Wastewater as a potential source of recycling in the Perth-Peel region

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3rd January 2019

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Prepared for the West Australian Department of Water and Environmental Regulation

TRIM: WT13112

Citation

McFarlane, D.J. (2019). Wastewater as a possible source of recycling in the Perth-Peel region. Report to the Department of Water and Environmental Regulation

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1. Summary

The Department of Water and Environmental Regulation (DWER) is identifying water supply and demand management options for addressing the long-term water needs of the Perth-Peel region. The work supports Government strategic planning for the Greater Perth region that was initiated by the Department of Planning, Land and Heritage's Perth Peel@3.5million strategic land use plan. This plan aims to accommodate 3.5 million people in Perth and Peel by mid-century.

This report assesses the potential of wastewater as a potential source of water for recycling. It accompanies two other reports, one on the potential of drainage water (McFarlane 2018a), and another on the feasibility of managed aquifer recharge (MAR), third pipes and direct piped schemes in the Perth Peel region (McFarlane 2018b).

There were more than 140 GL/y of inflows to 14 wastewater treatment plants (WWTPs) in the Perth-Peel region in 2017, an increase of over 40 GL/y or 40% since 2000. These inflows are expected to increase to 170 GL/y by 2030, and to 243 GL/y by 2060 if water use efficiencies of 115 kL/person/year are achieved by 2030. Volumes will be about 4% greater if these efficiencies are not attained.

Direct and indirect reuse (i.e. infiltration and subsequent extraction) is currently about 24 GL/y, or 17% of inflows. The Water Corporation has a target of 30% reuse by 2030, which would require the current volume of reuse to more than double in the next 12 years. An additional 14 GL/y is planned for Groundwater Replenishment[1] of highly treated wastewater from the Beenyup WWTP for scheme supply. There is therefore scope for increased non-potable reuse.

Of the 133 GL/y that flows into WWTPs connected to an ocean outfall about 19 G/y is currently reused. The capacity of the Beenyup Groundwater Replenishment scheme is 14 GL/y and due to be doubled in 2019. The 8 GL/y that is discharged to land sites provides valuable experience of managed aquifer recharge (MAR). The land-discharged treated wastewater is often indirectly reused for non-potable purposes such as public open space irrigation by local government in the City of Mandurah and Mundaring Shire, by industry at Kwinana and Pinjarra, and on a tree lot at Bullsbrook.

By 2020, three small WWTPs will have been closed; Yanchep (closed in 2016), Two Rocks and Bullsbrook (to close in 2020). After 2020 there will be only the small Mundaring and Pinjarra WWTPs operating in the North East and South East Sub-regions of the Perth Peel Region. This will reduce the opportunities for inland local recycled use for non-potable purposes. Concentrating treatment in large coastal plants can reduce both the unit treatment costs and the risk of groundwater and stream contamination. It also increases the amount of water available for scheme supply by Groundwater Replenishment which requires large volumes and deep permeable aquifers. The benefits and costs of local treatment and reuse at inland sites are currently being investigated by the Department of Water and Environmental Regulation.

The quality of treated wastewater in WWTPs has improved following the installation of oxidation ditch methods at new plants, and during plant upgrades. This reduces the risk of nitrogen pollution especially, and the risk of clogging of surface infiltration sites and of aquifers where suspended solid concentrations are reduced.

The land-based disposal of treated wastewater over several decades provides real-world data that can inform deliberate MAR schemes. Those sites infiltrating through the Quindalup or Spearwood Dunes and over Tamala Limestone aquifers (i.e. Yanchep, Two Rocks, Gordon Road, Halls Head and

[1] Groundwater Replenishment is the temporary storage of highly-treated wastewater before its extraction for drinking water use.

Caddadup) show similar experiences to the Floreat Infiltration Gallery experiments. The limestone greatly reduces the concentration of phosphorus, but nitrogen remains little changed by the soil and aquifer because conditions do not suit denitrification. Microbial pathogens are reduced markedly in these schemes and an assessment is underway to better document their fate.

The potential for additional MAR of treated wastewater for scheme and self-supply reuse appears high in coastal areas. Inland areas, where the need for recycled water for self-supply non-potable use is probably greatest, are no longer close to WWTPs and have less suitable soils and aquifers for both in-situ treatment and storage.

2. Background

Population growth and a warmer, drier climate are increasing the gap between water demands and supplies in Perth and Peel. The supply of drinking water is increasingly being met with seawater desalination and highly treated wastewater for Groundwater Replenishment. The relatively high costs of these treatments do not make them suited for meeting non-potable water demands. Attention is increasingly focussed on reuse of drainage and wastewater sources to meet self-supply non-potable water needs.

Given the wide occurrence of an unconfined ('Superficial') aquifer in sand dunes under the Swan Coastal Plain (except where there is clay alluvium around major rivers and the Darling Scarp) and its partial depletion in recent decades, there is increasing interest in MAR of seasonal stormwater, and year-round wastewater streams for non-potable use. The confined Leederville Aquifer is also of interest for MAR, especially in areas where the Superficial aquifer is absent.

This is one of several high-level guidance notes prepared for the Department of Water and Environmental Regulation (DWER) to provide contextual and planning guidance information for self-supply non-potable water users in the region. It has been prepared to assist them to better identify and assess specific reuse proposals to meet potential demand-supply gaps as the population of Perth-Peel expands from 2.1 to 3.5 million people by mid-century.

Three related guidance notes are:

1. Wastewater as a potential source of recycling in the Perth-Peel region (**this report**);
2. Drainage water as a potential source of recycling in the Perth-Peel region (McFarlane 2018a); and
3. The potential for managed aquifer recharge, third-pipe and direct piping systems in the Perth-Peel region (McFarlane 2018b).

Chapter 3 identifies the current WWTPs, their catchments and inflows projected to 2060. Treated wastewater qualities, as related to MAR considerations, are discussed in Chapter 4. WWTPs are being constantly upgraded so water quality and flows will change in future as explained in this chapter.

Some wastewater is already re-used, and there are plans by the Water Corporation to expand Groundwater Replenishment of confined aquifers for drinking water use. Large coastal WWTPs currently discharge treated wastewater to four ocean outfalls. There are also eight small WWTPs that discharge to the environment. Where known, the effect of this discharge on groundwater levels and quality is briefly outlined in Chapter 5. While the purpose of these sites is to safely dispose of treated wastewater, they mimic MAR. A study of the feasibility of several non-potable water supply schemes is underway in the North East Sub-region. Chapter 6 outlines what is being evaluated but the economic results are still being finalised. The overall report findings are discussed in relation to the six Western Australian Planning Commission planning sub-regions (Figure 2-1) in Chapter 7 before general conclusions are drawn and recommendations made for further work in the final two chapters.

Figure 2-1 WAPC Perth-Peel planning sub-regions (Source: DWER)

3. Wastewater treatment plant catchments, inflows and outflows

Catchments

A map of WWTPs and catchments is shown in Figure 3-1. The size of the catchments is a guide to their inflows, with the Beenyup and Woodman Point WWTPs constituting 70% between them, and Subiaco adding a further 16%. Details on flows are provided in a later section.

The Two Rocks and Bullsbrook plants are due to close in 2020 with their water going to the Alkimos Plant which opened in 2011. The Yanchep WWTP closed in 2016 so from having 15 plants in 2015, there will only be 12 from 2020. This consolidation of WWTPs at major coastal locations reduces treatment costs and the risk of contamination of inland disposal sites. However, it can make non-potable reuse less feasible when the treated wastewater is in high-value coastal urban areas far from demand centres such as large irrigators and industry. The exception is the Woodman Point WWTP which is located close to both heavy and light industrial areas.

Wellfields on the Gnangara and Jandakot mounds require drinking water quality protection zones to avoid contamination (Figure 3-2). Sewer pipes are unable to cross drinking water protection zones which explains the U-shapes of the Beenyup and Woodman Point wastewater catchments shown in Figure 3-1. In the North East sub-region, sewage is pumped south from Ellenbrook and the Swan Valley, west around the Gnangara Mound P1 protection area and then north to Beenyup. The same inverted U-shaped path occurs for sewage from Byford and Armadale in the South East sub-region before it reaches the Woodman Point WWTP.

There are ocean outfall lines taking treated wastewater from the Alkimos, Beenyup and Subiaco WWTPs. The Sepia Depression Ocean Outfall Line (SDOOL) off Point Peron discharges water from the Woodman Point, East Rockingham and Point Peron WWTPs, and excess flow from the Kwinana WWTP.

There are currently five small coastal plants discharging treated wastewater to the Superficial Aquifer – Two Rocks, Kwinana, Gordon Road, Halls Head and Caddadup. At Kwinana the aquifer accepts all treated wastewater except flows greater than 4.7 ML/d (1.7 GL/y), which are diverted to the SDOOL.

In addition to discharge to the ocean and Superficial Aquifer, highly treated wastewater is injected into the Leederville aquifer near the Beenyup WWTP and more Groundwater Replenishment is being installed into both the Leederville and Yarragadee aquifers north of Joondalup. Some SDOOL water is diverted to the Kwinana Wastewater Recycling Plant (KWRP) for treatment and use by heavy industry. Treated wastewater is also used on tree crops at Bullsbrook and by industry at Pinjarra. Some additionally treated wastewater is used for irrigation at Subiaco and Mundaring, the details of which are provided in a later section.

Prior to the building of large WWTPs close to ocean outfalls, the Perth-Peel region had several small WWTPs located in inland areas. There is interest in decentralised wastewater schemes (sourcing, treating, storing and reusing) in the North East sub-region for non-potable use, especially green space and agricultural use. The cost of returning treated wastewater to inland areas for use is high because constructing pipes in urban settings is expensive, and they cannot be laid through the drinking water source protection areas as explained above.

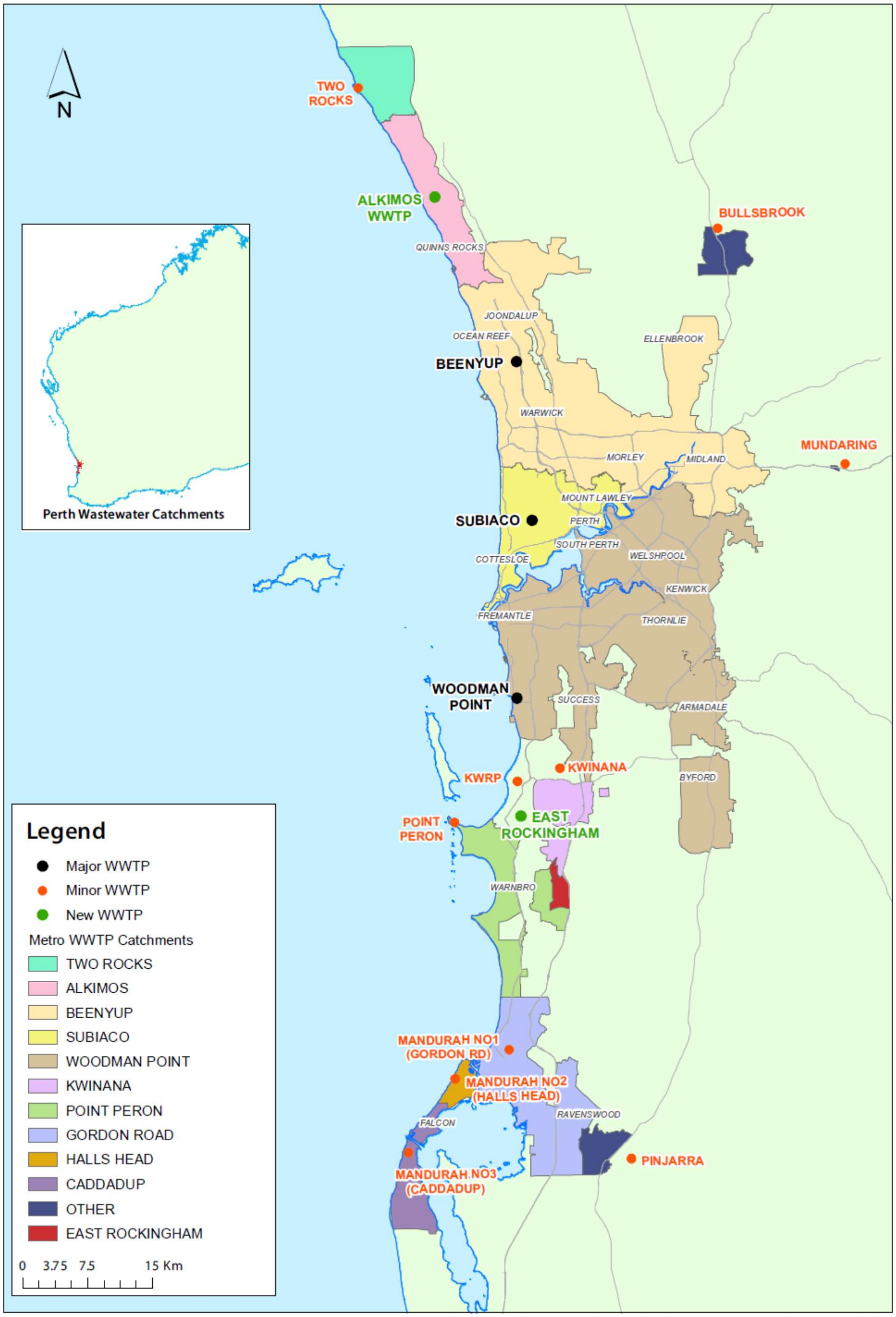

Figure 3-1. Wastewater treatment plants and their catchments in the Perth-Peel region (Source: Water Corporation 2018d).

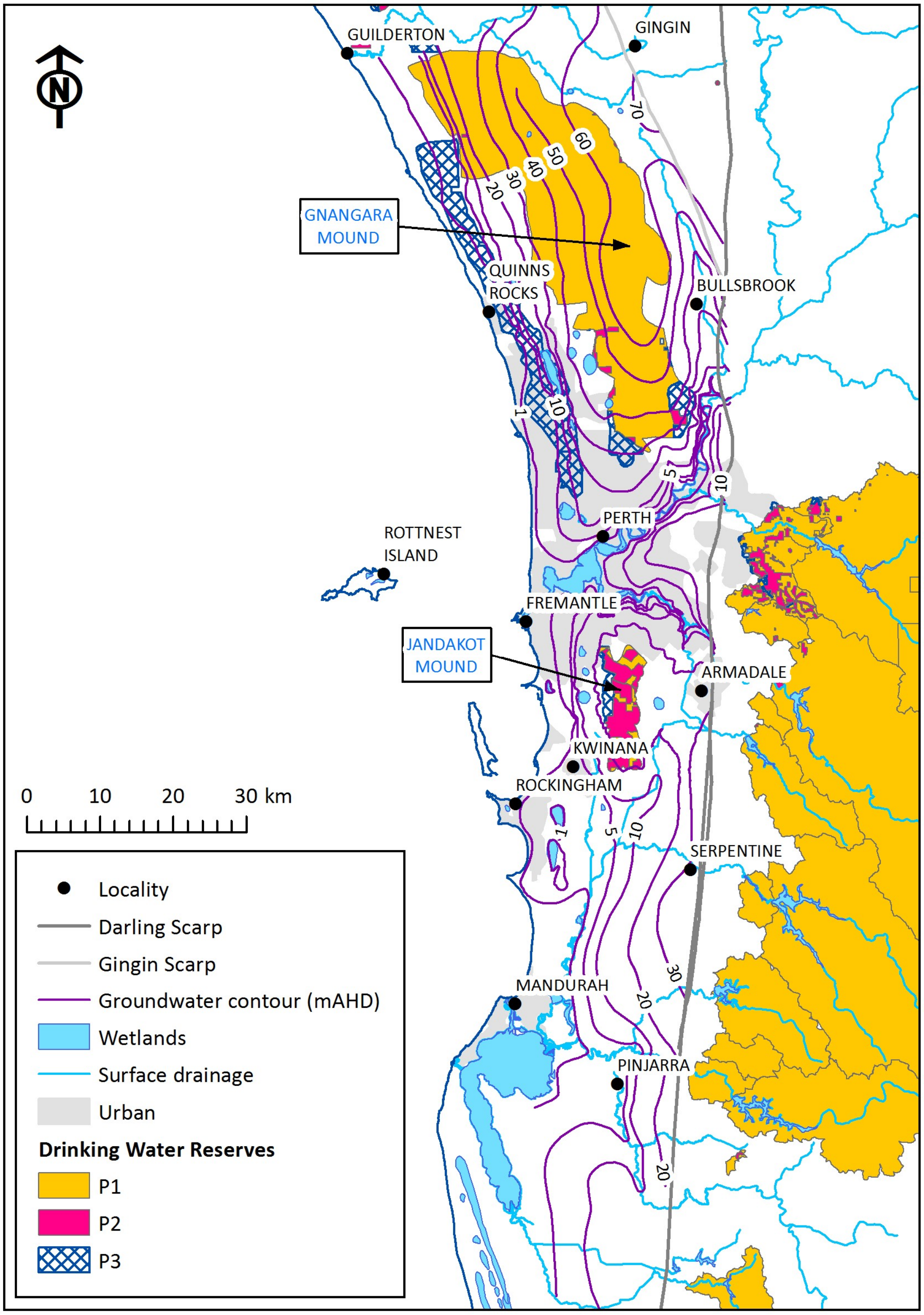

Figure 3-2. Location of the main surface water and groundwater supplies for Greater Perth along with drinking water reserves

Inflows

Currently only the Water Corporation has a licence to provide wastewater treatment services in the Perth-Peel region and this analysis assumes that this will continue to be the case for new services.

Inflows between 2000 and 2060 to fifteen WWTPs were provided by the Water Corporation. Forecasts includes allowance for water efficiency; i.e. allowance for the water glidepath to 115 kL/person/y in 2030. Beyond 2030 the rate per person is assumed to be constant. Without the water efficiencies inflows will be about 4% higher between 2030 and 2060.

Total inflows grew from 100.3 GL/y in 2000 to 140.8 GL/y in 2017; an increase of over 40 GL/y or 40%. Assuming efficiency targets will be achieved, inflows will grow to 196.0 GL/y by 2040 (39% greater than in 2017), and to 243.5 GL/y (73%) by 2060.

About 92% of the growth to 2060 will be experienced by the five largest WWTPs, all of which are connected to ocean outfalls (Figure 3-3). Inflection points in the graphs are when catchment boundaries are changed, and water is moved between plants. For example, Alkimos is expected to take some of Beenyup inflows in 2045. The growth rates are fastest in those WWTPs that service rapidly growing areas such as the southern and northern suburbs (Woodman Point and Alkimos respectively) and lower in those that respond mainly to urban infill (e.g. Subiaco).

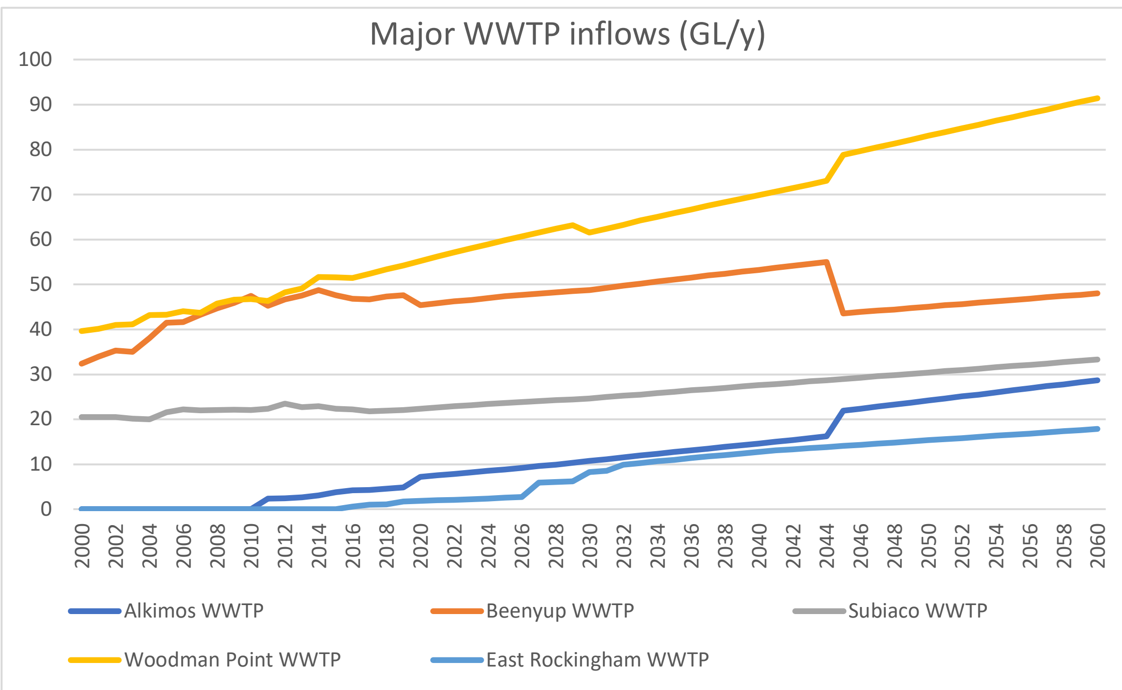

Figure 3-3 Sewerage inflows for the five large WWTPs in Perth-Peel. Inflows after 2017 have been projected. Source: Water Corporation

Actual and projected inflows to ten small WWTPs are shown in Figure 3-4. The vertical scale in Figure 3-3 is about ten times that in Figure 3-4. Alkimos took over flow to the Yanchep WWTP in 2016 and will take over Two Rocks in 2020. About half of the inflow to the Point Peron WWTP is expected to be transferred to East Rockingham in 2027 and a proportion of the Kwinana inflow will also transfer to East Rockingham in about 2032.

Inflows to Gordon Road in Mandurah are expected to increase at an accelerating rate until 2060 while inflows to Halls Head and Caddadup, also located in the Peel Sub-region, will grow at slower rates (Figure 3-4). This reflects urbanisation to the north and south-east of the Gordon Road plant.

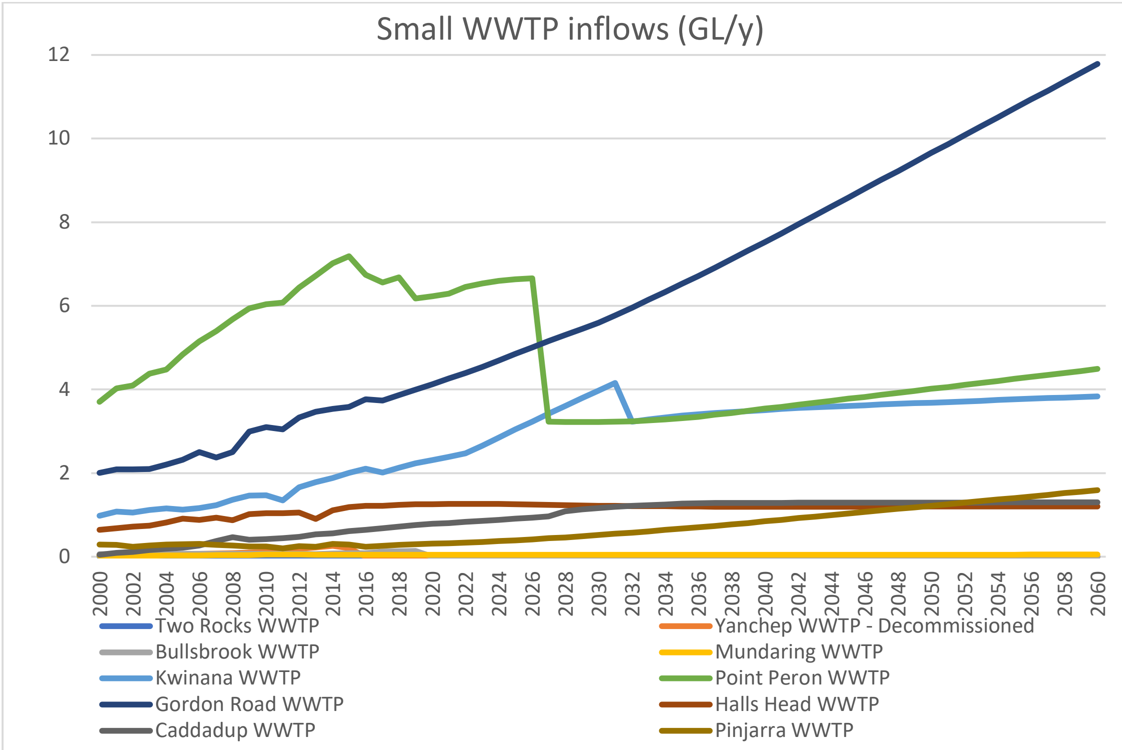

Figure 3-4. Sewerage inflows for ten small WWTPs in Perth Peel. Inflows after 2017 have been projected. Source: Water Corporation

Outflows

There are four ocean outfalls for treated wastewater in the Perth Peel region; at Alkimos for the Alkimos WWTP, at Ocean Reef for the Beenyup WWTP, at Swanbourne for the Subiaco WWTP and the Sepia Depression Ocean Outfall Line (SDOOL) off Point Peron for the Woodman Point, East Rockingham and Point Peron WWTPs (Table 3-1). The SDOOL also caters for excess flows from the Kwinana WWTP and saline discharge from the Kwinana Water Recycling Plant. In 2017 the outfalls disposed on 133 GL of water, most of it advanced secondary treated wastewater, but including higher quality water from oxidation ditch plants at the Alkimos, Kwinana at the East Rockingham WWTPs (see next section) and 6.5 GL of primary treated wastewater from the Point Peron WWTP.

There is also almost 8 GL/y discharged to land with Pinjarra treated wastewater being used by industry (Table 3-2) but most of the rest being indirectly used for irrigation of public open space. More information on these discharges are included in a later section.

Increasingly the Water Corporation is using treated wastewater as feedstock for recharging confined aquifers in the North West Sub-region after intensive treatment with microfiltration, reverse osmosis membranes and ultraviolet disinfection. Stage 2 Groundwater Replenishment will involve both the Yarragadee and Leederville aquifers, with injection at Beenyup and at Neerabup (Water Corporation 2018a). Groundwater replenishment in 2017 was 14 GL/y, increasing to 28 GL/y by about 2019.

Table 3-1. Wastewater discharges (GL/y) to ocean outfalls, infiltration and reuse in 2017. (Water Corporation sources)

Ocean outfall	WWTPs	Sub-region	Inflows (GL/y)	Outflows (GL/y)	Reused (GL/y)
Alkimos	Alkimos	North West	4.3	4.3	0.0
Ocean Reef	Beenyup	North West	46.7	32.7	14.0 Groundwater Replenishment
Swanbourne	Subiaco	Central	21.6	18.1	0.2 McGillivray Oval, Venues West, Christchurch sporting oval site works*
Point Peron	Woodman Point, East Rockingham, Point Peron, Kwinana inflow > 1.72 GL/y	South West	60.3	55.7	4.6 Kwinana Wastewater Treatment Plant
Total			**132.9**	**110.8**	**18.8***

* 3.3 GL/y unaccounted for in this table

Table 3-2 Wastewater discharges to land based on inflow data and assuming few in-plant losses. (Water Corporation Sources)

WWTP	Sub-region	Inflow and outflow (GL/y)	Comments on indirect use
Two Rocks	North West	0.03	Infiltrated and partly used for irrigation
Kwinana	South West	1.72	Groundwater modelling shows that much of the added water goes to ALCOA bores
Mandurah No 1 Gordon Rd	Peel	3.73	Flow tracing shows that much of the added water goes to City of Mandurah irrigation
Mandurah No 2 Halls Head	Peel	1.22	Infiltrated and then used by the City of Mandurah for irrigation
Mandurah No 3 Caddadup	Peel	0.68	Infiltrated and then extracted for irrigation by the City of Mandurah
Bullsbrook	North East	0.13	Used on a tree lot
Mundaring	North East	0.05	Used for local government irrigation
Pinjarra	Peel	0.26	Provided to the ALCOA bauxite refinery
Total		**7.82**	

4. Treated wastewater qualities related to MAR

Synoptic and comprehensive data on treated wastewater quality from the WWTPs was not available for this report so analyses have been taken from published reports. The National MAR guidelines and ANZECC guidelines include comprehensive lists of potential contaminants, not all of which could be compared with wastewater quality from Perth – Peel WWTPs so the following summary is limited. Individual MAR proposal would require detailed assessments of treated water qualities and potential receptors.

Details of Perth and Peel WWTPs are summarised in Table 4-1. Advanced secondary treatment involves screening to remove solids, grit tanks and sedimentation (primary treatment), followed by aeration and activated sludge biological treatment before secondary sedimentation. Oxidation ditch treatments involve a modified activated sludge biological treatment process that uses long solids retention times to remove biodegradable organics.

While the inflow water quality may change between plants, the outflow quality is more affected by the treatment process. The large plants at Beenyup, Subiaco and Woodman Point all use advanced secondary treatment processes but the smaller and/or modern plants at Kwinana, East Rockingham, Alkimos, Gordon Road and Caddadup all use oxidation ditch which reduces the concentration of some nutrients, especially nitrogen. This section uses examples for the water quality of outputs from representative types of plant to provide a guide to others for which data were not available.

Table 4-1. Treatment processes used at wastewater treatment plants in the Perth Peel region. Source: Various Water Corporation sources

Plant	**Treatment process**	**Inflow in 2017** ML/d
Alkimos	Oxidation ditch	11.7
Beenyup	Advanced secondary	127.9
Bullsbrook	Advanced secondary	0.35
Caddadup	Oxidation ditch	3.35
East Rockingham	Oxidation ditch	2.69
Gordon Road	Oxidation ditch	10.2
Halls Head	Oxidation ditch	3.35
Kwinana	Oxidation ditch	5.52
Mundaring	Advanced secondary	0.13
Pinjarra	Advanced secondary	0.72
Point Peron	Primary	18.0
Subiaco	Advanced secondary	59.5
Woodman Point	Advanced secondary	143.6
Two Rocks	Advanced secondary	0.09
TOTAL		**387.1**

Donn and McFarlane (2015) analysed water quality data from the Woodman Point, Beenyup and Kwinana WWTPs which had combined inflows of 277 ML/d (or 101 GL/y) in 2017, 72% of the total inflows entering the 14 active WWTPs listed in Table 4-1. The Kwinana water quality data are representative of oxidation ditch plants, Beenyup of an upgraded advanced secondary treatment plant, and Woodman Point an advanced secondary treatment plant before upgrading (which is due in 2019).

The salinity at the Kwinana WWTP was lower between 2010-2013 than in the other two plants, probably reflecting the low salinity of source water (desalinated seawater, reservoir water). Beenyup receives predominantly Superficial and confined aquifer groundwater having the highest salinity (Figure 4-1). Salinity levels of the treated wastewater at Kwinana (60 mS/m) were generally below the 25th percentile of the ambient groundwater so would reduce salinity after addition (Donn and McFarlane 2015).

All WWTPs had slightly alkaline treated wastewater and, as for salinity, all were within the indicated guidelines (Figure 4-1). Median total suspended solids (TSS) were generally high but there were occasional very high values at the two advanced secondary treatment plants, indicating that soil or aquifer clogging may be an issue unless there was either pre-treatment or the spikes were detected, and the affected water diverted. This is especially important for infiltration galleries which, being buried, are more difficult to access than infiltration pits. Investigations at Perry Lakes indicated that deep bed filtration could reduce the TSS values to less than 5 mg/L. The high values pose little problems for open pits at WWTPs because they, and algae and benthic weeds, can be removed with small skid-steer loaders such as a bobcat.

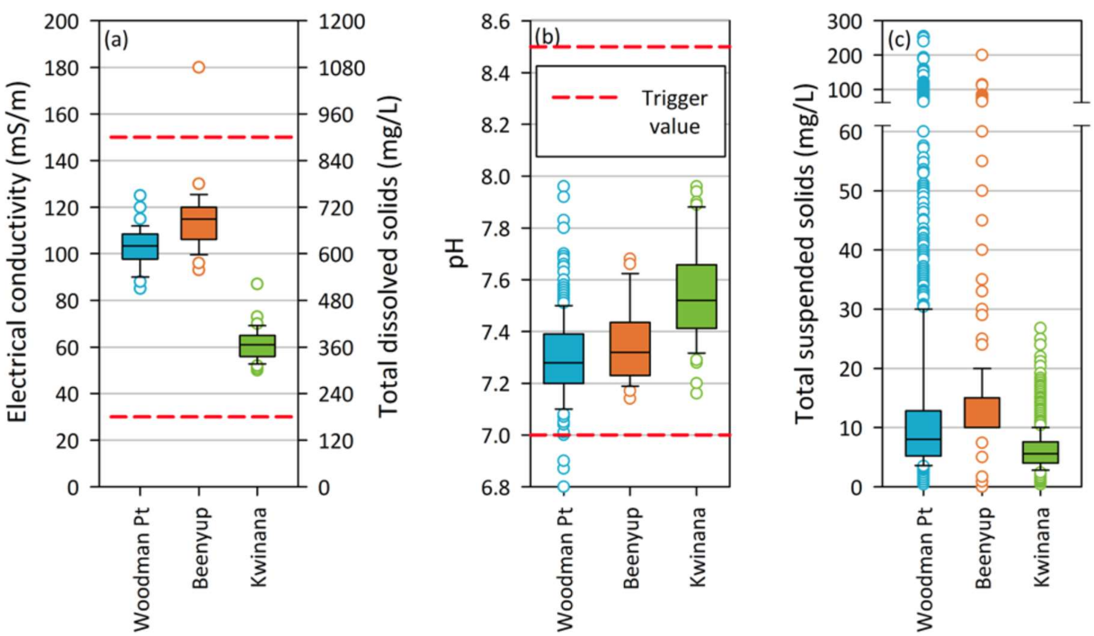

Figure 4-1. Salinity (left), pH (centre) and total suspended solids (right) for the Woodman Point, Beenyup and Kwinana WWTPS (2010-2013). The boxes show the 25th and 75th percentiles with the 50th shown as the line within the box. The whiskers represent the 10th and 90th percentiles and the points the outliers. Trigger values represent the upper and lower limits for wetland aquatic ecosystems south-west Australia under ANZECC-ARMCANZ guidelines. Source: Donn and McFarlane 2015

Total nitrogen concentrations in the oxidation ditch plant at Kwinana are only about a quarter that of the two advanced secondary plants (Figure 4-2). The Total N of treated wastewater at Kwinana was almost 2.5 times that of ambient groundwater but less than that in areas impacted by horticulture, industrial pollution and drying wetlands (Donn and McFarlane 2015). Total P in the treated wastewater is about ten times that of the ambient groundwater but the experience of treated wastewater additions at Halls Head (Toze et al. 2002, 2004), the Floreat Infiltration Galleries (Bekele et al. 2011) and at Gordon Road (Pavlov 2015) show that levels reduce rapidly in areas containing limestone. All nitrogen and phosphate values in treated wastewater exceed the aquatic ecosystem trigger values indicating there is a risk of adverse biological effects if added directly to these systems.

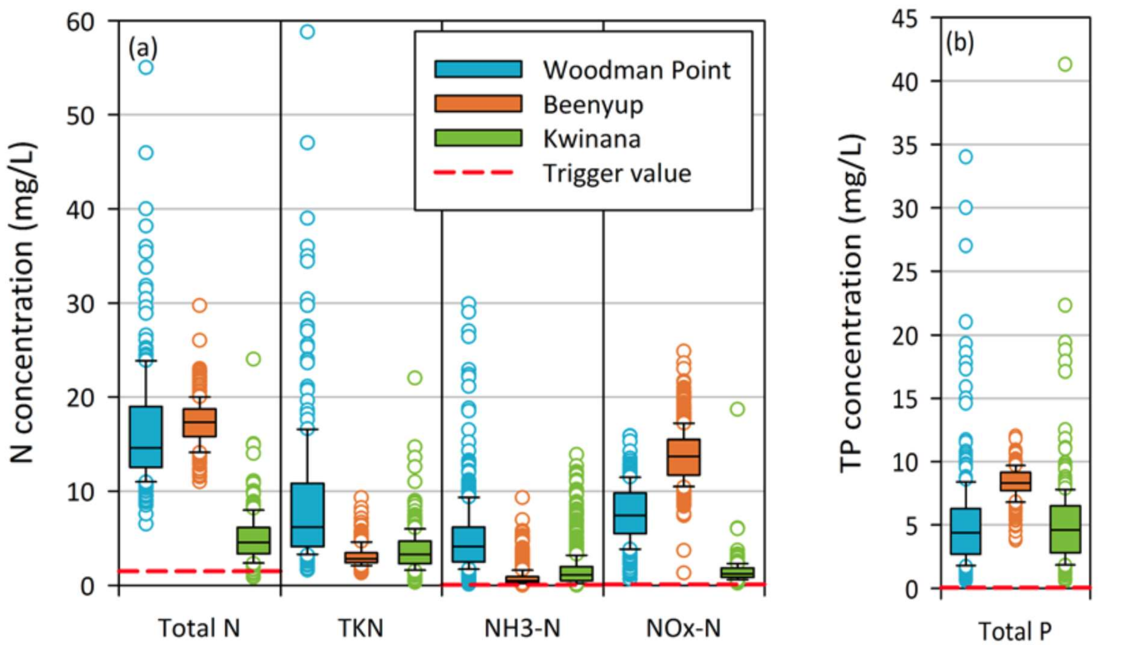

Figure 4-2. Nitrogen species (left) and phosphorus (right) for the Woodman Point, Beenyup and Kwinana WWTPS (2010-2013). Box plots and trigger values as explained in Figure 4-1. Source: Donn and McFarlane 2015

The biological oxygen demand (BOD) is only 11 to 14% of the chemical oxygen demand (COD) of the treated wastewater at the three WWTPs (Figure 4-3). Therefore, the bioavailability of the organic carbon present is likely to be low which reduces the potential for denitrification to occur in the aquifer without an additional source of organic carbon being added.

Most of the heavy metals monitored at the three WWTPs were below the trigger values for wetland aquatic ecosystems in south-west Australia (Figure 4-4). Cobalt, mercury and silver were at or below detection levels, with most concern being for copper and zinc were the water to be directly added to aquatic ecosystems. When wastewater is added to alkaline water in the Tamala Limestone the mobility of heavy metals is likely to be significantly attenuated.

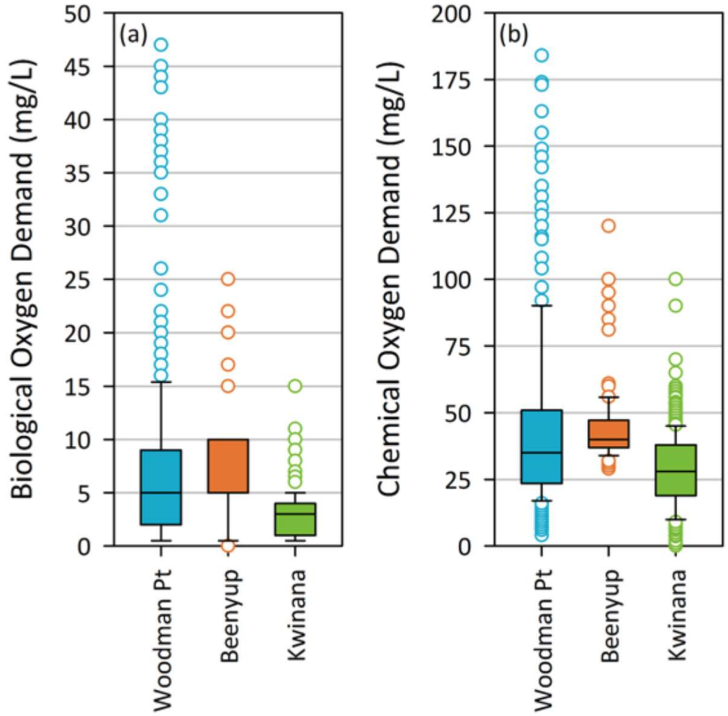

Figure 4-3. Biological and chemical oxygen demand in treated wastewater at the Woodman Point, Beenyup and Kwinana WWTPs. Source: Donn and McFarlane 2015.

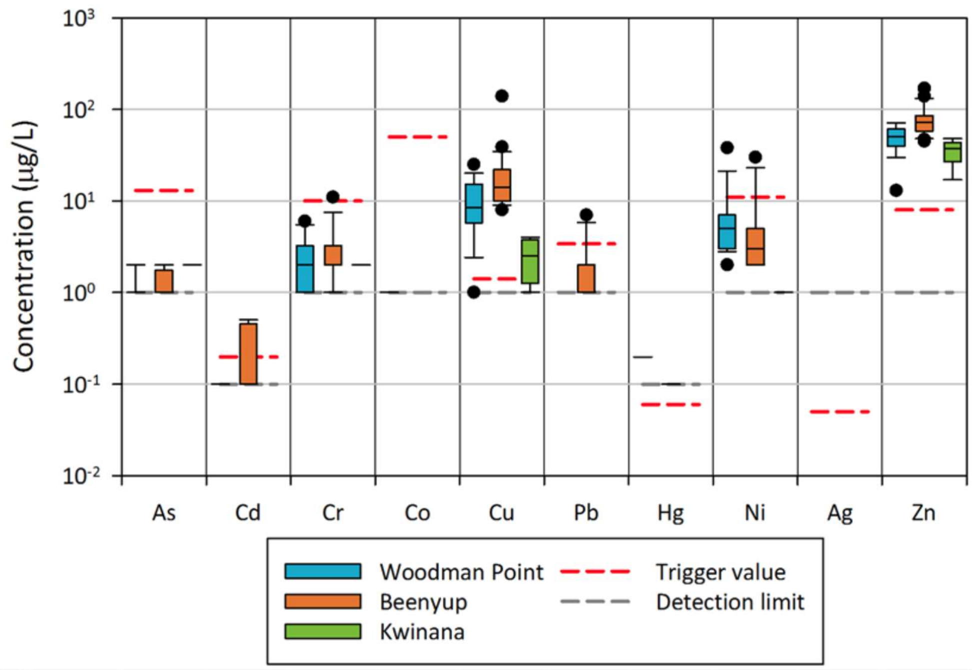

Figure 4-4. Heavy metal concentrations in treated wastewater from the Woodman Point, Beenyup and Kwinana WWTPs. Source: Donn and McFarlane 2015

Wastewater quality at the Subiaco WWTP was reviewed by GHD (2016). Upgrades to the plant are not anticipated to affect water quality other than to reduce spikes in suspended solids (and associated elements) and nitrification of ammonia is likely to be more robust. The following results are summarised from GHD (2016).

As expected for treated wastewater, all nutrients exceed the ANZECC guidelines for south west Australia wetlands meaning that direct discharge to a wetland or stream would create unacceptable risks. Compared with the three WWTPs shown in Figure 4-1Figure 4-2Figure 4-3:

- Median suspended solids at Subiaco is much higher but may be similar after the upgrade;
- Total N is like Woodman Point, lower than Beenyup and more than twice Kwinana which uses oxidation ditch technology;
- Total P is like Woodman Point and Kwinana, and less than Beenyup;
- As for all other WWTPs, chemical oxygen demand is much higher than biological oxygen demand, indicating that denitrification may not be possible after MAR unless a source of carbon is added to the water;
- Salinity at Subiaco is like Beenyup because the northern drinking water sources have a higher salinity, coming predominantly from unconfined and confined groundwater sources.

Table 4-2. Wastewater quality at Subiaco WWTP July 2013 to June 2015. Source: GHD (2016)

Parameter	Mean mg/L	0 percentile	50 percentile	90 percentile	100 percentile
Suspended solids	25.9	2.0	20.0	46.0	175.0
Alkalinity (CaCO3)	120.0	92.0	118.5	133.2	234.0
Biochemical oxygen demand	9.1	2.0	8.6	16.0	29.5
Filtered biochemical oxygen demand	1.9	0.02	1.5	4.6	5.0
Chemical oxygen demand (COD)	41.2	5.5	36.5	71.8	133.0
Ammonia-nitrogen (NH4-N)	0.9	0.1	0.4	2.7	4.1
Total Kjeldahl nitrogen (TKN)	4.7	0.3	4.0	7.1	25.9
Nitrate plus nitrite-nitrogen (NOX-N)	7.5	0.7	7.8	9.4	23.8
Total nitrogen (TN)	12.2	4.0	12.0	17.1	28.5
Total phosphorus (TP)	6.2	0.5	6.6	8.9	11.4
Salinity*			813		

* for period January 2017 to December 2018 (GHD 2016)

The only heavy metals that exceeded ANZECC guidelines for fresh water at Subiaco were copper and zinc (GHD 2016), the same as at Woodman Point, Kwinana and Beenyup (Donn and McFarlane 2015). Heavy metal concentrations are mainly affected by the type of industries in wastewater plant catchments and about 80% end up in the sewerage sludge.

All treated wastewater contains bacterial pathogens, viruses and protozoa and therefore pose health risks if there are opportunities for exposure to humans or the environment unless their concentrations are reduced below accepted levels. The MAR Phase 2 Guidelines (NRMMC 2009) use three reference pathogens; Campylobacter for bacteria, rotavirus for viruses and cryptosporidium for protozoa. To achieve the required performance target GHD (2016) estimated that a MAR scheme will require an aquifer residence time of 128 days if wastewater isn't treated to tertiary standard before use. Bacteria are rapidly degraded in the aquifer, but viruses and protozoa persist for much longer, which results in a long residence time.

In summary, the water quality at Perth WWTPs can be characterised by their level of treatment and by the water quality of the drinking water that was supplied. Oxidation ditch plants provide wastewater with much lower nitrogen levels, and possibly suspended solid levels as well. The salinity of the treated wastewater is similar, if not lower than ambient groundwater, but nutrient levels are greater in most, but not all cases.

Water from septic tanks

While most of Perth-Peel is now sewered, the presence of dunal sands suited to infiltration, and in some cases the treatment of contaminated water in the soil profile and aquifer, resulted in Perth and Peel retaining large unsewered areas until the 1980s (Figure 4-5). There remain a few areas on septic tanks, and the special rural wedges between the urban corridors and areas such as the Kwinana Industrial Area that are not likely to be sewered. The water that comes from septic tank systems is partially treated in that most solids settle to the bottom of watertight tanks and grease and oils float to the surface. Anaerobic digestion reduces some of the solids. The effluent discharges to a drain where it can percolate through the soil to the watertable. The remaining solids, grease and oils (septage) has to be periodically pumped from the tanks.

There are several reasons for sewering; the need to reduce nutrient and pathogen loads in the Bassendean Dune Sands especially, extending residential areas into areas with high watertables, the poor performance of septic tanks in areas underlain by clay (mainly the Guildford Formation around the rivers and in the hills) and the need to increase urban density to reduce urban sprawl.

Collecting, treating and disposing of sewerage is often costlier than the provision of drinking water. The collection system flows under gravity to primary collection points from which the sewage is pumped to treatment plants which are now mainly on the coast to be able to connect to ocean disposal sites.

Given the flat nature of the eastern part of the Swan Coastal Plain in particular, gravity-fed systems require careful design and frequent pump stations. High water efficiency household appliances reduce the amount of water in sewerage systems and could affect performances based on the assumption of there being a specified amount of water in the system.

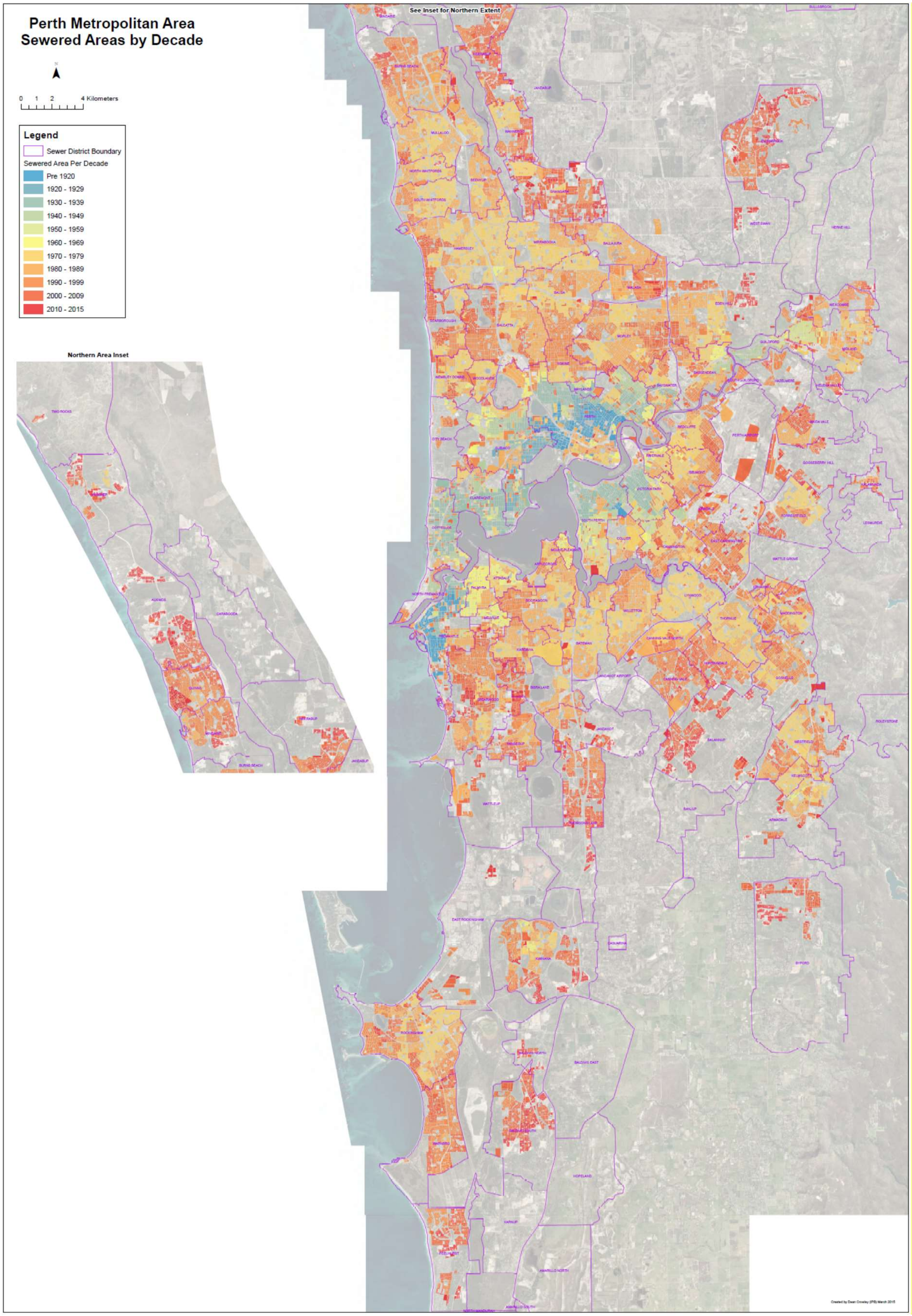

Figure 4-5. The pattern of sewer coverage and infill in Perth and Peel. Source: Water Corporation

5. The land disposal of treated wastewater in the Perth-Peel region

Several recent investigations of land-disposal of treated wastewater have clarified the effect of long-term additions on groundwater levels and quality. Another DWER guidance paper is being prepared on the impact of adding treated wastewater to aquifers. Donn et al. (2017) have reviewed the wider Western Australian experience of aquifer effectiveness as a natural treatment barrier, and further analyses are being concluded by the Water Corporation and CSIRO.

The impacts of land disposal of treated wastewater in the Perth Peel Region are summarised below.

Kwinana WWTP

Secondary-treated wastewater has been added to Bassendean Sands, close to the boundary with Spearwood Sands, since the Kwinana Townsite was progressively sewered from 1975. The amount added has plateaued at 4.7 ML/d since 2012, the regulatory limit beyond which excess water goes to the SDOOL (Bekele et al. 2015). To date about 32 GL have been added at this site. This has resulted in a groundwater mound of about 4m forming and maintaining more stable groundwater levels around The Spectacle lakes, located about 500m up-gradient. Satellite remote sensing indicates other lakes in the Beeliar Wetlands have been more impacted by the drying climate and pumping than The Spectacles and Bollard Bulrush Swamp, which are both connected to the Peel Main Drain (Irina Emelyanova, unpublished data).

The two pairs of infiltration basins have required limited maintenance, just occasional scraping with a bob-cat. The surrounding area is monitored by over 25 bores because the WWTP is so close to Conservation-Category wetlands. Between 25 and 33% of shallow groundwater immediately down-gradient of the lakes may be composed of treated wastewater, but there is none at depth. High ammonia levels at depth down-gradient of the lakes have been attributed to the breakdown of exposed organic matter in the lake beds. These levels are much higher than that added by the WWTP, especially since the plant was upgraded in 2009. This site is unusual in that the nitrogen persists as ammonia rather than being oxidised to nitrate (Donn et al. 2017).

Phosphate levels were not as much reduced following the plant upgrade. There is evidence that the absorption capacity of the sands has been exceeded by P added from the breakdown of organic matter in the wetland and the additions from the WWTP. However, phosphate levels rapidly decrease after the groundwater enters the down-gradient Tamala Limestone aquifer.

Groundwater modelling indicates that the treated wastewater may not have travelled far from the pits because of heavy industry extraction of groundwater to the north west. The additions therefore appear to be have been beneficial to both the wetlands and users of non-potable groundwater. The WWTP managers have requested that the 4.7 ML/d restriction on infiltration be lifted as the risk of inundation in a low area on the Medina Agricultural Research Station is now estimated to be low. However, there is still a possibility that larger infiltration volumes would increase flow towards The Spectacles. This example shows that drying wetlands are a major source of nutrients in down-gradient groundwater resources.

Mandurah No 1 WWTP at Gordon Road

Treated wastewater from the City of Mandurah has been added to the Spearwood Dunes overlying the Tamala Limestone aquifer since the early 1970s. Currently the amount being infiltrated through four open basins is 10 ML/d, and the total amount infiltrated in the past 45 years is between 200 and 240 GL. The City of Mandurah takes 110 ML/y directly from the plant, but its main impact has been through the creation of a 0.5m mound under the basins with radial flow towards irrigated ovals and a golf course to the north west, and some flow towards Lake Goegrup to the south east.

Pavlov (2015) used sucralose and other indicators to show that almost all treated wastewater flowed to the north west. The groundwater containing treated wastewater under the basins has a lower salinity and a higher temperature, fluoride, bromide and boron content than the native groundwater. High Total Nitrogen in groundwater was associated with historical biosolid drying beds on the south of the WWTP site. Total Phosphorus levels were very low except under irrigated ovals and golf courses. The Tamala Limestone is almost certainly a major cause of the low P in the aquifer. There is no evidence of breakthrough P because of overloading the aquifer after 45 years of infiltration.

The experience of Gordon Road is that infiltration of treated wastewater has been used to supplement and freshen groundwater supplies for public open space and a golf course for decades, but it has not always been recognised as playing this role. At one stage the 'unused' treated wastewater was considered for sale to an industrial user. Had infiltration ceased, the local mound would have dissipated, and groundwater allocations might have been reduced as there are saline wedges extending from both the Indian Ocean to the west and Peel Inlet – Lake Goegrup to the south east. Inflows to this WWTP are expected to treble by 2060 so there appears to be scope for further indirect or direct use in future.

Mandurah No 2 WWTP at Halls Head

Over 1 GL/y of tertiary-treated (oxidation ditch and clarifiers) wastewater is currently infiltrated through ponds located only a few hundred metres from the ocean. The aquifer consists of very high transmissivity Tamala Limestone and the watertable is only 2-2.5m deep. The site has infiltrated treated wastewater since the mid to late 1980s and 15-25 GL has been added since that time.

The current disposal licence (DWER 2018d) requires that the infiltration ponds need to be "*Designed to support effective infiltration as part of the groundwater supply to the City of Mandurah under the managed aquifer recharge program*". Some of the infiltrated wastewater is recovered via bores around the WWTP and used to irrigate public open space in the Seascapes urban development.

Recovery trials using bores located 80 and 100m from the basins in the early 2000s showed considerable chemical and microbiological improvement of the recovery water despite the short residence time and the possibility of poor contact between the water and the aquifer (Toze et al. 2002; 2004). The pumps removed about 15% of the volume that was added through the basins over a 22-month period. About 80% of the recovered water was treated wastewater so the extracted water showed qualities different from both the effluent and the native groundwater.

Viruses were removed to below detection limits in the two recovery bores. Toze et al. (2004) concluded that there was adequate residence time for complete removal of all six pathogen types tested. Total nitrogen values in the recovery water were lower than in the effluent and close to that in the brackish native groundwater. Ammonia in the effluent was converted to nitrate in the aquifer but not denitrified because of a lack of carbon and anoxic conditions. Total Organic Carbon and total phosphorus were greatly reduced, something that has also been recorded in the Floreat Infiltration Gallery trials in similar hydrogeological conditions (Bekele et al. 2001).

Mandurah No 3 WWTP at Caddadup

This treatment plant is located on the narrow peninsula between the Ocean and the Harvey Estuary, immediately east of The Cut Golf Course. It was established in 1994 and upgraded to an oxidation ditch system in about 2008. Such treatment reduces the amount of Total Nitrogen in effluent by an order of magnitude. Since its establishment, the ponds have infiltrated between 6 and 9 GL of treated wastewater. Given the high extraction for irrigating the nearby 18-hole golf course, it is very likely that this is a major indirect user of this water.

Yanchep and Two Rocks WWTPs

The Yanchep WWTP closed in 2016 and Two Rocks is due to close in 2020. These small, once isolated plants are no longer needed now that the Alkimos WWTP has been built. This has resulted in wastewater that used to be recharged to the Superficial Aquifer now being treated and sent for ocean discharge. There is very limited monitoring data from these two WWTPs but they are expected to perform similarly to the Halls Head and Caddadup WWTPs which are located in the same environment.

Bullsbrook WWTP

The Bullsbrook WWTP is designed to serve a population of approximately 2000, with current usage at about 1500 (DWER 2018a). Treated wastewater is licensed to be disposed of by evaporation and infiltration via a constructed woodlot/wetland area on site. The wastewater is treated using the Intermittently Decanted Extended Aeration (IDEA) system to remove nutrients and pathogens from the raw wastewater (GHD 2012). The WWTP will close in 2019.

Mundaring WWTP

The Mundaring WWTP was upgraded in July 2016 to in-part allow increased water reuse on local community sports ovals and a nearby equestrian centre during summer (Water Corporation 2018b). The DWER licence authorises discharges to land (irrigation) and water (Jarrah Creek, when the reuse option is not available) with water quality monitoring requirements (DWER 2018b).

Pinjarra WWTP

All treated wastewater from the Pinjarra WWTP is discharged to the adjacent Alcoa alumina refinery for reuse in processing (DWER 2018c). Current inflows are only about 40% of the plant capacity.

6. Treatment and use of inland wastewater – the North East Corridor study

As previously detailed, wastewater from the north east corridor of Perth (e.g. Ellenbrook and urban areas in the Swan Valley) is collected and pumped to the Beenyup wastewater treatment plant about 20 kilometres to the coast. There has been growing interest in developing non-potable supplies to meet the needs of local councils for irrigating POS, viticulturalists in the Swan Valley, golf clubs and nearby private irrigators (e.g. horse owners in Brigadoon, horticulturalists in the Chittering Valley). To evaluate a variety of options, a draft report on water supply options for the North-East Corridor of Perth has been prepared for DWER by Synergies Economic Consulting (2018). The options for reusing some of this water are as described in Potential benefits of recycling were assessed to be:

- avoided wastewater treatment costs;
- public open space benefits;
- agriculture benefits;
- tourism benefits; and
- household benefits.

The results from this study are still being assessed but it will provide a guide to the viability of meeting non-potable water supply needs in inland sub-regions, including the South East and inland parts of the Peel sub-region.

Table 6-1.

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- avoided wastewater treatment costs;
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Table 6-1. Summary of water reuse options being assessed by Synergies Economic Consulting (2018)

Option		Description
Option 1	Base case (status quo)	Collection and transportation of all NEC wastewater for centralised treatment at Water Corporation's Beenyup treatment plant, equivalent to 5.8GL/year by 2040. Provides no new non-potable water to the NEC region to make up shortfalls arising from reduced allocations.
Option 2	Subregional recycling	Semi-decentralised treatment involving a single recycling facility in NEC, utilising wastewater diverted from existing and new urban developments to produce sufficient volumes of recycled water to meet the total forecast shortfall in supply (4.3GL by 2040). A single MAR injection point.
Option 3	Local recycling	Extensively decentralised wastewater treatment involving three wastewater recycling facilities in NEC. Utilises wastewater diverted from existing and new urban developments to produce sufficient volumes of recycled water to meet the total forecast shortfall in supply (4.3GL by 2040). Three MAR injection points.
Option 4	Local recycling and third pipe	As for Option 3, but with a third pipe system to supply recycled non-potable water to households. Total volume of recycled water is the same as Option 3 (4.3GL by 2040) but some of this water is supplied to households. Once household demand for non-potable water is met at the two participating developments (0.8GL by 2040), the surplus is used for MAR (3.5GL by 2040).
Option 5	Subsoil water recycling	Wastewater treatment as for Option 1, but with subsoil drainage water incepted, treated and injected at two subdivisions (Lexia and Brabham). Total volume of new non-potable water supplied to the NEC is 300ML per year by 2040 – assumed to be delivered via MAR to POS irrigation.
Option 6	Reduced scale local recycling	Similar to Option 3, but with reduced volumes of recycled water production (2.4GL by 2040). Only wastewater from new urban developments at Bullsbrook, Lexia and Brabham is received and treated at three local treatment facilities. Three MAR injection points. Construction of Lexia WWTP is deferred until urban development commences

7. Discussion

Wastewater is currently collected from all six of the Perth-Peel sub-regions (Figure 2-1). After the Two Rocks and Bullsbrook WWTPs have closed in 2020, there will be only the small Mundaring WWTP in the North East Sub-region, and only the similarly small Pinjarra WWTP in the South East sub-region. The large WWTPs, and seven of the twelve WWTPS, are in the North West, Central and South West Sub-regions: Alkimos WWTP is in the North West; Beenyup and Subiaco are in the Central; and Woodman Point, Kwinana, East Rockingham and Point Peron are in the South West. All WWTPs in the Peel Sub-region are relatively small (Figure 3-4) and will continue to dispose of treated wastewater into the Superficial Aquifer.

While located for treatment efficiency and ease of ocean disposal, the WWTPs are not ideally located for reuse by agriculture in the Swan Valley or by local governments. Inland areas have limited access to non-potable water supplies because the hills suburbs lack suitable aquifers, and riverine areas are often underlain by Guildford Clay and/or the Kings Park Formation which has eroded the Leederville Aquifer (McFarlane 2018b).

Most of the large WWTPs are well located for Groundwater Replenishment (scheme supply reuse), except for the Subiaco WWTP which is underlain by a thick sequence of the Kings Park Formation. The Water Corporation aims to achieve 30% reuse by 2030, it being 12.6% in 2012 (Water Corporation 2013). Most recycling currently takes place in regional centres with only 9.3 GL/y (6.6%) of treated wastewater recycled in the Perth-Peel Region in 2014/15 (Water Corporation 2018c). However, there is now the capacity to inject a further 14 GL/y into the Leederville Aquifer as part of its Groundwater Replenishment for scheme supply program. The expansion to 28 GL/y should be completed by 2019. Groundwater replenishment for scheme supply options are now being investigated at several WWTPs to help meet the 30% by 2030 target. Non-potable water uses are being considered in the Western Suburbs Regional Organisation of Councils (WESROC) area (McFarlane 2018b) and in the North East corridor as outlined in the previous section so it is likely that part of the reuse target will be met through these and other initiatives.

All except the Point Peron WWTP produce advanced secondary treated wastewater, with the most recently built and upgraded plants (Alkimos, Caddadup, East Rockingham, Gordon Road and Kwinana) using oxidation ditch methods which reduce the amount of nitrogen in the effluent and lower the risk of eutrophication, especially of coastal and saline estuarine water. These improvements should reduce concerns expressed by regulators such as in previous investigations of the Mosman Peninsula (Prommer et al. 2004) and Perry Lakes (Drummond et al. 2011).

The two-remaining inland WWTPs, Mundaring and Pinjarra, have direct reuse for irrigation and industrial use respectively. The Kwinana, Gordon Road, Halls Head and Caddadup WWTPs discharge to the Superficial Aquifer. By raising or maintaining groundwater levels, these plants provide indirect reuse to industry (Kwinana) or public open space irrigation (the three City of Mandurah plants). Even though this reuse is indirect, it is an important supply and could be considered in reuse targets. The land disposal sites are ideal for investigating the feasibility of long-term managed aquifer recharge using treated wastewater.

Overflow from the Kwinana WWTP is conducted to the SDOOL and offshore from Point Peron. Most of this water is disposed to the Superficial Aquifer in the Bassendean Dunes and east of the Tamala Limestone which has been shown by several studies to remove phosphorus and metals. The Kwinana land disposal site therefore offers insights that are not provided by the more westerly sites.

The experience of many decades has been that treated wastewater from relatively small WWTPs can be safely disposed to the aquifer (Donn et al. 2017). Whether treated wastewater can be economically and safely discharged to inland sites is less clear.

Estimates of a 40% increase in inflows to Perth and Peel WWTPs by 2040, and over 70% increase by 2060, indicate that the volumes of treated wastewater are such that reuse for potable and non-potable uses needs to be seriously considered in planning for Perth-Peel@3.5m. This is especially urgent given the drying climate is reducing naturally-available water and the population increase will require irrigated public open space for both active and passive recreation.

7. Conclusions

In a drying climate, treated wastewater is a growing resource that is being increasingly recognised as essential for helping to meet the water needs of Perth and Peel as the population is expected to grow to about 3.5m by mid-century.

While treated wastewater has been used as a valuable non-potable resource in inland parts of Western Australia, recycling in the Perth-Peel region is comparatively small (probably about 26 GL/y, or 17%, assuming that infiltrated wastewater that is subsequently used by local government is included as reuse). There is a desire to increase reuse to 30% (or to 51GL/y) by 2030. Much of this reuse is expected to come from an expansion of the Groundwater Replenishment program which treats wastewater to drinking water standards.

Land disposal of treated wastewater provides an indirect form of recycling for non-potable use, not dissimilar to Groundwater Replenishment in that there is within-aquifer treatment of the water before it is used. As the population grows, the demand for non-potable water by local councils, industry and horticulturists is increasing while natural recharge rates are decreasing because of a drier, warmer climate. While there may be some local competition between wastewater used for potable and non-potable uses, the volume that is being discharged to the ocean is substantial and increasing each year.

8. Recommendations

A synoptic summary of treated wastewater quality from the WWTPs in Perth and Peel would facilitate consideration of reuse options for both potable and non-potable purposes. An understanding of the impact of treatment process on water quality would help decide whether further treatment is required if residence times in aquifers are too short before the added water is used or will reach an environmental asset.

The feasibility of decentralised local wastewater treatment and MAR in the North East and South East sub-regions for non-potable use needs to be further investigated. The viability of decentralised wastewater treatment for non-potable reuse is currently being investigated for the north east corridor which includes the Swan Valley. Depending on the results of this work there may be scope for trial interceptions of sewer water.

The land disposal of treated wastewater for infiltration to groundwater needs further investigation and acceptance as an indirect form of wastewater reuse. Otherwise it could be considered unused and reassigned.

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10. Acknowledgements

The following people are gratefully acknowledged:

The project was initiated and managed by Roy Stone and Neil McGuinness.

Mae Shahabi and Craig Scott coordinated DWER advice and access to departmental information.

Stephen Beckwith, Water Corporation, provided information on wastewater plant inflows.

The report was amended after review by Roy Stone, Mae Shahabi, Dan Ferguson, Beatrice Franke and Craig Scott.