the water supplied. Scheme water will remain the 'back stop' supply source once other sources have been fully allocated. The Water Corporation has new supply sources for bulk potable available to it, for instance in the form of seawater desalination and groundwater replenishment using recycled water that are effectively unconstrained, although potentially costly. Further, industrial demand is unlikely to become constrained due to lack of water, as water is a very small component of industrial input costs (estimated at 0.2% of the total

---

23 This is a conservative assumption because there may also be scope for water to shift from low value uses (e.g. agriculture) to higher value, industrial uses as groundwater in the WTC becomes scarcer

24 Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105

production value of the types of industries represented in the WTC[25]) and therefore businesses will be prepared to pay for scheme water if this is the only available water source.

[25] Based on share of output from "Water Supply, Sewerage and Drainage Services" into relevant WTC industries by basic prices, compared to total Australian production across those industries, ABS data 5209.0.55.001 Australian National Accounts: Input-Output Tables – 2014-15.

3 MAR supply options

This study is focussed on producing and delivering additional water through recycling treated wastewater, recharging the superficial aquifer and assigning additional new allocations to water users, thereby allowing them to abstract a corresponding amount of water from the aquifer.

MAR water is expected to require treatment by users onsite, before it can be used in industrial processes. Assuming access to the treated wastewater transported through the Water Corporation's SDOOL, MAR could supply very large quantities water within two years.

An alternative source of treated wastewater has been identified in the South of the WTC, but the volumes available in the near term would limit the potential scale of MAR, at least until around 2027. The cost of MAR water in the WTC has been assessed by GHD and will need to be below the final cost of scheme water in order to be competitive.[26]

In this section we examine the features of two MAR supply options (Site 1 and Site 2) that have been proposed through previous investigations. An overview is provided on:

- the areas capable of being supplied by each site;
- key features of each site, including pros and cons;
- the volumes of wastewater required to implement each option;
- the direct capital and operating costs of each option; and
- a summary of other, indirect costs, and potential benefits of MAR.

3.1 MAR supply areas

Key Assumptions:

- the MAR supply area for Site 1 (MAR Zone 1) overlays much of the Thompsons and Valley groundwater subareas.
- the MAR supply area for Site 2 (MAR Zone 2) overlays much of the Valley and Wellard groundwater subareas.

MAR contributes an additional input to natural groundwater resources, so recharge and recovery volumes will be managed separately to existing resources. Licensing of the

[26] Here the final cost includes the cost including any additional treatment costs incurred by the customer prior to using the water.

MAR scheme would not be subject to existing groundwater subarea boundaries used to manage allocation limits. The location of infiltration and abstraction sites will be dependent on the extent of the recharge and the hydraulic connection between these sites.

A MAR scheme will comprise several components, of which the MAR facility (at either Site 1 or Site 2) will form the production component. The MAR scheme will also need to define a MAR Zone. The MAR management zone boundary should define the zone of influence around the infiltration structure(s). It should incorporate the area of influence of water quality changes, taking into account factors such as water quality requirements for intended end uses, and the protection of water users and environmental values of aquifers and ecosystems.

The MAR Scheme would include a regulatory and contractual framework to allow customers to access the MAR water. This framework would define a MAR zone – being the area within which water customers were permitted to access the MAR water using abstraction bores. This MAR zone would be prescribed based on a hydrological assessment of how far and how quickly groundwater recharge associated with infiltration at Site 1 or Site 2 extended.

Figure 4 shows the CSIRO's modelling assessment of the groundwater mounding associated with MAR at the two sites.

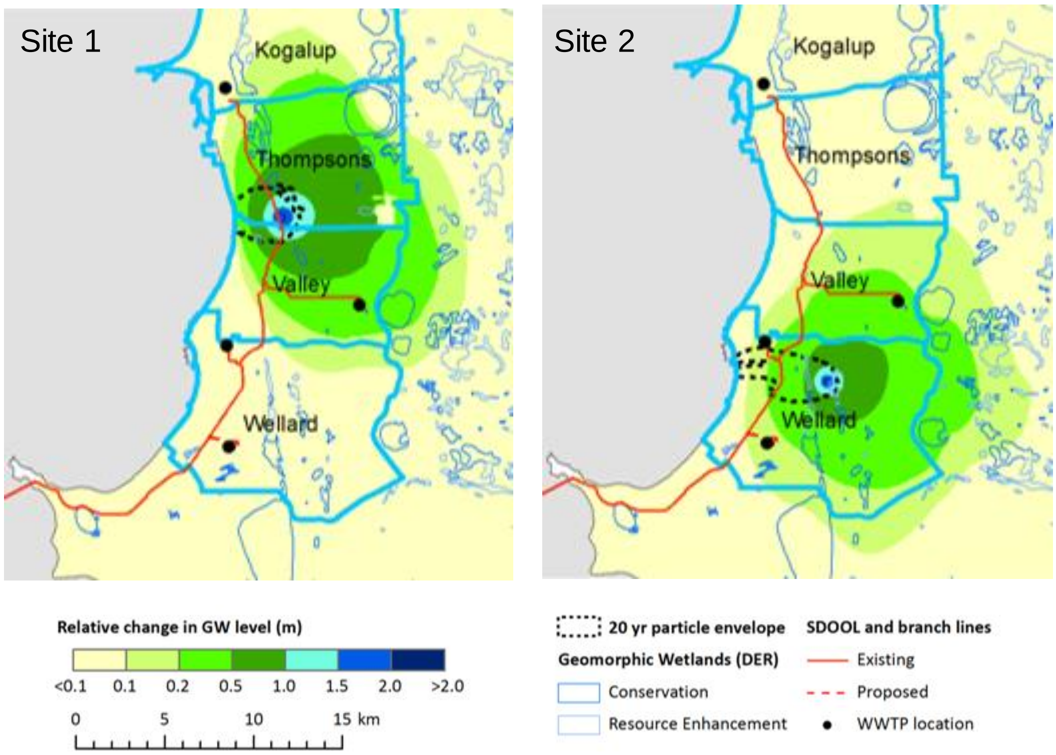
The groundwater subareas that comprise the Cockburn Groundwater Area are overlaid to illustrate the geographic extent of each MAR zone. The map shows that groundwater recharge associated with Site 1 is most pronounced within the Thompsons and Valley groundwater subareas and very limited for the Kogalup and Wellard groundwater subareas. The effect of MAR at Site 2 is most pronounced for the Wellard and Valley groundwater subareas, very limited at Thompsons groundwater subarea and not apparent at all for the Kogalup groundwater subarea.

On the basis of Figure 4, the project Working Group determined that:

- the MAR zone for Site 1 will be assumed to extend throughout Thompsons and Valley groundwater subareas and
- the MAR zone for Site 2 will be assumed to extend throughout Valley and Wellard groundwater subareas.

Thus defined, these two MAR zones would allow the alternative MAR schemes associated with Sites 1 and 2 to supply demand arising anywhere within the corresponding groundwater subareas.

Figure 4 Modelled groundwater mounds from infiltration at Site 1 (North) and Site 2 (South)



Source: McFarlane DJ (ed.) (2015). *Recycled water for heavy industry and preventing sea water intrusion*. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship, page 160

3.2 Key features of each option

The two options considered for implementing MAR are:

- a recycling and infiltration facility at Site 1, located in the mid to northern part of the WTC, tailored to the treatment requirements associated with taking treated wastewater from the SDOOL; and

- a recycling and infiltration facility at Site 2, located in the southern part of the WTC, tailored to treatment requirements associated with taking treated wastewater from the East Rockingham Wastewater Treatment Plant (WWTP) and the land constraints of that site.

The two facilities assessed in this study are capable of producing an equivalent volume of water for MAR (3.55 GL/yr), but have different configurations because of their different inputs and land constraints, which are reflected in different capital and operating costs. Further, the two sites will supply different geographic areas (referred to as 'MAR zones'), which is governed by the expected radial distance of groundwater recharge from the central injection point.

Table 1 summarises the key features of each MAR option. Additional detail on the assumptions and design of each site and facility is provided in Appendix B.

Table 1 Summary of MAR Options

	Option 1 – Site 1 (Northern site)	Option 2 – Site 2 (Southern site)
Treated wastewater source	Directly from SDOOL (wastewater has undergone treatment at Woodman Point WWTP located to the north of the site, then transported via SDOOL prior to being extracted for use)	From East Rockingham WWTP. This wastewater is higher quality than that sourced directly from SDOOL.
Production volumes	10 ML/day (3.55GL/yr) immediately, subject to requirements	10 ML/day (3.55GL/yr) from 2027 when sufficient feedstock becomes available.
Treated wastewater quality and implications for treatment level at MAR plant	The planned development of the Woodman Point Advanced Wastewater Treatment Plant (AWTP) will increase the concentration of salts in wastewater flows, and thus require the wastewater input will require treatment with reverse osmosis (post 2030)	Low conductivity, low nitrogen, no reverse osmosis or denitrification required.
Staging	Two stages if commissioned prior to 2030 (with the first stage only requiring a lower level of treatment of wastewater inputs compared to after the AWTP commences operation)	Single stage
Treatment of recycling plant effluent	• To be returned to the SDOOL • This may give rise to increased treatment costs for Water Corporation as it reduces the quality of wastewater in the SDOOL (these costs have not been specified by Water Corporation)	• Comparatively low volume of effluent discharged to SDOOL, and not expected to cause any additional costs for Water Corporation
Efficiency in producing MAR water from treated wastewater	81% due to reverse osmosis losses (from 2030)	95%
MAR Supply Area	MAR Zone 1: Thompsons and Valley groundwater subareas	MAR Zone 2: Valley and Wellard groundwater subareas
Existing water users in MAR area	• 19 licensees have one or more bores close to Site 1 • Total allocated volumes for these licensed are 7.53GL	• 20 licensees have one or more bores close to Site 2 • Total allocated volumes for these licensed are 9.59GL
Key risks	• Site may become landlocked by surrounding transport infrastructure and require substantial civil works costs to resolve this • If Site 1 had to be shut down for maintenance, that would mean an increase of wastewater going through the SDOOL and the Water Corporation indicates that it would have to build in greater risk management measures for this, adding to its costs.	• Frequency of gallery renovations uncertain due to limited precedents • treated wastewater volumes may grow more slowly than assumed. • According to Water Corp, Site 2 is a 'less complex' process than Site 1, so there's less risk overall of Site 2 having to be shut down

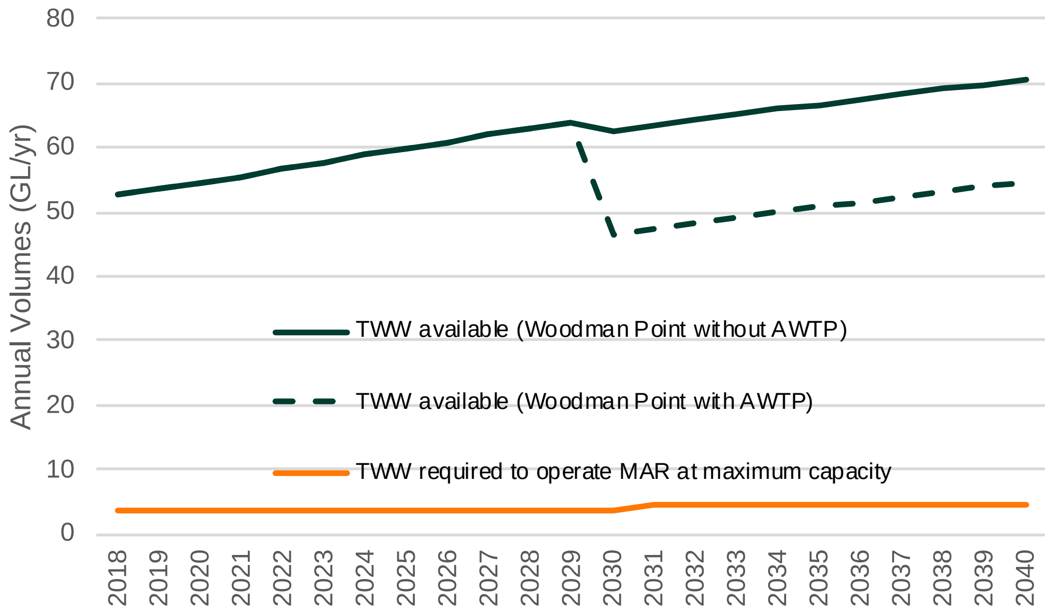
3.3 Treated wastewater supply for each option

Key Assumptions:

- treated wastewater supply is never limiting at Site 1
- treated wastewater supply is limiting at Site 2 until 2027 and ceases to be a limiting factor from that year on.

Site 1 relies on the SDOOL for its source water. The flows through SDOOL greatly exceed the treated wastewater volumes required to operate the MAR facility at Site 1 at full capacity, even after allowing for an offtake of 16GL for Water Corporation's proposed Groundwater Replenishment Scheme at Woodman Point, which is planned to commence production in 2030 (See Figure 5). Site 1 is therefore assumed not to be subject to supply constraints.

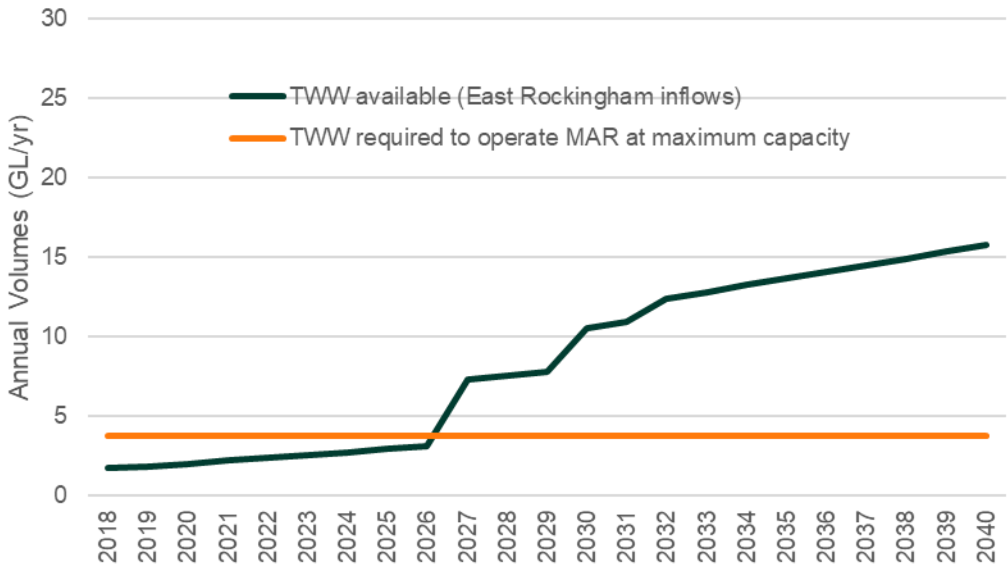
Figure 5 Treated wastewater supply compared to MAR requirement – Site 1



Note: treated wastewater available doesn't account for diversion of treated wastewater to other uses like KWRP
Data source: Water Corporation and GHD figures

Site 2 relies on the treated wastewater discharged by the East Rockingham WWTP which currently is expected to gradually increase its throughput prior to 2027 and then see a step change increase in wastewater volumes when some of the load at Point Peron WWTP will be transferred across to East Rockingham. Figure 6 compares the treated wastewater available at Site 2 with the volume required to satisfy demand and shows how the available volume is below the MAR requirement in all years up to and including 2026. From 2027 onwards, this supply constraint does not apply.

Figure 6 Treated wastewater supply compared to MAR requirement – Site 2



Data source: Water Corporation and GHD figures

3.4 Direct costs of each option

The costs of producing MAR water at each of the two sites differ for the following reasons.

- Each site is proposed to take treated wastewater (TWW) from different WWTPs. The water quality of TWW at the two WWTPs varies, requiring different treatment processes and costs prior to injection. Further the average cost of treatment at Site 1 will change depending on when the facility is assumed to be built, since the cost of treatment will be higher from 2030 onwards due to the increased salinity of feedstock from this time.
- The two sites are also subject to different physical layout constraints. Limitations atSite 2 require the adoption of a higher cost infiltration strategy.

3.4.1 Cost breakdown

Synergies has used GHD[27] estimates of the capital and operating costs of each site to develop measures of the levelised unit cost of recycled water that can be produced through each option (a levelised cost is calculated by dividing the net present value of water supply cost by the discounted value of all future annual volumes of water

[27] GHD, 2018, Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study, March 2018.

delivered by the scheme, in kilolitres). The costs of each MAR option are summarised in Table 2. Site 1 is significantly more expensive than Site 2 ($0.95/kL and $0.60/kL, respectively, based on full utilisation).

Further details on the capital and operating costs considered in the modelling are provided in Appendix B.

Table 2 Overview of costs assumed for Sites 1 and 2 ($2018)

	Units	Site 1		Site 2
		Phase 1	Phase 2	
Initial Capex	$	$21,457,000	$6,620,000	$17,264,000
Replacement Capex[a]	$	$3,816,000	$3,731,000	$3,882,000
Opex Fixed	$/year	$328,000	$427,000	$302,000
Opex Variable	$/kL	$0.122	$0.251	$0.119
Facility unit costs				
Levelised unit cost		Construct 2020 and upgrade 2030	Construct after 2030	
100% utilisation	$/kL	$0.95/kL[b]	$1.13/kL	$0.60/kL
10% utilisation	$/kL	$9.46/kL	$11.3/kL	$5.97/kL

a Replacement capex is required at different intervals for different types of equipment. The assumed replacement schedule for relevant items is detailed in Appendix B.

b Costing assumes construction starts in 2020, commissioning in 2022, before switchover to phase 2 cost structure in 2030.

Source: Cost estimates from GHD, 2018, Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study, March 2018

3.5 Indirect costs

Several other (indirect) costs have been evaluated as part of the analysis.

3.5.1 Customer-side abstraction and treatment costs

Key Assumptions:

- All MAR customers must pre-treat MAR water prior to using it for industrial processes.
- All MAR will require reverse osmosis (RO) treatment at a cost of $1.20/kL and our estimated unit cost for a small (1ML/day) RO facility.[28]
- We have also examined the impact of using lower treatment costs on the financial viability of MAR).

[28] While the level and form of treatment is expected to vary from one customer to the next, depending on their individual use requirements and their existing treatment capacity, we take a conservative approach by assuming a cost at the upper end of the likely range for all customers.

- MAR customers are assumed to incur no material abstraction costs to take MAR water from the superficial aquifer.

Synergies' rationale for incorporating an on-site RO treatment cost for MAR water is based on the information we received in our consultations with several industrial users. We were told that:

- Users are treating groundwater onsite with RO, and that they expected that this would also be necessary for MAR water if it became available (whether this is a perception or reality is to be established. Seawater intrusion and increasing salinity levels in groundwater may be partly responsible for the RO treatment that users are currently implementing, but this needs further investigation).
- Several firms that possessed underutilised groundwater allocations stated that on-site water treatment capacity is their key constraint to using this water[29].
- Several firms that said they would have to install a larger RO treatment plant if their groundwater or MAR water needs increased, because they were 'at capacity'.
- While it was acknowledged by stakeholders that some groundwater could be used for particular purposes with little or no treatment, this was the exception as opposed to the rule.

Given that the sample of users we spoke to was fairly small (ten in total), there is some uncertainty around the $1.20/kL cost assumption and how widely it applies. It could be said that:

- The water quality requirements of individual industrial customers will vary, with some requiring higher water quality than others.
- In some instances, MAR water could be 'shandied' with potable scheme water or KWRP water (with much lower salinity concentrations) to produce 'fit for purpose' water.
- The actual post-abstraction treatment costs for MAR will vary from one customer to the next. Those that already have spare on-site treatment capacity may only incur minimal additional costs, however those that are reaching capacity will have to make new capital investments to upgrade their treatment plant.

Given these uncertainties, $1.20/kL should be regarded as an upper bound cost. Sensitivity tests using lower treatment costs of $0.80/kL and $0.50/kL have been

---

[29] Synergies acknowledges that this may not be a universal problem. It will depend on the groundwater resource from which a industrial user is abstracting

conducted to examine the impact of using lower treatment costs on the financial viability of MAR.

The cost of installing and operating bores to access the superficial aquifer is expected to be immaterial. In many cases, customers will already possess working bores that are capable of increasing production without further investment and where new bores are required, the cost of developing the relatively shallow bores required is expected to be small compared to the ongoing value of water. Pumping costs are also relatively small.

3.5.2 Wastewater resource cost

Key Assumptions:

The resource cost (opportunity cost) of using wastewater for MAR is assumed to be zero.

Using wastewater for MAR could impose resource costs on the community, if it prevents the water from being used in other beneficial applications, such as future scheme water supply through Water Corporation's groundwater replenishment (GWR) program. This can also be thought of as the 'opportunity cost' of using treated wastewater for MAR.

In this analysis, the resource cost associated with MAR at either site is assumed to be zero, primarily because there are sufficient volumes of treated wastewater to meet both the needs of Water Corporation's proposed GWR at Woodman Point (for augmentation of future drinking water), and the production of MAR water for industrial use. We expand on this reasoning below:

- The Water Corporation expects continuing growth in demand for drinking water and has identified GWR as part of its supply strategy, with plans to produce 16GL of recycled water at Woodman Point AWTP by 2030[30]. Synergies understands GWR to be considerably cheaper than desalination – the Water Corporation's next best option for potable water production.
- Thus, in theory the diversion of treated wastewater into MAR for industrial use could impose resource costs on the State if it forces the Water Corporation to expand its desalination program, instead of utilising GWR.
- On the basis of the Water Corporation's stated plans for GWR and the volumes of treated wastewater discharged into the SDOOL, we do not see evidence for the availability of wastewater becoming limiting on the Water Corporation's GWR program in the foreseeable future.

---

30 GHD (2018) Western Trade Coast Managed Aquifer Recharge Scheme Engineering Design and Costing Study, March 2018, page 11

- Further, if industrial users cannot be supplied with non-potable recycled water on the grounds that wastewater is scarce, they will demand additional scheme water. This would force the Water Corporation to undertake additional desalination.
- Finally, the Water Corporation advises that the quantity of treated wastewater projected to be produced at the Woodman Point WWTP is large enough to supply treated wastewater to both a Water Corporation groundwater replenishment scheme and the MAR facility being investigated in this project.

3.5.3 Facilitation costs imposed on Water Corporation

Key Assumptions:

The incremental cost to the Water Corporation of facilitating MAR at either site is assumed to be zero.

Facilitation costs are defined as the potential costs to the Water Corporation from servicing a MAR operator (or introducing a MAR scheme into its own operations) that are additional to what the Water Corporation would have otherwise incurred. Examples could include:

- capital costs arising from the need to 'bring forward' an extension or upgrade to pipeline
- costs of connecting a wastewater customer (i.e. MAR operator) to the SDOOL
- additional operational activities, such as monitoring the quality and volume of effluent discharged from a MAR facility into the sewage network.

Based on discussions with Water Corporation, Synergies has assumed that facilitation costs would be negligible. The following matters were taken into consideration in reaching this position:

Effluent from the Site 1 treatment process would be discharged back into the SDOOL, thereby increasing the salinity of the treated wastewater in the SDOOL. This could have process implications for the KWRP and could increase the Water Corporation's costs. However, since the quantity of treated wastewater withdrawn for MAR at Site 1 is small compared to the total flow in the SDOOL, any impact is assumed to be small and is ignored for the purposes of this study.

Comparatively small volumes of effluent are discharged from Site 2, and therefore the costs of treating this would be negligible.

The Water Corporation indicated that it might need to make additional provision for MAR scheme shutdowns (e.g. due to faults or maintenance) in the design and operation of the SDOOL. However, we were advised that this could be managed and would not impose material costs.

3.6 Benefits

3.6.1 Potable water savings

Key Assumptions:

Potable water savings valued at the LRMC of potable water supply, which is assumed to be $2.40/kL at present, but increasing to $4.30/kL in real terms by 2040.

To the extent that the use of MAR water would displace an equal volume of potable water use, the development of a wastewater recycling scheme for WTC will deliver an economic cost saving. The value of this benefit is calculated as the volume of water saved in a given year, multiplied by the LRMC of potable water (applicable for the same year). We value scheme water for both the financial and economic analysis in accordance with the Economic Regulation Authority's 2017 LRMC forecast[31].

3.6.2 Avoided costs

Key Assumptions:

- The Water Corporation will not avoid any infrastructure upgrade costs as a result of MAR proceeding at either site.
- The Water Corporation's wastewater treatment operating costs (e.g. chemicals and energy) will remain unchanged.

According to Water Corporation, Site 1 could lead to some avoided costs (minor deferral in timing of SDOOL) but the avoided costs would not be material. This is because the volume of off-take by Site 1 would be relatively small (just 10-20 ML/day, or 3GL/yr) compared to the overall amount of wastewater going down the SDOOL (200 ML/day).

In the case of Site 2 the potential avoided costs would be even less. This is because there is only a short section of SDOOL between East Rockingham and the point at which the SDOOL discharges into the ocean. So, most of the upgrade cost would be incurred anyway, north of the off-take.

[31] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105

GHD advised that the Water Corporation might consider it too risky to rely on the reductions in treated wastewater volumes associated with the MAR facility, when planning SDOOL capacity upgrades. Should the MAR facility need to be temporarily shutdown, the SDOOL would still need to be able to handle peak flows including the treated wastewater that would otherwise have been handled by the MAR facility. GHD considered that it would be difficult for an operator of a MAR facility to provide the Water Corporation with the necessary guarantees of service availability that would allow the Water Corporation to realise savings by deferring SDOOL capacity upgrades.

The Water Corporation's wastewater treatment operating costs will remain unchanged, since the 'raw' wastewater will continue to be treated at Woodman Point and East Rockingham WWTPs – upstream and hence unaffected by the MAR facilities. The lower volumes of wastewater transported down the SDOOL as a consequence of MAR are expected to have only a marginal (negligible) impact on pumping costs

3.6.3 Environmental benefits (and costs)

Key Assumptions:

No environmental benefits or costs are accounted for in the analysis due to the lack of sufficiently specific data on environmental outcomes when the location and rate of MAR abstractions is taken into account.

CSIRO studied the proposed MAR schemes, at both Sites 1 and 2, as reported in a 2015 report for the Australian Water Recycling Centre of Excellence[32] and considered the potential environmental impacts (positive or negative) that a MAR scheme might bring. CSIRO considered several potential impacts:

- Reduced or increased risk of salt water intrusion
- Increased nutrient inflows into wetlands
- Increased nutrient inflows into the Cockburn Sound
- Improved water levels in wetlands

CSIRO found limited cause for environmental concern about a MAR scheme in the WTC, noting the long historical experience with the infiltration of treated wastewater in Kwinana by the Water Corporation. However, CSIRO considered that more analysis

[32] McFarlane DJ (ed.) (2015). *Recycled water for heavy industry and preventing sea water intrusion*. A report to the Australian Water Recycling Centre of Excellence Government and industry partners from the CSIRO Land and Water Flagship

might be required to confirm the level of additional treatment required, in light of any particular environmental receptors affected.

Under base case, this analysis does not consider the loss of wetlands as a potential environmental cost, because DWER has capped abstractions.

Further, the MAR scheme modelled in this analysis does not contemplate putting more water into the aquifer than is being removed, and hence does not offer any opportunity to recharge groundwater to benefit groundwater dependent ecosystems (such as wetlands).

CSIRO did not model the combined effect of MAR infiltration and corresponding MAR scheme abstractions, which would be approximately equal over time and across the MAR zone. CSIRO's analysis did not, nor was it intended to, evaluate environmental outcomes associated with the location of specific MAR customers and the intensity of their abstractions. Thus, while the CSIRO study provides a sound basis for evaluating the likely workability of a MAR scheme from an environmental perspective, it cannot support detailed consideration of environmental outcomes in a cost benefit analysis.

4 Evaluation approach

This study assesses the proposal for a MAR Scheme from both a financial (enterprise) and an economic (whole of state) perspective. Whereas the financial analysis evaluates whether the project looks attractive and viable to a potential MAR Scheme operator, the economic analysis must assess whether the project leaves the Western Australian community better or worse off. To be financially viable, a project must be expected to raise sufficient revenues to cover costs. To be economically beneficial, a project must be expected to produce economic benefits in excess of its economic costs.

For projects where there are significant unpriced, or 'non-market' impacts (also referred to as 'externalities') the results of a Cost Benefit Analysis (CBA) can be quite different to a financial analysis. However, as was shown in the previous section, the MAR options being considered in this study are assessed as not giving rise to any material externalities. That is, we have identified and assumed:

- Zero wastewater resource cost;
- Negligible facilitation costs;
- Zero avoided wastewater treatment and infrastructure upgrade costs; and
- No identified material environmental benefits[33] or costs.

It follows that in this analysis, the financial and CBA assessments will be very closely aligned. The main differences between the two assessments will be that the financial analysis will assume a charge is imposed by the Water Corporation for the use of treated wastewater and that the operator of the MAR scheme offers a discount to its customers compared to scheme water to generate business.

4.1 Analytical steps

The financial and economic analysis is conducted according to the following steps.

1. The value generated per unit of MAR water delivered (either financial or economic depending on the case) is estimated. This is calculated as the difference between total unit revenue (or benefit) and the unit costs of delivering usable water.
   a) For the financial analysis, value per unit of MAR water supplied, termed Marginal Revenue, is calculated as the difference between:

[33] Noting that MAR schemes could be used to deliver environmental benefits, our analysis assumes that the MAR facility is built for commercial purposes and previous research did not assess the possibility of environmental side-benefits from a MAR scheme that sees all additional recharge offset by additional abstractions.

- the total unit revenue, which will reflect
  - a benchmark price to beat (the price per kL of scheme water[34]); minus
  - a discount to secure customers; minus
  - the cost to customers of treating a kL of MAR water onsite to a suitable standard.
- The unit costs of supply, which will reflect:
  - all MAR facility costs; and
  - unit charges for treated wastewater.

b) For the economic analysis, value per unit of MAR water supplied, termed Marginal Economic Benefit, is calculated as the difference between:

- the economic benefit per unit of MAR water delivered, calculated as the difference between:
  - the avoided cost of the next best alternative supply source (assumed to be the price of scheme water[35]); minus
  - the cost to customers of treating a kL of MAR water onsite to a suitable standard.
- the unit costs of supply which will reflect MAR facility costs alone.

2. Application of the REU demand forecasts, complemented by supply and demand 'events'

3. Project net present values (NPVs) are determined by combining the inputs, namely:
   - MAR facility costs, as varied by making different assumptions as to investment timing;
   - Volumes demand, as given by estimated supply shortfalls. This is calculated using:
     - different assumptions as to underlying growth rates (REU forecasts for the areas able to be serviced by Sites 1 and 2, respectively) and
     - demand and supply 'events';
   - The unit value per unit of MAR water delivered, as varied by the effect of timing on the unit price (cost) of scheme water and MAR facility costs.

---

[34] The price is assumed to equal the Water Corporation's long run marginal cost.

[35] The price is assumed to equal the Water Corporation's long run marginal cost.

4. Sensitivity test other key parameters (besides demand[36]).

We have assessed the project first in financial terms and optimised investment timing realistically in light of the significant demand uncertainties. Based on the timing assumptions established by this analysis, we subsequent assess the project from an economic perspective (CBA).

[36] Our modelling approach explicitly considers the exposure of the project to demand risk and hence no further sensitivity analysis of this parameter is required.

5 Financial and economic analysis

This section summarises the financial analysis of the MAR Scheme, carried out in accordance with the steps described in Section 4. The section concludes with a discussion around demand-related risks faced by the project, the impact of these risks on project viability, and what actions a scheme proponent could take to mitigate against these risks.

5.1 Calculating the marginal revenue for MAR

We start the analysis by estimating the value per unit (marginal revenue) potentially available to a MAR supplier. This is set equal to the price of potable scheme water, less the unit cost of wastewater input and less the cost to the customer of any on-site treatment of MAR water to bring it up to a standard for industrial use.

The logic of the calculation is that, in the absence of a MAR scheme, once existing groundwater and KWRP supply sources have become fully utilised users would have no alternative but to service their additional demand with scheme water.[37] If MAR was available, users would be willing to pay up to price of scheme water for the MAR water, less any cost incurred themselves in having to treat the water to a suitable standard for industrial use. Further, we subtract the cost of wastewater input from the marginal revenue able to be earned by the MAR supplier, as this is a payment to Water Corporation.

The following costs and price assumptions have been adopted:

- The value for potable water is initially set to $2.40/kL, increasing over time, which is the current LRMC of bulk water production for the Water Corporation, as estimated by the Economic Regulation Authority[38]
- A wastewater input cost of $0.50/kL, which the Water Corporation has advised is the price it would look to charge for the take of treated wastewater (in practice, this charge would be negotiated between the MAR scheme operator and the Water Corporation. In principle, the charge should reflect the cost to the Water

[37] Scheme water is assumed to be the 'backstop' water source. Water Corporation has confirmed that all industrial customers in WTC, including future customers in greenfield developments, could be serviced through the IWSS if required. In addition to the standard infrastructure contribution charge, customers would be required to pay for any distribution scheme upgrades or mains extensions to their site. Further, our assumption of an inclining LRMC for potable water captures the effect of progressive infrastructure augmentation to support increasing demand for water in Perth

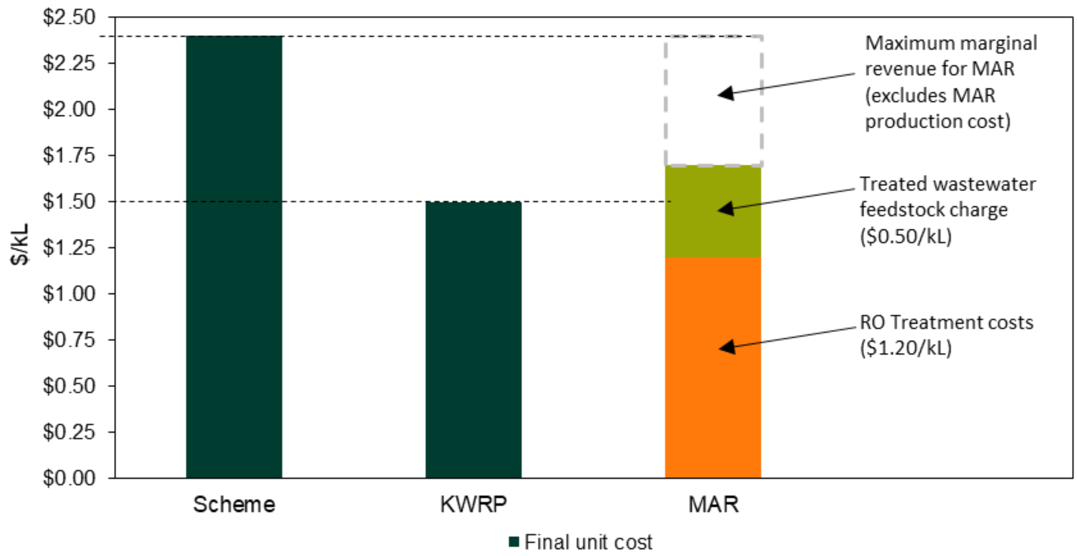
[38] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105

Corporation of facilitating access to the wastewater product, less any costs avoided by the Water Corporation as a result of supplying the wastewater)

- On-site treatment costs are assumed to be no greater than $1.20/kL, which is the cost of treating MAR water with a small reverse osmosis plant (this parameter is quite uncertain, as the water quality requirements of each industrial customer vary, as does the existing capacity of customers to perform on site treatment – e.g. some would have to upgrade their treatment equipment while others would not). To reflect this uncertainty, we have conducted a sensitivity analysis using lower costs of $0.50/kL and $0.80/kL.

The approach is illustrated in Figure 7. Based on the above price and cost assumptions, the marginal revenue potentially available to a MAR scheme operator is $0.70/kL

Figure 7 Illustration of the approach to calculating marginal revenue relative to the cost of scheme water



Data source: Synergies diagram

A marginal revenue of $0.70/kL also implies that total recycling costs (the operating and capital cost components) can be no more than $0.70/kL for the MAR scheme to be financially viable. This suggests that MAR water produced at Site 2 at an estimated cost of $0.60/kL would be cost-competitive with scheme water, at the current scheme water price. But not so for Site 1, where production costs range between $0.95/kL and $1.13/kL.

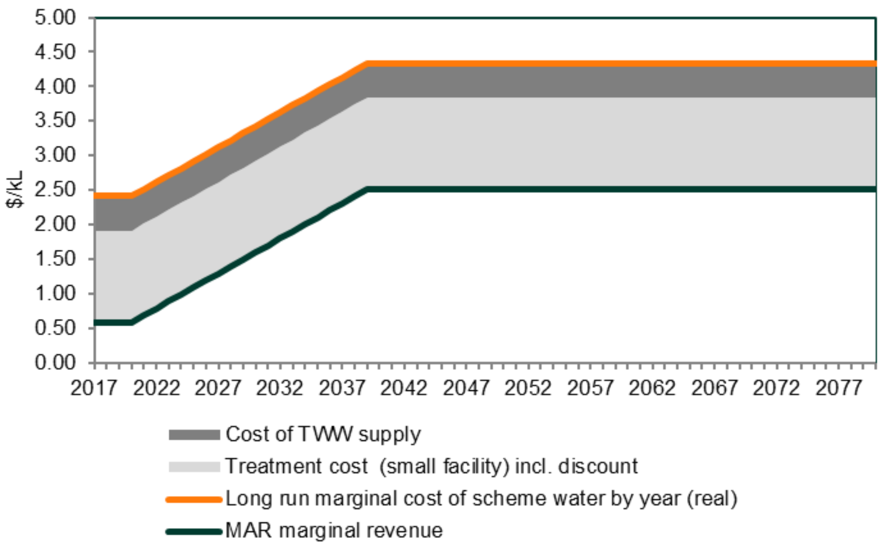
Looking further into the future, our modelling assumes that the price of scheme water will rise in real terms to $4.30/kL by 2040 due to increases in the LRMC of water supply as 'low cost' sources such as dams and groundwater become a smaller share of Perth's

drinking water supply[39]. This means that recycling costs can be somewhat higher than $0.70/kL without jeopardising the financial viability of MAR. This may allow a scheme operator to offer a price discount to customers on MAR water to incentivise additional take up of supply contracts (we assume a 10% discount in our standard modelling runs).

Figure 7 also shows that KWRP water, at a current price of $1.50/kL (treated and delivered to customer), is less expensive than the estimated cost of producing an equivalent quality recycled product through MAR. Therefore, our modelling assumes that all spare capacity of the KWRP will be taken up before the MAR scheme can sell water. This is a simplifying assumption, as we acknowledge that some customers may not be able to physically access KWRP water due to their geographic location within the WTC, or the cost of installing new reticulation infrastructure would be prohibitive. In practice, there could be scope for MAR to be developed ahead of all KWRP capacity being used. To the extent that this occurs, the financial returns to MAR would somewhat higher than what is estimated in this analysis.

The rising potential to derive higher marginal revenue from MAR water as a result of the increasing cost of scheme water is shown by the way marginal revenue (green line) increases in step with the scheme water cost (orange line) in Figure 8 below.

Figure 8 MAR marginal revenue (real), 2017 to 2080



Data source: Synergies modelling

[39] Economic Regulation Authority (2017) *Inquiry into the efficient costs and tariffs of the Water Corporation, Aqwest and Busselton Water: Final Report*, page 105.

This representation of marginal revenue shows how it tracks the cost of scheme water, less deductions to account for:

- treated wastewater feedstock for the MAR plant;
- treatment cost for MAR water upon abstraction and prior to use; and
- a 10% price discount as an incentive payment to switch to the MAR scheme.

The treated wastewater supply charge and the incentive discount both constitute transfer payments triggered by the development of the MAR scheme. Specifically, the treated wastewater supply charge would represent a cost to the MAR Scheme operator and a corresponding increase in revenue for the Water Corporation. The incentive payment reduces the users' water usage costs by the same amount as the MAR Scheme operator foregoes in revenue. Both financial transfers are not true economic costs and are not included when estimating the net economic benefit.

5.2 Application of demand forecasts

Synergies' investigations and interviews with the Water Corporation and major water users in the region identified a range of complications that reinforced Synergies' view that basing the project evaluation on a deterministic demand forecast might distort the analysis.

For instance, the competing supply options discussed in Section 2.5 could detract from demand for MAR water. Conversely, through our consultations we identified specific customer-side decisions that each may generate new demand for MAR water. We account for these possibilities by modifying the REU forecasts of underlying growth with a number of possible 'events' on the demand-side and supply-side to achieve a more realistic depiction of future demand scenarios. To balance our addition of potential new demand events, we also considered a zero demand growth scenario.

5.2.1 Events affecting growth in demand for MAR

Some large users are currently exploring options to substitute their current scheme water usage with an alternative source and others are considering selling or trading currently unused groundwater allocations.

This analysis includes these findings as potential future events that can create demand or supply tranches independent of growth associated with the REU forecasts. In total Synergies has identified 13 such events, of which eight result in additional direct demand for MAR water and five create competing (lower cost) supply.

Demand events

We model two types of demand events:

- A decision by existing scheme water users to switch to MAR water, if it was available at a competitive price
- A decision by one or more existing users to expand their production and utilise MAR water, if it was available at a competitive price

These potential events have been formulated on the basis of information collected through our interviews with major water users in the WTC. Four manufacturers of products associated with the resources sector stated that they are considering substituting (a share of) their current scheme water demand with an alternative source. Two of these producers also have substantial expansion plans. We assume that if an expansion goes ahead it will only use MAR.

Table 3 shows the demand events, the associated quantities, the year they are expected to occur and the share of runs in which they were included (i.e. the assumed probability of occurrence).

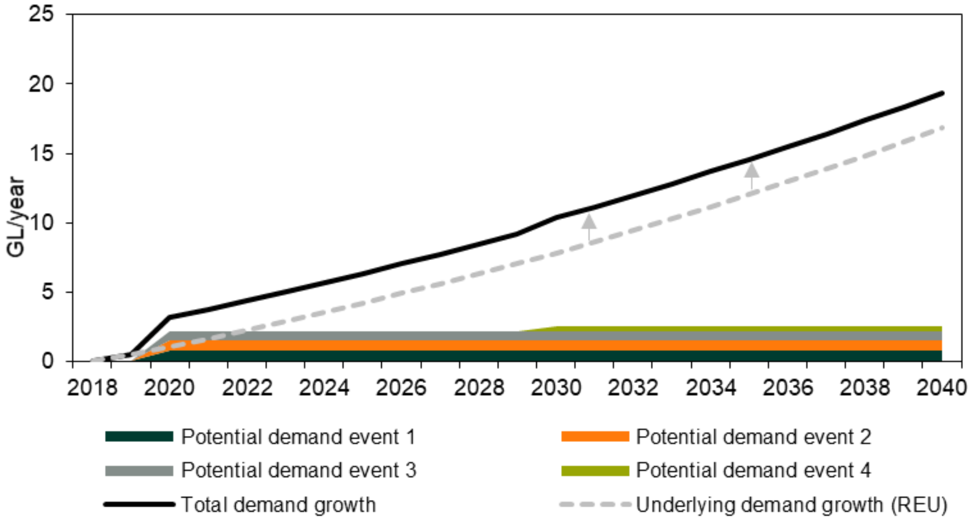
Table 3 Demand events

Event	Demand	Expected year	Included in share of runs	Site 1	Site 2
Producer 1 switches from scheme to MAR	0.04GL/y	2020	50.00%	No	Yes
Producer 2 switches from scheme to MAR	0.75 GL/y	2020	50.00%	No	Yes
Producer 3 switches from scheme to MAR	0.78 GL/y	2020	50.00%	No	Yes
Producer 3 expansion*	0.39 GL/y	2030	16.50%	No	Yes
Producer 4 switches from scheme to MAR	0.60 GL/y	2020	50.00%	No	Yes
Producer 4 expansion 1*	0.09 GL/y	2020	50.00%	No	Yes
Producer 4 expansion 2*	0.04 GL/y	2025	16.50%	No	Yes
Producer 4 expansion 3*	0.04 GL/y	2030	8.25%	No	Yes

***** Demand associated with expansion using MAR is conditional of the associated producer switching the main usage to MAR.
Source: Synergies stakeholder consultation

The model combines the underlying demand forecasts from REU with the demand events summarised above, in a probabilistic manner. Thus, a given modelling run might assume demand that looks similar to Figure 9. It shows several demand events in tranches that commence at different times. When summed with underlying demand (ie. whichever REU forecast has been selected for that run), these demand events contribute to a higher total demand growth curve.

Figure 9 Illustration of the combination of underlying and event growth



Supply events

Two different supply-side events are examined in the analysis:

- A decision by one or more groundwater licensees to trade their water license that they longer require because of changes in their business, and/or water that is currently underutilised
- A decision to expand the existing KWRP facility, lifting total supply capacity from 6 GL/yr to 9.6 GL/yr (i.e. an increment of 3.6 GL).

Again, these supply events have been formulated on the basis of discussions Synergies has had with a number of major water users in the WTC and the Water Corporation. Table 4 shows the supply events, the associated quantity, the year they are expected to occur and the share of runs in which they were included.

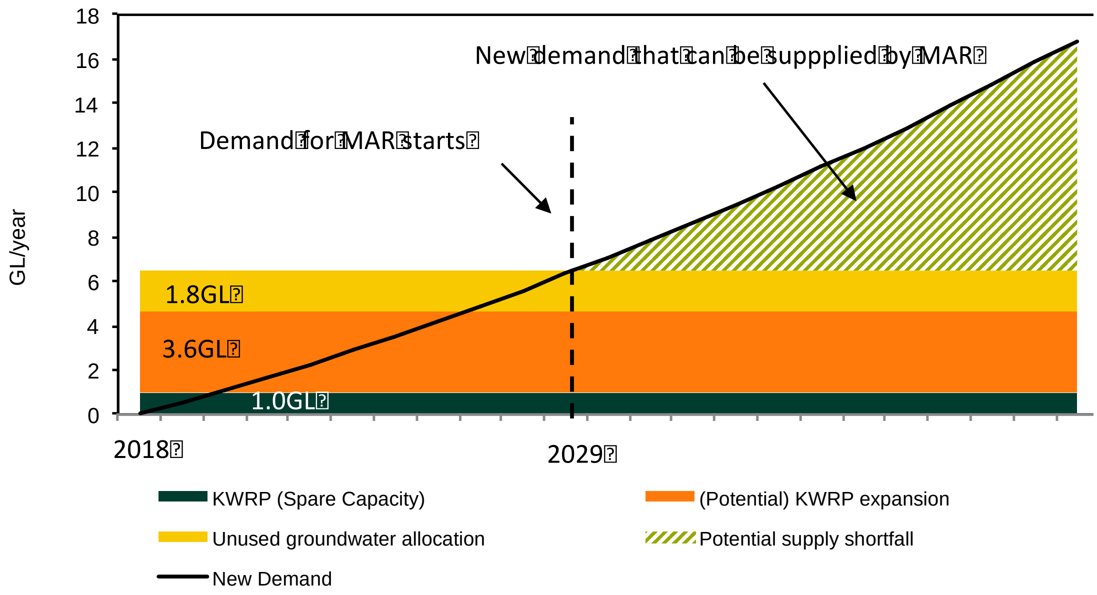
Table 4 Supply events

Event	Supply	Expected year	Included in share of runs	Site 1	Site 2
Major license holder 1 sells/trades currently unused allocation	0.60GL/y	2020	50.00%	Yes	Yes
Major license holder 2 sells/trades currently unused allocation	0.90GL/y	2020	50.00%	Yes	No
Expansion of the KWRP	3.60GL/y	2030	33.00%	No	Yes
Selling/trading of currently unused allocation in Valley	1.54GL/y	2020	25.00%	Yes	Yes
Selling/trading of currently unused allocation in Wellard	1.22GL/y	2020	25.00%	No	Yes

Source: Synergies stakeholder consultation and analysis of DWER data

Figure 10 shows the same total new demand curve from Figure 9 overlaid with competing supply options. It illustrates how new demand for water in the WTC would be met through one of the cheaper alternative sources of supply, before it would translate into demand for MAR water.

Figure 10 Representation of demand for MAR and the alternative sources of supply



Note: The supply associated with a groundwater trade is not additional water, but rather a reallocation of water from existing to new uses. However, for the purposes of modelling, this transfer can be treated as if it were an additional supply source.

Data source: Synergies diagram

The supply sources shown in Figure 10 include:

- the existing spare capacity of the KWRP, which is assumed to be used first ahead of MAR owing to it being a less expensive supply source[40];
- the potential future expansion of KWRP (which this analysis treats as uncertain); and
- the potential trade of 1.84 GL of surplus water allocation (which this analysis treats as certain).

Based on the mid-level REU demand forecasts, the supply shortfall for the illustrated modelling run is shown in Figure 10 to first occur in 2029. This is subject to all available

[40] This is a simplifying assumption, as we acknowledge that some customers may not be able to physically access KWRP water due to their geographic location within the WTC, or the cost of installing new reticulation infrastructure would be prohibitive. In practice, there could be scope for MAR to be developed ahead of all KWRP capacity being used. To the extent that this occurs, the financial returns to MAR would somewhat higher than what is estimated in this analysis

groundwater being used first, as well as the KWRP being expanded to 9.6 GL capacity. In practice, we have used a probabilistic approach for modelling supply and demand, which means that the timing of first shortfall differs from one model run to the next.

5.2.2 Total potential demand for MAR water in any given year

The total potential demand for MAR water in any given year is given by the 'realised' supply shortfall in that year. Total demand is calculated as the sum of the demand derived from the REU forecasts, and the realised demand events, less the realised supply events.

5.2.3 Assessment of site differentials

There are a number of key differences between the sites that influence their relative financial viability. Instead of preparing a detailed financial analysis of both sites, we have confined our detailed analysis to Site 2, based on a critieria-based assessment that Site 2 is significantly more likely to deliver a positive net financial return than Site 1. Our assessment is as follows:

- Site 2 can supply both the Valley and Wellard subareas whereas Site 1 can only supply Valley.
- While Site 1 could also supply potential customers in Thompsons subarea this is academic because there is no new industrial demand for that region for the foreseeable future.
- Potential demand for MAR water in the vicinity of Site 1 both starts at a substantially lower base and grows a slower rate.
- All demand events are only associated with Site 2, but three of the five supply events are also associated with Site 1. This means that Site 1 faces a large share of the downside risk and none of the additional opportunities of Site 2.
- Site 1 is also expected to be costlier to develop and will require a major modification in 2030. GHD estimates the total capital expenditure (including the 2030 modification) for developing Site 1 to be $28.0 million. Site 2 is expected to cost $17.3 million.

For the above reasons, we focus our analysis on Site 2.

5.3 Net financial value

The financial viability of the MAR Scheme is measured by its Financial Net Present Value (FNPV), calculated as the sum of all discounted revenues available to the MAR Scheme minus the sum of all discounted costs incurred to establish and operate it.

Synergies has adopted a dynamic approach to modelling FNPV involving many runs, with each run combining a different combination of the demand drivers outlined above. In this framework, demand is determined by randomly drawing one of the four growth scenarios and adding a set of demand and supply events (probabilistically drawn from Table 3 and Table 4). All random draws follow a uniform distribution.

FNPV is modelled by following these steps:

1. For a given MAR site, the FNPV is calculated using:
   – A draw from the growth rates and a set of demand and supply events;
   – The marginal revenue shown in Figure 8; and
   – The facility capital and operating costs outlined in Section 3.4, based on commissioning in any year between 2020 and 2040[41].
2. The resulting FNPVs are compared to show:
   – For a given set of input assumptions what the optimal (FNPV maximising) commissioning year would be.
   – For the optimal commissioning year (for the given set of input assumptions), the FNPV at a discount rate of 7%.

5.3.1 Timing the start date to maximise the financial returns

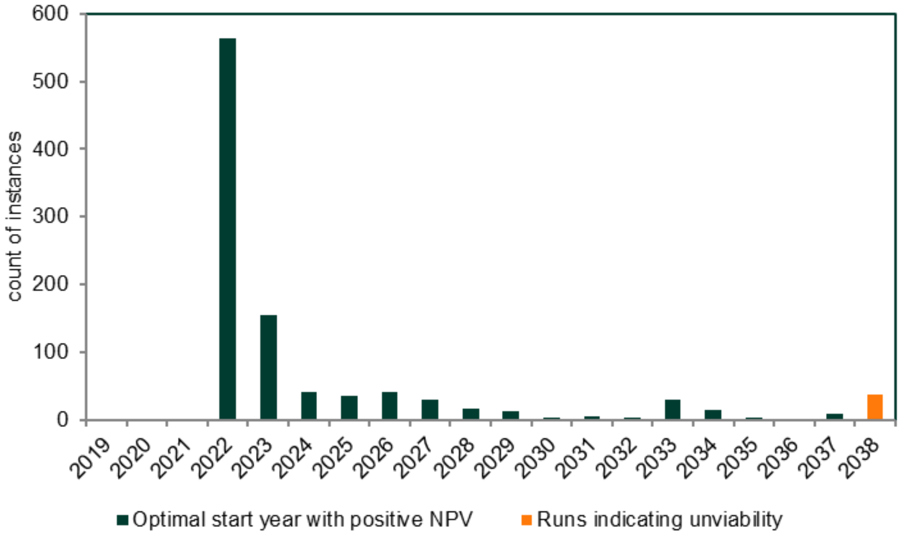
Our modelling approach optimises the commissioning date for a given set of demand assumptions. This approach maximises the FNPV of the MAR Scheme and thus the probability of being financially viable. It is more realistic than a static facility start date, in that it reflects the way a proponent would schedule its investments in the face of a given set of expectations about demand.

Figure 11 shows the optimal start years as determined for 1000 iterations, combining all four growth scenarios and including event demand and supply. The figure shows that in most cases the model predicts the optimal start date for Site 2 to be very likely to fall

[41] That is, a unique capex and opex schedule is prepared to match each potential commissioning date between 2020 and 2040. Note also that variable operating costs reflect the particular demand assumptions relevant to each modelling run.

in 2022 or 2023. Commissioning after 2030 is only NPV maximising under very specific circumstances. In only 4% of runs the model predicted the project to be unviable.

Figure 11 Site 2: optimal start years for all four growth scenarios including event demand

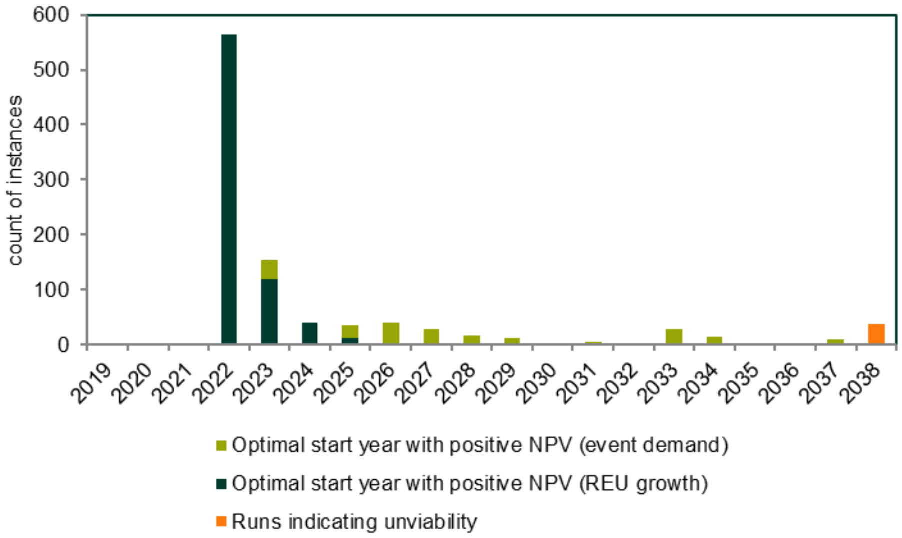


Presented results are based on 1,000 iterations
Data source: Synergies modelling

5.3.2 The importance of demand events

The demand events are an important contributor to the project's (modelled) success in those instances where the underlying growth assumptions are conservative. When these events are considered separately, the model predicts that the project is non-viable in 25% of instances. Figure 12 shows the optimal start years and highlights that cases in which viability is a result of event demand (because underlying demand in those runs was set at zero).

Figure 12 Site 2: optimal start years for all four growth scenarios separate event demand



Presented results are based on 1,000 iterations and measured in 2018 terms
Data source: Synergies modelling

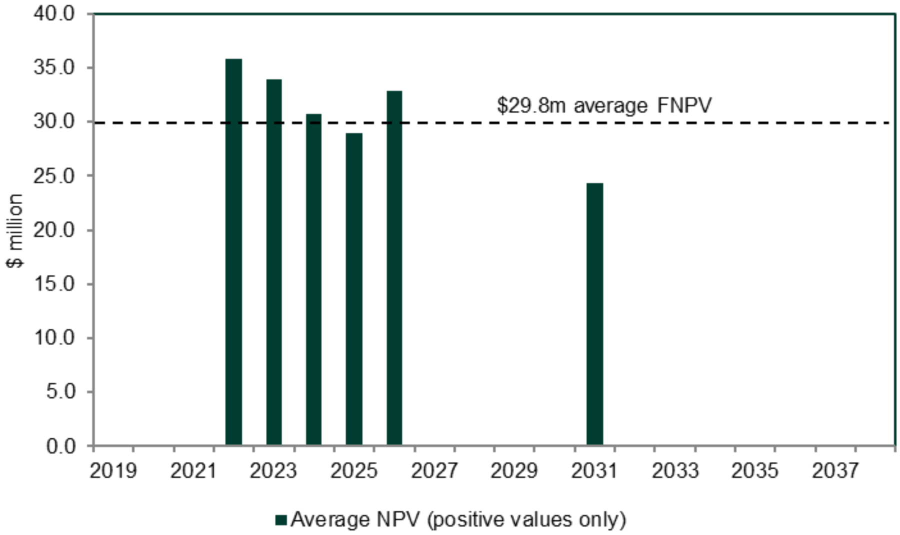
5.3.3 The quantum of financial returns

The expected financial value delivered by a MAR facility at Site 2 could be very large if the REU demand forecasts are realised. Figure 13 shows the FNPV associated with the project, for each of the identified optimal start dates. The value shown for each year represents the average of all FNPVs returned for that year. These averages exclude any negative FNPVs.

The average value across all instances with a positive FNPV is $29.8 million (in 2018 terms).[42] Values in the early commencement years tend to exceed this level. The result that FNPVs generally decline over time partly reflects the fact that developing the project later leaves significant early revenue opportunities unexploited.

42 In this context cases with negative NPVs are irrelevant. Each model run can be interpreted as s a separate business case and if it finds a negative NPV we assume the project does not go ahead. Since the average project value should only consider cases in which the project goes ahead, the negative NPV cases can be excluded.

Figure 13 Site 2: average project value (NPV) by optimal commencement year, 2019 to 2038



Presented results are based on 1,000 iterations and measured in 2018 terms
Data source: Synergies modelling

5.4 Sensitivity testing and demand risk

5.4.1 Sensitivity analyses

These findings do vary with changes to key assumptions, as shown by the following sensitivity analysis results in Table 5. The sensitivity tests were performed by varying just one parameter at a time, holding all others constant.

Key results from the sensitivity analysis are follows:

- If the price of scheme water is assumed to remain constant at today's price of $2.40/kL, MAR is never financially viable (this is an unrealistic scenario, but included nevertheless for reference)
- The MAR project breaks-even, on average, at a potable scheme water price of $2.45/kL (at prices below than this, MAR water would become more expensive than scheme water)
- If the scheme water price only rises to $3.00/kL over the study timeframe, the project still returns a positive NPV of $13.6 million
- If all surplus groundwater is traded into the market, average NPV of the MAR project reduces to $27.3 million

- If the incentive discount is increased from 10% to 40%, expected NPV reduces to $15.3 million
- If the wastewater input can be acquired at no cost, the NPV becomes $45.8 million
- If the unit cost of MAR water treatment by customers can be reduced to $0.80/kL (down from $1.20/kL), expected NPV increases to $42.0 million. At a treatment cost of $0.50/kL, the NPV increases to $53.5 million

Table 5 Summary of sensitivity analyses

Sensitivity	Assumptions				Expected NPV
	Incentive discount	Customer treatment cost	Price of scheme water	Charge for feedstock	
Units	%	$/kL	$/kL	$/kL	
Base	10%	$1.20	$2.40 growing to $4.30	$0.50	$29.8 million
Trade of all spare groundwater[(a)]	10%				$27.3 million
40% incentive discount	***40%***				$15.3 million
Alternative assumptions for cost of scheme water					
Fixed at $2.40/kL	10%	$1.20	***$2.40 constant***	$0.50	N/A – never viable
Growing to $3.00/kL	10%	$1.20	***$2.40 growing to $3.00***	$0.50	$13.6 million
Growing to $3.50/kL	10%	$1.20	***$2.40 growing to $3.50***	$0.50	$21.6 million
No charge for wastewater input	10%	$1.20	$2.40 growing to $4.30	***$0.00***	$45.8 million
Customer treatment cost					
Medium RO facility	10%	***$1.20***		$0.50	$31.2 million
Large RO facility	10%	***$0.80***		$0.50	$42.0 million
Other treatment	10%	***$0.50***		$0.50	$53.5 million

Notes: Presented results are based on 50 iterations and measured in 2018 terms. Bold and italicised values represent tested variables. Shaded cells show key finding. (a) Sets the probability of trade of unused allocations (after allowing for recouping of unused entitlements) at 100%.

Data source: Synergies modelling

5.4.2 Demand risk

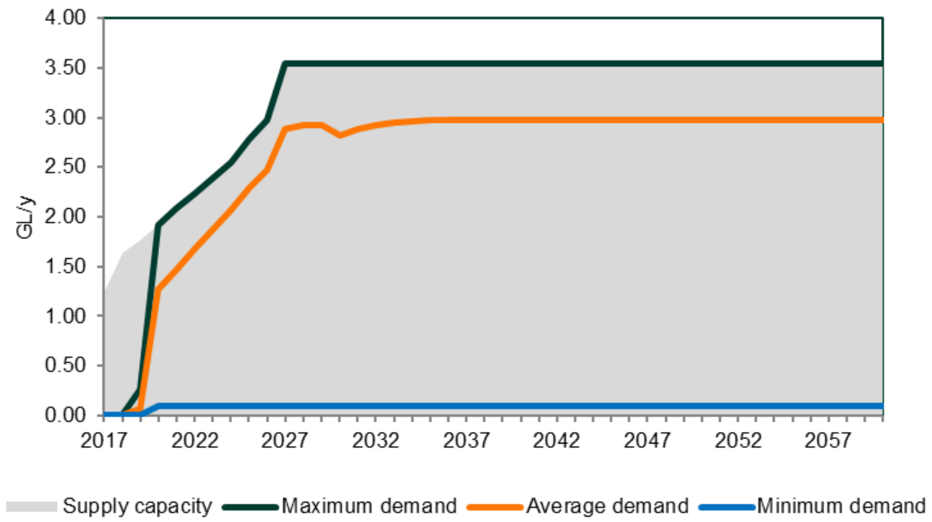
Our analysis of demand indicates that the commercial strategy of a MAR service provider should focus on securing contracts with the customers associated with the event demand. These demand events (or rather, the potential foundation customers they represent) could mitigate the risk faced by the developer during the start-up phase of the facility. If the REU forecasts hold, filling the remaining capacity with demand from currently unknown customers will not be an issue. However, the more important point

is that the facility will be financially viable even without this demand. For instance, if all identified demand events were converted into MAR sales, the project would have an FNPV of just under $24 million with an optimal commencement year of 2023.

Total demand – REU forecasts, plus a zero-growth scenario, plus demand events

Figure 14 presents the range of demand for the MAR scheme as modelled in Synergies central case. It includes the three REU growth projections, a zero-growth scenario and all demand events for Site 2.

Figure 14 Site 2: Full range of demand outcomes



Note: The original REU forecast has been extended from 2031 to 2040. As longer-term forecasts tend to be very uncertain, this analysis assumes demand stabilising in 2041.
Data source: Synergies modelling

Each line in the chart represents additional demand for MAR water, being demand growth that can't be met with either groundwater or existing KWRP capacity. Demand is always capped by the assumed MAR supply capacity of 3.55GL per year (shown as grey shaded area).

Figure 14 shows that best case demand (green line) follows the supply capacity growth of the MAR scheme from 2020 onwards. In the worst cases (blue line), demand for MAR water is close to but greater than zero[43]. Average demand (orange line), which includes the cases with zero demand, grows rapidly between 2020 and 2030 until it stabilises at just under 3GL/y or at a utilisation of around 85%. Average demand should be

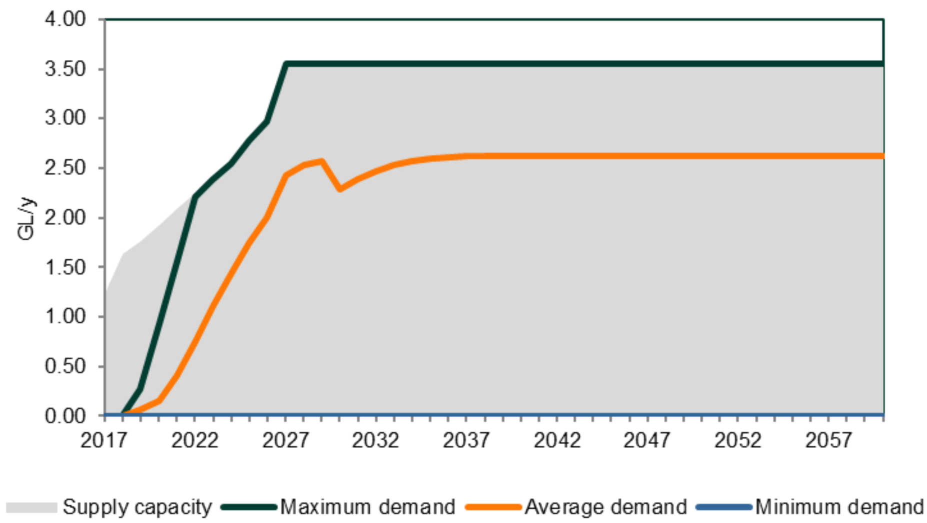
[43] This reflects that the probability of no demand events occurring at all and coinciding with zero underlying demand growth is very low.

understood as a statistical concept – representing a potential investor's expected demand outcome assuming they were able to diversify through 1000 equivalent investments in MAR facilities in the WTC.

Demand excluding demand events

Excluding the event demand from the above range does not have a significant effect on the best or worst case as comparison between Figure 14 and Figure 15 illustrates. However, average demand grows slower in the first years of the study period and stabilises at a lower level of around 2.5GL/y. Again, average demand includes the cases with zero growth. Minimum demand in this case is exactly zero – reflecting the zero-growth scenario in the absence of any demand events.

Figure 15 Site 2: demand ranges excluding event demand



Note: The original REU forecast has been extended from 2031 to 2040. As longer-term forecasts tend to be very uncertain, this analysis assumes demand stabilising in 2041.

Data source: Synergies modelling

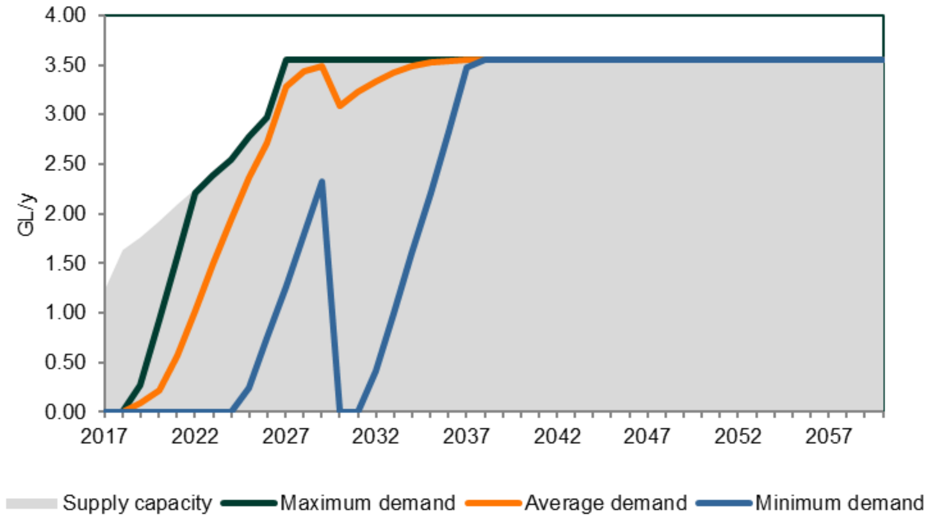
Demand based on underlying growth and supply events

If demand events and the zero-growth scenario are excluded, demand reaches capacity even in the worst-case scenario (now the REU low demand growth projection) as demonstrated in Figure 16. Here, average demand grows much faster and converges with the supply capacity in 2035. Minimum demand in contrast is virtually zero until 2030– the result of competing supply and the comparatively low growth rate. After 2030 minimum demand grows rapidly until converging with supply capacity in 2039.

This result illustrates the magnitude of growth that is triggered by the REU growth rates. Towards the end of the growth period even the lowest growth rate results in annual

groundwater demand growth of almost 0.7GL (4% of the current total or the equivalent of two major expansion events of large producers). We note that the sharp peak in minimum demand around 2029 reflects demand exceeding available supply around 2025, before the expansion of KWRP in 2030 temporarily meets the demand growth and is then itself rapidly overtaken by continued demand growth.

Figure 16 Site 2: demand ranges reflecting only REU forecasts and supply events



Note: The original REU forecast has been extended from 2031 to 2040. As longer-term forecasts tend to be very uncertain, this analysis assumes demand stabilising in 2041. No zero-growth scenario is included in this figure.

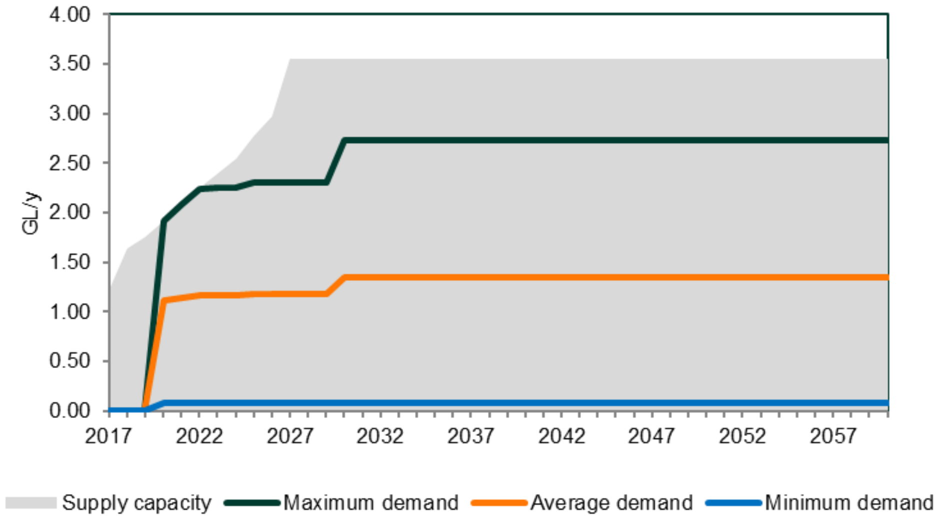
Data source: Synergies modelling

While Figure 16 suggests a favourable business case for the MAR facility, it relies entirely on confidence in the REU forecasts. We consider that the level of risk in these forecasts is likely to be too high for potential investors to rely on this projection alone.

Demand based on event demand alone

Figure 17 presents minimum, maximum and average event demand forecasts, when only event demand is considered (that is, underlying growth is set equal to zero within the model). Under a best-case scenario, event demand reaches around 2.7GL/y or a MAR scheme utilisation of 76%. On average, demand from events reaches around 1.3GL/y (37% utilisation).

Figure 17 Site 2: Event demand with underlying growth excluded



Data source: Synergies modelling

The expected financial result if only event demand is relied on, that is the financial return associated with the orange line in Figure 17, has an NPV of around $9.2 million – enough to make the investment favourable. Maximum demand (green line) in Figure 17 represents the maximum potential business that the MAR scheme operator could secure through foundation contracts. If all of this demand could be secured then the financial NPV would increase to $24 million. The magnitude of event demand suggests significant scope to mitigate the risk faced by the developer during the start-up phase of the facility.

5.5 Economic analysis

As explained in Section 4, the difference between the economic and financial analyses in this study is minor. The only difference between the two is that the calculation of the Marginal Economic Benefit excludes both the charge for treated wastewater and the discount assumed to be offered by the service provider to incentivise potential customers.

Thus, the economic value generated per unit of MAR water used is greater than the financial value generated for the service provider, while the economic and financial costs to establish the MAR scheme are the same. Therefore, the economic NPV of the MAR scheme is larger than the FNPV. The results of the economic analysis and associated sensitivity testing are presented in Table 6 below.

Table 6 Summary of economic analysis findings

Sensitivity	Assumptions		Expected Economic NPV
	Customer treatment cost	Cost of scheme water	
Units	$/kL	$/kL	
Base	$1.20	$2.40 growing to $4.30	$46.1 million
Trade of all spare groundwater[(a)]	$1.20		$40.4 million
Alternative assumptions for cost of scheme water			
Fixed at $2.41/kL	$1.20	***$2.40 constant***	$5.1 million
Growing to $3.00/kL	$1.20	***$2.40 growing to $3.00***	$28.8 million
Growing to $3.50/kL	$1.20	***$2.40 growing to $3.50***	$36.5 million
Customer treatment cost			
Medium RO facility	***$1.20***	$2.40 growing to $4.30	$46.1 million
Large RO facility	***$0.80***		$57.2 million
Other treatment	***$0.50***		$64.1 million
Scheme water price at which economic NPV ~ 0 (Break Even Point)	$1.20	$1.82 constant	~$0.1 million

Notes: Presented results are based on 50 iterations and measured in 2018 terms. Bold and italicised values represent tested variables. Shaded cells show key finding. (a) Sets the probability of trade of unused allocations (after allowing for recouping of unused entitlements) at 100%.

Data source: Synergies modelling

6 Commercial analysis

6.1 Considerations in development of MAR Scheme

6.1.1 Risks

The MAR scheme will require a range of commercial risks to be assigned and managed, of which some of the most important are discussed below.

Demand risk

Like any project with large fixed costs, the MAR Scheme faces the risk that demand for its product (non-potable water) will be less than forecast. This risk has been explicitly modelled by Synergies and discussed in detail in Section 5.4.2.

Demand in an industrial precinct like those within the WTC is likely to be affected by economic conditions, but may be less seasonally variable than irrigation water uses. Moreover, potential industrial customers tend to be small in number but have relatively large water requirements, making demand more likely to grow in halting step-changes, rather than following a smooth year on year growth pattern. This 'lumpy' growth pattern increases demand risk.

Unless the MAR Scheme operator is itself intending to be a user of MAR water, it will have little no direct control over this risk.

Competition risk

The MAR Scheme faces potential competition from competing water supply options. In the case of the existing spare capacity of the KWRP, Synergies modelled this not as a risk but as a definite reduction in demand for MAR water. However, other competing supply sources that may or may not eventuate were explicitly modelled as potential 'supply events' (see Section 5.2.1).

The MAR Scheme operator can only manage competition risks directly if it is also a user of MAR water, in which case it could opt not to consider competing supply sources. Even this may not insulate it adequately against competition risk.

Regulatory risk

The MAR scheme requires a supporting regulatory framework to ensure that licensed MAR customers are able to access the MAR water. Synergies believes that the existing

groundwater licensing framework, read in conjunction with DWER's MAR policy[44], can indeed support a workable MAR scheme. However, the regulatory framework does appear to afford the State Government significant discretion. The MAR Policy states that:[45]

- ownership of recharged water vests in the Crown; and
- MAR proponents must obtain a licence to recover the recharge water, which the Department will grant at its discretion, according to the policy.

The proponent of a MAR scheme will need to make long-term investments and may seek from its customers long-term commitments. Either might consider the possibility that new policy imperatives might cause the State Government to change its MAR Policy – for instance if drought or other environmental concerns caused it to consider demand restrictions that also applied to MAR abstractions. Regulatory risks of this type are difficult for businesses to manage as only the State Government can control the outcome. The Government could introduce procedural, institutional or legislative constraints on itself in order to help reduce the perceived risks from a policy change.

Feedstock risk

The MAR service provider is likely to face exposure to the risk of its feedstock of treated wastewater being interrupted or withdrawn. In this event, the service provider could face:

- Loss of sales revenues;
- Contractual damages for failing to deliver MAR water as committed; and/or
- Fines for failure to comply with licence obligations.

Only in the case where the MAR service provider is the Water Corporation will it have the ability to directly manage this risk. Other service providers, would need to obtain contractual assurances and indemnities from the Water Corporation to manage this risk. From the perspective of the Water Corporation entering into a commitment of this kind would impose a financial risk (the possibility of paying compensation if it cannot deliver the treated wastewater) and the acceptance of some future operating and commercial constraints. It is very likely the Water Corporation would expect compensation – hence the charge modelled in Synergies financial analysis (Section 5).

[44] Department of Water (2011) "Operational policy 1.01 — Managed aquifer recharge in Western Australia".

[45] Department of Water (2011) "Operational policy 1.01 — Managed aquifer recharge in Western Australia", page 18.

Construction and engineering risk

Like any construction and engineering project, there are risks that the MAR facility will be more expensive to build than expected, not perform as well as expected or be more expensive to operate than expected. For instance, if the facility fails to achieve the water quality levels for which it was designed, there is a risk that it will not be permitted to proceed with infiltrating the water into the superficial aquifer.

Operational risk

The MAR facility will operate within a broader system of water infrastructure and there may be interactions between the parts of this system with economic or financial implications for the project. For instance, there may be times when the Water Corporation requires the MAR Scheme Operator to stop discharging into the SDOOL, which may impose commercial risks for the MAR operator unless these operating rules were specified in a contractual agreement with Water Corporation.

Another example is the fact that the MAR facility in normal operation reduces the flow carried by the SDOOL. If the Water Corporation considered this effect to be highly reliable, it might consider relying on it to defer capacity upgrades to the SDOOL. This planning approach would rely on the Water Corporation perceiving there to be limited risk that the MAR facility might be offline during periods of high flow through the SDOOL. The Water Corporation's assessment of this type of operational risk might be different depending on who operates the MAR facility. It is reasonable to assume that the Water Corporation would consider the risk to be lowest where it designs, builds and operates the facility, since it would then be best placed to configure and operate the facility in ways that avoid or ameliorate problems in the broader system.

Other risks

A range of other risks should also be flagged, although these will not be considered in further detail here:

- Hydrological risks such as the risk that losses of MAR water are greater than assumed or that new hydrological information results in the regulator reducing the extent of the MAR Zone;
- Production risks such as lost opportunities to harvest water due to equipment failure the feedstock treated wastewater being outside the necessary specifications;

- The identification of new environmental risks which lead to new restrictions on MAR or new treatment requirements not anticipated at the time the MAR Scheme is established[46].

6.1.2 Longer versus shorter term contracting

The MAR Scheme operator and the water users may face commercial considerations that are not well aligned in respect of the duration of contract. Long-dated contractual commitments are likely to be required to underpin investment in a MAR Scheme, while the ability to obtain water on flexible terms may be necessary for some customers.

From the service provider's perspective, it will try to use contracts to defray some of the commercial risks outlined above over which it has limited control – such as demand risk and competition risk. This primarily means long-term foundation contracts. Synergies considers that there is insufficient hard evidence of demand growing very rapidly in the next decade and interviews with stakeholders have revealed several potential competing sources of supply. A service provider that builds a facility with substantial uncontracted capacity faces significant risk of finding insufficient demand or of being bypassed by potential customers able to negotiate cheaper supplies from other sources.

It is less clear what contractual arrangements will be most favourable from the customer's perspective. Provided there is little prospect of a hard supply shortfall in the future, it may suit customers to seek short-term supply arrangements, while taking advantage of cheaper, less secure supply solutions such as leasing groundwater allocations, in the knowledge that scheme water can always provide a back-up. However, as groundwater users approach full utilisation of available allocations and as the marginal cost of scheme water rises, users may be more prepared to enter into long-term commitments. It may also be the case that some large customers are willing to become foundation customers (that is enter long-term contracts from the inception of the MAR Scheme) because of a preference for recycled water – for instance due to the benefits this might provide in terms of public image.

In summary then, Synergies considers that the MAR Scheme operator will strongly prefer long-term contracts covering the majority of its MAR production capacity, while customers, at least initially, may prefer a lower level of commitment. Unless there are other drivers for MAR, for instance reputation enhancement, this mismatch could see

---

[46] For instance, there has been growing regulatory interest in controlling exposure to per- and poly-fluoroalkyl substances (PFAS), which is found in fire suppression foams. PFAS widespread in the environment and is found in wastewater effluent. See WA State Government, December 2017, "Government Statement on Per- and Poly-Fluoroalkyl Substances", https://www.der.wa.gov.au/images/documents/our-work/community-updates/PFAS/WA_Government_Statement_PFAS.pdf.

the development of a MAR scheme deferred for some time. We note that the implication of this outcome is that the water requirements of heavy industry in the WTC would still be met by sources besides MAR.

6.1.3 Pricing

There are several potential pricing strategies that a MAR service provider could apply to generate the required revenue to make the scheme financially viable. One possible structure could include

- charging a temporary operating contribution from MAR customers (applies for say three years of a project once it is in operational mode); and
- an ongoing customer tariff (which could be a two-part tariff comprising a fixed service charge and volumetric charge).

Pricing to promote competition

The ERA's Inquiry into Pricing of Recycled Water in Western Australia[47] recommended a set of pricing principles to ensure that there is a level playing field between all potential providers of recycled water services. ERA's pricing principles allow for three components to be included in the price of the wastewater resource:

- A charge associated with the costs of delivering the wastewater resource to the customer, including any incremental costs that might be incurred in treating the wastewater to be fit for purpose (Synergies notes that this is equivalent to our 'facilitation' costs, which we assess as being zero in the case of WTC)
- A negative adjustment in price to take into account any costs that would be avoided as a result of selling the wastewater resource. For example, the operating costs of discharging the wastewater to the environment would be avoided. The negative adjustment should not exceed the direct costs associated with the project (Synergies notes that this is equivalent to the 'avoided costs' term - inclusive of avoided environmental costs - that we assess as being negligible, and thus set to zero in the case of WTC).
- If the amount of wastewater available to be recycled is less than the demand for the wastewater, then an additional premium should be added to the price to reflect its relative scarcity. The premium should be determined by a neutral tendering process

[47] ERA (2009) Inquiry into Pricing of Recycled Water in Western Australia, Final Report, February 2009

(Synergies notes that this is equivalent to the wastewater resource cost term in our economic analysis, which we assess as being zero in the case of WTC).

To give effect to these principles, the ERA gave support to the development of a dispute resolution mechanism, regulatory approval of avoidable costs, and the establishment of a transparent neutral tender process for the allocation of wastewater resources from wastewater treatment plants.

Other jurisdictions

We note that Sydney Water has a policy of not charging for its wastewater when supplied to another party as an input to a water recycling plant (see Sydney Water, 2006, *Sewer mining: How to establish a sewer mining scheme*, SW8 07/13). This policy has been in place since 2006 and Synergies understands that Sydney Water has sewer mining agreements with eight customers. The wastewater product supplied under these agreements is raw sewage. Sydney Water does however charge for

- all costs it incurs to enable the sewer mining connection and its operation (less any financial savings it receives from the sewer mining operation); and
- the cost of receiving, treating and disposing industrial trade wastewater (effluent from the recycling plant), if the sewer mining operation requires this service.

The policy makes provision for the NSW Independent Pricing and Regulatory Tribunal have an arbitration role to settle disputes surrounding sewer mining agreements.

6.2 Service Models

There are numerous possible commercial arrangements for structuring a MAR scheme. Such 'service models' may include (but are not limited to) the following.

- The Water Corporation could own and operates the scheme and establish supply contracts with licensed MAR customers in the WTC.
- A private, independent water utility (IWU) could own and operate the scheme and establishes supply contracts with licensed MAR customers in the WTC.
- A joint venture (JV) of major water users in the WTC could develop, own and operate the MAR scheme and grant the members of the JV rights to water under that scheme.

We consider each model in turn.

6.2.1 Water Corporation

The Water Corporation could establish and operate the MAR Scheme. It is an existing water service provider that has already demonstrated the:

- engineering and financial capacity to fund, build and operate a MAR facility; and
- commercial capacity to enter into and manage contracts to deliver recycled water.

In addition, it is likely to possess the legal and regulatory knowledge and resources to apply for and establish a MAR scheme under the administrative frameworks maintained by the Department of Water and Environmental Regulation. The Water Corporation also has the necessary mandate to pursue new business areas of this kind, on prudent commercial principles[48]. The Water Corporation would be expected to evaluate, fund and market the MAR scheme in the same manner as a private, for-profit company.

As the entity responsible for wastewater treatment and disposal in the region, the Water Corporation owns and controls the treated wastewater flowing through both the SDOOL and out of the East Rockingham WWTP. The Water Corporation could therefore commit to a MAR facility without needing to enter into separate contracts to ensure continued access to the input treated wastewater.

6.2.2 Independent water utility

An IWU could establish and operate the MAR Scheme. This could be any company with the engineering, financial and commercial capacity to develop and operate the MAR Scheme. An IWU is distinguished from the Water Corporation by virtue of not being subject to any mandated obligations to provide water services in the region.

The IWU would need to secure a reliable supply of treated wastewater flowing through either the SDOOL or the East Rockingham WWTP, which is owned and controlled by the Water Corporation. Thus, an IWU could only develop a MAR scheme if the Water Corporation provides a long-term treated wastewater supply commitment to the IWU on viable terms.

6.2.3 Joint venture

A JV between water users in the region could establish and operate the MAR Scheme. The JV could comprise any number of water users although for practical reasons it would be most likely to comprise a small number of large users. The members of the JV

[48] Consistent with section 30 of the *Water Corporations Act 1995*

would fund and/or underwrite the facility and the legal, regulatory and commercial costs in return for the right to abstract a proportion of the MAR water and, potentially, a share of future commercial opportunities. The JV might size the facility to produce more water than required for the JV members, with the intention of profiting from the sale of surplus MAR water to other users in the region.

A JV could only develop a MAR scheme if the Water Corporation provides a long-term treated wastewater supply commitment to the JV on viable terms.

6.3 Assessment of service models

The three main service models presented here all have strengths and weaknesses and none is likely to be inherently superior. However, the different models raise different types of issues and may present different trade-offs that should be understood and managed. In this section we discuss some of the most relevant issues by evaluating the models against the following criteria listed in Table 7, which also provides a summary of our assessment of the models against each criterion. Detailed discussion against all criteria follows below.

Table 7 Overview of Service Provision Options

	Model 1 *Water Corporation*	**Model 2** *IWU*	**Model 3** *JV*
Complexity of governance arrangements	✓ moderate	✓ simplest	✓ complex
Capacity to bear and manage risk	✓ moderate	✓ lowest	✓ highest
Whether regulatory changes could be required for successful implementation	✓ few issues	✓ manageable issues	✓ manageable issues
Local or interstate precedents	✓ proven	✓ unproven	✓ unproven
Suitability for supply of incumbents compared to new customers	✓ straightfoward	✓ straightfoward	✓ favours incumbents
Impacts on State budget and public risk burden	✓ direct impact	✓ no direct impact	✓ no direct impact
Alignment with service preferences of major customers	✓ less control	✓ less control	✓ customer controlled

Source: Synergies Economic Consulting

6.3.1 Complexity of governance arrangements

The governance of the corporate entity responsible for creating and managing the MAR Scheme will be more complicated in the case of a JV than for either the Water Corporation or IWU models. The establishment of the JV will require sophisticated negotiations and legal execution. Achieving and documenting consensus across multiple parties regarding the assignment of risk, control and rewards may take many attempts. The JV's decision making and reporting arrangements are all likely to require considerable resources, goodwill and time to create and maintain.

By contrast, if the Water Corporation or an IWU choose to establish a MAR scheme, a single organisation will assume responsibility for decision making and implementation. The MAR Scheme operator will separately need to strike contracts with customers, but these bilateral negotiations are likely to be more straight-forward and involve simpler choices for the counterparties.

6.3.2 Capacity to bear and manage risk

Achieving an assignment of risk that is acceptable to all parties will be one of the most important factors in the creation of a commercially viable MAR scheme. Risks are most efficiently assigned to the parties best able to manage them and, by this logic, some of the risks discussed in Section 6.1.1 should be assigned to MAR customers, rather than the service provider. However, some risks should rest with the service provider and service providers may differ in their capacities to bear and manage these risks.

A JV would directly manage demand risk, because its members will fund their respective shares of the investment based largely on their respect future water requirements. The JV members directly assume the risk that they won't need this water in the future, but they are also best placed to evaluate and control this risk. Further, assuming water supply costs are a small proportion of the overall costs of the member firms, it is reasonable to assume they have the financial scale and flexibility to bear this risk. The Water Corporation and an IWU would need to manage demand risks through bilateral contracts, which could achieve a similar result, provide that equivalent long-dated take-or-pay commitments can be secured.

A JV would also see the major water customers directly assume the risk of competition winning business away from the MAR Scheme. By committing to the JV, its members are essentially giving up some of the options they might otherwise have to select alternative supply sources if water becomes available on more favourable terms. Once again, the Water Corporation or IWU may be able to manage this risk to a similar extent through long-dated bilateral contracts.

Initially at least, the Water Corporation may be better placed to manage regulatory risks than either the JV or IWU, in part because of its existing regulatory resources and experience and in part because it is owned by Government. The Water Corporation already has experience in managing water recycling and GWR schemes around Perth and ensuring compliance with, among other things:

- Water Services Operating Licence under the *Economic Regulation Authority Act 2003*
- Licence to Operate prescribed plant under the *Environmental Protection Act 1986*;[49]
- The Department of Water (now DWER) Operational Policy 1.01 – Managed aquifer recharge in Western Australia under the *Rights in Water Irrigation Act 1914*
- The *Memorandum of Understanding for Wastewater Services and Groundwater Replenishment between the Department of Health and Water Corporation (October 2014)*

An IWU or JV may also perceive greater risk than would the Water Corporation that future changes in regulatory arrangements or requirements could reduce the profitability or viability of the MAR Scheme.

6.3.3 Whether regulatory changes could be required for successful implementation

If delivered by an IWU or JV, the MAR Scheme will require the proponent to negotiate with the Water Corporation to secure permission to connect to and withdraw treated wastewater from Water Corporation infrastructure and, potentially, discharge reject water back into that infrastructure[50]. With limited precedents for this type of commercial negotiation, it is not clear whether the Water Corporation's market power as a monopoly wastewater service provider might impair this commercial negotiation. Regulatory changes might be necessary to balance the respective negotiating positions of the parties.

The Water Services Act 2012 provides that it is a condition of a Water Services licence that the licensee[51]:

> "if requested to provide a water service authorised by the licence to persons not covered by paragraph (a) but within the operating area or areas of the licence

[49] Eg the licence applicable to the Beenyup Advanced Water Recycling Plant https://www.der.wa.gov.au/images/documents/our-work/licences-and-works-approvals/Applications/L9034_ap2.pdf

[50] It does not appear that there will be any need to secure rights to use Water Corporation infrastructure to transport treated wastewater – simplifying the commercial negotiations somewhat.

[51] Section 21, *Water Services Act 2012 (WA)*.

specified for the service — must offer to provide the service on reasonable terms, unless provision of the service is not financially viable or is otherwise not practicable"

The Water Corporation's Water Services Licence authorises the Water Corporation to supply, among other services, "non-potable water supply services"[52], which, it might reasonably be assumed would extend to the supply of treated wastewater as a feedstock for the MAR Scheme. Therefore, in its commercial negotiation for connection and treated wastewater supply, the Water Corporation appears to owe a statutory obligation to provide these on "reasonable terms".

In practice, the ability of the IWU or JV to secure the required contractual commitments from the Water Corporation may depend on that organisation's internal priorities and future strategic plans for the treated wastewater. Further, the meaning of "reasonable terms" for the purposes of determining the price the Water Corporation will charge for treated wastewater is not clear. It might be interpreted as implying a price that reflects the Water Corporation's reasonable costs, or it could be consistent with a higher price that allows the MAR Scheme to break even, while capturing for the Water Corporation any excess returns to the MAR Scheme.

These questions do not arise if the Water Corporation is responsible for the MAR Scheme, since is its ability to secure treated wastewater on reasonable terms and to connect MAR infrastructure to its existing network can be assumed.

Synergies understands that the Water Corporation's right to inject recycled water into the Leederville Aquifer for GWR relies on multiple licenses and permissions, some of which are listed in the previous section. The Department of Health imposes requirements on the quality and safety of the water injected by means of a Memorandum of Understanding (MOU)[53] rather than by way of a licence under a clearly specified regulatory framework. This form of regulation may not be considered appropriate for other classes of service provider and new regulatory arrangements may be required to regularise the permitting and control of water quality for MAR purposes.

There is no formal scheme of economic regulation for the provision of water supply services in Western Australia. The State Government sets the prices of most of the Water Corporation services, although it takes advice from the ERA on efficient pricing levels[54]. The prices charged by non-statutory providers of water supply services are currently left

---

52 Clause 1.1.1 WL32, Version 15, 19 July 2016, ERA website.

53 Department of Health, 2018, "Groundwater replenishment scheme", https://ww2.health.wa.gov.au/Articles/F_I/Groundwater-replenishment-scheme

54 The Treasurer requests the ERA to carry out an inquiry under section 32(1) of the *Economic Regulation Authority Act 2003*

to the market. If the MAR Scheme operator was considered to possess undue market power, it would need to be considered what measures are available to constrain this market power. Establishing a framework for the economic regulation of water supply services would be an ambitious regulatory reform. Alternatively, it might be considered sufficient to rely on a standard obligation within its Water Services licence to negotiate services on reasonable terms.

6.3.4 Precedents

There are many precedents for the establishment of MAR schemes by statutory water authorities, but Synergies has not identified any precedents for the creation of a MAR scheme by an IWU or JV without involvement of the local monopoly water service provider.

There are numerous MAR Schemes already established across Australia. For instance, South Australia has more than 60 operating MAR systems[55], all of which are operated by either SA Water (the SA equivalent of the Water Corporation) or local councils, many with Commonwealth funding support[56]. Vanderzalm et al prepared a series of case studies on MAR in 2015, which reviewed 11 MAR projects, all of which were carried out by the statutory water service provider for the region in which each MAR project occurred[57].

6.3.5 Suitability for supply of incumbents compared to supply of new customers

A JV model is more likely to be workable if the demand to be supplied by MAR arises among existing WTC businesses. It is likely to be more difficult to coordinate between multiple parties where some of the members of the JV have not yet entered the WTC.

If a JV is established and successfully implements a MAR scheme, then it is possible that the JV might be less responsive to meeting the needs of new entrants. Indeed, in the case of a business that may be a direct competitor to one of the JV members, it is conceivable that the JV could simply refuse to supply MAR water to the new business. If this outcome were considered a sufficient risk (we consider it unlikely), it might warrant imposing additional conditions through the Water Services Licence[58].

---

[55] Russell Martin, "Is South Australia so much better than Western Australia at Managed Aquifer Recharge?", UWA Environment Seminar, 19 April 2018.

[56] *Pers comm*, Russell Martin, 22 May 2018.

[57] Vanderzalm, J, Dillon P, Tapsuwan S, Pickering P, Arold N, Bekele E, Barry K, Donn M, McFarlane D, 2015, *Economics and experiences of managed aquifer recharge (MAR) with recycled water in Australia*, a report for the Australian Water Recycling Centre of Excellence.

[58] Noting that it would be for the ERA to decide what licence conditions are appropriate.

An IWU is likely to have clear and straightforward commercial objectives to maximise revenues from the sale of MAR water. It would, therefore, be expected to try to maximise new business wherever possible. However, we expect that the IWU would allow only a relatively small exposure to demand risk (ie the risk of under-utilisation and asset stranding) by contracting most of its capacity to foundation customers. Thus it may have a relatively small amount of uncontracted MAR water to offer to non-foundation customers.

The Water Corporation should have similar commercial objectives to an IWU, although its ownership by Government might create expectations that other considerations will be taken into account, such as state development objectives. To the extent that this is true, the Water Corporation may be willing to take slightly greater demand risk, which would mean a greater level of uncontracted capacity and greater scope to make water available to new businesses entering the area over time.

6.3.6 Impacts on State budget and public risk burden

If the Water Corporation was to establish a MAR Scheme the investment costs would affect the net operating balance, the net worth and the net debt of the Total Public Sector. Given the interest in reducing the State Government's debt, this impact may be considered a significant drawback of this service delivery model. Investment by either a JV or IWU would be expected to have no direct impact on the State Budget, unless the State Government intervened with some form of direct subsidy.

Public ownership of the MAR Scheme would impose risks, such as the risk of asset stranding, on the Western Australian public. Similar risks are frequently imposed on the public where the Government funds infrastructure investments, such as in the case of roads, bridges and during the establishment of much of the State's water and electricity infrastructure. More recently, State-owned service providers like the Water Corporation and Western Power seek to push many development risks back onto the parties seeking to connect or obtain new services. If the Water Corporation takes a purely commercial view of its role in providing water supply services through MAR, then it may adopt a contracting and development strategy[59] that imposes little additional risk on the Western Australian public.

6.3.7 Alignment with service preferences of major customers

Other considerations that could affect the likelihood of any one model succeeding include the service preferences of key MAR Scheme customers. Synergies interviews

[59] Such as by sizing the MAR scheme capacity to match the contracted commitments of foundation customers.

with large water users within the WTC indicated a preference for higher levels of control and service provider responsiveness that might suggest more interest in a JV approach than would otherwise be the case. Some water users indicated a degree of impatience for the longer lead times they perceived to be required by the Water Corporation compared to what they might expect if they were delivering the solution themselves. If individual perceptions such as these are representative of views held across the relevant businesses, this could lead some customers to more strongly favour a JV approach.

7 Conclusions

7.1 Financial viability

A MAR scheme at Site 2 appears to be financially viable and has the potential to deliver very large financial returns if REU growth scenarios are realised (FNPV ~$30 million). The project could be almost riskless if demand events are included (i.e. a decision by several major users to switch from scheme water to MAR, and several producers going ahead with expansion plans), but it faces considerable risk without them. The project can be viable even if the REU forecasts are excluded and one assumes zero underlying growth, but the service provider would need to secure the event demand before being confident of proceeding.

REU growth is uncertain and even if it eventuates there remains a risk that the MAR scheme operator will not be able identify the relevant customers and find its supply stranded. To the extent that event demand can be secured through foundation contracts, the uncertainty and risk associated with relying on the REU forecasts would be mitigated.

Synergies identified four potential customers who have expressed interest in substituting their current scheme water usage with an alternative source. The combined demand of these customers has the potential to utilise up to 76% of the MAR facility's capacity and make it commercially viable. Attempting to make these four parties the facility's foundations customers appears the least risk strategy to developing this project from a commercial perspective. The operator should have scope to offer supply for these foundation customers at a significant discount to scheme water, providing them with a commercial incentive to enter into long term contracts.

In practice, Synergies expects that a proponent would likely build its business case around identified tranches of demand for which it believed it could secure foundation contracts. The proponent may then build some capacity in addition to the level required to meet the foundation demand as a calculated risk that there will be reasonably strong underlying demand growth, from which the service provider could earn additional returns. Thus, the service provider might intend to offer subsequent customers lower discounts relative to scheme water than it negotiates with its foundation customers.

7.2 Commercial considerations

A MAR Scheme in the WTC faces several significant risks that would need to be managed, including

- Demand risk;

- Competition risk;
- Regulatory risk;
- Feedstock risk;
- Construction and engineering risk; and
- Operational risk.

The most important risk mitigation for a potential MAR Scheme operator will be to secure foundation contracts that reduce demand and competition risks. However, it will also be important to ensure that the rights of the operator are well protected by the regulatory regime and that suitable contractual commitments are secured regarding the supply of treated wastewater.

There seems likely to be a tension between the requirements of a MAR Scheme operator for long-dated contractual commitments and the likely preference of potential customers for flexibility. If there is presently scope for customers to access alternative supply sources on the basis of comparatively short-term contracts, they may not yet be willing to commit to long-term arrangements. However, there is sufficient reason to expect that a MAR scheme will offer some users a compelling product – for instance providing a means of avoiding the cost of increasingly expensive scheme supply or offering environmental reputational benefits. On this basis, it seems reasonable to expect that the MAR Scheme operator and customers would negotiate mutually satisfactory arrangements, though it may take several years before water users are willing to commit.

7.3 Service models

The Water Corporation could own and operates the scheme and establish supply contracts with licensed MAR customers in the WTC. Key considerations for this approach include:

- Some complexity in governance but relatively little risk in implementation and operation
- Avoids issues concerning potential discriminatory access to MAR water
- Increases the debt burden on Government and may expose the public to asset stranding risks

A private IWU could own and operate the scheme and establishes supply contracts with licensed MAR customers in the WTC. Key considerations for this approach include:

- Provides a simple model at arms' length from Government that leaves customers to negotiate the services they require.
- Potentially large demand risks may mean investment is deferred longer, pending highly favourable expected return.
- No impact on State finances.
- Greater exposure to regulatory risks than for the Water Corporation model.

A JV of major water users in the WTC could develop, own and operate the MAR scheme and grant the members of the JV rights to water under that scheme. Key considerations for this approach include:

- Relatively complex initial multiparty negotiations to secure a JV agreement
- Customers retain demand and competition risk which is the optimal allocation;
- Greater exposure to regulatory risks than for the Water Corporation model.
- Introduces potential risk of discrimination between customers in providing access to water.
- No impact on State finances.

7.4 Next steps

What further steps should the Government take in respect of this proposal? Synergies considers that the following steps are important.

Clarify the objectives of further Government involvement

Synergies considers that the investigations carried out to date suggest that the water supplies available to the WTC are not yet limiting to the development of heavy industry and probably will not become so over the next 10 years. In this context, a MAR Scheme servicing the WTC should be considered a potentially desirable although not essential supplement to the region's water supply options. Given this, Government may consider that its main objective should be to identify and remove potential barriers to development of a MAR Scheme by private entities.

Resolving uncertainty around industrial customer demand for water of differing quality

One of the key areas of debate among stakeholders over the course of this project is whether or not industrial users would incur additional on-site costs of treating MAR water prior to use – and if so, the magnitude of these costs. This is an important issue

because it will influence the future strength of demand for MAR water relative to 'ready-treated' water sources such as KWRP and scheme water. We recommend that further investigations be done on this issue establish a more robust assessment of costs and customer preferences.

Review the negotiation framework by which a service provider could secure access to treated wastewater.

The Water Corporation has an effective monopoly over the supply of treated wastewater. Despite the fact that there looks set to be a continuing surplus of this potential recycling feedstock, the Water Corporation will be in a strong position to extract economic rent by charging for parties to take treated wastewater. This is not only a simple cost barrier to the development of a MAR Scheme, but also gives the Water Corporation a competitive advantage in water recycling compared to an IWU. There are clearly implications for competition policy of the Water Corporation being able to access feedstock for its own purposes at no charge. This might be an area requiring policy attention from the State Government if it wishes to encourage the private sector to compete to provide water recycling services. The principles in ERA's 2009 inquiry into pricing of recycled water provide a good starting basis, but further work is likely needed to operationalise these principles.

Confirm that the regulatory framework offers sufficiently clear and stable rights for MAR Scheme operators

Synergies is not aware of any issues with the existing regulatory framework under which a MAR Scheme would operate. DWER's current MAR Policy does appear to afford a considerable degree of discretion to the Department in how each MAR Scheme is to be structured and what rights will be granted. This may be appropriate for this early phase in the development of the framework. However, the Government may need to be prepared to develop more detailed and restrictive policies to provide the necessary regulatory certainty to a specific MAR Scheme operator, before it is able to invest.

Determine the means by which to make Site 2 available to potential developers

Site 2 is currently vested with management order to the City of Kwinana. It is not clear what steps would be required to make the site available for development. The site has apparent value the location of a MAR facility, but may also be suitable for other competing uses. The Government may wish to secure the site and offer it to potential developers. Should it do so, it may consider trying to capture potential project value by means of competitive tender.

A Adaption of REU demand forecasts

REU generated three sets of demand growth forecasts: i) a central case based on value added projections, ii) a low case based on employment projections and iii) a high case based on total output projections. These three forecasts reflect three different assumptions about the relationship between economic growth and water demand growth, but all three forecasts are based on a single economic growth scenario.

The above forecasts were further disaggregated by groundwater subarea. Synergies notes that only the Valley and Wellard subareas are relevant to forecasting the potential customer base in the MAR Zones associated with Sites 1 and 2 (see Section 3.1). This conclusion is based on the following judgements.

- The Kogalup groundwater subarea is too far to the North of either site for the MAR water to be accessible by users in that groundwater subarea.
- The Thompsons groundwater subarea is forecast by REU to experience no industrial growth and no growth in demand for water by heavy industry.
- The Valley groundwater subarea is forecast to experience growth and the MAR zones associated with Site 1 and Site 2 would extend well into this area.
- The Wellard groundwater subarea is forecast to experience strong growth and the MAR zone associated with Site 2 would extend well into this area.

Synergies took the REU estimates of water use in heavy industry for Valley and Wellard in 2016 and adjusted these downwards by 13% to remove assumed demand for scheme water. Table A1 presents the resulting base demand estimates by source for the two areas.

Table A1 Base demand estimates; Valley and Wellard by source in 2016

Area	Source	Quantity
Valley	All sources	9.82 GL/y
	Scheme water	1.28 GL/y
	Groundwater	8.54 GL/y
Wellard	All sources	10.57 GL/y
	Scheme water	1.37 GL/y
	Groundwater	9.20 GL/y

Source: Synergies analysis of REU and DWER data

Table A2 presents the growth rates tested by the model.

Table A2 Tested annual demand growth rates

Area	Scenario	2017 to 2021	2022 to 2040	2041 to 2080
Valley	REU base	1.3%	1.7%	0.0%
	REU low	1.1%	1.2%	0.0%
	REU high	1.6%	1.8%	0.0%
	No growth	0.0%	0.0%	0.0%
Wellard	REU base	3.8%	4.0%	0.0%
	REU low	3.4%	3.1%	0.0%
	REU high	4.6%	4.0%	0.0%
	No growth	0.0%	0.0%	0.0%
Combined	REU base	2.6%	2.9%	0.0%
	REU low	2.3%	2.2%	0.0%
	REU high	3.2%	2.9%	0.0%
	No growth	0.0%	0.0%	0.0%

Note:
The combined growth rates are calculated as the average of the area specific growth rates weighted by the base demand presented in Table A1. The original REU forecast has been extended from 2031 to 2040. As longer-term forecasts tend to be very uncertain, this analysis assumes zero demand growth from 2041 onwards.

Source: Synergies adaptation of REU data

B Additional Information on MAR Facilities

B.1 Summary of Options

Table B1 Summary of MAR Options

	Option 1 – Site 1 (Northern site)	Option 2 – Site 2 (Southern site)
Treated wastewater (treated wastewater) source	• Directly from SDOOL - initially comprising treated wastewater from Woodman Point WWTP, then from 2030 the treated wastewater will also come from the proposed Advanced Wastewater Recycling Plant (AWRP)	• From East Rockingham WWTP
treated wastewater volumes	• 10 ML/day (3.55GL/yr) immediately, subject to requirements	• 10 ML/day (3.55GL/yr) from 2027, but only 1.9GL/yr in 2020
treated wastewater quality and implications for treatment level at MAR plant	• Quality reduces post 2030 once the AWRP becomes operational (due to reject water from AWRP) • The higher conductivity wastewater post 2030 will require additional treatment costs at the Site 1 recycling plant. This has been incorporated into GHD costings	• Treatment requirements could increase in the long term if East Rockingham is reconfigured from its current oxidation ditch technology. • However, even if East Rockingham WWTP is reconfigured, this risk is largely mitigated by GHD design. A small increase in operating costs is conceivable but can be ignored due to low probability and magnitude.
Staging	• Up until 2030, the treated wastewater is of a quality that requires no reverse osmosis • From 2030, lower treated wastewater input quality (due to commissioning of Woodman Point AWRP) requires reverse osmosis. • Will be a single stage if MAR facility built after 2030 (with reverse osmosis from the start) • MAR facility will be built in two stages if built before 2030 (with reverse osmosis added in 2030 as a second stage)	• Single stage
Staging and timing of plant commissioning	• Single stage, to be built when there is sufficient demand to make the plant commercially viable (single stage approach assumes commissioning from 2030 onwards) • Alternatively, the option to built in two stages, with stage 1 to meet initial demand prior to 2030, and a second stage to be built in 2030 to coincide with commissioning of Woodman Point AWRP (the second-stage plant will require reverse osmosis to treat the lower-quality wastewater entering the plant)	• Single stage, to be built when there is sufficient demand to make the plant commercially viable
Treatment of recycling plant effluent	• To be returned to the SDOOL	• No effluent to leave site

	• This may give rise to increased treatment costs for Water Corporation as it reduces the quality of wastewater in the SDOOL (these costs have not been specified by Water Corporation)	• No additional treatment costs for Water Corporation
Recovery rate (proportion of treated wastewater received that converts to useable MAR water)	• 95% initially • 81% from 2030 onwards due to reverse osmosis losses	• 95% throughout
Max processing capacity	• Input up to 10.5ML/day treated wastewater, increasing to 12.3ML/day as input quality falls • Deliver up to 10 ML/day MAR water (or 3.6 GL/yr)	• Input up to 10.5ML/day treated wastewater • Deliver up to 10 ML/day MAR water (or 3.6GL/yr)
Existing water users in MAR area	• 19 licensees have one or more bores close to Site 1 • Total allocated volumes for these licensed are 7.53GL • Note uncertainty associated with which users would actually lie within the MAR area (see below)	• 20 licensees have one or more bores close to Site 2 • Total allocated volumes for these licensed are 9.59GL • Note uncertainty associated with which users would actually lie within the MAR area (see below)
Notable environmental assets / potential issues	• Two wetlands with potential to receive increased nutrient loadings, Lake Mt Brown and an unnamed wetland SW of the infiltration site (CSIRO, 2015, page 169) • Nutrients could reach these wetlands within 14 and 8 years respectively (ignoring impact of increased abstractions) • Potential for increased nitrogen loading into Cockburn Sound within around 20 years (ignoring impact of increased abstractions). • Potential for increased abstractions along the coast to exacerbate salt water intrusion – dependent on location and intensity.	• Up and down gradient wetlands with potential to receive nutrients • High likelihood that upgradient wetlands within adjacent golf course could receive additional nutrients within 1 year (CSIRO, 2015, page 174) • Potential for downgradient wetlands to receive additional nutrients within 4 years (CSIRO, 2015, page 174) • Potential for increased nitrogen loading into Cockburn Sound within around 15 years (ignoring impact of increased abstractions) – see CSIRO, 2015, page 173. • Potential for increased abstractions along the coast to exacerbate salt water intrusion – dependent on location and intensity.
Key risks	• Site may become landlocked by surrounding transport infrastructure and require substantial civil works costs to resolve this • If Site 1 had to be shut down for maintenance, that would mean an increase of wastewater going through the SDOOL and Water Corp would have to build-in greater risk management measures for this, adding to its costs. This is not such a concern for Site 2, because there's only a short section south of East Rockingham	• Frequency of gallery renovations uncertain due to limited precedents • treated wastewater volumes may grow more slowly than assumed. • According to Water Corp, Site 2 is a 'less complex' process than Site 1, so there's less risk overall of Site 2 having to be shut down

B.2 Detailed Capital and Operating Cost Information

B.2.1 Summary Breakdown of Capital costs

- Capital cost data are as provided by GHD, see Table B.1
- Costs were aggregated into categories of Conveyancing, Treatment, Monitoring and Infiltration and Indirect costs
- All costs include a 25% mark-up to account for capital cost contingencies as per GHD's report
- Capital costs for Site 1 allowed for the potential two phase development of that site to accommodate the change in treated wastewater feedstock characteristics assumed to occur in 2030;
- Replacement capex is scheduled to occur at different times depending on the types of assets. While not shown in Table B.1, the costs were modelled at the level of disaggregation required to apply an appropriate asset replacement timing assumption to each cost item;
- Replacement capex was estimated by GHD inclusive of estimated indirect project costs for those replacements;

Table B.1 Initial and replacement capital costs assumed for Sites 1 and 2 ($2018)

	Units	Site 1		Site 2
		Phase 1	Phase 2	
Initial Capex				
Conveyance	$	$1,354,000	$0	$5,310,000
Treatment	$	$16,877,000	$5,735,000	$6,815,000
Monitoring	$	$177,000	$0	$142,000
Infiltration	$	$0	$0	$2,309,000
Indirect Costs	$	$3,049,000	$885,000	$2,687,000
Total		**$21,457,000**	**$6,620,000**	**$17,264,000**
Replacement Capex				
Conveyance	$			
Treatment	$	$3,738,000	$3,731,000	$2,912,000
Monitoring	$	$0	$0	$0
Infiltration	$	$0	$0	$718,000
Total		**$3,816,000**	**$3,731,000**	**$3,882,000**

B.3 Summary Breakdown of Operating costs

- Operating cost assumptions are as provided by GHD, see Table B.2
- Costs were aggregated into categories of Conveyancing, Treatment, Monitoring and Infiltration and Indirect costs
- All costs include a 20% markup to account for operating cost contingencies as per GHD's report
- Variable operating costs for Site 1 allowed for the potential two phase development of that site to accommodate the change in treated wastewater feedstock characteristics assumed to occur in 2030;
- GHD included a mark-up of operating costs to represent the financial burden of having carry working capital to cover operating costs. Synergies excluded this mark-up to allow the financial costs and revenues to be compared without factoring-in complicating commercial practices.

Table B.2 Operating costs assumed for Sites 1 and 2 ($2018)

	Units	Site 1		Site 2
		Phase 1	Phase 2	
Fixed Opex				
Conveyance	$/year	$11,000	$11,000	$24,000
Treatment	$/year	$210,000	$309,000	$200,000
Monitoring	$/year	$64,000	$64,000	$47,000
Infiltration	$/year	$44,000	$44,000	$31,000
Total	$/year	**$328,000**	**$427,000**	**$302,000**
Variable Opex				
Conveyance	$/kL	0.005	0.021	0.083
Treatment	$/kL	0.109	0.223	0.036
Monitoring	$/kL	0.000	0.000	0.000
Infiltration	$/kL	0.007	0.007	0.000
Total	$/kL	**0.122**	**0.251**	**0.119**

All Capital and Operating Costs – Full detail

Table B.3 Site 1 detailed capital, replacement and operating costs

Cost type	Phase	Process	Fix /Var	Description	Units	Cost	Timing	Construction Phasing		Earliest start year
Capex	1	Conveyance		SDOOL Connection Works - Procurement	$	146,941	Start	0%	100%	2018
Capex	1	Conveyance		SCOOL Connection Works - Construction/Installation	$	251,699	Start	0%	100%	2018
Capex	1	Conveyance		Open-cut service installation	$	733,741	Start	0%	100%	2018
Capex	1	Conveyance		Trenchless crossing of service corridor & future FRCAH ramp	$	221,813	Start	0%	100%	2018
Capex	1	Treatment		General Site/Civil Works and Access Roads	$	9,031,921	Start	0%	100%	2018
Capex	1	Treatment		Tertiary Treatment Facilities - Denitrifying Gravity Filters and Desalination Packages	$	5,541,250	Start	0%	100%	2018
Capex	1	Treatment		Tertiary Treatment Facilities - Balance of Plant	$	2,304,025	Start	0%	100%	2018
Capex	1	Monitoring		Monitoring Bores	$	176,813	Start	0%	100%	2018
Capex	1	Indirect Costs		Investigations and Approvals	$	287,500	Start	100%	0%	2018
Capex	1	Indirect Costs		Design and Project Management	$	2,761,230	Start	50%	50%	2018
Capex	2	Treatment		Tertiary Treatment Facilities - Denitrifying Gravity Filters and Desalination Packages	$	4,813,250	2030	0%	100%	2030
Capex	2	Treatment		Tertiary Treatment Facilities - Balance of Plant	$	921,666	2030	0%	100%	2030
Capex	2	Indirect Costs		Investigations and Approvals	$	25,000	2030	100%	0%	2030
Capex	2	Indirect Costs		Design and Project Management	$	860,238	2030	50%	50%	2030
Repex	1	Conveyance		MIEC Infrastructure	$	77,750	25	0%	100%	2018
Repex	1	Treatment		MIEC Infrastructure	$	3,194,802	25	0%	100%	2018

Repex	1	Treatment		Tanks	$	543,400	20	0%	100%	2018
Repex	2	Treatment		MIEC Infrastructure	$	3,234,336	25	0%	100%	2018
Repex	2	Treatment		Tanks	$	107,900	20	0%	100%	2018
Repex	2	Treatment		RO Membranes	$	388,800	7	0%	100%	2018
Opex	1	Conveyance	Fixed		$/year	11,074	Start	N/A	N/A	2018
Opex	1	Treatment	Fixed		$/year	209,576	Start	N/A	N/A	2018
Opex	1	Infiltration	Fixed		$/year	43,748	Start	N/A	N/A	2018
Opex	1	Monitoring	Fixed		$/year	63,840	Start	N/A	N/A	2018
Opex	1	Conveyance	Variable		$/kL	0.005	Start	N/A	N/A	2018
Opex	1	Treatment	Variable		$/kL	0.109	Start	N/A	N/A	2018
Opex	1	Infiltration	Variable		$/kL	0.007	Start	N/A	N/A	2018
Opex	1	Monitoring	Variable		$/kL	0.000	Start	N/A	N/A	2018
Opex	2	Conveyance	Fixed		$/year	11,074	2030	N/A	N/A	2030
Opex	2	Treatment	Fixed		$/year	308,527	2030	N/A	N/A	2030
Opex	2	Infiltration	Fixed		$/year	43,748	2030	N/A	N/A	2030
Opex	2	Monitoring	Fixed		$/year	63,840	2030	N/A	N/A	2030
Opex	2	Conveyance	Variable		$/kL	0.021	2030	N/A	N/A	2030
Opex	2	Treatment	Variable		$/kL	0.223	2030	N/A	N/A	2030
Opex	2	Infiltration	Variable		$/kL	0.007	2030	N/A	N/A	2030
Opex	2	Monitoring	Variable		$/kL	0.000	2030	N/A	N/A	2030

Table B.4 Site 2 detailed capital, replacement and operating costs

Cost type	Phase	Process	Fix /Var	Description	Units	Cost	Timing	Construction Phasing		Earliest start year	Replacement cycle (years)
Capex	1	Conveyance		Treated Wastewater Pump Station	$	469,211	Start	0%	100%	2018	
Capex	1	Conveyance		Pipelines between East Rockingham WWTP FEPS and Tertiary Treatment Plant	$	435,713	Start	0%	100%	2018	
Capex	1	Conveyance		Recycled Water Pipeline from Tertiary Treatment Plant and Gentle Road (Infiltration Gallery) Site	$	4,405,261	Start	0%	100%	2018	
Capex	1	Treatment		General Site/Civil Works and Access Roads	$	198,015	Start	0%	100%	2018	
Capex	1	Treatment		Tertiary Treatment Facilities - Denitrifying Gravity Filter Package	$	5,053,750	Start	0%	100%	2018	
Capex	1	Treatment		Tertiary Treatment Facilities - Balance of Plant	$	1,563,218	Start	0%	100%	2018	
Capex	1	Infiltration		General Site/Civil Works and Access Roads	$	936,893	Start	0%	100%	2018	
Capex	1	Infiltration		Infiltration Galleries (excluding bulk earthworks) and Pipework	$	1,372,518	Start	0%	100%	2018	
Capex	1	Monitoring		Monitoring Bores	$	142,438	Start	0%	100%	2018	
Capex	1	Indirect Costs		Investigations and Approvals	$	500,000	Start	100%	0%	2018	
Capex	1	Indirect Costs		Design and Project Management	$	2,186,553	Start	50%	50%	2018	
Repex	1	Conveyance		MIEC Infrastructure	$	252,405	25	0%	100%	2018	25
Repex	1	Treatment		MIEC Infrastructure	$	2,771,216	25	0%	100%	2018	25
Repex	1	Treatment		Tanks	$	140,400	20	0%	100%	2018	20
Opex	1	Conveyance	Fixed		$/year	23,828	Start	N/A	N/A	2018	
Opex	1	Treatment	Fixed		$/year	199,942	Start	N/A	N/A	2018	
Opex	1	Infiltration	Fixed		$/year	31,028	Start	N/A	N/A	2018	
Opex	1	Monitoring	Fixed		$/year	47,040	Start	N/A	N/A	2018	
Opex	1	Conveyance	Variable		$/kL	0.08	Start	N/A	N/A	2018	

Opex	1	Treatment	Variable		$/kL	0.04	Start	N/A	N/A	2018	
Opex	1	Infiltration	Variable		$/kL	0.00	Start	N/A	N/A	2018	
Opex	1	Monitoring	Variable		$/kL	0.00	Start	N/A	N/A	2018	
Repex	1	Infiltration		Renovating the infiltration galleries	$	718,140	10			2018	10

Appendix D – Approval requirements

Table D-1 Regulatory approvals for the MAR scheme

Agency	Approval Required	Regulatory Instrument	Application requirements (or supporting information)	Timeframe for approval (targeted approval unless stated)	Potential issues/ matters to be considered relevant to proposed MAR sites
Water Corporation	1.1 Approval to use/access stormwater or wastewater from Water Service Provider's infrastructure.	Recycled Water Supply Agreement Water Services Act 2012	RWSA is an over-arching contractual document regarding conditions of supply (e.g. price, duration of agreement, quality). It relies on completion of all other health and environmental approvals. Other approvals can be obtained on the basis of a "Letter of Intent to Supply" which confirms availability of water.	3 to 6 months (after other approvals complete. Timing depends on commercial negotiations not regulatory)	Site 1 – access to SDOOL, in particular timing of off-take and return with regard to pumping in the line. Site 2 – access to ERWWTP infrastructure, including requirements for maintenance and operation of pump taking water. Integration of off-take into future upgrades. Site 2 – return of filter backwash to discharge line from ERWWTP
	1.2 Disposal of treatment concentrate to the SDOOL or sewer.	Trade Waste Discharge Permit	Quality and volume of reject stream discharge	1 month	Impact of reject stream discharge on ability of Water Corporation to comply with Ministerial Statement 665 conditions (Use of the Cape Peron Outlet Pipeline to Dispose of Industrial Wastewater to the Sepia Depression, Kwinana)
Department of Water and Environmental Regulation	2.1 Assessment by the EPA under Part IV of the Environmental Protection Act 1986.	Ministerial Statement, Licence Part IV EP Act 1986	Risk assessment, hydrogeological assessment MAR proposals which are likely to have a significant effect on the environment should be referred to the EPA under section 38 of the Environmental Protection Act 1986 (EP Act).	28 day period to decide to assess under Part IV. Time frame of over 6 months could then be expected depending on level of assessment.	Decisions on applications under Part V EP Act 1986 and under the Rights in Water and Irrigation Act 1914 will not be inconsistent with any decision made under Part IV of the EP Act. Considered more likely for Site 2. 3rd party referral to the EPA applies. A decision not to assess under Part IV is appealable.
	2.2 Clearing of native vegetation.	Clearing Permit Under Part V, Division 2 of the EP Act 1986	Native vegetation clearing permit (possibility for parallel processing and combined instrument where related to a works approval or licence application)	80% of applications within 60 working days	Biological surveys of proposed clearing areas required to inform assessment of clearing permit application. Vegetation type would need to be confirmed. Banksia woodlands of the Swan Coastal Plan are a nationally protected ecological community under the Environment Protection and Biodiversity Conservation Act 1999
	2.3 Construction / amendment of wastewater treatment plant.	Works approval/licence under Part V EP Act 1986	Prescribed Premises (or potential) (Category 54/85) Information on Part V application form	80% of applications within 60 working days	Licence amendment to make changes to an operational WWTP (East Rockingham WWTP see note 2.6).
	2.4 Construction of injection bores / infiltration works intercepting groundwater or above water table.	Works approval under Part V EP Act 1986 Licence to construct or alter well under (Section 26D) Rights in Water Irrigation Act 1914	Information on Part V application form Information on Form 2 (non-artesian)	80% of applications within 60 working days	Infiltration basins won't intercept groundwater so 26D licence unlikely for basins
	2.5 Taking of source water from aquifers or surface water resources in areas proclaimed under the Rights in Water and Irrigation Act 1914.	Licence to take water under (Section 5C) Rights in Water Irrigation Act 1914	Information on Form 3G Hydrogeological assessment, risk assessment, operating strategy, groundwater monitoring program Operational policy: Management of water resources in managed aquifer recharge operations	80% of applications within High risk water licence 95 days (exclude stop the clock etc. EPA approval)	Cockburn Groundwater Area Allocation Plan 2018 – the recouping of unused entitlements will begin in 18/19 with large licences and licences in high risk areas, continuing until each resource returns to full allocation. This process will not impact the MAR licence process as it is managed separately. The determination of MAR management zones will dictate where the water may be abstracted from, recovery volumes and the time between recharge and recovery.

Agency	Approval Required	Regulatory Instrument	Application requirements (or supporting information)	Timeframe for approval (targeted approval unless stated)	Potential issues/ matters to be considered relevant to proposed MAR sites
	2.6 Licence to operate a MAR scheme / discharge to the environment (wastewater, treatment concentrate, chemicals).	Licence or registration under Part V EP Act 1986	Licence or registration (includes amendments) to operate a prescribed premise and discharge to the environment Information on Part V application form	Licence-80% of applications within 60 working days Registration- 80% of applications within 40 working days	The Department undertakes risk-based reviews on existing premises and licences to ensure the licences are effective in controlling risks posed to public health and the environment. If a premise is licensed, DWER is responsible to investigate complaints and administer noise regulation. If basins at East Rockingham WWTP are utilised for MAR, an amendment to Water Corporation's licence would be required
	2.7 Statutory requirement under CSA to advise on the suitability of land for subdivision or development, where a memorial has been registered on a land title due confirmed or possible contamination.	Contaminated Sites Act 2003	Classification of reported sites (Form 1) and part of hydrogeological assessment Feed into Development Approval.	45 calendar days (statutory)	Many contaminated sites within the WTC. Need to ensure injected TWW does not negatively impact contaminated sites i.e. move nitrate plumes.
	2.8 Controlled waste	Environmental Protection (Controlled Waste) Regulations 2004	Controlled waste licence	30 calendar days (statutory)	A carrier must hold a licence relevant to the type of controlled waste they transport. May be relevant to the maintenance of Basins and Galleries
Department of Health	3.0 Approval to install a wastewater treatment system	Licence to construct and install under Health (Miscellaneous Provisions) Act 1911	Proposed treatment train needs to demonstrate pathogen log removal targets to achieve fit for purpose recycled water quality.	30 calendar days after all information provided	Treatment train selected to treat water to the intended end-use. Treatment needs to demonstrate adequate protection of existing aquifer environmental health values.
	3.1 Approval to use recycled water	MoU, Guidelines for the non-potable uses of recycled water in Western Australia under Health (Miscellaneous Provisions) Act 1911	Recycled Water Quality Management Plan Recycled Water Supply Agreement (if different parties involved in the supply/reception of treated effluent).	30 calendar days after all information provided	Final approval to recharge subject to demonstration of water quality after a validation and verification sampling period Additional approval may be required for abstraction and use of the infiltrated/injected wastewater.
City of Kwinana	3.2 Development Approval and Building Permit for construction of infrastructure (e.g. infiltration structures, wastewater treatment plants).	Planning and Development Act 2005, Building Act 2011, Building Regulations 2012 (City of Kwinana Town Planning Scheme No. 2)	Council Consultation; Community Consultation; Tenant Consultation; Reserve is leased to tenant until 2033. Investigate sub-leasing or exercising options; JDAP – Kwinana support required; Native Veg Clearing Permit requires Kwinana support; Bush Forever Site; Heritage site; Contaminated site issues; Screening, engineering works and site management plans; Noise and odour considerations; Site security; MRS amendment/lease/ management order of site area;		City would be unlikely to support proposal if the footprint of the proposal includes native vegetation clearing given there are cleared areas adjacent to the proposed site. If native vegetation removal required, offset must be purchased and located within Kwinana.

Agency	Approval Required	Regulatory Instrument	Application requirements (or supporting information)	Timeframe for approval (targeted approval unless stated)	Potential issues/ matters to be considered relevant to proposed MAR sites
Economic Regulation Authority	3.3 Provision of MAR water (e.g. to the public or a third party).	Water Service Licence Water Services Act 2012	The requirements for a water services licence application are specified in the ERA's Licence Application Guidelines: Electricity, Gas and Water Licences	Section 11(4) of the Act requires the ERA to take all reasonable steps to make a decision in respect of an application within 90 days after the application is made.	The process for granting water services licence is in S11 of the Water Services Act 2012. There are three tests to show the applicant has, and will retain: The technical capacity to provide the water service The financial capacity to provide the service Granting the licence would not be contrary to the public interest (which is assessed by advertising the application for public comment)
Department of Planning Lands and Heritage for WAPC	3.4 Development approval under MRS if required 3.5 Advice regarding Bush forever	Planning and Development Act 2005			Site 1 – Hope Valley Wattleup Redevelopment Act Site 2 – Parks and Rec Reserve under MRS. Bush Forever would be a consideration under the Part IV or V assessment under the EP Act. The EPA will take into consideration the policy measures of State Planning Policy 2.8 Bushland Policy for the Perth Metropolitan Region and likely ask the Department of Planning, Lands and Heritage (DPLH) for input for interpretation, implementation and advice on the policy. If no Part IV or V is required then the proposed Bush Forever impact will be assessed through the planning process. The main aim of SPP 2.8 is to avoid and minimise any likely adverse (direct or indirect) impacts on regionally significant bushland in the first instance. If impacts are unavoidable then the impact assessment process and criteria (Appendix 1&2) should be adopted.

GHD

Level 10
999 Hay Street
T: 61 8 6222 8222   F: 61 8 6222 8555   E: permail@ghd.com

6137454-18011/https://projects.ghd.com/oc/WesternAustralia1/wtcmarstudyfinalfeas/Delivery/Documents/6137454-REP-1_Final Feasibility Study Report.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Draft A	S Woods	D Edgar J. Foley	*On file*	J. Foley	*On file*	02.10.18
Draft B	S Woods	D. Edgar J. Foley	*On file*	J. Foley	*On file*	17.10.18
Rev 0	S Woods	D. Edgar	*On file*	J. Foley	*On file*	22.10.18
Rev 1	S Woods	D. Edgar J. Foley	*On file*	J. Foley	*On file*	28.02.19
Rev 2	S Woods	J. Foley		J. Foley		02.04.19

www.ghd.com