



The potential for managed aquifer recharge, third-pipe and direct piping systems in the Perth-Peel region

Dr Don McFarlane
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Adjunct Professor, School of Agriculture and Environment, University of Western Australia
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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.

Less than half (45%) of the water used in the Perth-Peel region is from scheme supply. The remainder (55%) is self-supplied for non-potable water uses such as green spaces watering, irrigated agriculture, industry and domestic garden bores. The Water Corporation is responsible for meeting the current and future scheme supply water needs of the region. Consequently, the focus of DWER's work in identifying water supply options is on meeting self-supply non-potable water needs.

This report assesses the potential for managed aquifer recharge (MAR), third-pipe and direct piping systems to help meet demands for self-supplied non-potable water. MAR is the storage of water in aquifers at times of abundance and its use when needed, either later in a season, during dry years, or when demand exceeds short term supplies. It can also be used to maintain environmental values such as wetlands and groundwater-dependent ecosystems. Interest in MAR reflects the reduction in recharge rates over much of Perth and Peel because of reduced rainfall and increased potential evaporation.

Third pipes are an additional piped system, which brings non-potable water to residences for use in irrigation and in-house uses that do not require water of drinking water standard. Direct piping systems carry a non-potable water supply to users, especially to local governments to irrigate public open space (POS).

The water sources of non-potable water for MAR, third pipes and direct piping include drainage water, treated wastewater and sub-soil drainage. The potential for these water sources to provide non-potable water is examined in two companion reports (McFarlane 2018a, 2018b). Existing third pipe systems in Perth use groundwater from common bores into the Superficial Aquifer, as is detailed in this report.

This report finds that groundwater levels in the unconfined Superficial Aquifer, and pressure in the largely confined Leederville Aquifer, have generally declined over the past 20 years, but the rate of decline is lessening in both aquifers. There appears to be the capacity to replace some, if not all, of the groundwater that has been depleted over much of the Perth and Peel region, provided a cost-effective source is available that will not degrade water quality and where environment and health risks are appropriately managed.

MAR into the Superficial Aquifer appears most suited to western coastal-plain areas underlain by Tamala Limestone. This area has high transmissivity aquifers, which also can neutralise acidity and remove phosphorus and heavy metals. Under the limestone ridges and Spearwood Dunes the watertable is deep, providing room (or 'freeboard') and the ability of the soil to treat the added water if it is infiltrated at the surface rather than injected through bores. Where the watertable is close to the surface there are opportunities to deliberately raise levels above ground to save throughflow lakes that have been lost in recent decades.

MAR opportunities into the Superficial Aquifer in eastern coastal-plain areas are more limited because of less freeboard, lower transmissivities and a poorer ability of the Bassendean Sands to treat added water. Eastern areas also contain clayey soils and aquifers associated with the Guildford Formation. While less suited, by national standards the Bassendean Sands are good aquifers, which just require more work before they can be used.

MAR into the Leederville Aquifer requires consideration of its presence, depth, water quality, impacts on other users, pressure head and transmissivity. An absence of self-supply water and MAR opportunities in the overlying Superficial Aquifer may make MAR into the Leederville worth the additional cost of water treatment (to reduce the risk of clogging) and injection rather than surface

infiltration under gravity. MAR into the Leederville appears easiest in the North West sub-region, the Swan Valley, the eastern coastal plain in the South East sub-region, and in the eastern and central parts of the Peel sub-region. Ease of access for MAR also means ease of access for extraction by other extractors, so beneficial and deleterious impacts on these users need to be considered. Leederville MAR may be accepted where aquifers are deep and/or saline and therefore are not attractive for extraction. Adding lower salinity water may create a usable water resource in these less propitious aquifers over time.

The presence of shallow aquifers under the Swan Coastal Plain makes it more suitable than other parts of Australia for MAR. The presence of abundant shallow high-quality groundwater has probably inhibited MAR because it has not been necessary until recently. The aquifers are highly valued so there are concerns that MAR will cause contamination. Examples from the eastern states and overseas are valuable as they have solved problems, especially in well injection methods, in less conducive circumstances. In the Perth and Peel region, stormwater and some treated wastewater sources can have a higher quality than in other parts of Australia. Perth coastal sands are more permeable and aquifers more transmissive and able to treat and dilute added water, reducing the need for prior treatment. It also allows cheap surface applications that increase in-situ soil and aquifer treatment opportunities, rather than well injection. The long experience of disposing of roof and road runoff, and treated wastewater when not sent to an ocean outfall, is a testament to the soil and aquifers' abilities to passively infiltrate and treat wastewater streams. In addition, the very large investment in existing self-supply abstraction bore infrastructure make MAR of recycled water an attractive and cost-effective option for supplementing/offsetting the reducing availability of natural groundwater.

Third pipe schemes installed in parts of Perth and Peel have had limited success in achieving their aims and some have closed as a result. It is likely that none of the schemes provide water at lower cost than drinking water alternatives. If residents are prepared to pay more to reduce their demand on valuable drinking water supplies, and they are aware of this differential, then that would be a desirable outcome. Some third pipe schemes have increased total water use by providing an additional water supply with fewer restrictions in its use. Schemes installed to intercept nutrients or to dispose of a wastewater do not need to be low cost to meet their aims. Third pipe schemes where both the Superficial and Leederville aquifers are absent may be more viable and could be trialled. This mainly involves the eastern riverine suburbs.

Direct piped schemes to irrigate POS have been investigated by local governments and have some advantages over MAR, namely more control over water quality, possibly greater acceptance by the community and no need for a water licence from DWER. However, compared to MAR they are more expensive, only use water when irrigation demand is high and do not provide a water source for domestic bore users. They also do not provide environmental services such as raising lake levels, providing water for plants that depend on access to the watertable, push back intruding seawater or flush salts from the aquifer. To date neither direct piping nor distributed MAR schemes have been trialled on a large scale. However, there is increasing interest in both, especially in the western suburbs between Cambridge and Mosman Park.

MAR opportunities in hill suburbs are more difficult because of a reduction in rainfall and runoff, and the absence of high yielding aquifers for storing and supplying non-potable water.

MAR of treated wastewater is increasingly being concentrated in the Peel sub-region because of population growth and rising demand for non-potable water, the availability of suitable aquifers and the absence of an ocean outfall, resulting in land disposal of treated wastewater. Opportunities for similar wastewater diversions in the north west and north east sub-regions have diminished because the Water Corporation's small wastewater treatment plants (WWTPs) at Two Rocks, Yanchep and Bullsbrook have, or are, closing with all water being directed to the large Alkimos or Beenypup WWTPs. The high cost of returning treated wastewater from coastal WWTPs to inland areas, especially the Swan Valley, is reviving interest in intercepting and treating sewerage for local non-potable use before it reaches a WWTP.

MAR of drainage water is most viable in the Central sub-region where most main drains occur. It is easiest where those main drains cross the Spearwood Dune system and the Tamala Limestone aquifer can accommodate and treat any added water. Diversion in the Bassendean Dune system is more difficult, but potentially more needed given the absence of treated wastewater in inland areas. Additional diversion of street drains may reduce salt water intrusion into groundwater in areas adjacent to the estuary and ocean. The diversion of sub-surface drains to aquifers is inhibited by their relatively small volumes of water and a lack of suitable storage. While sub-surface drains may meet local water supply shortages, they are unlikely to be significant contributors of recharge.

Opportunities to draw down aquifers in summer to create storage for winter flows look promising in eastern palusplain areas, but the risks of doing so need to be assessed carefully. Diverting agricultural drainage to Spearwood Dunes and the Myalup Irrigation area in the Peel sub-region is also promising.

In summary, conditions look very favourable for increasing MAR in most parts of Perth and Peel to meet the needs for non-potable water for a population of 3.5 million people in a drying and warming climate. Experiences with MAR schemes and the long history of stormwater and wastewater disposal to aquifers need to be shared to raise awareness of the possibilities. Irrigation water needs to be supplemented to avoid the intensification of the urban heat island effect that will intensify should irrigated green spaces be lost.

2. Background

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

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 in the hills) and its partial depletion in recent decades, there is increasing interest in managed aquifer recharge (MAR) of seasonal stormwater, and year-round wastewater streams. The confined Leederville Aquifer is also of interest for MAR where the Superficial Aquifer is absent or unsuitable.

This is one of several high-level guidance notes prepared by 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. This will 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.

The three related guidance papers are:

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

Chapter 3 identifies areas in the Perth and Peel region that are suitable for MAR in the Superficial Aquifer, while Chapter 4 does the same for the Leederville. Chapter 5 puts MAR opportunities in the Perth and Peel region into a national context.

Comparisons between MAR and direct piping for irrigating green spaces and peri-urban agriculture are made in Chapter 6, and with third pipe schemes in Chapter 7.

The findings are discussed in relation to the six planning sub-regions (Figure 2-1) in Chapter 8 before some general conclusions are drawn and recommendations made for further work in the final two chapters.



Figure 2-1. West Australian Planning Commission planning sub-regions for the Perth-Peel region (Source: DWER)

3. Areas in Perth-Peel that may be suitable for MAR into the Superficial Aquifer

One criterion for identifying areas suitable for MAR is whether there is an aquifer present within about 200 m of the surface.

The unconfined Superficial Aquifer forms within siliceous Bassendean and calcarenite dunal sands (Tamala Limestone, Safety Bay Sands) as shown in Figure 3-1 and Figure 3-2, but is largely absent in the clayey Guildford Formation, which is comprised of alluvium deposited around the Swan and Canning rivers. The Bassendean Sands can overlie the Guildford Formation and there can be sandy lenses within the Formation, so Figure 3-1Figure 3-2 are only a guide to the presence of an aquifer.

The ancient Swan River deposited the clay-rich Kings Park Formation, which has eroded and replaced the underlying Leederville Aquifer, further reducing the availability of aquifers for MAR near the current and past rivers. An exception is the sandy Mullaloo Sandstone component of the Kings Park Formation, whose extent is shown in Figure 3-1 and Figure 3-2.

MAR will therefore be particularly difficult in eastern hills suburbs and where the Guildford and Kings Park Formation overlie each other, and the Mullaloo Sandstone is also absent from the Kings Park Formation. Fortunately, this is very small part of the coastal plain.

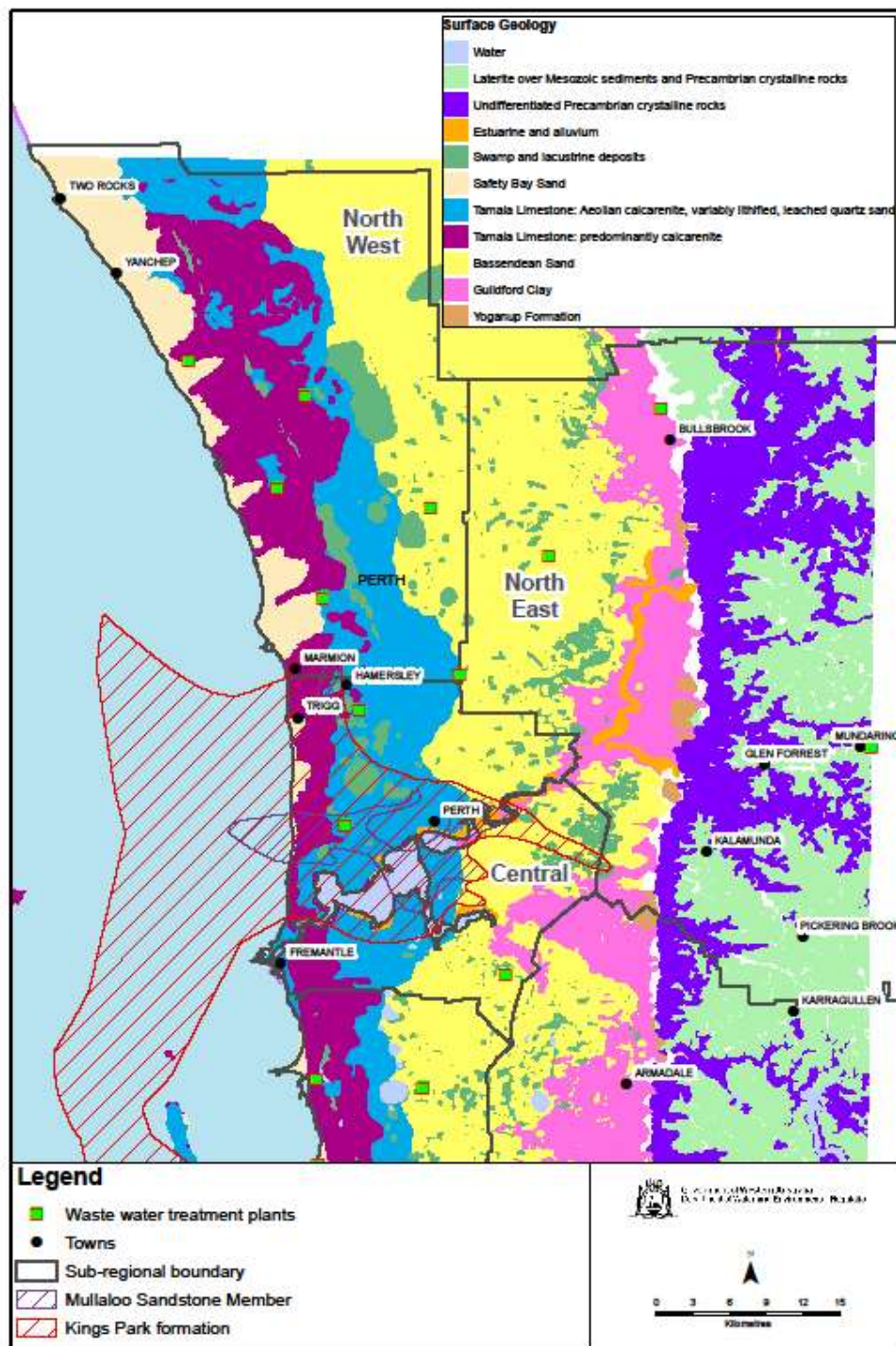


Figure 3-1 Surface geology of the three northern sub-regions overlain on the boundaries of the Kings Park Formation and Mullaloo Sandstone

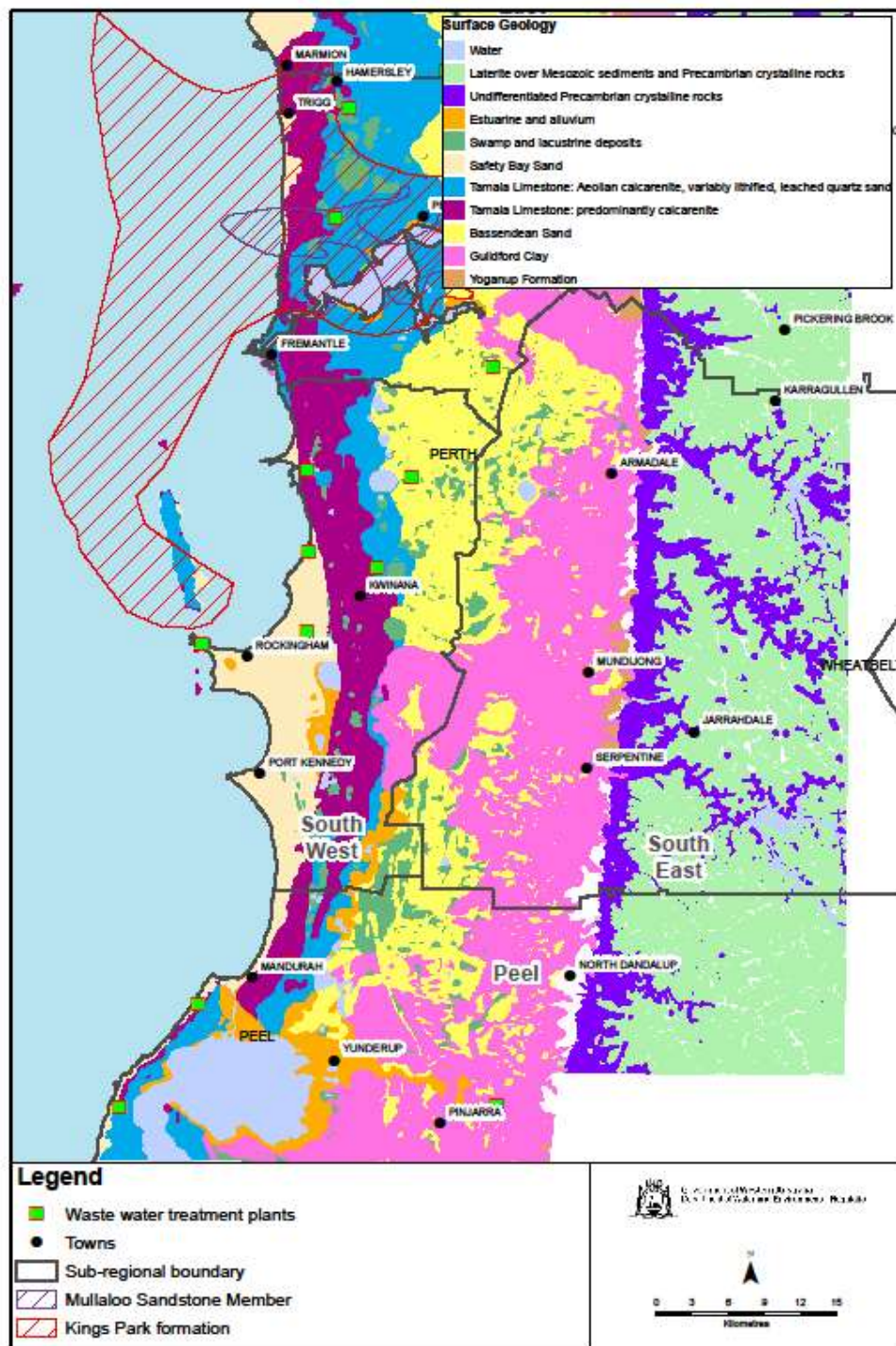


Figure 3-2. Surface geology of the three southern sub-regions overlain on the boundaries of the Kings Park Formation and Mullaloo Sandstone

3.1 Changes in groundwater level in the Superficial Aquifer

Another criterion for selecting sites suited to MAR is whether the aquifer has been depleted in recent decades. High groundwater levels would have supported passive (e.g. wetlands) and active (e.g. pumping) uses and a return to these levels may be beneficial provided MAR does not cause inundation or reduces water quality. Mapping depletion identifies the capacity of aquifers to receive MAR water.

Average groundwater levels in 43 long-term monitoring bores on the Gnangara Mound have declined by about 3m since January 1979 but recovered by about half a metre in the past two years (Figure 3-3). To determine where there is room for MAR water, changes in the Superficial Aquifer levels were plotted for the periods between 1988 and 2007, 2008 and 2017, and 1988 and 2017 in Figure 3-4, Figure 3-5 and Figure 3-6 respectively.

The maps were constructed using bores with records that extend over long periods. In areas with few bores it is possible that the mapped trends reflect bores located some distance away and are therefore only a guide. Specific bore records would need to be used when assessing the feasibility of MAR.

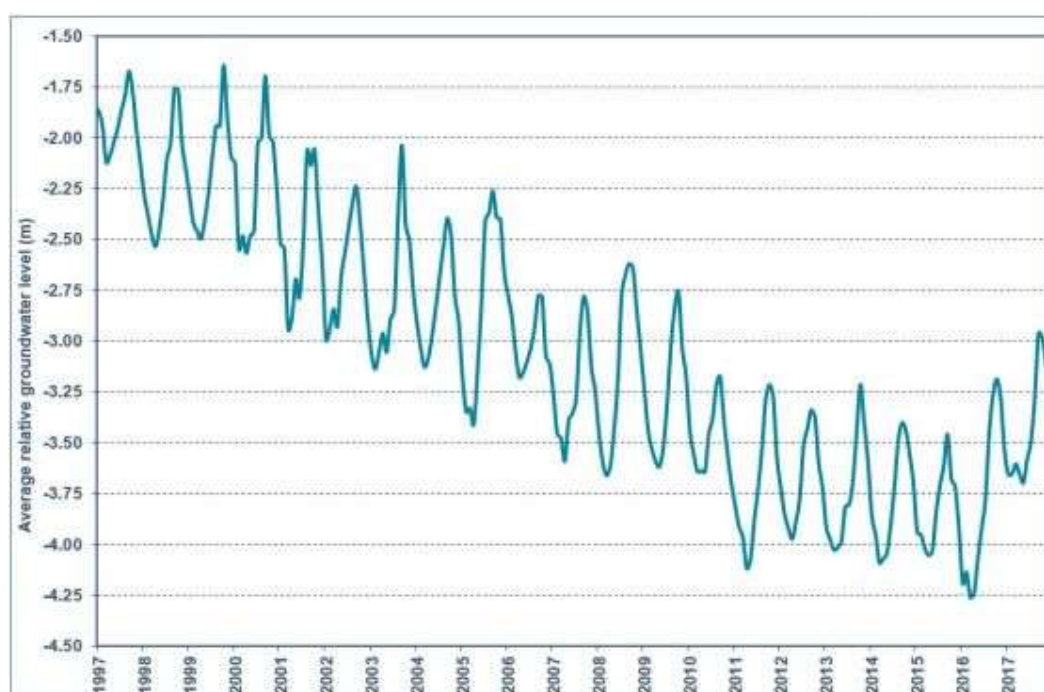


Figure 3-3. Average groundwater levels of the Gnangara Mound (Superficial Aquifer). Source DWER (2018)

The 1988 to 2007 period is dominated by declines in groundwater levels (Figure 3-4). Anything 'hotter' in colour than light blue represents a fall. Dark orange areas, indicating a reduction of more than 4m, occurred in the North West sub-region; and in eastern parts of the North East, South East and Peel sub-regions. Areas around Mandurah recording falls of 1 to 2m are of concern because falls near the coast can be masked by seawater intrusion as is shown later.

Overall, groundwater levels in the 2008 to 2017 period (Figure 3-5) have risen over about half of the Perth and Peel region, with some areas recording rising levels after substantial falls in the previous decade (e.g. around Hamersley, Perth, North Dandalup). However, some areas recorded falling levels in both decades (e.g. northern North West, Mundijong, east of Pinjarra).

The overall change in the past 20 years (Figure 3-6) consists of falls between 4 and 15 m in the northern North West (the western flanks of the Gnangara Mound), west of Bullsbrook (the eastern flank of the Gnangara Mound), east of Hamersley, in the Swan Valley, near the Darling Escarpment at Cloverdale,

south of Armadale to Serpentine, between Mandurah and Pinjarra, and in the south between Preston Beach and Lake Clifton. Rises of more than 1m have taken place in the new North West sub-region coastal suburbs south of Yanchep, around Perth Airport, the urbanising coastal strip south of Fremantle and between Nambelup and North Dandalup. Rises in the Cockburn Sound Catchment shown in Figure 3-6 may be overstated because more detailed analyses (e.g. Figure 8.7 in Bekele et al. 2015) show that while there have been rises associated with bores that have been switched off, there is a wider trend for falling levels.

It is likely that in recent, slightly wetter years, reductions in water allocations and intensive urbanisation have slowed, and in some cases reversed, the fall of groundwater levels in the previous ten-year period. As groundwater levels fall, the gradient and therefore the rate of flow reduces towards river, ocean and main drain discharges. Evapotranspiration losses from areas with high watertables also reduce as groundwater levels fall. The rate of groundwater decline could not therefore be sustained for purely hydrological reasons.

Groundwater levels over large parts of the Gnangara Groundwater System probably peaked in 1968 (Yesertener 2008), so a rise since 1998 may still be to a level that is lower than at that time.

Eastern and northern areas appear more impacted by reduced groundwater levels. These areas are often not close to non-potable water sources such as drainage water and secondary-treated wastewater from regional plants. These non-potable sources can be used for MAR as explained later in this report and also in the accompanying reports on wastewater (McFarlane 2018a) and drainage water (McFarlane 2018b) availability.

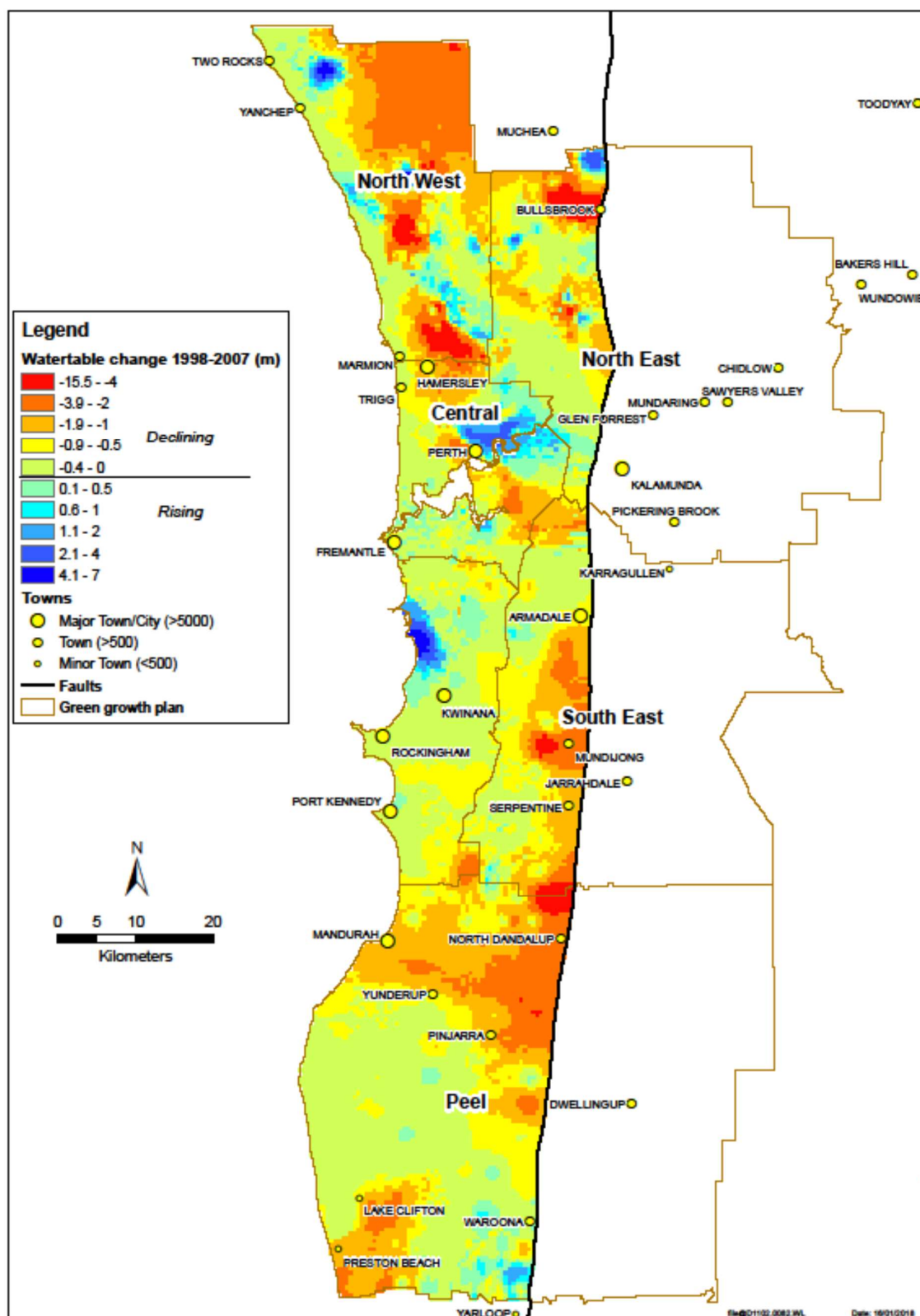


Figure 3-4. Groundwater level changes in the Superficial Aquifer between 1998 and 2007

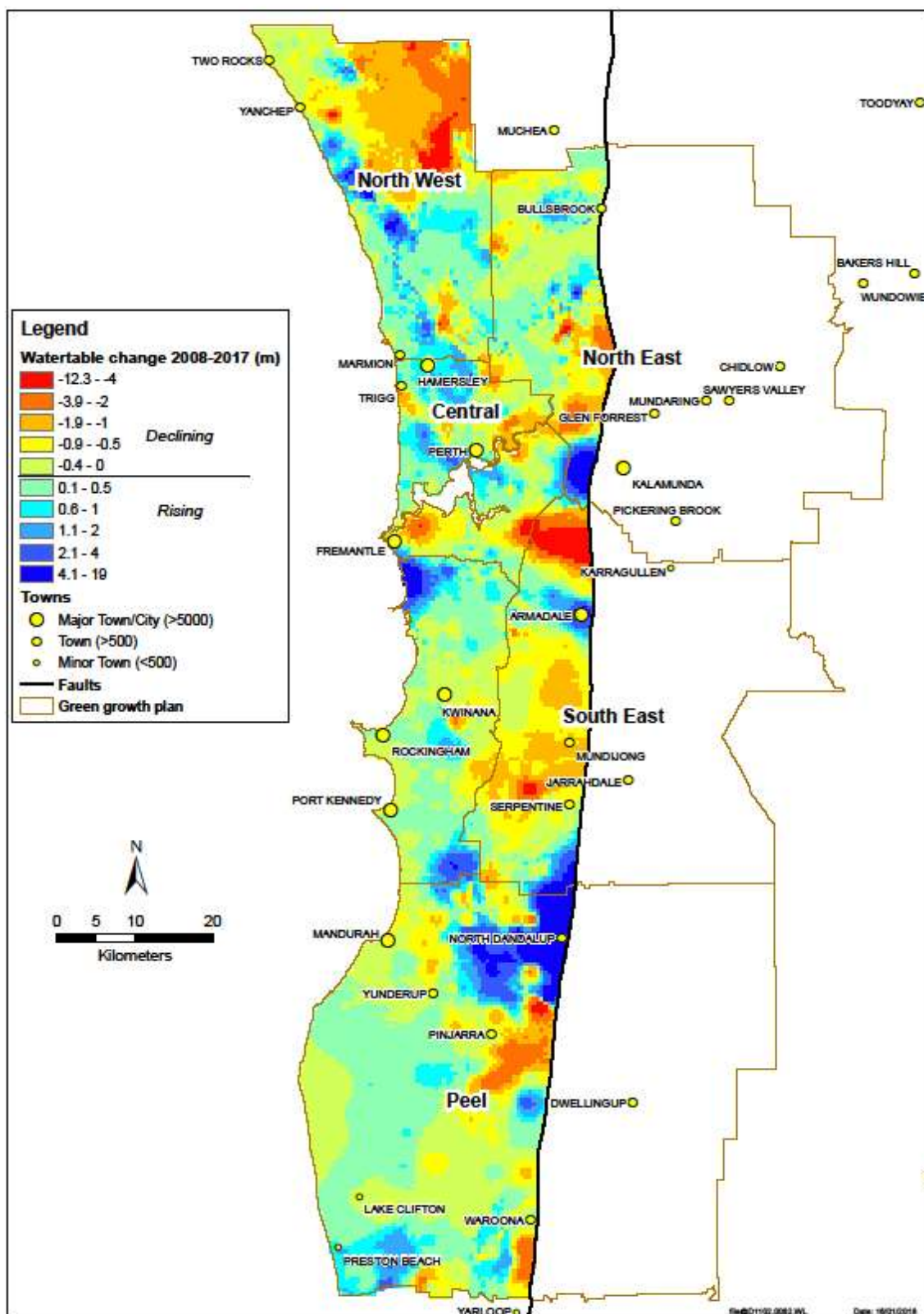


Figure 3-5. Groundwater level changes in the Superficial Aquifer between 2008 and 2017

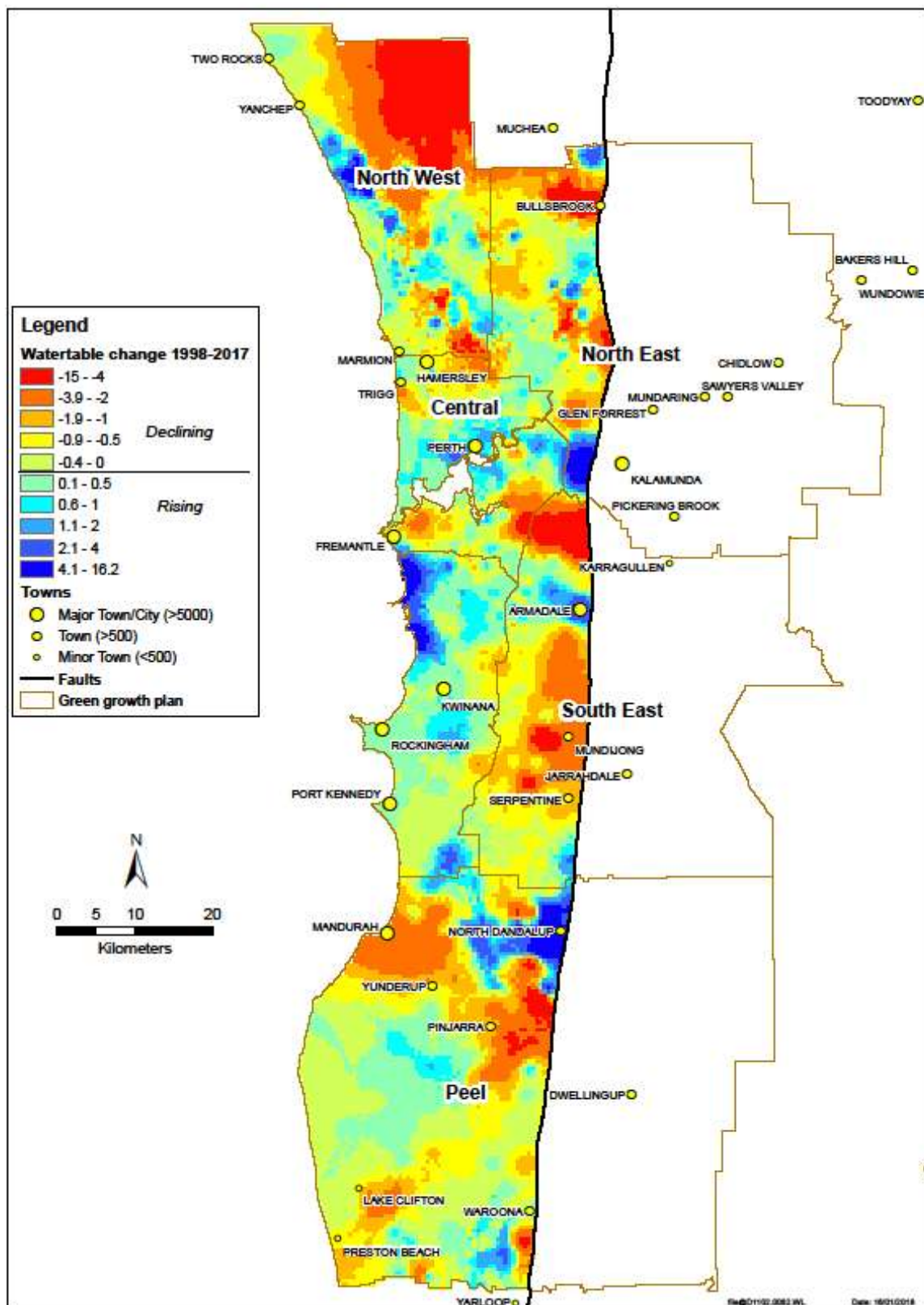


Figure 3-6 Groundwater level changes in the Superficial Aquifer between 1998 and 2017

3.2 Ability of the Superficial Aquifer to accept water without expressing at the surface

In addition to assessing reductions in groundwater storage in recent years, another way of estimating MAR feasibility is to assess the capacity of aquifers to accept water additions without discharging MAR water at the surface. This is a measure of both depth of the watertable from the soil surface (or freeboard) and aquifer hydraulic properties that enable the added water to flow away from its point of addition.

Smith and Pollock (2011) estimated the relative watertable rise (<10, 25, 50, 75 and 100% of the available freeboard) for 1 and 10 ML/day additions over 30 days to assess the feasibility of the Superficial Aquifer in the Perth and Peel region to accept added water (Figure 3-7). Areas underlain by Guildford Clay are unsuitable (shown in red or as 'oversized basin' in Figure 3-7), as are areas with shallow watertables and/or low hydraulic conductivities.

Large parts of the Bassendean Sands, especially south of the Swan River are unsuited, with the unsuitable area increasing when the size of water additions was increased from 1 to 10 ML/day. The limestone ridges underlain by the Tamala Limestone aquifer close to the coast can accept very high quantities of water.

It is important not to assume that all areas shown in light blue or even red cannot be considered for MAR. If the purpose is to raise groundwater levels to revive throughflow wetlands, surface expression of groundwater may be a valid aim and may be achieved with modest additions of water. Areas with shallow or only modest hydraulic conductivities may also be adapted to MAR by lowering levels to create freeboard over summer and replenishing the aquifer in winter.

Figure 3-7c shows the change in freshwater thickness between 1998 and 2007 using a slightly different set of bores than was used to construct Figure 3-4. The map of changes in 'freshwater thickness' shows areas where seawater is replacing freshwater in parts underlain by a salt water wedge. Coastal areas in the North West sub-region, South Fremantle-Coogee, and the Cockburn Sound catchment all had their freshwater thickness reduced during this ten-year period, while groundwater levels may have changed relatively little.

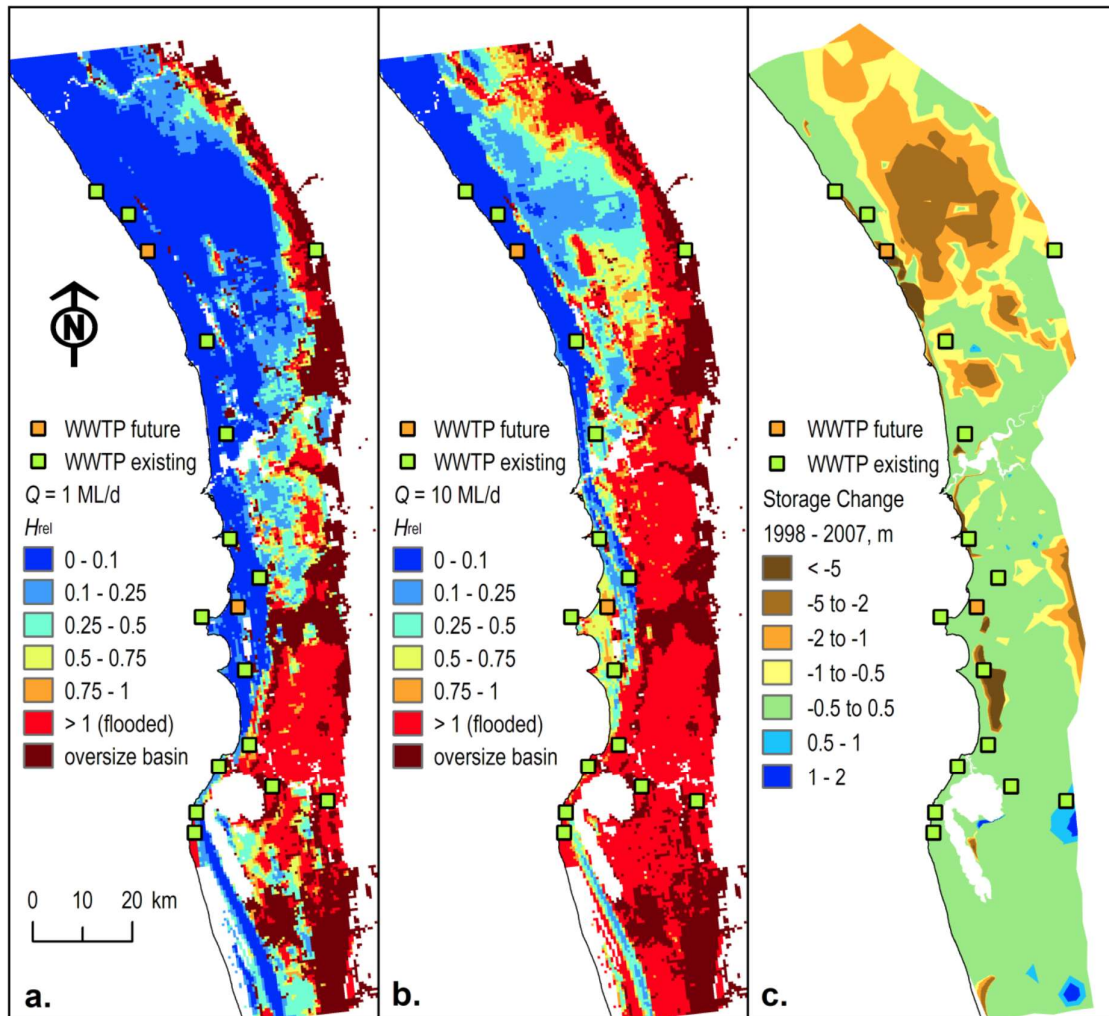


Figure 3-7. Relative watertable rise beneath the centre of a square recharge basin at 30 days continuous operation calculated in 21,335 contiguous cells using Glover's (1961) solution. (a) Small (1 ML/day) hydraulic load. (b) Large (10 ML/day) hydraulic load. (c) Calculated 10-year change of aquifer storage expressed as change of fresh water thickness in the superficial aquifer between 1998 and 2007 (from: Smith and Pollock 2011). The future WWTPs shown in this 2011 figure are now existing.

4. Areas in Perth that may be suitable for MAR into the Leederville aquifer

4.1 Access to the Leederville Aquifer

MAR into the Leederville Aquifer will generally be more expensive than into the Superficial Aquifer because it is deeper, often confined and under pressure, and requires injection bores rather than infiltration basins or galleries. Clogging will be harder to address, which means that MAR water will need to be of a higher quality, especially low levels of suspended solids, dissolved organic carbon, nutrients and iron, which increase physical, chemical and biological clogging risks. One criterion for using the Leederville may be that the Superficial Aquifer is unsuitable in that area because of the occurrence of clayey soils (especially the Guildford Formation) or there is insufficient capacity in the Superficial Aquifer to accept MAR water without expressing at the surface (Figure 3-7a and b).

The eastern half of the Swan Coastal Plain is therefore more likely to be a target for MAR into the Leederville. In the west the Superficial Aquifer often has high transmissivities, available freeboard and soils (Spearwood Sands) and aquifers (Tamala Limestone) that have a record of improving the quality of added treated wastewater (McFarlane 2018a) and stormwater (McFarlane 2018b).

The potentiometric surface for the Leederville Aquifer shows that groundwater flow is from the north-east (70 m Australian Height Datum or AHD) towards the Gwelup wellfield (10 m AHD) north of the Swan River, and westwards from the Scarp (40 m AHD) towards Cockburn Sound (< 5 m AHD) south of the river (Figure 4-1).

Salinity would normally increase with distance down flow lines. For the Leederville, however, salinity is lowest in mid-flow lines in the north, highest near Kenwick between the rivers, and mixed to the south (Figure 4-2). This can be attributed to several factors; the Leederville is not a single aquifer but contains the upper Pinjar, middle Wanneroo and lower Mariginiup members. The Wanneroo member is the most productive and may be the easiest to inject water into for this reason. Another factor affecting salinity is the nature of the confining beds above the Leederville. Most of the low salinity (<500 mg/L TDS) in the north is associated with the Leederville directly sub-cropping and receiving fresh recharge from the overlying Superficial Aquifer on the Gnangara Mound. However, the Superficial Aquifer is not fresh everywhere. The Leederville in the southern part of the Cockburn Catchment directly underlies the Superficial Aquifer, but is more saline than the north, which relates to a saline zone in the Superficial Aquifer (DWER 2018). A similar higher salinity zone in the Superficial Aquifer in the Kenwick area aligns with a saline area in the Leederville.

Figure 4-2 shows the Leederville to be continuous, but it is cut by the Kings Park Formation under the Swan and Canning rivers as is shown later. Also, the low salinity water under the Jandakot Mound occurs where the Leederville is confined by the Kardinya Shale and probably comes from an area of low salinity to the east, near the scarp. This relationship cannot be verified due to a lack of data points (Phil Commander pers. comm. 23rd February 2018).

The depths of the three Leederville members under the urban area are shown in west-east cross sections in Figure 4-3 (approximately Clarkson to Bullsbrook), Figure 4-4 (Craigie to Baskerville – close to Gnangara Road), Figure 4-5 (Munster to Kelmscott), Figure 4-6 (northern Peel area), Figure 4-7 (central Peel area) and Figure 4-8 (southern Peel area).

In the northern transect (Figure 4-3), the most permeable Wanneroo member is only 30-70 m below AHD in the west, increasing to about 100 m and becoming more confined in the east. The Pinjar member comes close to 0 m AHD, but this is under the part of the Gnangara Mound that is used as a drinking water source and therefore MAR using non-potable water is unlikely to be permitted.

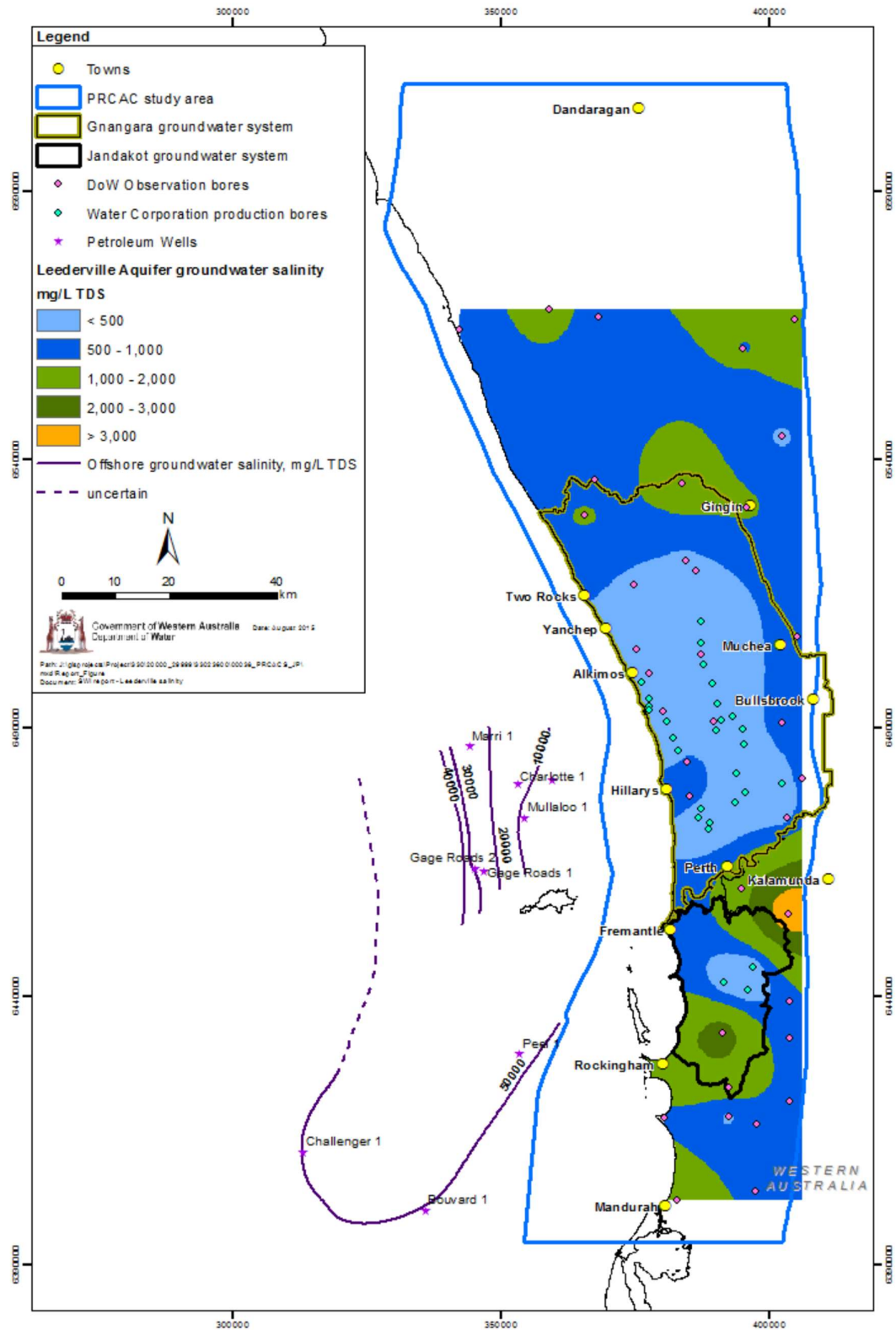


Figure 4-2. Leederville aquifer salinity, mg/L TDS. Source: DoW (2016).

The transect between Craigie and Baskerville (Figure 4-4) shows the Wanneroo member to be confined and mainly between -100 and -200 m AHD in the west and centre. The eastern, Swan Valley part of the section becomes shallow making it more conducive for MAR.

The southern Perth transect shows the Wanneroo member to be about -100 m AHD on the coast, about -175 m in the centre but rising to around -50 m AHD and less confined in the east (Figure 4-4). This area has the highest potentiometric heads indicating it is a recharge zone. The thinning Leederville in the west is accompanied by a thickening of the Kardinya Shale of the Osborne Formation. Some of the mapped Osborne Formation may be Leederville and the changes may not be marked as indicated (Phil Commander pes comm. 23rd February 2018).

The three members of the Leederville Formation are present at relatively shallow levels in the Peel region. North of Mandurah the east-to-west dipping Wanneroo member (the most prospective for MAR) can be intercepted at -50m AHD (Figure 4-6). A west-to-east cross-section through the City of Mandurah shows that the Wanneroo member is very close to the surface over most of the coastal plain (Figure 4-7**Error! Reference source not found.**). Further south, the Wanneroo member is absent in the east and becomes deep in the west (Figure 4-8).

In summary, the Leederville aquifer (and the Wanneroo member especially) is located at less than -200 m AHD, and often less than -100 m (to which needs to be added the surface elevation above AHD) over large parts of the Perth-Peel region. The Groundwater Replenishment project by Water Corporation at Beenyup has shown that the aquifer can accept high-quality injection water without clogging. It has also shown the re-pressurisation of the aquifer away from injection bores can reverse the falls in pressure.

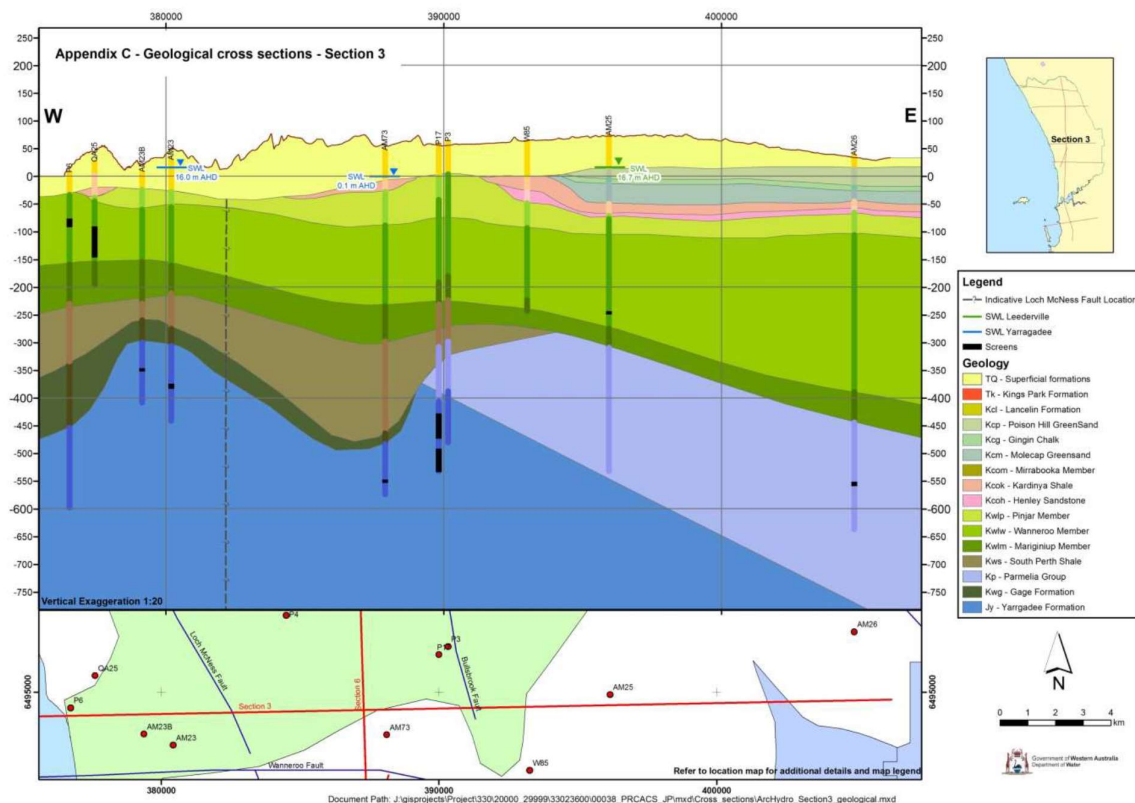


Figure 4-3. West to east cross-section in the northern suburbs showing the Leederville Aquifer members (light to dark green) recharging from the overlying Superficial Aquifer. Source: DoW (2017).

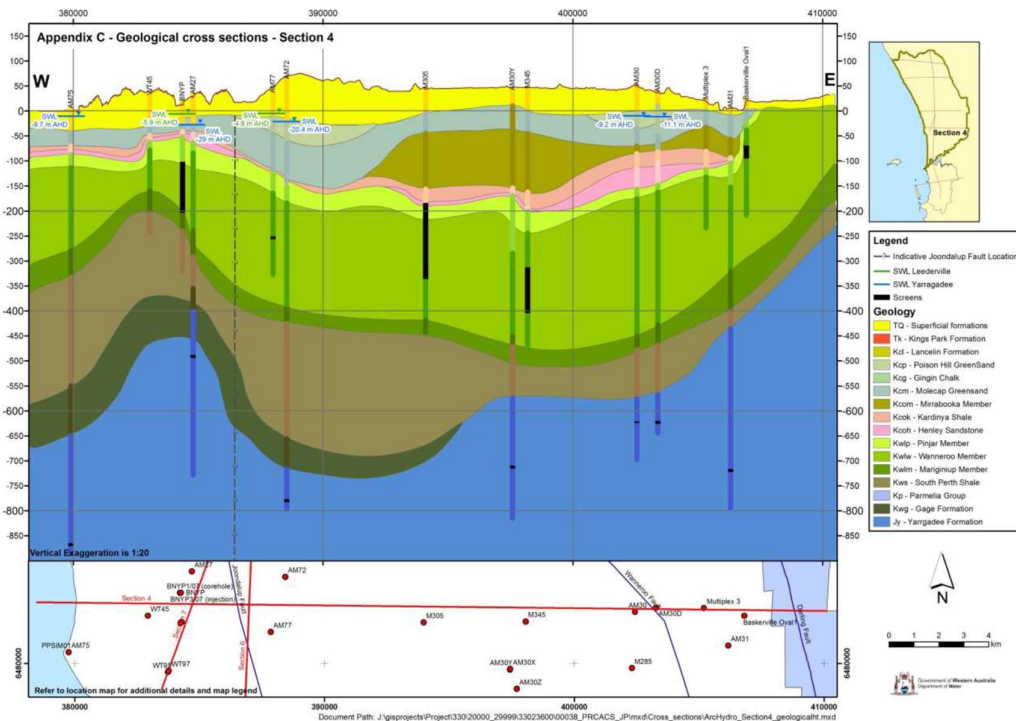


Figure 4-4. West to east cross-section north of the river through urban areas showing the Leederville Aquifer members (light to dark green) recharging mainly in the east. Source: DoW (2017).

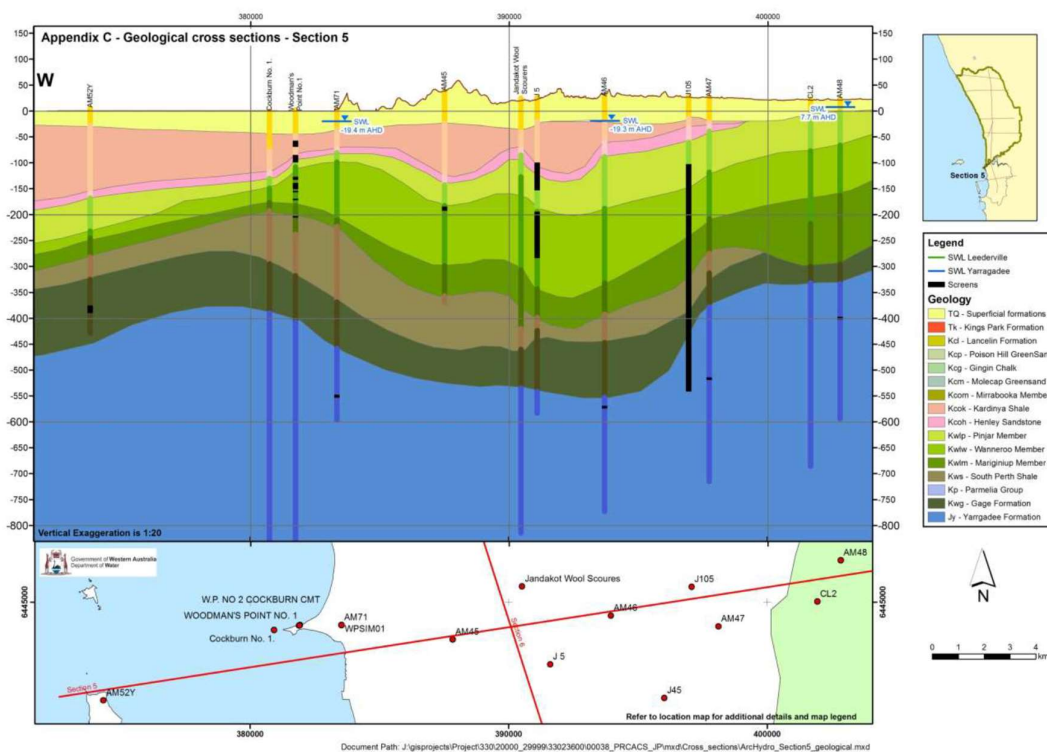


Figure 4-5 West to east cross-section south of the river showing the three Leederville Aquifer members (light to dark green) recharging near the scarp and becoming more confined as it flows westwards. Source: DoW (2017).

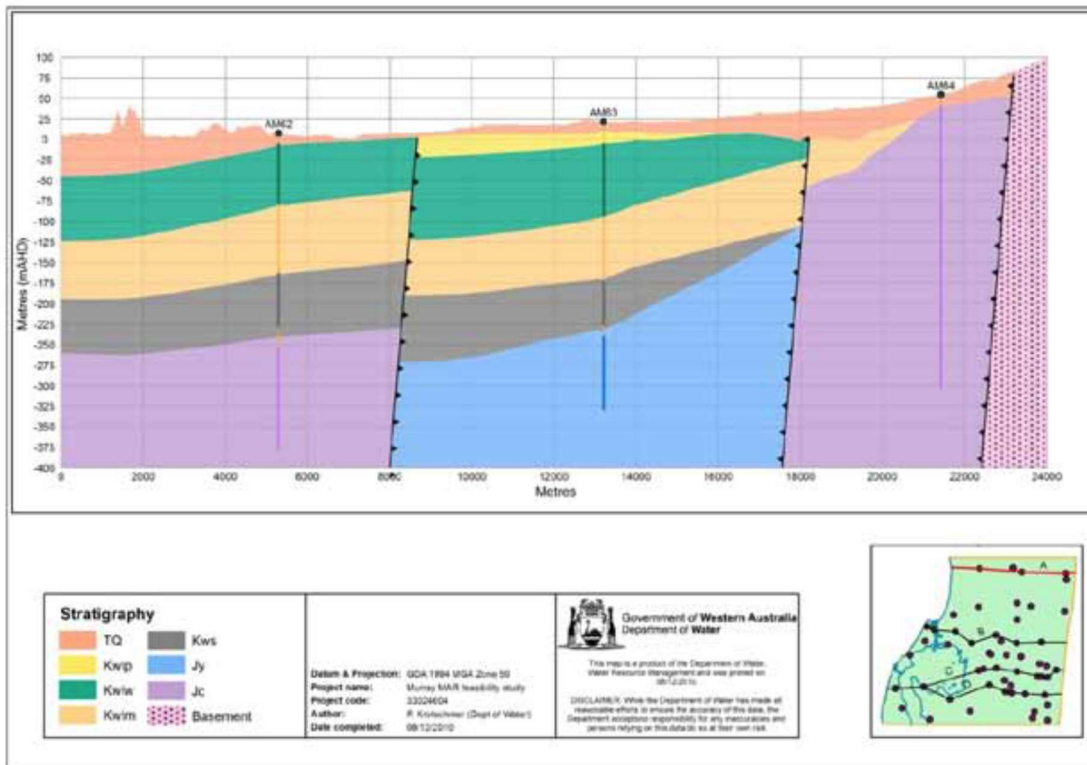


Figure 4-6. West to east cross-section in the northern Peel area (see inset) showing the Leederville Aquifer members; Pinjar in light yellow; Wanneroo in green and Mariginiup in dark yellow). Source: Kretschmer et al. (2011).

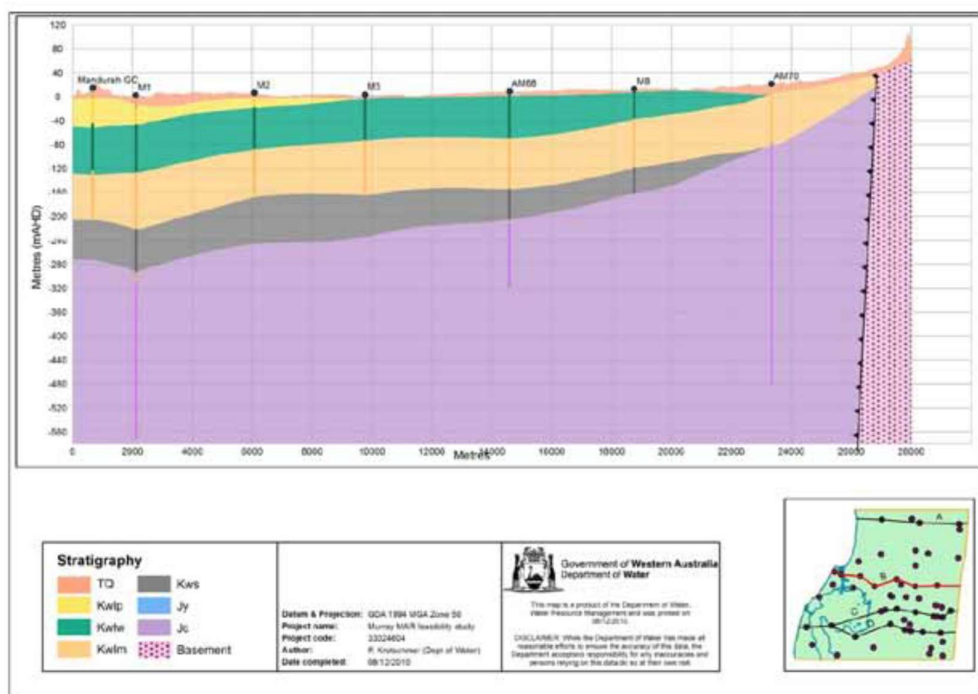


Figure 4-7. West to east cross-section in the central Peel area (see inset) showing the Leederville Aquifer members; Pinjar in light yellow; Wanneroo in green and Mariginiup in dark yellow). Source: Kretschmer et al. (2011).

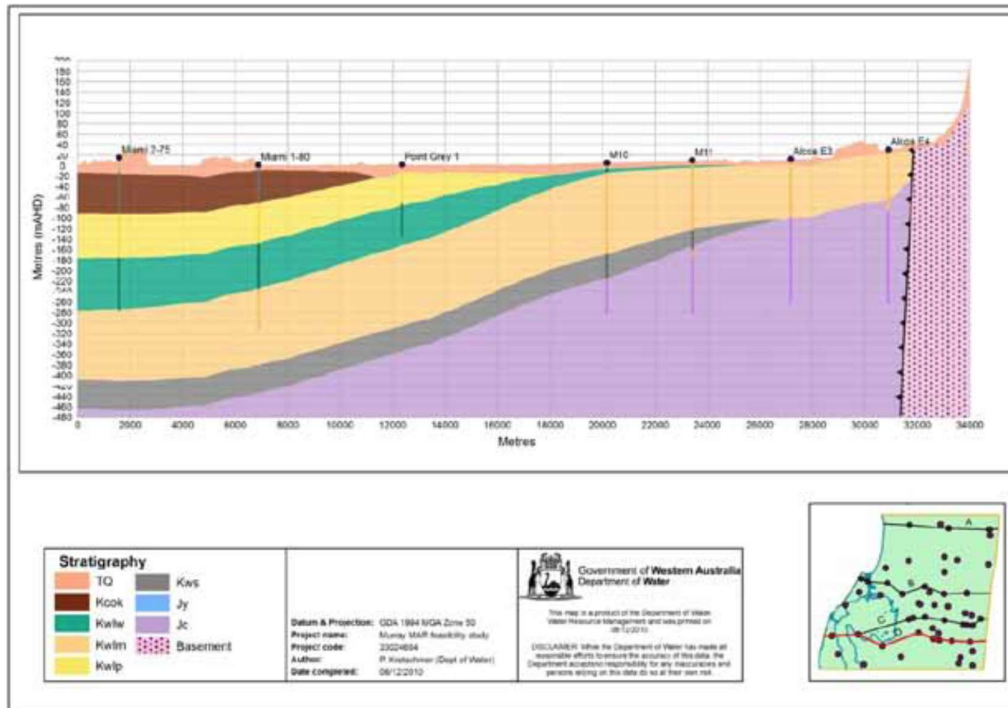


Figure 4-8 West to east cross-section in the southern Peel area (see inset) showing the Leederville Aquifer members; Pinjar in light yellow; Wanneroo in green and Mariginiup in dark yellow). Source: Kretschmer et al. (2011).

The northern and southern Leederville aquifers are separated by the Kings Park Formation, which corresponds to the ancient Swan River. A north-south cross-section between Gingin Brook in the north, through the Dalkeith Peninsula and as far south as East Rockingham shows this separation (Figure 4-9). This means that changes in pressure cannot be transmitted and water cannot easily flow between the members across this formation. As a result, both extraction and MAR on one side of the Kings Park Formation embayment will have less influence on the other.

MAR into confined aquifers is under consideration for the Cattamarra Coal Measures in the Nambeelup area (Kretschmer et al. 2011; Russell Martin pers. comm. 2018). It was also considered for stormwater from the Adroit Street and Merley Way drainage catchments to be injected into the Henley Sandstone member of the Osborne Formation or into the Leederville Aquifer in the City of Canning (GHD 2008; GHD 2010a; Petricevic 2010; Colin Leek pers. comm. 2017).

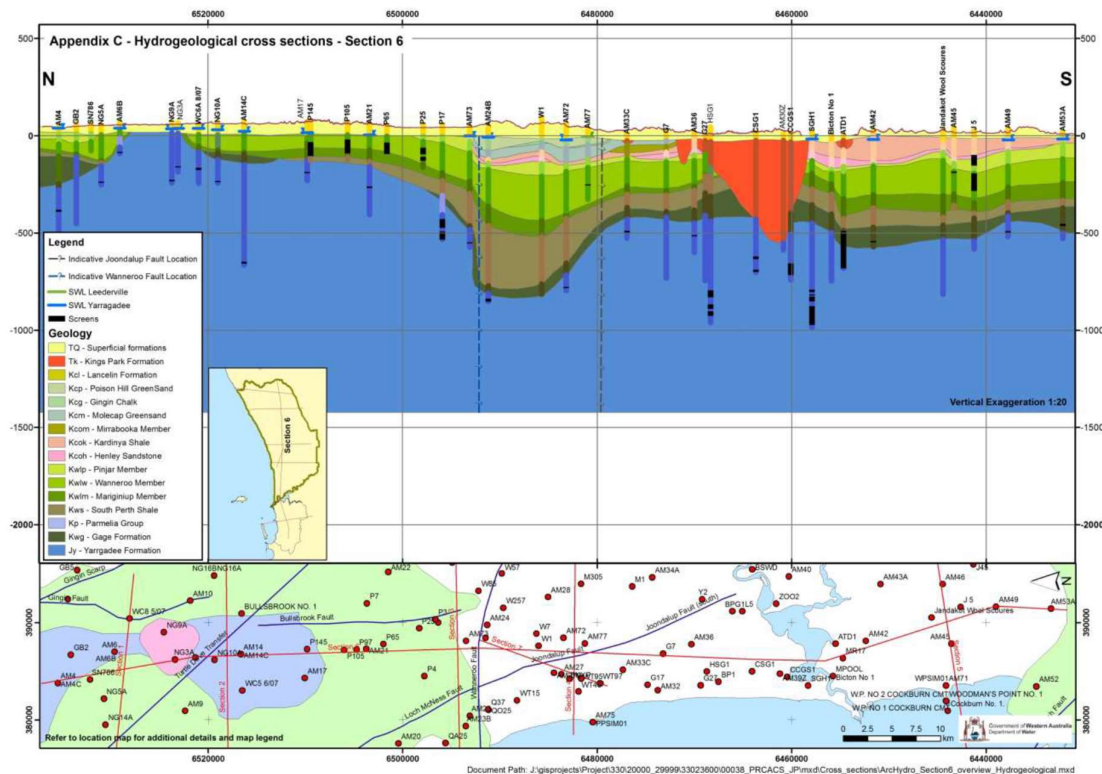


Figure 4-9. North to south cross-section across the Dalkeith Peninsula showing the Leederville Aquifer members (green) north of the river being separated by the Kings Park Formation (red) from that south of the river. Source: DWER (2017).

4.2 Changes in potentiometric head in the Leederville Aquifer

An assessment of the Leederville Aquifer's ability to accept MAR water by injection can be made by examining changes in potentiometric head. Between 1998 and 2007 the head in the aquifer declined by between 1 and 10 m over most of the Perth Peel area (Figure 4-10) with small increases near Gwelup and Swan Valley, presumably because of bores being switched off (i.e. there may have been recovery from a low level rather than a net rise).

In the next ten-year period (2008-2017), heads continued to decline in the north and to the south of Hamersley, but there were rises of several metres in the North West and Peel sub-regions (Figure 4-11).

Potentiometric heads between 1998 and 2017 have declined by more than 1 m (and often by 4 to 10 m) except in the Gwelup and Swan Valley areas (Figure 4-12), reflecting changes to extraction rates. There therefore appears scope for MAR in most parts of this aquifer. Groundwater Replenishment of the Leederville using highly-treated wastewater near Beenypup has raised groundwater pressures in nearby monitoring bores, but these changes were not detected in this regional assessment of pressures.

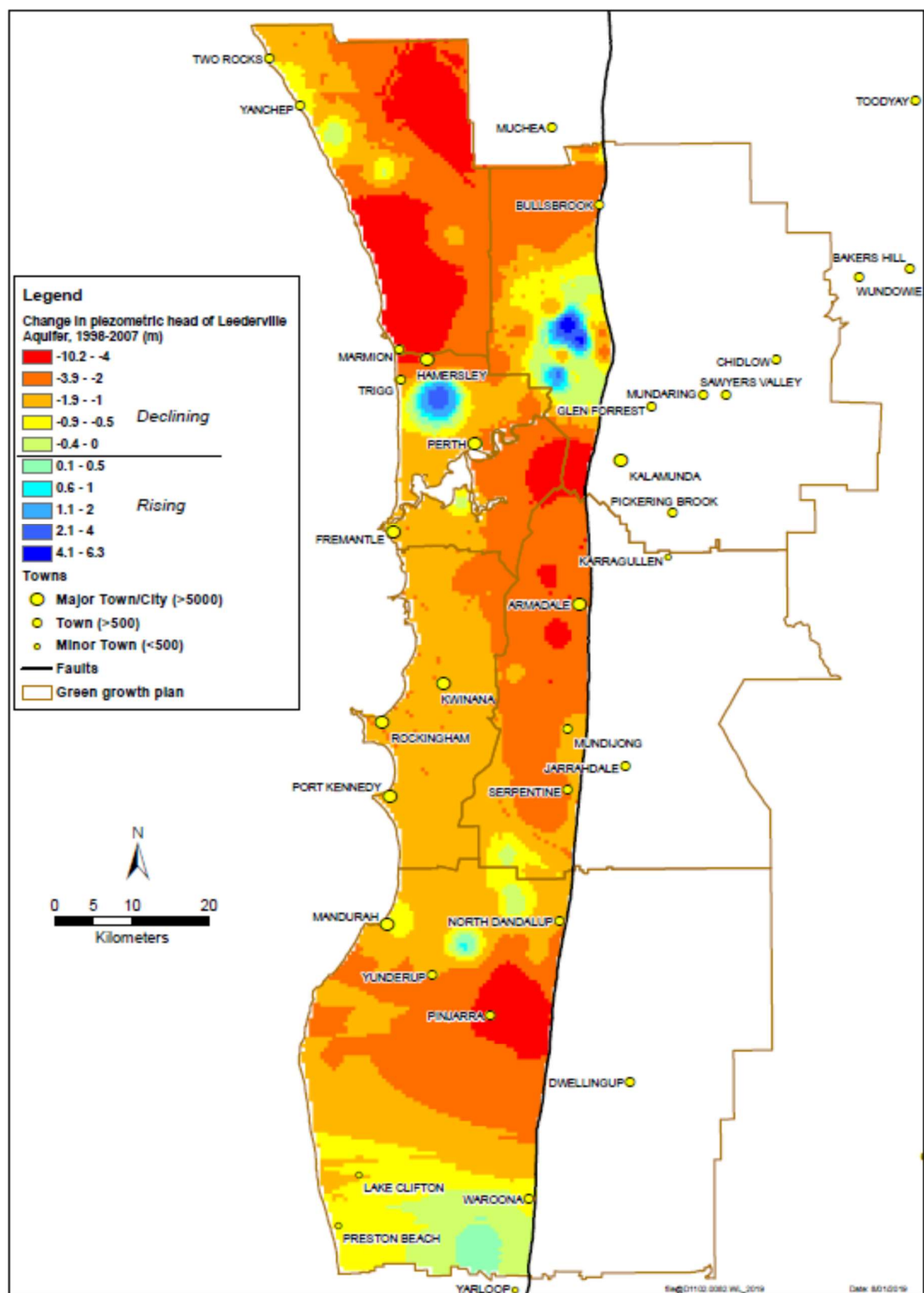


Figure 4-10. Changes in the potentiometric pressure in the Leederville Aquifer between 1998-2007

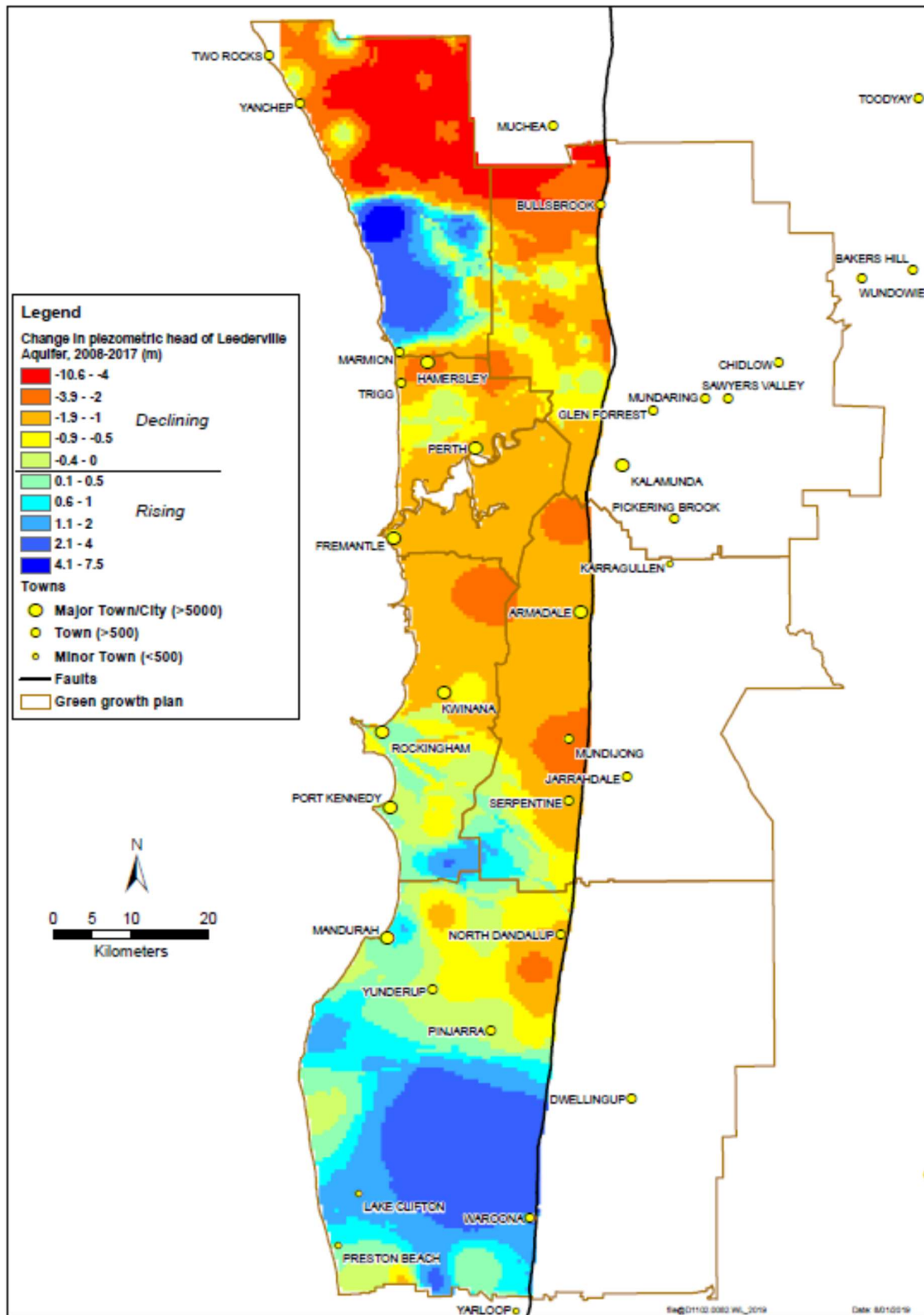


Figure 4-11 Changes in the potentiometric pressure in the Leederville Aquifer between 2008-2017

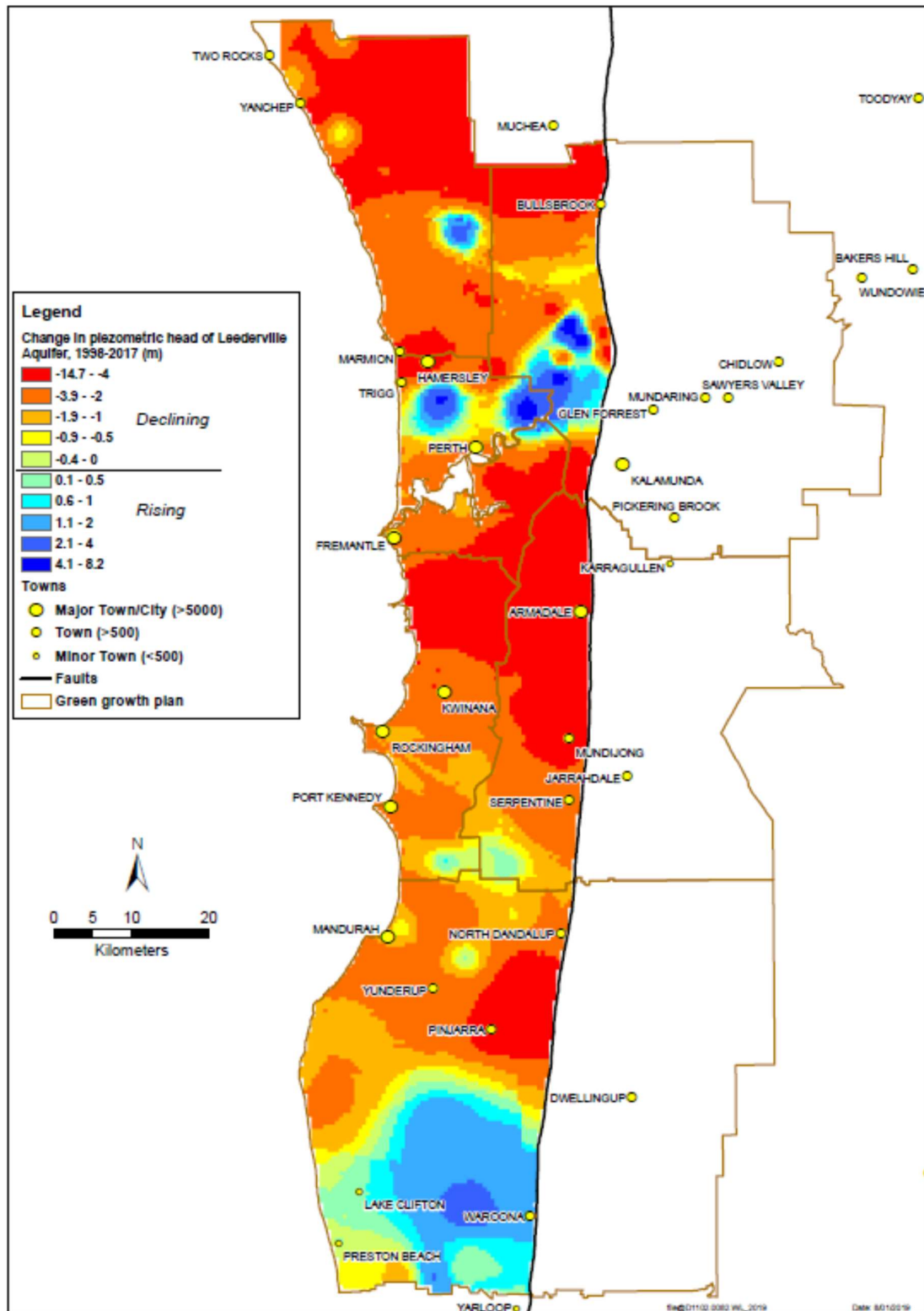


Figure 4-12. Changes in the potentiometric head in the Leederville Aquifer between 1998-2017

5. Suitability of Perth-Peel region groundwater aquifers for MAR in comparison with other cities in Australia and elsewhere

Many coastal cities are located on river deltas containing fine-textured alluvial sediments or over hard rock that weather to form clayey soils and regoliths (e.g. Melbourne). These are much less suited to MAR than are the medium-grained aeolian sand dunes in those parts of Perth and Peel that are underlain by the Swan Coastal Plain portion of the Perth sedimentary basin. The Superficial Aquifer is poor to absent where the clayey Guildford Formation is present in the upper Swan, Canning and Serpentine river catchments, making these areas more like other cities. The Leederville Aquifer is likewise absent where the often-clayey Kings Park Formation is abundant around the ancient Swan River.

Adelaide has the most intensively developed MAR schemes involving well injection of any Australian city, partly because of a history of water shortages and the presence of fractured rock, Quaternary and two Tertiary aquifers. None of these aquifers are as suited to MAR as are the Superficial and Leederville aquifers in Perth. The Adelaide aquifers almost always need injection using bores and high-quality water to avoid clogging. Until recently, natural direct recharge through Perth-Peel soils, and indirect recharge of stormwater and wastewater (where not connected to ocean outfalls), was able to keep groundwater levels in a range that did not inconvenience users and residents, who valued wetlands and groundwater-dependent ecosystems. There are also strong interests in such valuable aquifers not being contaminated by adding low-quality water. For these reasons, Perth has come relatively late to deliberate (rather than incidental) MAR compared with Adelaide.

Kretschmer (2017) identified 58 MAR schemes in the Adelaide Metropolitan Area, which have been built since 1989. They range in size from single well operations with a capacity of < 10 ML/year to schemes of up to 1000 ML/year. Hundreds of millions of dollars have been invested in 750 km of pipelines to transport non-potable water from MAR schemes and wastewater treatment plants to areas of demand. These areas include school ovals, public reserves, industry and private residential areas within the metropolitan area, and large horticultural and viticultural areas to the north and south of the city. The largest scheme is based in the northern Adelaide Plains and mainly uses water from the Bolivar Wastewater Treatment plant (WWTP). The experience of using both treated wastewater and stormwater for MAR in this area is relevant to those parts of Perth underlain by poor-quality aquifers or in areas with poor surface drainage or seasonally waterlogged (palusplain) features.

Until the Millennium Drought (1996 to 2010) most eastern states cities were considered to have relatively secure surface water supplies, so there was not much interest in groundwater, and therefore MAR. The drought, and the establishment of centres of excellence in water recycling (based in Brisbane) and desalination (based in Perth), revived interest in groundwater and its natural and enhanced recharge rates.

The centres accelerated the development of guidelines and the scientific and technical understanding and economics of reuse, including MAR in Western Australia (Bekele 2015a; McFarlane 2015). But most cities lacked suitable aquifers, expertise and a history of using groundwater and/or the time to develop alternative schemes before the Millennium Drought ended and normal water supplies were again more reliable and low cost.

The Werribee scheme in western Melbourne uses year-round treated wastewater for MAR and seasonal horticultural use in a peri-urban area. As well as producing 40 GL/year of treated wastewater for recycling, the plant uses a low-energy lagoon system that has become an important bird habitat (Melbourne Water 2018).

Other Australian cities with access to aquifers that may be suited to recharge include parts of Sydney and surrounding areas underlain by Botany Sand Beds or Hawkesbury Sandstone, and limestone near Geelong. However, these have never been major water resources or had a history of diversion of water to augment natural recharge.

6. Comparisons of managed aquifer recharge and direct piping for irrigating green spaces and peri-urban agriculture

In areas lacking an aquifer to store water (e.g. many inland towns, Margaret River) it has been the practice to treat, pump and store wastewater in tanks close to its point of use; and then to chlorinate it prior to irrigating sporting ovals, golf courses and areas of POS.

This method has been investigated for the Western Regional Organisation of Councils (WESROC) area, which comprises the western suburbs between Cambridge and Mosman Park (Mark Goodlet 2014). GHD (2016) have evaluated three MAR schemes for the same area. Advantages of direct piping when compared with MAR, are:

- There can be more control over water quality as the water is always contained within pipes and tanks. The system may therefore have the perception of having less risk. The risk that an aquifer may not reduce pathogens by 4 to 5 log reductions, as has been found in MAR experience (Russell Martin pers. comm. 19th April 2018), needs to be compared with the risk that chlorination may not be properly carried out by a direct pipe manager, or than users of a facility may not wait the required period after irrigation;
- There is no loss of water to the proponent, as may occur when water is added to an aquifer and an access licence is required to recover it¹;
- Land for infiltrating or injecting water to an aquifer is not required;
- Aquifer clogging issues are avoided;
- Nutrient levels in aquifers are not raised provided the irrigated plants use all the nutrients that are contained within wastewater; and
- Residents may not be comfortable with treated wastewater being added beneath their homes as may occur in MAR schemes.

The advantage of storing and distributing the water through a MAR scheme are:

- Water can be taken year-round and stored over winter for summer use. This is often an advantage to the non-potable water supplier as they do not need to start and stop systems used only over summer, and to a wastewater service provider in having to find alternative outlets for winter treated wastewater flows;
- Added water can raise the watertable and therefore benefit all groundwater users;
- If not all the added water is extracted, MAR can help recover throughflow wetlands and any groundwater dependent ecosystems (GDEs). Urban trees, especially in unirrigated areas, can access groundwater when the watertable is within about 15 m of the surface, so GDEs are wider than immediately around wetlands;

¹ In proclaimed areas, all water in an aquifer is the property of the Crown irrespective of how it got there

- If not all the added water is extracted, raising groundwater levels and increasing hydraulic gradients will push back salt-water wedges around the ocean and estuaries, and flush salts caused by evaporation cycling to the ocean²;
- Infiltration through the soil, and transmission through the aquifer, can improve water quality and reduce the need (and cost) of treatment and disinfection;
- The length of piping is greatly reduced because larger volumes of water can be added at fewer sites. These create a mound composed of both added water and groundwater, which dams behind the added water. Over time this mound can build and provide water to multiple demand areas;
- There is no need to advertise that treated wastewater is being used, or the need for irrigated areas not be used for a period after irrigation as may be the case when direct piped schemes are used;
- MAR water can be abstracted from the pressure head zone of influence, which is usually much larger than the recycled water solute transport infiltration zone. Hence abstraction water quality is often that of the natural groundwater rather than that of the recycled water;
- If the added water has a lower salinity it can improve groundwater quality for all users (e.g. Halls Head); and
- Any existing bore and reticulation systems can be used because the added water is in the aquifer, not in a tank.

WESROC (Figure 6-1) and the City of Mandurah (Dale Robinson, pers. comm 2018) are comparing both MAR and direct piping water supply options so there will soon be data for two urban locations. The often-hidden benefits of maintaining high groundwater levels (e.g. wetlands, GDEs, seawater intrusion, salt flushing) are hard to quantify and may be ignored in comparisons based on cost to local government to irrigate POS.

² Long term monitoring of groundwater quality by the City of Nedlands shows a slow build-up of salinity in aquifers now that gradients have declined

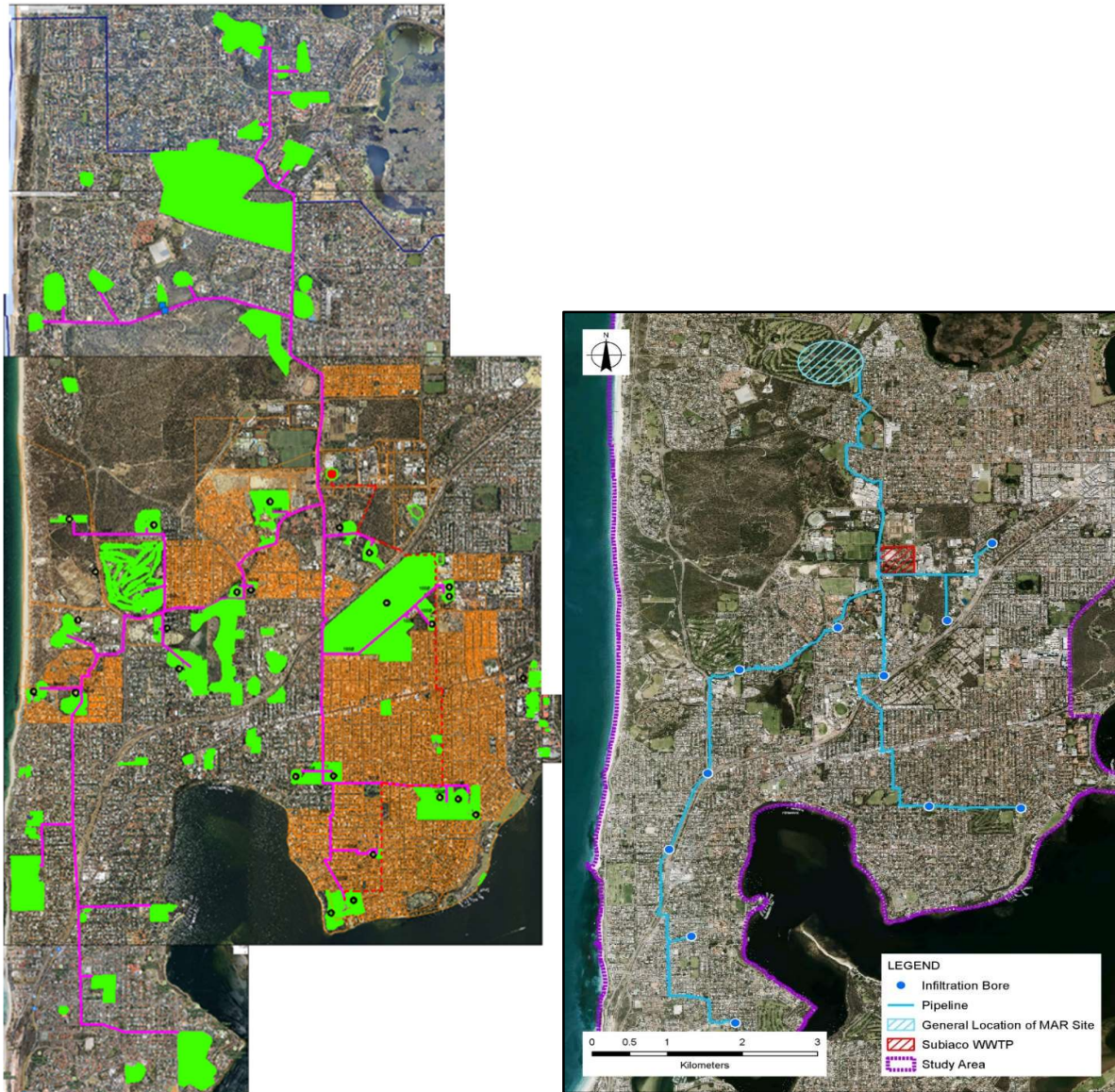


Figure 6-1. Two alternative methods of reticulating non-potable water from the Subiaco WWTP in WESROC. Left: through pipes to each local government area requiring water (Goodlet, 2014). Right: through pipes to infiltration basins, which add water to the Superficial Aquifer that stores, treats and distributes the water to the entire WESROC area (GHD 2016).

7. Third pipe systems as alternatives to managed aquifer recharge

7.1 Background and eastern states examples

Third pipe systems refer to piped non-potable water supplies in residential areas in addition to drinking water (first pipe) and sewerage (second pipe) services. The pipes containing the non-potable water are usually purple in colour to avoid cross-connections. They are therefore sometimes referred to as ‘purple pipe’ supplies. The sources of the non-potable water can be stormwater, treated wastewater, greywater, rainwater or groundwater from outside the area. There are similarities with the piped system for irrigating POS outlined in the previous section, except that in third pipe systems the water goes to residences for non-drinking use and sometimes to irrigate municipal POS as well.

To date, only groundwater has been tried in third pipe systems in Perth, mainly through community bore schemes. Examples include Brighton (North West sub-region), Evermore Heights in Baldivis and Port Coogee (South West sub-region), and White Gum Valley (Central sub-region). More details on these schemes are provided below.

Many households in the Perth-Peel region share a domestic garden bore across residential premises. A garden bore that is shared between neighbours is exempt from licensing if the total irrigated area of all properties that share the bore is smaller than 0.2 ha in total. Shared bore arrangements are common where the cost of drilling 20-30m through limestone is high for individual residences, or where small gardens do not require all the water that a bore can provide. Currently bore users can irrigate three days per week, which is an incentive for self-supply compared with scheme users, who are restricted to only two days per week.

Several third pipe system in eastern state cities have been established because of a shortage of drinking water (e.g. during the Millennium Drought), treated wastewater could not be discharged to rivers, and/or they lacked access to self-supply options as exist over much of Perth and Peel.

Australia’s biggest residential water recycling system is at Rouse Hill, 42 km northwest of the Sydney CBD. Up to 2 GL/year of tertiary-treated wastewater is provided to 32,000 properties each year for flushing toilets, watering gardens, washing cars and other outdoor uses. On average, customers in the recycled water area use up to 40% less drinking water than other customers in greater Sydney (Sydney Water Corporation 2017). Chen et al. (2013) reviewed recycling schemes in Sydney and described both in-house and irrigation uses for treated wastewater and greywater. As the water has a high-risk of exposure to customers and potential cross connection errors, advanced tertiary water treatment technologies (e.g., microfiltration, reverse osmosis [RO], chlorination and ultraviolet [UV] disinfection) are used. Cost was only one of many criteria applied by Chen et al. (2013) through a multi-criteria analysis framework. The Sydney Water Corporation is continuing to install recycling systems in new developments, which is an indication of their viability and acceptance in the relevant circumstances.

One of the largest third pipe schemes developed in Australia is at Pimpama Coomera in the northern Gold Coast, Queensland. Class A+ recycled water is supplied to dual reticulated homes and businesses through a separate water network. The water is used to flush toilets, water gardens and for other outside use. The water is the highest classification of recycled water for non-drinking purposes in Queensland, having undergone media and ultra-filtration, UV and chlorine disinfection. In mid-2017 there were over 9,000 homes and businesses in the region with around 6,700 of these homes connected to the recycled water system (City of Gold Coast 2018). However, in late 2013 it was decided that the high cost of the scheme outweighed the values to the City of Gold Coast and new developments did not have a dual reticulation scheme installed. The existing supplied area is transitioning to using drinking water to replace the recycled water. Excess treated wastewater from the city’s four WWTPs is now discharged to the ocean. The scheme was devised to reduce demand from drinking water sources and to improve water quality in receiving water bodies such as the Pimpama River and Southern Morton Bay (WateReuse Research Foundation 2013). This study concluded that the operating and administration costs in the scheme meant that only

very large water utilities have the resources to effectively manage a similar project. The study expected that there would need to be a 50-year period to optimise the system, but it began transitioning back to a conventional dual pipe scheme soon after this assessment was made.

City West Water in south-west Melbourne operates the West Wyndham recycled water project (previously the West Werribee Dual Water Supply project) based on the Western Wastewater Treatment Plants. The motivation for the project was the need to conserve drinking water, especially given the impact of the Millennium Drought on Melbourne's traditional surface water supplies (WaterReuse Research Foundation 2013). After UV/RO treatment, and salt reduction (so that it will suit most types of plants and the soil conditions) Class A recycled water is supplied to residential customers for toilet flushing, car washing, washing machines and outdoor use, and for municipal-scale irrigation. The project was subject to significant delays and major cost overruns (*The Age* 2015).

The risks associated with reuse schemes need to be well identified, placed in a wide context and monitored as they can change and affect scheme viability. The Institute for Sustainable Futures examined recycling decision through eight case studies, all in the eastern states (ISF 2013). They found that risks and uncertainty go well beyond the technical realm and need to be considered up front at the planning stage to avoid significant costs and impacts.

7.2 Experience of third pipe schemes in Western Australia

7.2.1 The Green in Brighton

As at 2018, the only third pipe schemes being operated by the Water Corporation are at Brighton and Denham. The latter uses saline artesian water from which iron and manganese is removed for toilet and ex-house use. The same water source is desalinated for in-house consumption and hygiene uses.

In 2008 five communal bores were installed into the Superficial Aquifer to supply irrigation water to residences and POS via a ring main within the Butler Estate in Brighton in the North West sub-region. The project was a partnership between the developer (Satterley Property Group or SPG), Water Corporation and the City of Wanneroo. Being in an urban area where private bores are expensive to install (due to the depth of the watertable and the presence of limestone), it allowed the Superficial Aquifer to be used for residential as well as local government use. The Tamala Limestone aquifer at Butler is free of iron and organic staining, making this an ideal location for a third pipe trial. Garden areas at Butler are also small making backyard bores uneconomic unless widely shared.

Just under 900 residential lots are serviced by the scheme, with small lots not being interested in connecting (John Todd, pers. comm. 7th February 2018). The ring main is only pressurised between 10 pm and 6 am, and until recently irrigation rates were controlled by a local weather station. The weather station was discontinued, because the program may decide irrigation was not necessary due to mild or wet conditions. However, if subsequent days were very hot, the system had to wait until the next scheduled watering day before gardens could be watered. This could result in plants not being watered for 4 to 5 days and therefore dying.

Residents only have the power to shut the system off, not to start irrigating. Theoretically, automation should make it more likely that water savings would be achieved. Residents were charged a fixed price for irrigation water based on lot size, irrespective of their use. This rate has been increased in line with other water charge increases.

Before the scheme commenced a survey of residents and proponents was conducted by Davis and Farrelly (2009). This showed that champions within SPG and the Water Corporation had to work hard to convince people within their organisations to proceed with the \$4-5m scheme. Regulatory gaps were identified and had to be addressed. Davis and Farrelly (2009) identified the Health Department as posing the greatest challenge amongst the regulators of the scheme. This is despite it using the same groundwater as used on over 177,000 residential properties extracting over 88 GL/year in Perth and Peel (DWER 2018c). While potentially the water could be used for toilet flushing and washing machine use, it is currently only used

for outdoor irrigation. Davis and Farrelly (2009) reported other developers installing third pipes in their developments because of the Brighton announcement, but not getting a water licence from the Department of Water because of aquifer over-allocation concerns. These are now stranded assets.

The predicted total water savings from the scheme were not met and, at a whole-of-estate level, water usage is significantly higher in The Green in comparison to surrounding areas (John Todd, pers. comm. 7 February 2018). The reasons for this are:

1. Because groundwater is used for irrigation, it is possible to water 3 days-a-week rather than 2 that is possible with scheme water;
2. The system is pressured on Saturday to allow residents to check their sprinklers. Some use this to do an extra watering;
3. The original irrigation system had hydrozones for high-, medium- and low-water requiring plants. Over time, high-water using plants were planted in low-water zones, which required all zones to be set at the higher level;
4. The settings for each irrigation stage were locked using a PIN that was common to all residents. Once known, it was possible for residents to reset their timing system;
5. Expensive high-efficiency sprinklers that required long watering times were progressively replaced by cheap, high water-using sprinklers, but the times were not adjusted;
6. Sub-soil irrigation systems did not satisfy residents' expectations of seeing wet leaves after watering, and were replaced by above-ground sprinklers; and
7. There were no meters or charging for irrigation water use (unlike for scheme water users in neighbouring areas), so there was little incentive to restrict watering.

To address some of these deficiencies meters have just been installed by SPG and a charging system (possibly 75% of scheme water) is being introduced. This requires two meters to be read, charged and reported to residents. Additional capability had to be included in the Water Corporation's billing system because of this scheme.

Drinking water consumption should have reduced by up to 40% in those residences, which now used non-potable water instead of scheme water for irrigation (this being the approximate proportion of water that is used outside, although the proportion is much less for apartment blocks with small gardens and verges).

Reductions in irrigation water use on POS by the City of Wanneroo have been in line with similar reductions achieved by the City in areas outside The Green.

In summary, The Green has been a great opportunity to learn about third pipe schemes using a water source that requires no additional treatment. There were economies of scale (about 900 residences; POS watering) and it is unlikely that the residents would have used a non-potable source had it not been provided (given the cost of installing bores and the small garden sizes in the development). However, there was no economic incentive for residents to reduce their outdoor water use and the third pipe scheme made it feasible to increase total water use compared with surrounding areas. It remains to be seen if introducing meters and charges will affect consumption. However, the lack of interest in installing similar schemes in later developments may indicate that third pipe systems are not feasible under these circumstances (i.e. suburbs with small gardens).

It is likely that the cost of supplying the non-potable water at Brighton exceeds the price of scheme water, which is \$1.782 for the first 150 kL, \$2.375 for 151-500 kL and \$4.442/kL thereafter (Water Corporation website 13/11/18).

7.2.2 Evermore Heights

At about the same time as the Brighton scheme, a third pipe scheme also using groundwater from the Superficial Aquifer was developed for a subdivision planned for 362 (later 466) lots in the Evermore

Heights estate in the Baldivis area (Water Corporation 2017). For commercial reasons the residential plot sizes were reduced from 400 to 250m², which greatly decreased the demand for outdoor irrigation water. Water savings were to come from applying water sensitive design principles that included a weather station-controlled third pipe scheme using locally-sourced groundwater for household garden and POS irrigation.

A Memorandum of Understanding was signed in 2008 by Satterley Property Group, LandCorp, the City of Rockingham, the Department of Health and Water Corporation to undertake a demonstration project to:

- i) assist the Department of Health form a view of third pipe schemes of this type;
- ii) determine the customer acceptance of a centrally-controlled irrigation scheme;
- iii) determine design standards for third pipe schemes that the Water Corporation could take over;
- iv) reduce total water demand to 90 kL/person/year; to 234 kL/household/year and irrigation water use to 92 kL/household/year. Stretch targets for these amounts were proposed to be 70 kL/person/year, 182 kL/household/year and 71 kL/household/year respectively;
- v) reduce POS water demands from 7500 to 5000 kL/ha/year (i.e. by 30%); and
- vi) determine if the provision of non-drinking water is commercially viable for a small scheme.

The scheme was decommissioned in 2016 with the third pipes in the 234 lots that had been developed now receiving just scheme water. The City of Rockingham has taken over the bores and water licence for its POS irrigation.

A “Close out and lessons learnt report” by Water Corporation (2016) contains detailed reasons for the scheme’s closure, some of which are summarised below. In relation to the six objectives listed above:

- i) A water quality risk management plan met the first objective;
- ii) There was limited customer understanding and acceptance of the scheme. More resources would have been required to achieve this objective;
- iii) A third-pipe design standard was developed so this objective was met;
- iv) Irrigated water use by residents was 208, not 92 kL/household/year. This was because of a softening in the requirement for water-wise landscaping for very dry conditions; residents replacing expensive high-efficiency sprinklers when they broke with cheap high water-using ones; the inability of residents to change their irrigation when not required; decommissioning of the weather control station after it failed to apply enough water in hot periods; and individual customer behaviour aimed at increasing irrigation rates. As at Brighton, groundwater can be used three days a week and was not metered nor charged. Issues of potential over-extraction from the supply bores arose during the trial, and there were concerns of salt water intrusion.
- v) Irrigation rates for POS did not differ from surrounding areas, so no savings were achieved. The full licensed amount of water was used, but the area planned for POS was reduced, so this target failed.
- vi) The scheme was not cost effective as supplying the non-potable water cost 97% of the scheme water equivalent, and more capital would be required if water meters were installed amongst other things. Duplication of the piped water supply system raised costs.

There was no clear education program about the trial at Evermore Heights, nor for new residents at Brighton (John Todd, pers. com. 7th February 2018). Some residents bought into the areas because of their sustainability credentials, but their requirements were often not a major factor when buying land. A lack of metering, understood and agreed targets, and a price signal meant that the scheme lacked

feedback that could have improved its chances of success. Decommissioning may have occurred three years earlier except alternative water service providers were investigated in the hope of finding an investor. The inability to find a commercial provider probably indicates a lack of profitability.

In summary, the learnings from Evermore Heights are like those from Brighton, although the development never reached the scale achieved at Brighton. The absence of third pipe schemes in major land developments since 2008 may indicate that they are not as cost-effective as scheme water supplies. Additional drivers such as the need to dispose of wastewater or to prevent pollution of the intercepted groundwater was not a benefit in either the Brighton or Evermore schemes.

7.2.3 Port Coogee

The Port Coogee development has a non-potable third pipe scheme to improve groundwater quality entering the marina and reduce demand for drinking water (City of Cockburn 2018). The water comes from a groundwater-intercepting drain located about 200 m upgradient of the marina, with the intercepted water pumped to a large underground storage tank beneath a park just south of the marina. The intercepted groundwater has elevated nutrient levels because of past market garden operations to the east. The groundwater is untreated and made available to residential property owners connected to the scheme (except between June and August). It is also used to irrigate POS and streetscapes. Any excess water is reinjected into the aquifer north of the development.

The driver of this scheme is the avoidance of algal blooms in the harbour, and therefore the economic viability of the non-potable water supply for irrigation is not relevant.

7.2.4 White Gum Valley residential development

A 2.3 ha redevelopment site at White Gum Valley is aiming to achieve a 60-70% reduction in scheme water consumption equating to 30 to 40 kL per person per year (CRC WSC 2017). Scheme water is saved by using a community bore for irrigating public and private gardens. The development also has lot-scale rainwater harvesting systems for toilets and washing machines. Units are fitted with dual plumbing to allow for the future connection to an alternative water source (e.g. rainwater), and space for installation of a rainwater tank with a minimum capacity of 3,000 L. The City of Fremantle will operate the irrigation system and become a water service provider for the non-potable scheme. Water use will be separately metered at each lot, but all residents will pay a fixed charge for the service. The total for all project-related bore infrastructure (POS irrigation and lot connections, including monitoring equipment) was \$235,000 (Josh Byrne pers. comm. 12th February 2018).

When completed the development will have 80 residential dwellings and 180 new residents through a range of housing options including apartments, maisonettes and 23 single residential home sites. All single residential homes have access to a rainwater tank offer – which is connected to toilets and washing machine cold water tap (Warren Phillip, pers. comm. 14th February 2018). A minimum 70 m² of roof catchment is required, but homes still require soak wells. Grey water guidance is provided.

A total of 5000 kL/year is supplied by the community bore scheme, with 2000 kL supplied to irrigate POS, and 3000 kL supplied to individual properties. The Fremantle City Council recover operational costs through a special area rate amounting to \$300/lot/year instead of directly charging residents for water use. Assuming 24 dwellings pay this rate (and not the 80 dwellings), this provides 125 kL/lot and raises \$7,200 per year, so the cost of providing non-potable water through the community bore scheme is about \$2.40 /kL. A volume of 125 kL/lot will allow 50 watering events of 2.5 kL per year.

Rainwater interception across the site is minor with most of it directed to on-lot soak wells. Road run-off is directed to distributed infiltration galleries (Josh Byrne pers. comm. 13th February 2018). Prior to development the site had a 15,000 kL/year water allocation, only a proportion of which may have been used. The White Gum Valley development is small and rainwater interception using rainwater tanks is unlikely to cause salt water intrusion. Groundwater levels in this area have declined by between 1 and 4

meters in the past 20 years (Figure 3-4), making salt water intrusion a potential risk given the proximity to the estuary.

This third pipe and community bore site is monitored, so data is being collected to see if the projected water savings are realised. The in-house system needs mains back up for when the tanks are dry. This case study will be important in assessing the cost-effectiveness of third pipe schemes at the small development scale.

7.3 Current status of third pipe schemes in Perth and Peel

All third pipe schemes to date have used untreated Superficial Aquifer groundwater, so using treated wastewater is still to be attempted. All have also only been used outdoors, with the opportunity for replacing toilet flushing and cold taps for clothes washing still to be realised³. Indoor use of third pipe water was proposed at Brighton, but not implemented. As such the schemes are replacing drinking water use with groundwater on gardens on a multi-residency basis. As outlined above, the replacement can result in increased total water use, which may have hidden consequences.

An unknown proportion of the 177,000 existing domestic bores are shared between neighbours. There is therefore a gradation between what has been happening on an informal basis for decades, and community bores and third pipe schemes in new developments where there is a third-party provider of this service (i.e. the City of Fremantle at White Gum Valley, Satterley Property Group at Evermore Heights (until it ended) and Water Corporation at Brighton).

The WA Government introduced a range of rebates for products to save drinking water in February 2003. By the end of 2005 about a quarter of a million rebates had been granted, allowing an analysis of their water-saving potential to be carried out. Table 7-1 shows the savings per rebate (not per \$). New and re-drilled bores saved the most drinking water, although in these cases it was substitution of non-potable for drinking water (Henstridge et al. 2006). Total water use may have increased as occurred at Brighton and Evermore Heights given domestic bores can be operated three times a week and the additional water is unmetered and cheap (i.e. the cost of electricity). This may not be a problem where the Superficial Aquifer is underutilised, or the water is being removed by a main drain (a 'use it or lose it' situation). However, where there are risks of saltwater intrusion or the additional draw is near groundwater-dependent ecosystems, then the rebates could cause environmental and social damage. All unconfined groundwater north of the Swan River is either fully allocated or over-allocated and south of the Swan River it is either fully allocated or approaching full allocation (Roy Stone pers. comm. 3 April 2018). Thus, additional use of Superficial Aquifer groundwater from new domestic bores or community bores needs to be approached with caution.

After bores, rainwater tanks and washing machines had the next highest water saving rates, although these were only a quarter to a sixth that of a new bore. The uptake of subsidies was washing machines (133,326), soil wetting agents (52,972), showerheads (16,062), bores (15,650), rainwater tanks (8,298), tap timers (2019), aerobic treatment units (51) and greywater systems (50). The water saving impact of greywater diversion systems could not be assessed as they were not popular, and/or their impact was small (Table 7-1).

The impact on drinking water demand of losing backyard bores in the Mosman Peninsula and Rockingham areas was simulated in a case study (McFarlane et al. 2006). This showed that about 14,000 houses could need an increase in scheme water supply by an extra 2.1 GL/year and possibly rising to 5.4 GL/year after the five-year period. The substitution of scheme water with groundwater therefore needs to be carried out with a full understanding of the benefits, costs and risks.

If third pipe schemes were financially viable in Perth and Peel, it is likely that commercial service providers would have been interested in running the Evermore Heights scheme after all establishment costs had already been met. Currently the service providers are local government (Fremantle, Cockburn) and a

³ The roof runoff water at White Gum Valley is used within each unit, not shared between units

government trading enterprise (Water Corporation along with a property developer). Providers can accept losses if there are additional benefits such as decreased drinking water use, the interception of polluting groundwater or reduced costs of discharging the non-potable water. Users of third pipe schemes may be prepared to pay higher prices for non-potable water supplies if they are able to capture additional benefits, or an operating subsidy is agreed with the state or local government because of environmental and/or community benefits.

Table 7-1 Effect of Water-wise rebates on scheme-supplied domestic water consumption (Henstridge et al. 2006)

Rebate Item	Effect (kL/year)	95% Confidence Limits (kL/year)	Statistically Significant?
Bore	115.9 saving	114.4 to 117.4 saving	yes
Bore redrill	79.4 saving	73.3 to 85.4 saving	yes
Rainwater tank – plumbed*	31.5 saving	7.0 to 56.1 saving	yes
Washing machine (AAAAA)	22.9 saving	14.1 to 31.7 saving	yes
Rainwater tank	20.1 saving	17.4 to 22.9 saving	yes
Washing machine (AAAA)	11.5 saving	10.7 to 12.3 saving	yes
Showerhead	8.1 saving	6.7 to 9.4 saving	yes
Washing machine (unable to be classified)	7.7 saving	1.3 to 14.1 saving	yes
Tap timer	11.3 increase	3.2 to 19.5 increase	yes
Aerobic treatment unit	7.0 increase	63.8 saving to 77.8 increase	no
Greywater re-use system	3.3 increase	40.4 saving to 46.9 increase	no
Soil wetting agents	0.3 increase	1.0 saving to 1.6 increase	no

* Only 62 rebates so the figure should be used with caution (Henstridge et al. 2006)

7.4 Success factors for third pipe schemes

From liaison with DWER and Water Corporation experts, and a review of the literature, the success factors for third pipe schemes that relate to Perth and Peel appear to be:

- Clearly-defined objectives of the scheme (e.g. reducing drinking or total water use, improved water use efficiency, reduced pollutant discharge to the environment, lower costs) and how they are going to be monitored, assessed and reported on;
- Source water identified early, to ensure the overall sub-regional, district or local water balances are not adversely affected;
- The ability of the proponent to capture enough of the benefits to make the scheme feasible (e.g. free riders are identified and made to contribute where possible);
- An evaluation of alternatives to confirm that third pipe is the best available option. In Perth and Peel this requires a good understanding of self-supplied groundwater options, because this is the main source of non-potable water in most areas;
- The early identification and involvement of the scheme's long-term operator in the design;

- Engagement with local government and the community to build customer and community support, based on transparent information on the costs, benefits and risks; and an understanding of how these will be shared;
- Establishing long-term agreements with relevant stakeholders. These should reduce uncertainty regarding future roles and responsibilities. The abrupt termination of the Rouse Hill and Evermore Heights schemes may have violated this criterion given some consumers were caught unawares;
- Realistic and reliable estimates of the future demand for non-potable water over time. Thresholds for ongoing viability should be established;
- Economies of scale to help ensure that the project is commercially viable. The Water Corporation's minimum criteria are 25,000 residential connections in the Perth and Peel region and 49 kL/day for non-residential customers;
- Measures to ensure year-round supply reliability. Evermore Heights had uncertainty over its long-term licensed access to the Superficial Aquifer and risks of saltwater intrusion. Water sensitive urban design could help meet this criterion;
- Full understanding and early identification of the risks of the scheme, and implementation of risk assessment and mitigation measures;
- Clear identification of costs and who will bear them in the short and long term. If there are subsidies, these need to be clear to both the recipient and those who provide them (e.g. other customers, ratepayers, taxpayers). If there are external regulatory drivers (e.g. the need to avoid disposal of wastewater to a river) then these, and any subsidies need to be transparent;
- Presence of a strong willingness to pay by customers and other beneficiaries where they can be identified and quantified;
- Flexible approach and timelines. Sufficient time is needed to meet regulatory requirements, especially as there is limited experience in regulating third pipe schemes in Perth and Peel;
- Transparency about price, risks and compensation in the event of scheme failure, and of householder responsibilities must be provided to existing and potential customers;
- Evidence of adequate regulatory frameworks. Regulatory requirements need to achieve a balance between compliance costs to the service provider and customers, and protecting customers, the public and environment;
- Accessible advice from industry experts and key government agencies on expected timeframes, risk factors and estimated costs and benefits;
- The costs and benefits of monitoring (including metering) should be considered in the project design; and
- Operating subsidies should be claimed for non-potable water supply projects, which reduce the costs of water supply in communities that receive subsidised water supplies. This may extend to reduced wastewater disposal costs such as treatment (for sewer mining) and ocean or land disposal.

From reviewing the case studies in the previous section, third pipe schemes are likely to struggle to be viable in many parts of Perth and Peel. This is because householders can install unlicensed backyard bores where there is a need, aquifers are already highly allocated (if this is the third pipe water source) and users are not experienced with third pipe schemes that require management of two water supply systems, and less flexibility over their garden watering. Any cost savings are also likely to be small. All schemes that have been trialled are in new developments with involvement being a condition of purchase.

Third pipe systems may have a role where the Superficial and Leederville aquifers are absent or unable to be used (i.e. Guildford Clay areas where the Mullaloo Sandstone and Leederville aquifers are also absent, hills suburbs, possibly the palusplain areas in the South East and North East sub-regions) and the system is able to deliver water cheaper than drinking water. Having non-potable water more expensive than drinking water makes it unviable for commercial service providers unless other benefits can be included in fixed and/or consumptive rates or they are subsidised.

Third pipe systems may have a role if domestic bores are expensive for residents to install meaning that without the scheme only drinking water will be available for outdoor use. This is the case at Brighton, because the watertable is deep and under hard limestone. The introduction of meters and charging in this scheme may help achieve future water savings. The monitoring of the White Gum Valley and other LandCorp developments will also provide valuable data on customer behaviour and acceptance.

New suburbs with roofs occupying a large proportion of each block, and roads a higher percentage than suburbs with large blocks, almost certainly produce more recharge than they discharge (McFarlane and Caccetta 2017). They are also likely to be urban heat islands, because roofs and roads capture heat and there is a paucity of trees and transpiring gardens to reduce local temperatures. Water reuse schemes that help cool high-density developments may be justified if they reduce indoor cooling costs even if they cannot be justified economically from a water-saving perspective. More work would need to be done on multiple benefits.

8. Discussion

The suitability of MAR, third pipe and direct pipe systems in the Perth and Peel region is discussed below for each of the sub-regions shown in Figure 2-1.

8.1 North West sub-region

This sub-region has some aspects that make it very prospective for MAR; a Superficial Aquifer that is deep under limestone ridges, which have a high transmissivity and are able to accept and treat added water, particularly via the Tamala Limestone (Figure 3-7). Water levels have declined in a zone through the centre and in the north east on the flanks of the Gngangara Mound (Figure 3-4), indicating that MAR may assist the recovery of these levels, which may have supported groundwater-dependent ecosystems and private groundwater users.

The yellow Spearwood Dune sands have been the subject of several MAR investigations and are able to accept very high rates of infiltration through open infiltration basins at wastewater treatment plants (WWTPs) in the sub-region and further south in the Central, South West and Peel sub-regions. Infiltration galleries have also been successfully evaluated at the CSIRO Floreat Laboratories in the Central sub-region.

There may be concerns about cavernous flow in the Tamala Limestone aquifer in the Yanchep Caves area, but there is evidence from multiple assessments further south that water will contact and be treated after infiltration (Smith et al. 2012).

The sub-region contains the largest third pipe scheme in Western Australia at Brighton, where high quality groundwater is supplied to almost 900 residences. To date this scheme has not met most of its water saving or cost saving objectives but will continue with the adoption of meters and charging to see if total water use can be reduced and the system made cost-effective.

A direct pipe delivery system for non-potable self-supply water is probably not warranted in this sub-region given the abundant water supply from the Superficial Aquifer and the potential for MAR.

The sub-region also has a relatively shallow Leederville Aquifer that is successfully used for Groundwater Replenishment at Beenyup with an extension being developed further north. The sub-region has therefore trialled injection processes into a confined aquifer, which have wider applications in Perth and Peel. Leederville groundwater pressures in the sub-region declined between 1998 and 2007 (Figure 4-10),

but have partially recovered in the last decade (Figure 4-11). However, in 2017 pressures were mainly lower than they were in 1998 (Figure 4-12). Given this aquifer is being used for Groundwater Replenishment for drinking water use, it is less likely to be used for non-potable water MAR.

This sub-region has no main drain or sub-surface drainage water to be diverted (Figure 8-1). There may be potential to divert the remaining local road drains into the Superficial Aquifer to reduce the risk of saltwater intrusion, but the volumes, and therefore impacts, are likely to be very small.

In 2017 there were three active WWTPs in the sub-region (Table 8-1). Inflows will increase by 50% in the next 43 years if water efficiency targets are met, and by about 57% if current water efficiencies continue. Two Rocks WWTP will be decommissioned in 2020, and Yanchep WWTP was decommissioned in 2016. Flows from both these plants will then all go to the Alkimos WWTP. All Groundwater Replenishment for drinking water supply is being carried out in this sub-region, with a Beenyup Phase 2 capacity of 28 GL/year expected in 2019 (Water Corporation 2018), but no additional expansion is expected in the next 10 years.

Compared with the Peel sub-region, where several small coastal WWTPs remain close to demand centres, the consolidation of water treatment into the Alkimos and Beenyup plants makes it more difficult to do MAR to provide irrigation water to local government and to reduce seawater intrusion in coastal areas. A proposal to use water from the Beenyup and Alkimos WWTPs for irrigation in the Carabooda area was investigated in the Gngangara Sustainability Strategy but found to be unviable (Science Matters 2008). DWER is further investigating the use of treated wastewater from the Alkimos WWTP for use in the North Wanneroo area.

If groundwater allocation limits are further reduced in the forthcoming Gngangara Groundwater Management Area plan, there may be competition for treated wastewater between Water Corporation, local government and irrigators because it is the only underutilised resource in the North West sub-region. Therefore, the availability and cost of treated wastewater, and sectorial water demands, not the capacity of the Superficial or Leederville aquifers to accept and treat wastewater, are the factors that will determine MAR in this sub-region.

Table 8-1 Estimated wastewater flows in WWTPs in the North West sub-region

Wastewater Treatment Plant	Flows in 2017 (ML/day)	Flows in 2017 (GL/year)	Estimated flows in 2040 (ML/day)*	Estimated flows in 2040 (GL/year)*	Estimated flows in 2060 (ML/day)*	Estimated flows in 2060 (GL/year)*
Beenyup	127.9	46.7	145.9	53.3	131.6	48.0
Alkimos	11.7	4.3	40.0	14.6	78.6	28.7
Two Rocks	0.09	0.03	0	0	0	0
Total	139.7	51.0	185.9	67.9	210.2	76.7

* Assuming 115kL/person efficiency from 2030

8.2 Central sub-region

As in the North West sub-region, the Superficial Aquifer is prospective for MAR in the western and central parts of the Central sub-region under limestone ridges and in areas requiring the watertable to be raised around wetlands. Areas of clay near the rivers, and shallow watertables south of the Canning River (Figure 3-7) are not suited for MAR into this aquifer.

In the past 20 years groundwater levels in the Superficial Aquifer have declined east of Fremantle, in the upper Canning and in the north of the sub-region (Figure 3-6). Levels in the western suburbs, CBD and South Perth peninsula appear to be stabilising. Some throughflow wetlands have dried in recent decades (Lake Claremont, Perry Lakes, Lake Jualbup) and modest additions of MAR water could raise levels, especially given that levels are no longer falling rapidly.

The Kings Park Formation covers almost the entire sub-region making the Leederville Aquifer unavailable, although the Mullaloo Sandstone member of the Kings Park Formation occurs in parts of the sub-region (Figure 2-1). The Formation is thick and clayey, so there is a low likelihood that much Superficial Aquifer water is draining to lower aquifers.

This region has had investigations of treated wastewater proposals for a piped scheme (Goodlet 2014) and a distributed MAR scheme (GHD 2016). An assessment of their relative cost-effectiveness by DWER and WESROC has resulted in less interest in direct piping (Roy Stone, pers. comm 1 April 2018). Treated wastewater MAR has been proposed for the recovery of Perry Lakes (McFarlane et al. 2009), but there is now interest in direct-piping of Herdsman Main Drain water to the wetlands (Town of Cambridge 2018).

There is one WWTP in the sub-region; Subiaco. In 2017 it had an inflow of 59.9 ML/day (21.9 GL/year) of wastewater, which is expected to grow by 26% to 75.4 ML/day (27.5 GL/year) by 2040 and by 52% to 91.1 ML/day (33.3 GL/year) in 2060, if water use efficiencies of 115 kL/person/year are achieved from 2030 (McFarlane 2018b). If these efficiencies are not achieved the growth in wastewater available to be reused can be increased by a further 4 to 5%.

As for the North West sub-region, some of this treated wastewater could be used for drinking water supply via Groundwater Replenishment. However, the sub-region has much poorer confined aquifers compared to other sub-regions, in that they are either absent (the Leederville is replaced by the King Park Formation), deep, brackish or saline (Yarragadee Aquifer). They also have a high temperature, which may require them to be cooled before being added to the Integrated Water Supply Scheme. Water Corporation takes water only from the Yarragadee Formation in this sub-region, so Groundwater Replenishment would require new wellfields. For these reasons, both treated wastewater and main drains appear likely to be available for non-potable use in this sub-region.

The Central sub-region contains most of the main drains in the Perth and Peel Region (Figure 8-1, McFarlane 2018b), including three that discharge to the Indian Ocean (Carine, Floreat and Subiaco) and a number that discharge to the Swan-Canning Estuary (e.g. Mounts Bay Road, Claisebrook, Bennett Brook). The Herdsman to Floreat main drain has been considered for diversion into the Wembley Golf Course (GHD 2010b; 2011) and Perry Lakes (Rockwater 2017, Town of Cambridge 2018). The Subiaco Main Drain has a branch drain into Perry Lakes that could also be diverted. A similar diversion of drainage water from the Osborne Park Main Drain that helped maintain Jackadder Lake in Woodlands. Although successful in improving lake levels, the diversion volume was reduced because nutrients created algal and midge problems (ENV Australia Pty Ltd 2008).

Diversions of main drains could improve the quality of the estuary and beaches, given they contribute pollutants from industrial areas and low-lying areas that are drying and releasing stored nutrients and, in some cases, heavy metals after acidification (McFarlane 2018b). However, open drains maintain important environmental and cultural values, especially where they are integrated into natural drainages as is common in the upper Swan and Canning river catchments. It may be feasible to divert some water through the Superficial Aquifer to improve water quality and raise groundwater levels and maintain groundwater-dependent ecosystems at the same time. Examples include Bayswater, Mt Lawley, South Belmont, Bannister Creek, Mill Street and the North and South Airport main drains.

MAR of stormwater into the Leederville Aquifer has also been investigated by the City of Canning, because the Superficial Aquifer is clayey around the Canning River (Petricevic 2010). The experience of injections at Beenyup, Hartman Park and Nambeelup may help determine what may be done in this local government area.

The high value of land in this sub-region makes drain diversion more expensive than in other sub-regions. However, the value of water for irrigation and the need to reduce the urban heat island effect by up to 10°C (Peter Caccetta pers. comm 2018) may make diversions both economically and socially attractive.

Local drains that discharge to the ocean and estuary are progressively being diverted into the aquifer (e.g. JDA 2017), which should help reduce saltwater intrusion problems affecting bores used to irrigate POS around the river and beaches. Urban infill will increase these drain volumes.

There are therefore many options for using treated wastewater and main drains for MAR in the Central sub-region.

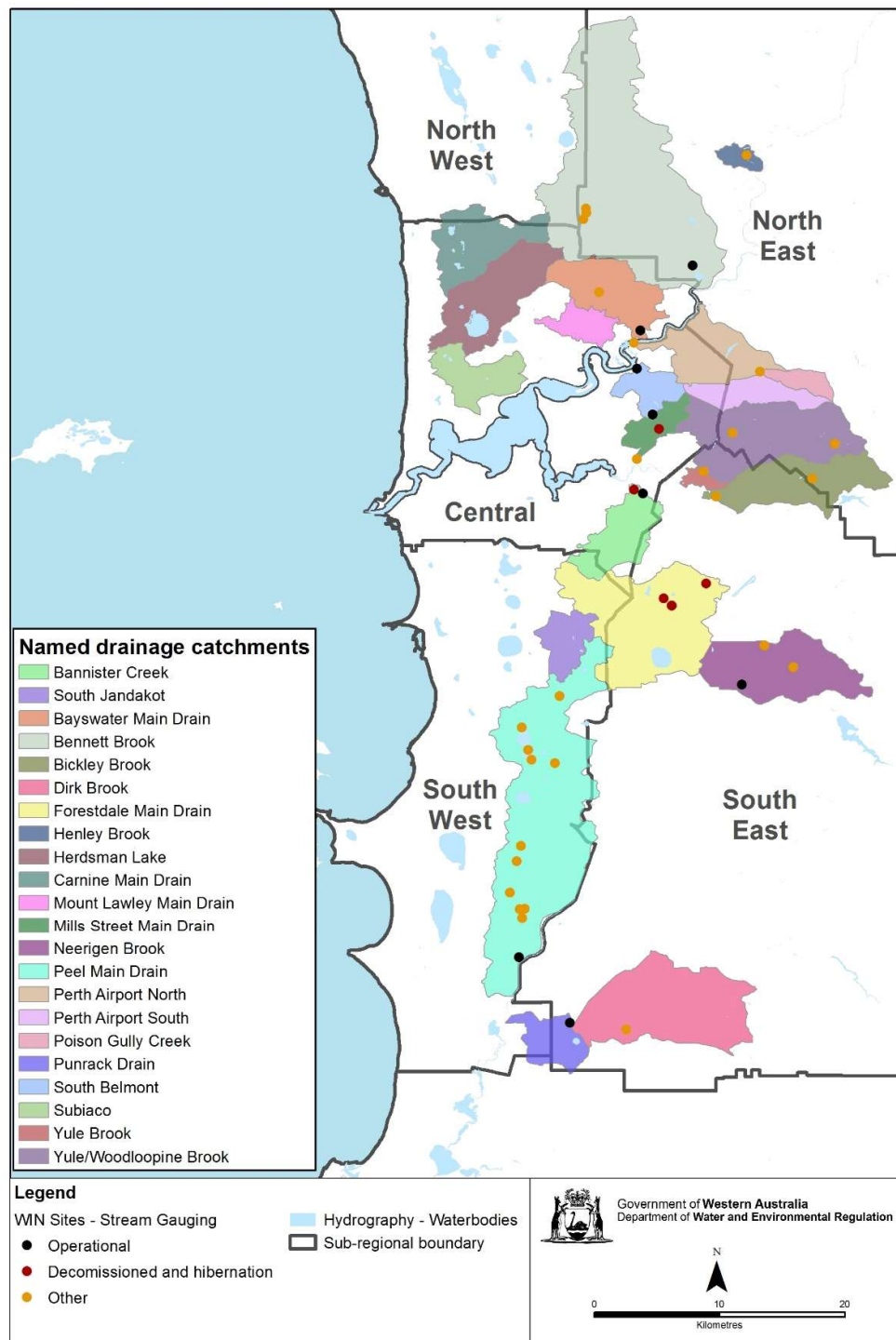


Figure 8-1. Main drain catchments referred to in the text

8.3 North East sub-Region

The Superficial Aquifer in this sub-region is almost completely contained within the Bassendean Dunes. A shallow watertable near Ellenbrook results in a lower ability to accept large volumes of MAR water, but the eastern flank of the Gngangara Mound does have available freeboard (Figure 3-7). Groundwater levels have declined in the Superficial Aquifer by 2 to 4 m in the north-east and central east of the sub-region (Figure 3-6), with the rate of decline continuing in the central east (Figure 3-4 and Figure 3-5). There may therefore be both a capacity and a need to add water to restore previous levels.

There are reductions in pressure in the Leederville Aquifer of more than 2 m over large parts of the sub-region except in the southern Swan Valley, where reductions in extraction have resulted in partial recovery (Figure 4-10). The Wanneroo member is relatively close to the surface in parts of the sub-region (Figure 4-3 and Figure 4-4) and may be suited to MAR.

There is a growing demand for non-potable water for irrigation of crops, POS, golf courses and private households in the sub-region. The only WWTPs in the sub-region are Bullsbrook and Mundaring and their flows are shown in Table 8-2. Treated wastewater at Bullsbrook (to service a population of up to 2000) is currently disposed of by evaporation and infiltration via a constructed woodlot/wetland area on site. It is due to close in 2019 with wastewater flows to be diverted to the Beenyup WWTP. The Mundaring WWTP is not expected to have much growth. The Mundaring plant was upgraded in 2016 to allow increased water reuse on local community sports ovals and a nearby equestrian centre during summer.

The low availability of treated wastewater does not reflect a lack of urban growth, but rather the diversion of sewage flows to coastal treatment plants for ocean disposal and for Groundwater Replenishment. Currently sewage from the Swan Valley and Ellenbrook is pumped south, west and then north around the Gngangara P1 water quality protection area to the Beenyup and Alkimos WWTPs. The possibility of local treatment and reuse of wastewater in the North East Corridor is being investigated (Synergies Economic Consulting 2018).

Table 8-2. Estimated wastewater flows in WWTPs in the North East Sub-region

Wastewater Treatment Plant	Flows in 2017 (ML/day)	Flows in 2017 (GL/year)	Estimated flows in 2040 (ML/day)*	Estimated flows in 2040 (GL/year)*	Estimated flows in 2060 (ML/day)*	Estimated flows in 2060 (GL/year)*
Bullsbrook	0.35	0.13	0	0	0	0
Mundaring	0.13	0.05	0.14	0.05	0.14	0.05
Total	0.48	0.18	0.14	0.05	0.14	0.05

* Assuming 115kL/person efficiency from 2030)

There are several main drains and streams that arise in the sub-region discharging mainly to the Ellen Brook and the Swan River. These include Bennett Brook, Henley Brook, Poison Gully, Airport North and South, Woodlupine and Bannister Creek (Figure 8-1). Estimates of their volumes are included in McFarlane 2018b. In general, falling groundwater levels in the Darling Range and on the eastern flanks of the Gngangara Mound are resulting in reduced base flows and therefore drain yields.

New developments in areas with high watertables in the North East sub-region increasingly contain sub-surface drains. Collecting and storing this water in winter and spring, for use mainly in summer and autumn may be a challenge because they are generated in areas with high watertables and include groundwater that is perched on clayey subsoils. The volume of subsoil drainage water in the North East sub-region may be about 2 GL/year if the drains remove 40% of annual rainfall (RPS 2017). However, harvesting this water will require on-site storage basins to capture stormwater peaks and probably MAR to store winter flows for summer green space and horticulture use.

In summary, the North East Sub-region has an increasing demand for non-potable water and the capacity in parts of the Superficial and Leederville aquifers to accommodate MAR water. The lack of access to treated wastewater requires that consideration be given to decentralised, local sourcing and treatment. As wastewater will be available year-round, but demand is seasonal, MAR offers an option for storage of this water. There also appears to be scope for diversion of main drain and possibly some natural drainage water into the aquifer when environmental flows are not impacted. MAR may also help divert nutrient flows from the Swan-Canning Estuary. Investigations are underway in this sub-region into options to supply the unmet demand for non-potable water.

8.4 South West sub-region

Groundwater levels in the Superficial Aquifer in this sub-region have changed less in the past 20 years than in any of the other sub-regions (Figure 3-6). This partly reflects the high transmissivity of the aquifer and the development of new urban areas around Coogee and nearby areas. Where there is a saltwater wedge, any reduction in fresh water thickness may be replaced by saltwater intrusion as shown in Figure 3-7c. The Cockburn Sound catchment is experiencing a growing gap between groundwater demand and supply (French et al. 2015). As a result, there is active interest in MAR using treated wastewater from the Woodman Point and East Rockingham WWTPs, mainly for industrial use (McFarlane 2015).

Between 1998 and 2017 groundwater pressures in the Leederville Aquifer have declined by more than 2 m in most of the sub-region (Figure 4-12). This impact on pressures may be due to drawdown in the east where the aquifer is closer to the surface, less confined (Figure 4-5) and more heavily used because of its low salinity (Figure 4-2).

This sub-region has large volumes of treated wastewater for centralised treatment at Woodman Point WWTP, because its sewerage catchment includes established urban areas in the South East sub-region as well as rapidly-growing new suburbs (Table 8-3). All treated wastewater, except 4.7 ML/day from the Kwinana WWTP, is disposed of through the Sepia Depression Ocean Outfall Line (SDOOL). The addition of 1.7 GL/year to the Superficial Aquifer at Kwinana has had a beneficial effect on groundwater levels as described by Bekele et al. (2015b). In addition to providing water for heavy industry, the mound under the disposal sites has benefited The Spectacles wetlands. Modelling of MAR options has shown that groundwater levels in the Superficial Aquifer could be increased by several metres over most of the Cockburn Sound catchment with a small fraction of the treated wastewater that currently goes into the ocean off Point Peron (Donn et al. 2015). The high quality of treated wastewater from the oxidation-ditch plants at Kwinana and East Rockingham WWTPs may make it possible to undertake MAR without further treatment.

Table 8-3 Estimated wastewater flows in WWTPs in the South West sub-region

Wastewater Treatment Plant	Flows in 2017 (ML/day)	Flows in 2017 (GL/year)	Estimated flows in 2040 (ML/day)*	Estimated flows in 2040 (GL/year)*	Estimated flows in 2060 (ML/day)*	Estimated flows in 2060 (GL/year)*
Woodman Point	143.6	52.4	191.3	69.8	250.5	91.4
Kwinana	5.5	2.0	9.6	3.5	10.5	3.8
East Rockingham	2.7	1.0	34.9	12.8	48.8	17.8
Point Peron	18.0	6.6	9.7	3.5	12.3	4.5
Total	169.8	62.0	245.5	89.6	322.1	117.5

* Assuming 115kL/person efficiency from 2030)

The region also contains the Jandakot South and Peel main drains (DoW 2009), as well as parts of Forrestdale and Punrak drains (Figure 8-1). Flow trends are varied, with urbanising areas experiencing modest increases in flows, but non-urbanised areas experiencing quite rapid declines (McFarlane 2018b). Diversion could help improve water quality in the Peel Inlet and it is likely that options will be investigated. Urbanisation rapidly increases the economic value of lakes (Tapsuwan et al. 2009), which may become a

driver for main drain diversion, and possibly contribute to MAR using treated wastewater in the Cockburn Sound catchment. There may also be opportunities to use the piped main drain system to transfer treated wastewater further inland where it is more needed. For example, a main drain from the Beeliar lake chain crosses near the Ramsar-listed Thomson Lake, Lake Coogee and the Woodman Point WWTP. Currently there are no interconnections between wastewater and main drainage networks, but the possibility may be worth exploring, especially as laying pipes in urban areas can be very expensive.

This sub-region therefore has abundant water for MAR, permeable soils and suitable aquifers for recharge. The main driver will be demand and possibly more restricted access of water users to the Superficial Aquifer through revised groundwater allocation plans.

8.5 South East sub-region

Groundwater level declines of more than 4 m in the Superficial Aquifer have occurred in the north and south-east of the coastal plain part of this sub-region (Figure 3-6). While most of the change occurred between 1998 and 2007 (Figure 3-4), the decline has continued in many areas between 2008 and 2017 (Figure 3-5). These coincide with similar or greater magnitude declines in the Leederville Aquifer (Figure 4-10, Figure 4-11 and Figure 4-12), which is expected because the aquifers are in contact and the area near the Darling Scarp is a recharge area for the Leederville (Figure 4-5 and Figure 4-6). These declines indicate that there is probably capacity within both aquifers for MAR, if there is suitable quality water available for use.

Being an inland sub-region, all old WWTPs (e.g. Brookdale) have been closed and sewage is pumped to the coast, especially to Woodman Point, which currently treats 37% of all sewage in the Perth and Peel region. The Metropolitan Regional Development Authority and the City of Armadale are investigating reuse options in the Wungong Urban development. There are sizable stream/drain flows in the Wungong Brook and tributaries that may be a viable supply source option for MAR.

The Woodlupine Main Drain is currently being diverted into the Superficial Aquifer at Hartfield Park in Kalamunda. Concern about clogging has required filtering of the water using activated carbon to remove organics that can form biofilms. Flow in the drain, which carries water from the Darling Scarp, has declined from about 1.5 to 1.3 GL/year (Nelson 2017). Water Sensitive Urban Design (WSUD) has been applied in new developments in the Armadale and Byford areas to increase recharge and available water.

In summary, this sub-region has a growing need for non-potable water, but probably less than the North East sub-region. Its main limitation may be securing water of sufficient volume and quality rather than storage options in the Superficial and Leederville aquifers. There do not appear to be any interested parties for operating third pipe or direct pipe schemes.

8.6 Peel sub-region

Unlike the other sub-regions, the Peel sub-region extends from the coast to the hills. As such it encompasses many of the attributes of areas further north. Groundwater levels in the Superficial Aquifer fell in most areas between 1998 and 2008 (Figure 3-4), but some recovered in the following 10 years (Figure 3-5). Over the 20 years the areas most impacted by the drying climate and increased extraction are around Mandurah, Pinjarra, Lake Clifton and Preston Beach (Figure 3-6). The beneficial impact of infiltrated treated wastewater from the Gordon Road WWTP can be detected in Figure 3-6 with the area not recording a change in levels.

Groundwater pressures in the Leederville Aquifer have declined by 1 to 4 m in the northern part of the sub-region in the past 20 years (Figure 4-12), with most of this occurring between 1998 and 2007 (Figure 4-10 and Figure 4-11). Areas in the south have increased pressures.

The sub-region has four WWTPs (Table 8-4), and all treated wastewater is disposed on-shore to aquifers because there are no ocean discharge pipelines in the Peel sub-region. All treated wastewater, except for Pinjarra, is infiltrated through open ponds constructed in Safety Bay Sands and thence into the Tamala

Limestone component of the Superficial Aquifer. At Pinjarra, all treated wastewater is discharged to the adjacent ALCOA alumina refinery for reuse in processing.

Local government has been very active in using the infiltrated wastewater. The mound that has formed under the Gordon Road site facilitates irrigation use at the Meadow Springs Reserve and golf course. At Halls Head the Water Corporation extracts water for use by the City of Mandurah. At Caddadup, Water Corporation disposes of the treated wastewater through a discharge licence, and the City of Mandurah extracts the added water through a water licence. The City is exploring additional uses of the added water at Gordon Road.

Table 8-4. Estimated wastewater flows in WWTPs in the Peel sub-region

Wastewater Treatment Plant	Flows in 2017 (ML/day)	Flows in 2017 (GL/year)	Estimated flows in 2040 (ML/day)*	Estimated flows in 2040 (GL/year)*	Estimated flows in 2060 (ML/day)*	Estimated flows in 2060 (GL/year)*
Gordon Road	10.2	3.7	20.6	7.5	32.3	11.8
Halls Head	3.4	1.2	3.3	1.2	3.3	1.2
Caddadup	1.9	0.7	3.5	1.3	3.6	1.3
Pinjarra	0.7	0.3	2.4	0.9	4.4	1.6
Total	16.2	5.9	29.8	10.9	43.6	15.9

* Assuming 115kL/person efficiency from 2030)

Drainage water in the Peel sub-region is mainly associated with agricultural drains in the Serpentine and Murray River catchments. These drains deliver nutrients to the Harvey Estuary and Peel Inlets and have been the subject of trials to improve water quality. There is increasing interest in diverting some drain waters to augment the aquifers that supply water for irrigation in the Myalup Irrigation Area and for new agricultural areas that may replace the Myalup Pines.

Drilling and investigations are underway in the Nambeelup area to divert winter runoff and inundation into the Cattamarra Coal Measures aquifer via MAR for irrigation and industrial use (Kretschmer 2011; Russell Martin pers. comm. 20th February 2018). This will provide information on injection into confined aquifers that may be applicable elsewhere, especially in the North East sub-region, where the demand for non-potable water is greater.

Having treated wastewater available in the west of the sub-region, and demands for this water in the east, adds a significant cost to reuse as pipeline infrastructure is needed. There have been investigations of transferring treated wastewater from the Gordon Road WWTP to areas around Ravenswood and Pinjarra. Currently this water is being indirectly used to maintain groundwater levels in the northern Mandurah area. Inflows to Gordon Road WWTP are expected to almost treble by 2060 (Table 8-4) so this may become a possibility.

In summary, there already are active and indirect MAR operations through wastewater disposal in the Peel sub-region and more are planned. The absence of an ocean outfall has facilitated the reuse of treated wastewater to the extent that all of it is diverted to the aquifer or used by industry. The remaining potential lies in diverting some of the water currently lying in surface depressions in the Bassendean Sands in the east, and agricultural drains in the south that contribute nutrients to estuaries.

9. Conclusions

Most of the western parts of the Swan Coastal Plain are highly suited to MAR given the depth of the watertable and high transmissivity and water-treating ability of the Tamala Limestone component of the Superficial Aquifer. Given its hydraulic properties it can readily infiltrate stormwater, but there are few main drains apart from when they cross from less well-drained inland areas.

The western sub-regions treat over 95% of the wastewater generated in Perth and Peel given the need for large wastewater treatment plants to be close to ocean outfalls. There is increased use of this water for potable scheme supply by MAR into confined aquifers in the north, and a history of safe on-shore disposal to the Superficial Aquifer in the south. Its injection to raise groundwater levels and create a barrier to saltwater intrusion could be considered in the Central and South West sub-regions, as in California. The Kwinana Industrial Area and WESROC proposals are examples of this practice. The long-term disposal of treated wastewater into the same soils and aquifers in the Peel sub-region provides evidence that MAR can be carried out in much the same way that treated wastewater has been disposed of under different guiding legislation.

Eastern parts of the Coastal Plain have a less suitable Superficial Aquifer for MAR because of the leached, low-lying Bassendean Sands and clayey Guildford Formation. However, these areas have a greater need for non-potable water, especially for irrigation. In addition to drainage water there is growing interest in local treatment of sewer water and local use or storage in aquifers.

Eastern parts may also be suited to recharging of the Leederville or Cattamarra aquifers with non-potable water given their depletion, proximity to the surface and the lack of use of drinking water bores that could be contaminated. The work being carried out at Nambeelup and Hartman Park offers opportunities to test options that may be later applied in the Swan Valley or City of Canning.

The main trigger for MAR is increasing demand, especially for POS irrigation, as Perth spreads along its four corridors. Another trigger is a reduction in existing allocations. Reuse water is more expensive than taking water from an aquifer under licence, so there can be reluctance to adopt more expensive options after a long period of access to naturally-recharged aquifers.

Piped schemes and third pipes appear uneconomic in Perth and Peel, especially in areas with a readily available groundwater source, and where 'extract-treat-deliver-meter-charge' costs exceed the cost of drinking water. Schemes that are continuing often have a subsidy component that needs to be transparent and accepted by both consumers and by those contributing to the subsidy. Often there are multiple hidden benefits arising from local reuse that should be considered, and cost-effectiveness should not be the only criterion.

Managed aquifer recharge is very suited to the Perth and Peel region and it may take many forms involving surface infiltration and injection of water from differing sources into several target aquifers. Transferring water from relatively water-rich western sub-regions to less water-rich eastern sub-regions with increasing demands may remain an impediment until the economics of doing so become favourable.

10. Additional work

Investigations of treated wastewater discharge sites are providing invaluable information on the benefits and risks of MAR using treated wastewater on the coastal plain. More detailed monitoring and groundwater modelling of these sites would provide real-world experience of MAR using a water resource that is increasing in the drying climate. It would be especially useful to have solute transport models to estimate chemical reactions after treated wastewater is added to aquifers.

Injection of stormwater or tertiary-treated wastewater into the Leederville Aquifer needs further investigation for those areas where the Superficial, Mullaloo and Como aquifers are absent (e.g. Cannington). Currently stormwater in these areas discharges to rivers and local governments have few

options for irrigating POS. Further investigation are needed into the potential for harvesting sub-soil drainage water flows from urban developments, in addition to natural ponding and drainage, in areas with high watertables on the eastern parts of the Swan Coastal Plain.

Main drain diversions have been done to improve lakes (e.g. Jackadder) and for MAR at Hartfield Park. The security of this water source given the drying climate is unclear. The flow and water quality of main drains is no longer monitored, which makes their diversion uncertain for proponents. Consideration should be given to installing continuous monitoring devices in key drains.

Clearer access policies to drain and treated wastewater streams are needed to encourage third parties to consider establishing non-potable water supply schemes. Property rights around accessing water added to aquifers also need to be clarified. A revised DWER policy on MAR will help meet these needs, but legislative reform of water resource management acts would provide a longer-term solution.

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