Appendix D Technical Modelling Advice

Geraldton No 2. WRRF

Technical Modelling Advice

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1 Purpose

The purpose of this memo is to provide technical supporting information to a licence amendment in relation to conditions 15, 16, 17, 18 and 22 of L5961/1991/12.

2 Background

The Geraldton WRRF No.2 site is licensed (L5961/1991/12) under Part V of the *Environmental Protection Act 1986* (EP Act) to treat up to 3.5 ML of wastewater (WW) per day. Treated wastewater (TWW) is disposed of on-site via a series of infiltration ponds in the southern portion (IP1-IP4) and the northern portion of the site (IP5-IP8). Groundwater in the vicinity of the southern infiltration ponds (IP1-IP4) is abstracted via production bore A1/97 under groundwater licence 64525 for off-site non-potable beneficial re-use by several recipients.

Interpolated groundwater heads for the shallow and intermediate portions of the aquifer indicate a south westerly to west south westerly flow direction towards the coast. The Indian Ocean is situated ~3 km west and ultimately receives groundwater discharge from the site. Non-potable beneficial use of groundwater is undertaken in the surrounding area and down-hydraulic gradient towards the coast.

Rockwater conducted numerical modelling to estimate the impacts of TWW and indirect re-use associated with inflows of 2.0 and 3.5 ML/day over a 10-year period (Rockwater 2009). This model was used to support the 2016 licence amendment for inclusion of the northern infiltration ponds (IP5-IP8) and increased treatment capacity at the site to 3.5 ML/day.

Additional nutrient modelling (Rockwater 2010) was undertaken to simulate an infiltration scenario of 20 ML/d. The summary report of this modelling was submitted to DWER along with Rockwater 2009 in support of 2016 licence amendment even though the simulation was not applicable to the proposed targeted 3.5 ML/day treatment capacity. Therefore, the Rockwater 2010 20 ML/d nutrient model is not considered relevant and not discussed further in this technical advice. DWER refers to *'Rockwater 2010' modelling data* in licence conditions 16 and 18 (refer Table 1), which, by association, is taken to mean the underpinning modelling works completed and reported in Rockwater 2009, this technical advice herein will refer to the correct Rockwater 2009 nutrient model.

The DWER decision document which supported the 2016 licence amendment referenced managed aquifer recharge (MAR) policy to regulate the discharge of TWW to land and groundwater via the infiltration ponds. The decision document assesses Rockwater 2009 and 2010 nutrient models against the 2011 Department of Water (DoW) MAR policy (DoW 2011). The site was not designed as a MAR scheme and production bore

A1/97 near the southern infiltration ponds draws groundwater for beneficial reuse. Prior to 2016, DWER had not assessed the licence as a MAR scheme.

The current DWER MAR policy (DWER, 2021) that replaced DoW 2011 considers that for a scheme to qualify as MAR, discharged water must be intended solely for re-use. The interpretation of the DWER 2021 guidelines is such that disposal of TWW through infiltration does not meet DWER's definition of MAR and is regulated by DWER through other legislation i.e. Part V of the EP Act 1986.

3 Relevant Licence conditions

3.1 Triennial review

Three conditions in the licence relate to a triennial review of ambient groundwater monitoring to validate the 'Rockwater 2010' modelling data. Condition 18 also requests a timeline for the installation of additional bores for monitoring the MAR area be included in the triennial review. The conditions are detailed in **Table 1.**

Table 1 Triennial review licence conditions (L5961/1991/12)

Licence Condition No.	Condition
16.	The licence holder must undertake a triennial review of the ambient groundwater monitoring data to validate the 'Rockwater 2010' modelling data, as submitted for the new infiltration ponds. The review shall incorporate all monitoring and production bore ambient quality data ambient quality data obtained since initiating discharge to the new infiltration ponds (IP5-IP8). The triennial review shall consider: (a) The 'Rockwater Report 2010' modelling data, as submitted for the new infiltration ponds; (b) 'Australian Guidelines for Water Recycling – Managed Aquifer Recharge, July 2009'; (c) the 'ANZECC 2000' guidelines; (d) nutrient loads to the irrigation and infiltration areas; and (e) groundwater directional flow
17.	The licence holder must submit the triennial review (as defined in condition 16 to the CEO by 25 February 2020 and by February every three years thereafter.
18.	The licence holder must include in the initial triennial review (to be submitted by 25 February 2020 in accordance with Condition 16, a timeline for the installation of additional bores for monitoring the MAR area, to be located on the basis of validating the modelled extent of the wastewater plume after 10 years of infiltration, as outlined within Section 10.1 of the 'Rockwater, 2010' report.

3.2 Ambient groundwater quality monitoring

The licence stipulates that Water Corporation completes ambient groundwater quality monitoring at one production bore (A1/97) and 16 groundwater monitoring bores as per Table 2. The monitoring bore locations are shown on Figure 1.

Monitoring bore 10/94 was damaged and replaced with shallow superficial monitoring bore 2/22. In addition, monitoring bore 5/94 was also damaged and replaced with deep superficial monitoring bore 1/22, and subsequently 1/23 (as 1/22 was blocked with a pump during sampling in early 2023).

Table 2 Licence ambient groundwater quality monitoring

Monitoring location	Parameter	Limits	Units	Averaging Period	Frequency
Monitoring and production bores: A1/97 1/94 2/94 3/94 4/94 5/94 6/94 7/94 8/94 9/94 10/94 1/17 2/17 3/17 4/17 5/17 6/17	Standing water level	-	m (BGL)	Spot sample	Six monthly
	Electrical conductivity	-	µS/cm		
	Total dissolved solids	-	mg/L		
	Total nitrogen	-			
	Total phosphorus	-			
	pH	6.5-8.5	pH		Monthly
	E.coli	<1,000	Cfu/100 ml		
	Aluminium	-	mg/L		Annual
	Arsenic	-			
	Beryllium	-			
	Boron	-			
	Cadmium	-			
	Chromium	-			
	Cobalt	-			
	Copper	-			
	Fluoride	-			
	Lead	-			
	Mercury	-			
	Nickel	-			
	Selenium	-			
	Zinc	-			

Figure 1 Map of licence monitoring bore locations

3.3 Records and reporting

The licence stipulates that Water Corporation must prepare an environmental report which includes a 'Summary of monitoring of ambient groundwater quality' (Condition 15) to be submitted to the CEO by 1 October each year.

4 Modelling review

Nutrient models have been completed at the site since the early 1990s, including:

- Rockwater (1993), Geraldton WWTP No. 2: Capacity for infiltration of treated wastewater, and groundwater effects.
- Rockwater (1997), Geraldton WWTP No. 2: Capacity for infiltration of treated wastewater, and groundwater effects.
- Rockwater (1998), Predicting effects of increased wastewater disposal, Geraldton WWTP No.2.
- Rockwater (2009), Geraldton WWTP2 Results of Numerical Modelling of Wastewater Infiltration and Extraction for Reuse. August 2009.

4.1 Rockwater 1993, 1997 and 1998

Rockwater consulting originally developed a numerical groundwater model in 1993 (based on Modflow 1988 finite difference modelling software and coupled MT3D solute transport software) to simulate TWW infiltration at the site. This model was updated in 1997 and 1998.

4.2 Rockwater 2009

4.2.1 Model set-up

Rockwater was engaged to carry out numerical modelling to update and re-calibrate the groundwater model constructed in 1993 and revised in 1997 and 1998 (Rockwater 1993, 1997 and 1998). The purpose was to use the model to estimate the volumes of TWW that could be infiltrated for WRRF inflows of 2.0 and 3.5 ML/d over a 10-year period.

The 3.5 ML/d inflow model to the WRRF was set-up with the following assumptions:

- TWW would be infiltrated via the existing southern infiltration basins and three new basins to the north (which were not yet constructed).
- he existing basins would be periodically allowed to dry and be cleaned and there would always be one of the new northern infiltration basins being rested.
- Five theoretical re-use bores were modelled, and it was assumed that the volume pumped would be 70 percent of the total volume infiltrated via the infiltration basins. Furthermore, existing bore A1/97 was not included as one of the five modelling bores.

4.2.2 Model findings

The findings of the model after 10 years of infiltration and re-use found:

- Model calculated total nitrogen (TN) concentrations (above background levels) after 10 years of infiltration and re-use would result in concentration changes of 1 mg/L of more extending up to 550 m from the infiltration basins. Solute transport modelling results indicated that TN in groundwater around the WRRF would stabilise after a short time at any new infiltration rate, with the extent of TN in the aquifer limited by continuing denitrification.
- Model calculated total phosphorus (TP) concentrations (above background levels) after 10 years of infiltration and re-use would result in elevated concentrations indicated to extent up to 90 m from the infiltration ponds. It was predicted that the Tamala Limestone would strongly adsorb TP and the rate of movement would gradually decrease.
- The modelling results indicated that the theoretical modelled re-use bores would not capture all the infiltrated TWW and recommended monitoring groundwater quality from the re-use bore and groundwater monitoring bore network.

4.2.3 Model limitations

The Rockwater 2009 nutrient model used has several limitations restricting the accuracy of the outputs:

- The base architecture of the Rockwater 2009 nutrient model (the conceptual model) remained unchanged from the original 1993 model. This includes a single layer representing the Tamala Limestone aquifer and alluvium east of the WRRF, with a single parameter zone for hydraulic conductivity, specific yield and rainfall recharge rate, with no-flow boundaries on all sides of the model apart from the ocean as a constant head boundary.

- This single layer model is limited as three-dimensional advective transport processes, as evidenced by multi-depth monitoring bore observations, is only represented in two dimensions by the model. This can mean that model parameters are adjusted during the history matching exercise but may take on compensatory roles to account for the poor spatial representation of observation data in the model. For example, if a TN observation is less in the shallow observation bore compared to the deeper bore at the same location, only one first order rection rate can be applied to attempt to force calibration for the single model layer. This averaged parameter value may result in poor calibration and/or an overestimation of denitrification expected in shallow bores and underestimation in deeper bores.
- The Australian Modelling Guidelines (Sinclair Knight Merz and NCGRT, 2012) provide a model confidence level classification which can guide the appropriate usage of a model. Despite model updates, the simplicity of the underlying conceptual model would mean that Rockwater 2009 would not meet the Class 3 confidence level classification required for *"Assessment of complex, large-scale solute transport processes"*, as is the requirement for the WRRF.

5 Future modelling constraints

5.1 Potential off-site sources of nutrient impacts to groundwater

The area between the WRRF and Indian Ocean (~3 km to the west) represents a diverse array of current land uses. Many of these land uses have the capacity to leach nutrients to the unconfined superficial aquifer as shown on Figure 2.

Figure 2 Surrounding land uses (Senversa, 2024)

Furthermore, a review of historical landgate aerial photography reveals that land immediately west of the WRRF was utilised for market gardens and horticulture since the 1950s. There were also several former dwellings (now demolished) that would have been on septic systems to manage sewage. These potential historical sources may have included the application of fertilisers and leachate from domestic septic systems and waste.

Monitoring data (Senversa, 2024) from the expanded bore network supports a high potential for off-site nitrogen sources to be impacting groundwater in the area, based on the following:

- A reverse TN concentration gradient between bores 4/24 & 5/24 (closest to the WRRF) and 2/24 & 3/24 (refer **Figure 3**) suggestive of an off-site source of impacts between these well pairs. Sucralose (WW tracer compound) was higher at 4/24 & 5/24 (closest to the WRRF) in comparison to 2/24 & 3/24, which further supports a likely off-site nitrogen source at 2/24 & 3/24.
- Isotopic fractionation signatures for bore 10/20 were distinct from those at 6/20 and 8/20, located the same distance from the WRRF. This in addition to a reverse TN concentration gradient at 10/20 and suggests nitrogen impacts were more likely due to an off-site source than being WRRF related.
- TN concentrations were notably lower at off-site well pair 1/24 and B0155 (City of Greater Geraldton monitoring bore not shown on Figure 3) in comparison to 12/20 & 13/20 (further west down-hydraulic gradient), indicating impacts at 12/20 and 13/20 are likely due to diffuse off-site nitrogen sources. Furthermore, the stable isotope signatures (δ2H and δ18O) for nitrogen impacted groundwater recovered from 12/20 and 13/20 were not consistent with the evaporative signatures identified for wells affected by WRRF related nitrogen impacts.

5.2 Calibration and validation constraints

The current and historical off-site nitrogen sources potentially impacting groundwater in the area means that predicting a nutrient load at the marine environment (Indian Ocean) with a deterministic groundwater model is challenging and potentially not possible with an appropriate level of confidence. There would not be sufficient information or data relating to the potential sources of contaminants to include as model inputs.

The development of a high confidence groundwater model appropriate to inform regulatory decisions is predicated on its capacity to reproduce past observations. The model calibration process seeks to modify a numerical model's adjustable parameters, within bounds that respect prior knowledge about aquifer and geochemical characteristics, iteratively until the model can reproduce historic observations, for example groundwater levels or nutrients. For the area down-hydraulic gradient of the WRRF, the first order reaction rate of a solute transport model would be adjusted, possibly in combination with other parameters, until the simulated denitrification rate is sufficient that the model can reproduce TN observations at monitoring bores within an acceptable tolerance.

This basic calibration principle would be applicable to any solute transport model for the area. However, this principle is reliant on the model including all major inputs that influence nutrient observations so that the resulting parameter adjustments are justifiable. For example, if it is justified that TWW infiltration is the only input to the environment that affects downgradient TN observations, the chances of developing plausible model parameters are enhanced. This is because TN is measured at the WRRF and can be included as a well constrained model input. Therefore, when the model's first order reaction rate is adjusted to calibrate to downgradient TN observations it is reasonable to assume the model's denitrification rate may be like that prevailing in the aquifer.

All previous modelling exercises for the WRRF have assumed that infiltration of TWW at the WRRF is the only nutrient input in the model domain. The model calibration therefore must assume that TWW infiltration from the WRRF explains all down-hydraulic gradient TN observations. The Rockwater 2009 model concentrated on the area close to the WRRF as that's where the original monitoring bores were located, the single nutrient input principal was more reasonable as TWW infiltration would dominate nutrient observations immediately down-hydraulic gradient of the WRRF making model calibration to TN more viable.

The current groundwater monitoring network is far more widespread and provides enhanced coverage of flow paths to the marine environment (refer **Figure 3**). This means that a model calibration scheme based on the principle of a single nutrient source is difficult to justify given the off-site nitrogen sources that are likely to be impacting groundwater between the WRRF and the marine environment.

In terms of calibrating and deploying solute transport models using the full suite of monitoring bores, the off-site nitrogen sources impacting groundwater indicate that assuming infiltrated TWW as the only nutrient input to the model is not justifiable. This means that a model calibrated to TN observations influenced by point sources not included as model inputs may be overly conservative and predict nutrient impacts further down-hydraulic gradient with less attenuation.

Possibly, this is already evidenced by the fact that the Rockwater model has utilised a first order reaction rate (denitrification rate) of 0.003/d which is half the calibrated value assumed for comprehensive solute transport modelling performed for the Gordon Road WWRF is a very similar hydrogeological setting.

5.3 Summary

In summary, licence conditions 16 and 17 are not considered appropriate for the key reasons summarised below, as discussed in the text of this report.

5.3.1 Rockwater 2009 constraints

- The model does not have an appropriate confidence level for complex solute transport applications as per The Australian Modelling Guidelines (Sinclair Knight Merz and NCGRT, 2012).
- Model geometry (e.g. single layer) is not appropriate to simulate three-dimensional advocative transport processes or reproduce multi-depth monitoring bore observations.
- The model only considers TWW as a nutrient source noting there is a high potential for off-site nitrogen sources to be impacting groundwater between the WRRF and the marine environment.

5.3.2 Future modelling constraints

- Further model calibration or validation exercises will be biased by current or historical potential off-site nitrogen sources not included as model inputs.
- Development of an updated coupled flow and solute transport model will be biased by potential off-site and unknowable nitrogen sources.

6 Monitoring network

Since the Rockwater 2009 model was developed, the groundwater monitoring network has been expanded from 10 near-site bores to 37 monitoring bores, variably targeting shallow, intermediate and deep intervals of the superficial aquifer. The well network was established in 1994 and has been incrementally expanded since then, the most recent wells were installed in 2024 (Senversa, 2024). The monitoring network is now far more widespread and designed to capture down-hydraulic gradient impacts and assess attenuation. Water Corporation considers that the improved bore network has closed out condition 18 of the licence noting that the purpose of the additional wells was not to validate Rockwater 2009. The network is listed in Table 3 and shown on Figure 3.

Table 3 Groundwater monitoring well network

Aquifer	No. of wells	Well IDs
Shallow superficial aquifer (total 21 bores)	Background: 3 On-site: 6 Cross-hydraulic gradient: 2 Down-hydraulic gradient: 10	Background: 1/20, 6/17, 4/94 On-site: 2/94, 6/94, 8/94, 1/17, 2/17, 5/17 Cross-hydraulic gradient: 3/17, 3/20 Down-hydraulic gradient: 4/17, 6/20, 8/20, 10/20, 12/20, 10/94 (decommissioned and replaced with 2/22), 1/24, 3/24, 5/24, 7/24
Intermediate superficial aquifer (total 12 bores)	Background: 1 On-site: 1 Cross-hydraulic gradient: 1 Down-hydraulic gradient: 9	Background: 2/20 On-site: 7/94 Cross-hydraulic gradient: 4/20 Down-hydraulic gradient: 5/20, 7/20, 9/20, 11/20, 13/20, 2/24, 4/24, 6/24, 8/24
Deep superficial aquifer (total 4 bores)	Background: 1 On-site: 2 Down-hydraulic gradient: 1	Background: 3/94 On-site: 1/94, 5/94 (decommissioned and replaced with 1/23) Down-hydraulic gradient: 9/94

Figure 3 Groundwater Monitoring Bore Network

7 Proposed groundwater monitoring plan

Water Corporation has prepared a groundwater monitoring plan (GMP) (Senversa, 2024) to document the proposed augmented monitoring locations, and sampling and analytical approaches that will be relied upon to collect ambient groundwater quality monitoring data under Condition 15 of the licence. A secondary objective of the GMP is to support continued representative data collection to demonstrate that site-related groundwater impacts remain stable and pose a low acceptable risk to relevant off-site environmental values.

Table 4 Proposed monitoring of ambient groundwater quality

Monitoring point reference location	Parameter	Limits	Units	Averaging period	Frequency
Production bore: A1/97 **Shallow monitoring locations**: 6/94, 8/94, 1/17, 2/17, 3/17, 4/17, 5/17, 6/17, 1/20, 6/20, 8/20, 10/20, 2/22, 1,24, 5/24, 7/24, **Intermediate monitoring locations**: 7/94, 2/20, 5/20, 7/20, 9/20, 11/20, 4/24, 6/24	Standing water level	-	m(BGL)	Spot sample	Annual
	Total dissolved solids	-	mg/L		Six monthly
	Total Nitrogen	-			
	Total Phosphorus	-			
	Ammonium as N	-			
	Nitrate + Nitrite as N	-			
	pH [1]	6.5-8.5	pH		
	E. coli[2]	<1000	cfu/100ml		
	Aluminium	-	mg/L		Annual
	Arsenic	-			
	Beryllium	-			
	Boron	-			
	Cadmium	-			
	Chromium	-			
	Cobalt	-			
	Copper	-			
	Fluoride	-			
	Lead	-			
	Mercury	-			
	Nickel	-			

Monitoring point reference location	Parameter	Limits	Units	Averaging period	Frequency
	Selenium	-			
	Zinc	-			

Note 1: In-field non-NATA accredited analysis

Note 2: Actual limits are to be reported except where the result in greater than the highest detectable levels of 24,000 cfu/100mL. In this case the reporting of the highest detectable level is permitted.

8 Recommendations

8.1 Condition 15

Condition 15 should be updated to reflect the GMP (Senversa, 2024), as summarised in Table 4 above.

8.2 Conditions 16 and 17

The expanded groundwater monitoring well network and proposed augmented ambient groundwater monitoring to be executed under condition 15 of the licence will provide a better understanding of nutrient attenuation and provide regulatory and operational controls based on empirical evidence as opposed to validation of a non-empirical, low confidence groundwater model. Considering this, Conditions 16 and 17 of the licence should be removed.

8.3 Condition 18

Water Corporation considers that the improved bore network has closed out condition 18 of the licence noting that the purpose of the additional wells was not to validate Rockwater 2009.

8.4 Condition 22

Condition 22 (Table 8) of the licence should be updated to include additional reporting parameters for the monitoring of ambient groundwater quality.

Table 5 Proposed additional environmental reporting requirements

Condition	Requirement
15	(a) A clear statement of the scope of work carried out; (b) A description of the field methodologies employed; (c) an assessment of reliability of field procedures and laboratory results; (d) an interpretive summary and assessment of results against previous monitoring results; (e) an interpretive summary and assessment of the results against relevant assessment levels, with rational provided to justify why assessment levels have been assigned; and (f) trend graphs to provide a graphical representation of historical results and to support the interpretive summary.

9 References

DWER (2021), Managed aquifer recharge in Western Australia

Rockwater (1993), Geraldton WWTP No. 2: Capacity for infiltration of treated wastewater, and groundwater effects.

Rockwater (1997), Geraldton WWTP No. 2: Capacity for infiltration of treated wastewater, and groundwater effects.

Rockwater (1998), Predicting effects of increased wastewater disposal, Geraldton WWTP No.2.

Rockwater (2009), Geraldton WWTP2 Results of Numerical Modelling of Wastewater Infiltration and Extraction for Reuse

Rockwater (2010), Results of Additional Modelling to Assess Impacts of up to 20 ML/day Infiltration at Narngulu and Geraldton No. 2 WWTPs

Senversa (2024a), Stage 2 Detailed Site Investigation – Geraldton No. 2 Wastewater Resource Recovery Facility, Wonthella, Western Australia, October 2024

Senversa (2024b), Groundwater Monitoring Plan – Geraldton No. 2 Wastewater Resource Recovery Facility, Wonthella, Western Australia, October 2024

Sinclair Knight Merz and National Centre for Groundwater Research and Training (2012), Australian groundwater modelling guidelines