


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

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1. Summary

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

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

There are four main types of drainage water in the Perth-Peel region; main drains, street drains, sub-surface drains and agricultural drains.

Main drains were mainly installed to lower groundwater levels to allow the building of houses, roads, industrial areas and (in earlier times) horticulture on waterlogged and peaty soils. These are managed by the Water Corporation and designed to remove excess water within a specified period. There has been concern about the impact of these drains adding pollutants, especially nutrients, to estuaries and beaches. Lower groundwater levels have resulted in many main drains having decreasing flows. Flows are increasing in a few areas, especially following urbanisation. It is estimated that these drains remove about 100 GL/y of water. They represent the best drainage target for augmenting recharge to the Superficial Aquifer in areas where higher groundwater levels are desirable. Main drain water would require treatment before injection into the Leederville Aquifer to avoid clogging. The impact of the diversion of main drain water on groundwater quality has been little investigated. However, based on the experiences of the additions of street drainage water and treated wastewater to groundwater, water quality is likely to be improved through filtration, dilution and reactions in the soil and aquifer. This could improve water quality at discharge points and therefore providing multiple benefits. Environmental and cultural flows need to be retained or improved in some open main drains, so only a proportion of main drain flows can be diverted.

Most street (and roof) drainage is already diverted to the Superficial Aquifer in the Perth-Peel region and provides the majority of recharge in most residential areas. This beneficial outcome results from on-site disposal being much cheaper than piping water to an estuary or the ocean, except in those areas which are close, or connect to a drainage system that directs flows to a surface water outlet. Those street drains that still reach the ocean and estuaries are progressively being diverted by councils, especially where their irrigation water is being affected by salt-water intrusion. While the diverted volumes may be small, the addition of fresh water at the interface may be beneficial. Assessments of the cost effectiveness of these diversions is limited, but ten-year volumetric costs may be similar to drinking water costs.

The expansion of residential areas onto land with a high watertable in the North East and South East corridors has necessitated sub-surface drainage be added to the normal combination of main and street drainage. Currently the volumes are small, and the water may be hard to collect and divert to aquifers with the capacity to accept the water. There exists an opportunity for groundwater levels to be lowered in summer and recharged in winter using both street and sub-surface drains. This is an active research area.

Finally, agricultural drains in the Peel sub-region currently discharge nutrient-rich water to the Peel-Harvey Estuary, but may be diverted to increase recharge for irrigated agriculture, wetland recovery and immobilisation or recycling of nutrients as part of the Myalup-Wellington project.

Given the increasing interest in augmenting existing recharge in Perth and Peel, there needs to be more drain flow monitoring and assessments of the impacts of diversion on both the proposed and existing receiving bodies. Single-benefit assessments may not capture all benefits, including those for both public and private water users, the environment and the community. Studies that examine biophysical and socio-economic aspects and take account of the drying and warming climate are needed to plan future drain management. Clarification of property rights and responsibilities also needs to be included in revisions of the state water management legislation.

2. Background

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

Given the wide occurrence of an unconfined ('Superficial') aquifer in sand dunes under the Swan Coastal Plain (except where there is clay alluvium around major rivers and the Darling Scarp) and its partial depletion in recent decades, there is increasing interest in managed aquifer recharge (MAR) of more seasonal stormwater, and year-round wastewater streams for non-potable use. The confined Leederville Aquifer is also of interest for MAR, especially in areas where the Superficial Aquifer is not able to be used.

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

The three discussion 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 (**this report**); and
3. The potential for managed aquifer recharge, third-pipe and direct piping systems in the Perth-Peel region (McFarlane 2018b).

Chapter 3 provides an overview of drainage types in Perth and Peel, highlighting the unusual situation that exists on the coastal plain where there are few surface water drainages in the dunal system that occupy large parts of the urban area.

Main drains, which were mainly installed to lower watertables in areas subject to inundation, are analysed in Chapter 6 after consideration is given to where watertables are close to the soil surface in Chapter 4 and trends in watertable levels (which affect main drain flows) are outlined in Chapter 5. Street drains, which remove runoff during immediately after rainfall events, are covered in Chapter 7 while residential sub-surface drains, used to lower watertables at an individual residential block level, are covered in Chapter 8.

The potential to divert drainage water into aquifers in the six planning sub-regions (Figure 2-1) is discussed in Chapter 9. The nature of aquifers suited to MAR is covered in more detail in McFarlane (2018b). Conclusions are drawn in Chapter 10 and recommendations in Chapter 11.

Drainage is site-specific, so this report covers general principles rather than specific cases unless they are useful for explanatory reasons.

Figure 2-1. Supply-demand sub-regions in the Perth Peel region (Source: DWER)

3. Overview of drainage types

A lack of natural surface drainage and defined catchment boundaries is a feature of those parts of the Swan Coastal Plain underlain by sandy aeolian dunes and a watertable more than a few metres from the surface. Defined drainages are associated with major rivers such as the Swan, Canning and Serpentine rivers, which enter the plain from the east, and areas where groundwater discharges into drainage lines that arise largely on the coastal plain. Examples of such streams on the plain include Gingin Brook, which has both gaining and losing sections along the drainage line (Department of Water 2011) and the Ellen Brook and its tributaries such as Henley and Bennett brooks.

The dunal systems, alluvial Guildford Formation and surface drainage features are shown for the three northern sub-regions in Figure 3-1 and for the three southern sub-regions in Figure 3-2. Digital terrain models of the Spearwood Dune system show that depressions, often associated with interdunal swales, would need to fill extensively before they overflow to adjacent low-lying areas (McFarlane and Caccetta 2017). The very high infiltration rates for the sands (usually 15-25m/d) makes runoff unlikely unless the interdunal swales are connected to the unconfined aquifer, in which case slow drainage may occur. The paucity of defined drainages in deep dunal areas indicates that there have been no rainfall events on the Swan Coastal Plain over tens (Spearwood Dunes) or even hundreds of thousands of years (Bassendean Dunes) to define normal drainage catchments since the dunes were deposited.

The Bassendean Dunes and associated clayey layers often have shallow depressions that constitute palusplain wetlands, which are unlikely to contribute surface water to rivers until impervious surfaces are created on urbanisation. Barron et al. (2012) estimated that the runoff coefficient rose from 0.01 to more than 0.40 after urbanising such areas. This doesn't mean that all rainfall infiltrates exactly where it falls. There is anecdotal and litter evidence that during intense storms runoff over the sands (especially when water repellent) can conduct water a few hundred metres before it infiltrates. However, such runoff isn't sufficient to create clearly defined drainages and catchments.

This feature of the sands has allowed local authorities in Perth and Peel to design street drains which only are large enough to accept road runoff and any driveways that drain towards roads. Councils have adopted by-laws which require residents to infiltrate roof runoff on their block, and for car-parks to similarly infiltrate runoff water within their domain. There are exceptions where the blocks are underlain by clay and/or the watertable is close to the surface (e.g. parts of the cities of Canning, Swan, Armadale and Gosnells).

Initially roof downpipes had 'splash blocks' to direct the water away from houses, but increasingly there is a requirement for underground soak wells to be installed to reduce the likelihood of discharge undermining foundations. Industrial and commercial zones with large shedding areas are also required to install large soak wells to dispose of stormwater. Industrial areas and high-density residential neighbourhoods with high proportions of impervious surfaces provide significant indirect recharge[1] to the Superficial Aquifer (McFarlane and Caccetta 2017). Recent work indicates that indirect recharge from roofs and roads greatly exceeds direct recharge through soils in the area underlain by the Kings Park Formation (McFarlane and Caccetta 2017, McFarlane et al. 2018, McFarlane and Caccetta 2018). Therefore, the management of drainage water is becoming increasingly important for maintaining groundwater levels under Perth and Peel.

Away from the river and coast, drains mainly discharge into open sumps that can be classified as absorption basins (which contain no outlets) or compensation basins (which can overflow or be pumped to another disposal site).

[1] Indirect recharge is water that had been moved laterally on an impervious surface (roof, road, car parks, industrial areas etc) before entering an aquifer, sometimes through the soil profile. Direct recharge is water that has infiltrated close to where it fell as rain or from a sprinkler before percolating through the soil to enter an aquifer.

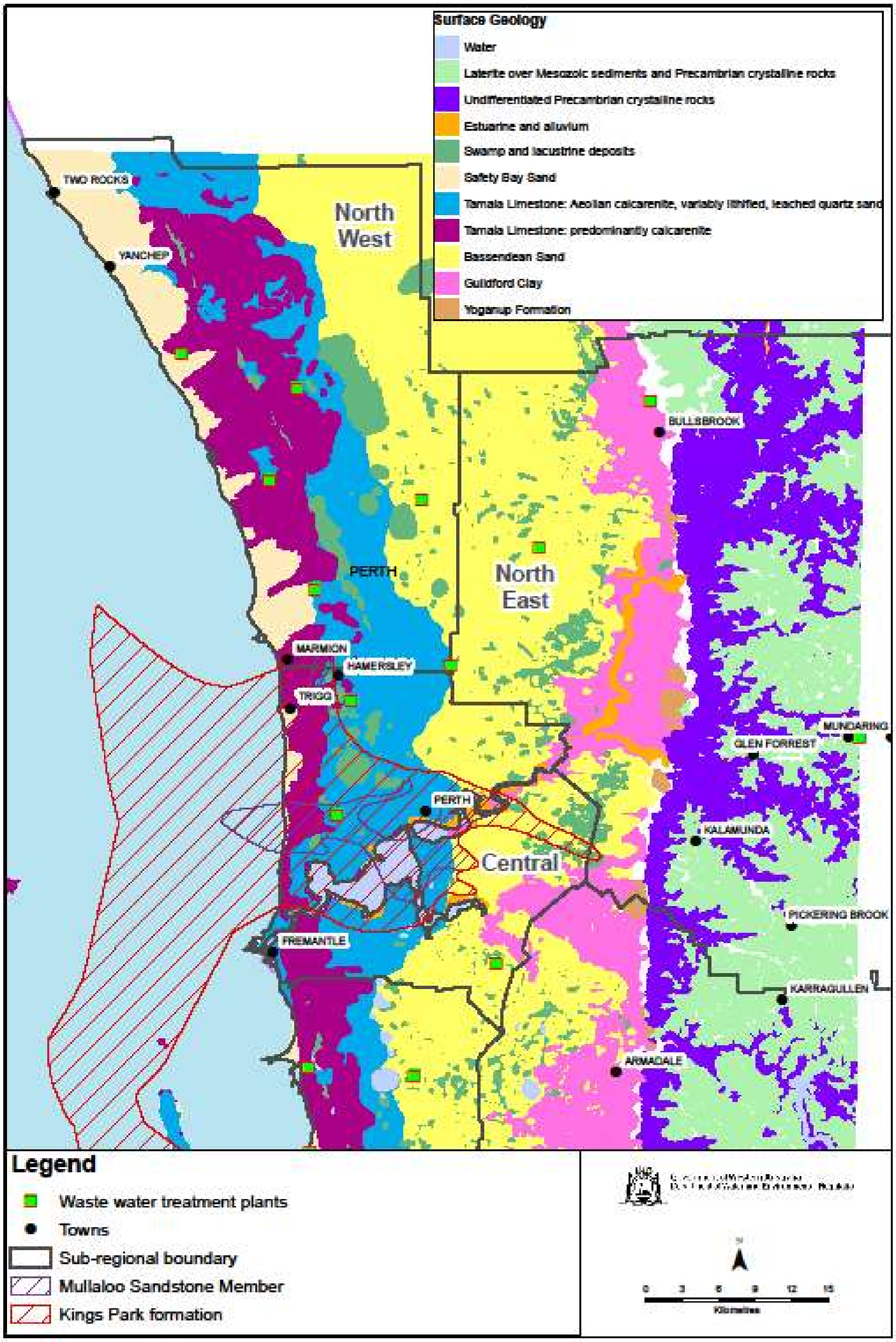

Figure 3-1. Surface geology of the three northern sub-regions in Perth and Peel (Source: DWER)

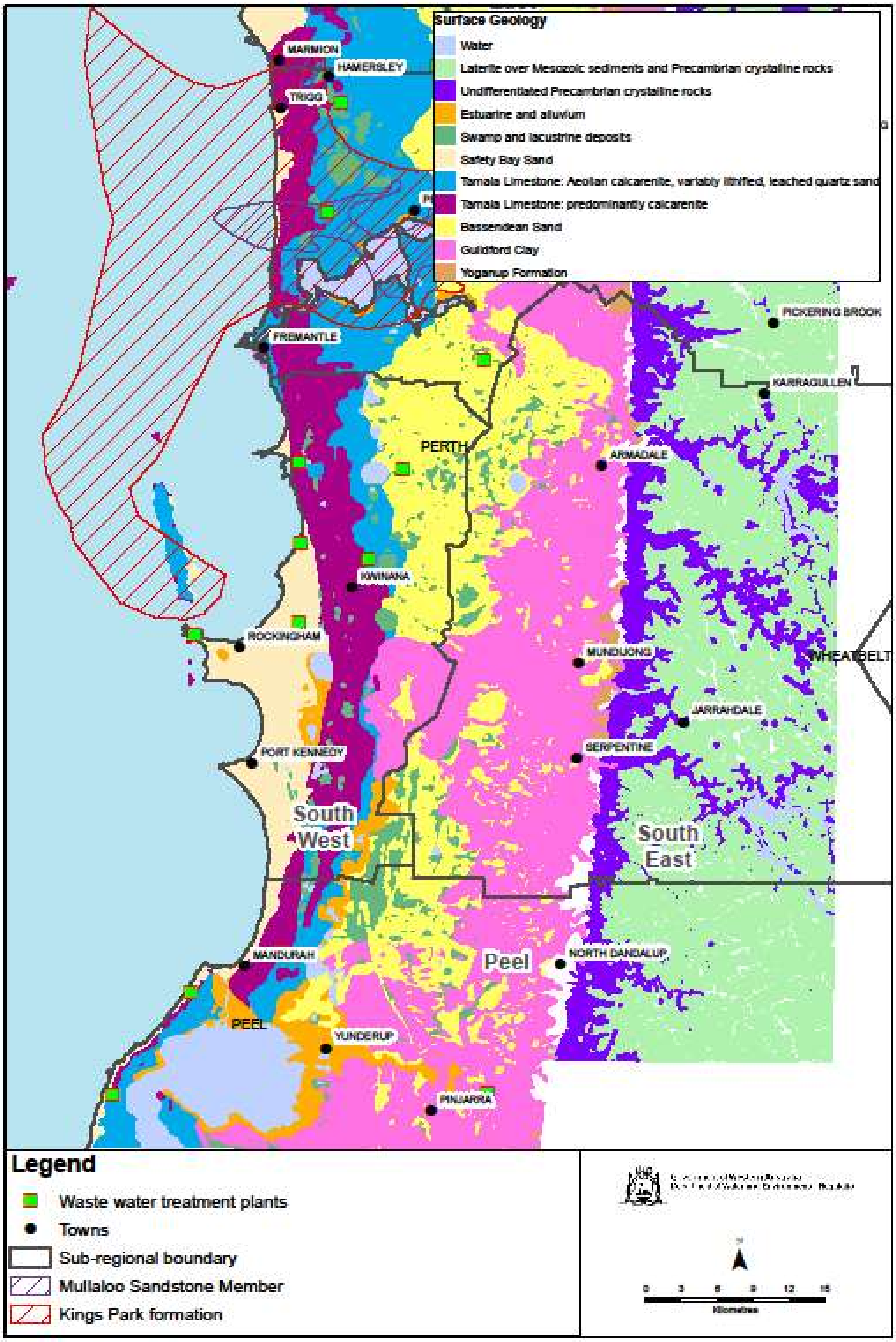

Figure 3-2. Surface geology of the three southern sub-regions in Perth and Peel (Source: DWER)

Details on water sensitive urban design principles and examples of managing urban runoff are contained in the Stormwater Manual (Department of Environment and Department of Water 2004 - 2007). Adding drain water to wetlands, which are often outcrops of the Superficial Aquifer, can result in them retaining areas of open water, at least during the winter and autumn in a drying climate. The quality of water additions and impacts on water levels on conservation values and flood risks needs to be carefully considered.

Infiltrating water running off roofs and roads close to where it fell allows recharge to the Superficial Aquifer to be distributed across large parts of Perth and Peel. Overloading compensation basins in storms can result in losses to the estuary and ocean through main drains. Local councils are increasingly making their road collection system leaky to avoid this occurrence. This is very beneficial in a drying climate where the aquifer is coming under increasing pressure for irrigation, which helps reduce the urban heat island.

The infiltration of stormwater through infiltration basins and soakwells is the cheapest and most convenient way to infiltrate excess water, and it was initially done for this reason. However, falling groundwater levels has resulted in increased interest in diverting any remaining stormwater that is still being discharged to estuaries and the Indian Ocean. Some open drains have important environmental and cultural flows and therefore cannot be completely diverted.

Main drains to remove shallow groundwater were installed in low-lying parts of Perth and Peel to enable buildings and roads to be built, and in the early years of Perth, for horticulture to be practiced in more-fertile peaty soils. These gazetted drains are managed by the Water Corporation because they often cross local government boundaries and required more capital to install. Low-lying wetland areas were also filled, often with domestic rubbish, as well as drained because they were then not valued parts of the landscape. This may affect water quality.

Using hedonic pricing of land values, a 2013 analysis put the value of Perth wetlands at $4 billion (Marsden Jacob Associates 2013). This provides an increasing incentive for local government to manage water levels in urban wetlands; through drain diversion (Town of Cambridge), partial sealing (City of Subiaco) and/or the addition of treated wastewater to the aquifer (Western Suburbs Regional Organisation of Councils).

Riverine and coastal areas are increasingly starting to experience salt water intrusion as outflow to the saline estuaries and ocean reduce. Local drains with estuarine and ocean discharge points have been diverted to the Superficial Aquifer to improve groundwater quality and increase the water available of irrigation of Public Open Space (Glover 2001: JDA 2017). This involves installing soak wells beside traditional road-side gully pits and only removing water that exceeds the capacity of these infiltration devices. Stormwater can also be diverted into absorption basins before they reach the ocean or river outlet. Davies (2015) showed that simple soak wells in dunal sands could easily deal with a 24 hour, one in ten-year storm event, without producing any runoff. Davies et al. (2016) found that the design of such pits is not critical as the capacity of the sands to conduct water away from them is often substantial.

The expansion of Perth's urban footprint along the North East and South East corridors, and inland parts of the Peel sub-region, requires building on areas with shallow depths to the watertable. These are often flat areas with clayey or iron-cemented (coffee rock) soils associated with the Guildford Formation and low-lying parts of Bassendean Sands (Figure 3-1Figure 3-2), which makes them unable to accept inundation resulting from winter rainfall, or to be easily drained. This necessitated sub-surface drainage at the residential lot level, often associated with sandy infill.

Shallow surface drains have been installed in the southern part of the Peel sub-region to remove water that accumulates over winter and inhibits spring and early summer pasture growth. The concern that these drains add nutrient loads in the Peel Harvey Estuary has resulted in them being investigated for water quality, but it is only recently that there has been interest in having them diverted for MAR.

The following sections provide more detailed information on these four drainage types. Before this it is necessary to first review where groundwater levels are shallow, and recent trends in groundwater levels to identify areas of freeboard (i.e. space to accommodate additional water) and how changes in levels may be used to estimate flows in ungauged main drains that intercept the watertable.

4. Depth of the watertable

In the northern three sub-regions there are extensive areas within the Bassendean Dunes and Guildford Formation on the eastern flank of the Gnangara Mound and within the Ellenbrook catchment that have watertables within 3m of the soil surface (Figure 4-1). As is shown later, urbanised parts of these areas have an extensive network of main drains, many of which are linked with, or are modifications of, natural drainage lines.

There are also elongate areas with shallow watertables associated with interdunal swales within the Spearwood Dune system (Figure 4-1). Some of these are also subject to drainage to enable areas to be built up, including industrial areas such as at Osborne Park. Areas under and north of the Central Business District (CBD) also have shallow watertables, which required the installation of drains to enable development.

The area of low-lying flat areas with shallow watertables is especially large in the three southern sub-regions (Figure 4-2). These areas often lack even rudimentary drainage lines unlike the northern areas. Rainfall ponds on palusplain wetland areas and urbanisation require construction of sub-surface drainage and sand infill.

Interdunal swales in the west contain areas that can be connected using regional drains such as the Peel Main Drain, which links parts of the Beeliar chain of wetlands.

Further south, in the Peel sub-region, the high watertables affect agricultural production and a network of local and additional regional drains needed to be installed.

Removing water from low-lying areas and use of that water for subsequent recharge of aquifers requires areas with freeboard before managed aquifer recharge can be considered. Figure 4-1 shows that here is more potential in the northern sub-regions to find areas with a sufficient depth of the watertable to accept additional water, unlike in southern areas as shown in Figure 4-2.

There is increasing interest in places such as Nambeelup to consider summer extraction of groundwater to create storage in the Superficial or deeper aquifers to make room for excess water during winter and spring. This may also entail moving soil to capture runoff and create water storages able to partly treat the water, as well as areas with more freeboard as has occurred in parts of the Virginia and Northern Adelaide Plains area (Jensen Planning and Design 2013).

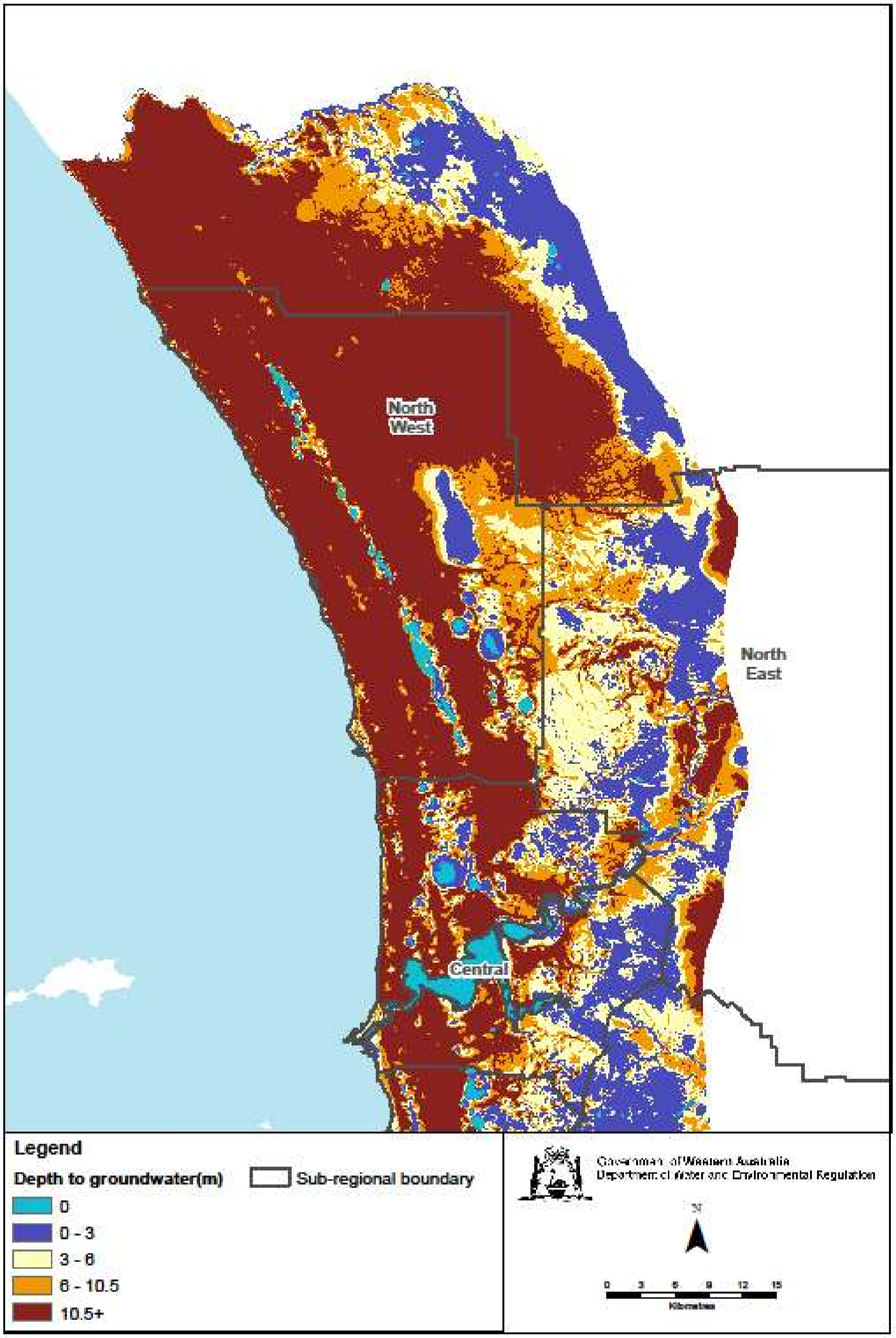

Figure 4-1. Depth of the watertable in the three northern sub-regions (Source: DWER)

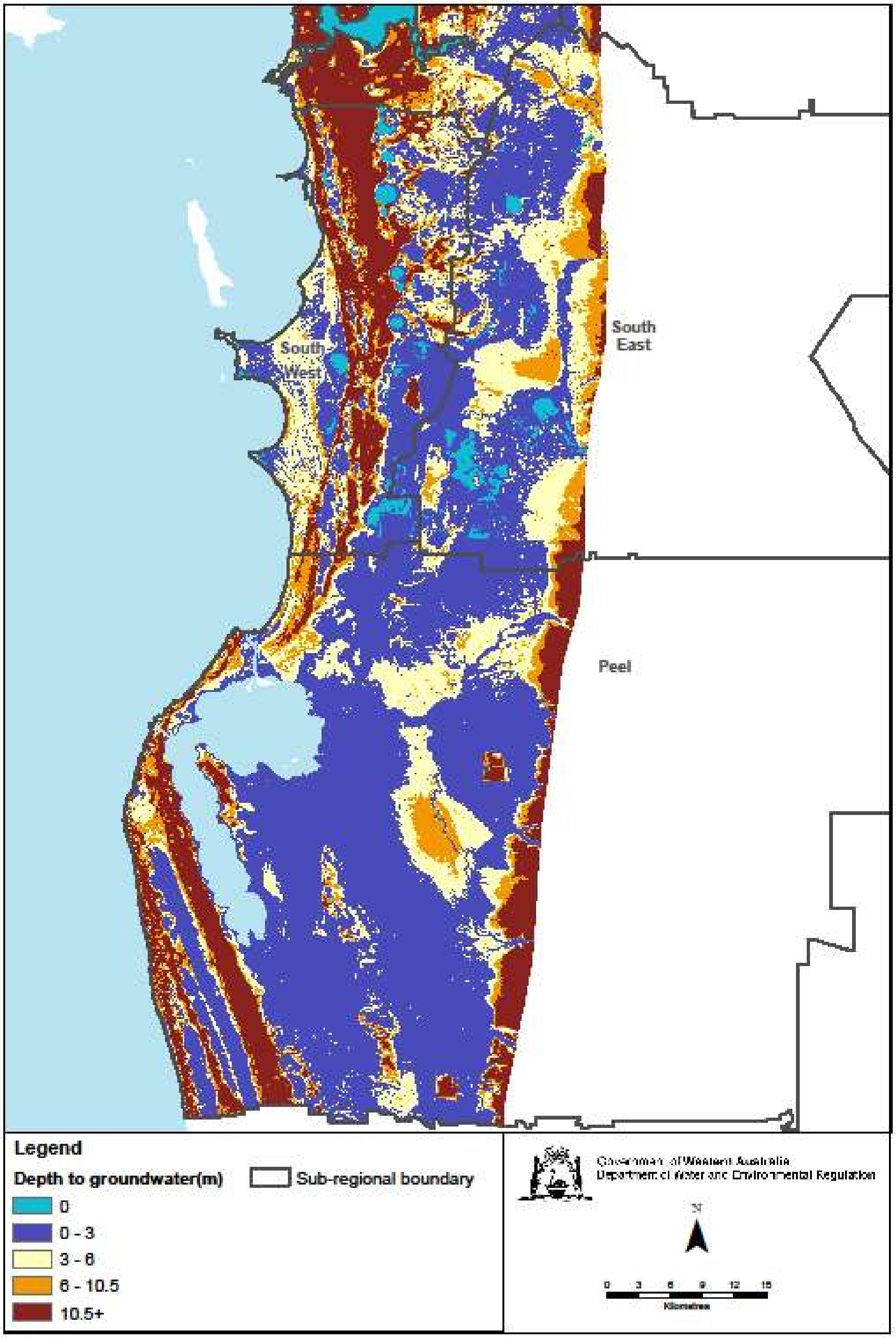

Figure 4-2. Depth of the watertable in the three southern sub-regions (Source: DWER)

5. Groundwater level trends

As shown in the next section, many main drains show a decrease in flow that is related to a fall in groundwater levels near the drains. However, some areas are recording increased flows.

Average groundwater levels recorded from 43 bores on Gnangara Mound since January 1979 show that there has been a long-term decline (Figure 5-1). There has been a partial recovery of levels since 2016, but there remains a decline of 3.5m since January 1979, the start of the series. This section examines trends in watertables over three periods; 1998 to 2007 (Figure 5-2), 2008 to 2017 (Figure 5-3) and 1998 to 2017 (Figure 5-4). These trend maps are based on a limited number of bores that have data extending over the decadal periods so need to be interpreted with care. A few bores in a sparsely monitored area can skew trends over a larger area.

Groundwater levels fell over most of the Perth Peel region between 1998 and 2007. Only blue areas shown in Figure 5-2 recorded a rise during this ten-year period. It was a continuation of a fall in groundwater levels that started in most parts of the Gnangara Mound from the drought year in 1969 (Yesertener 2008). By 1998 groundwater levels were therefore already several metres lower on parts of the Mound before this decade commenced. The greatest falls are associated with higher parts on the Gnangara Mound (the north and east), areas under pines and near wellfields. Areas close to the Darling Scarp are often intake areas to the confined aquifers and these also show declines between 1998 and 2007. Some increases in levels occurred east of the Perth Central Business District (CBD) and in the Kwinana Industrial Area although individual bores fell in this catchment (Figure 8.7 in Bekele et al. 2015).

Groundwater levels continued to decline over about half of the Perth-Peel region in the ensuing decade (Figure 5-3), but there was partial recovery under urban areas except for areas east of Fremantle and the CBD, in Cannington (north of Armadale), the Swan Valley and south of Trigg. Groundwater levels in northern areas continued to fall, as did areas around Mundijong and Serpentine. Much of the recovery was probably in the last two-year period (Figure 5-1).

When the trends in the two decades are combined, some areas indicate several metres decline in levels while others have had a 1 to 2m increase (Figure 5-4). The reasons for rises are complex and include urbanisation, reductions in extraction and pine removal. Most of the falls are probably due to the drying climate. These changes are later compared with drain flows over the last 20 years.

The rate of groundwater decline will decrease as hydraulic gradients towards rivers, estuaries, the ocean and drains reduce. Lower levels also reduce evapotranspiration from around wetlands. Where aquifers are full, rainfall is rejected over winter. Lowering groundwater levels over summer through pumping or drainage can create space for this winter recharge. Under these conditions, levels are buffered until summer depletion exceeds winter recharge. Once this point is reached, groundwater levels will progressively decline as shown in Ali et al. (2012).

Long-term monitoring of irrigation bores in the City of Nedlands has shown gradual increases in groundwater salinity, which is further evidence that flows and flushing are gradually decreasing as gradients reduce.

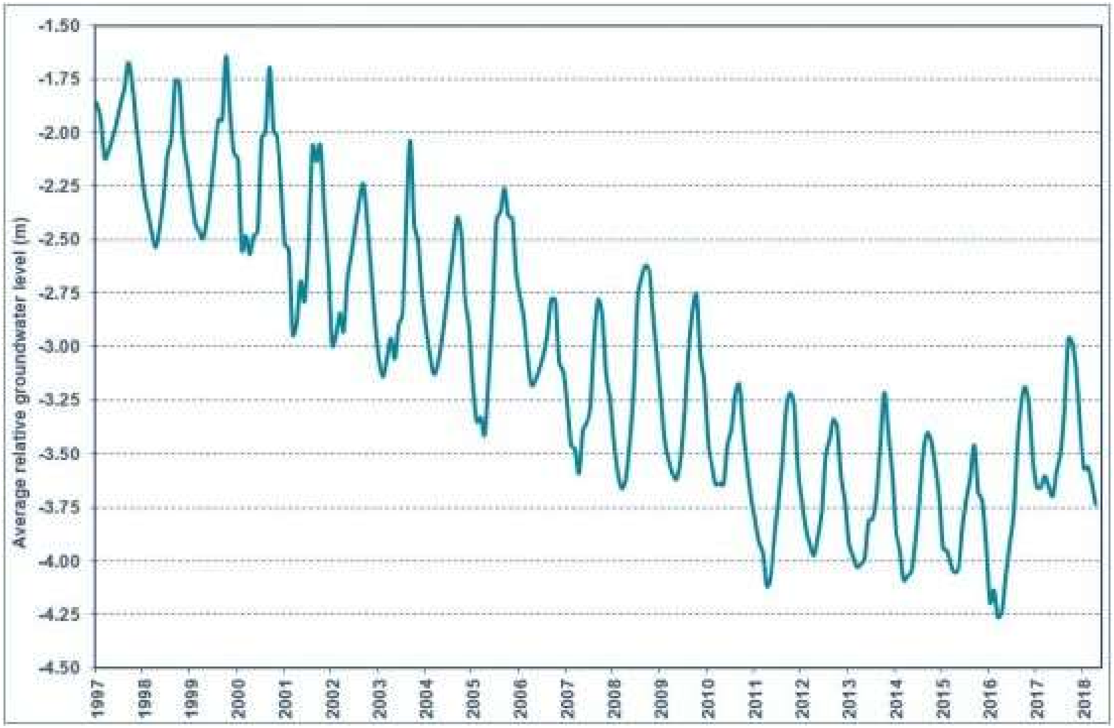

Figure 5-1. Average groundwater levels for 43 bores on Gnangara Mound since January 1979

Source: DWER 2018 http://www.water.wa.gov.au/water-topics/groundwater/understanding-groundwater/gnangara-groundwater-system

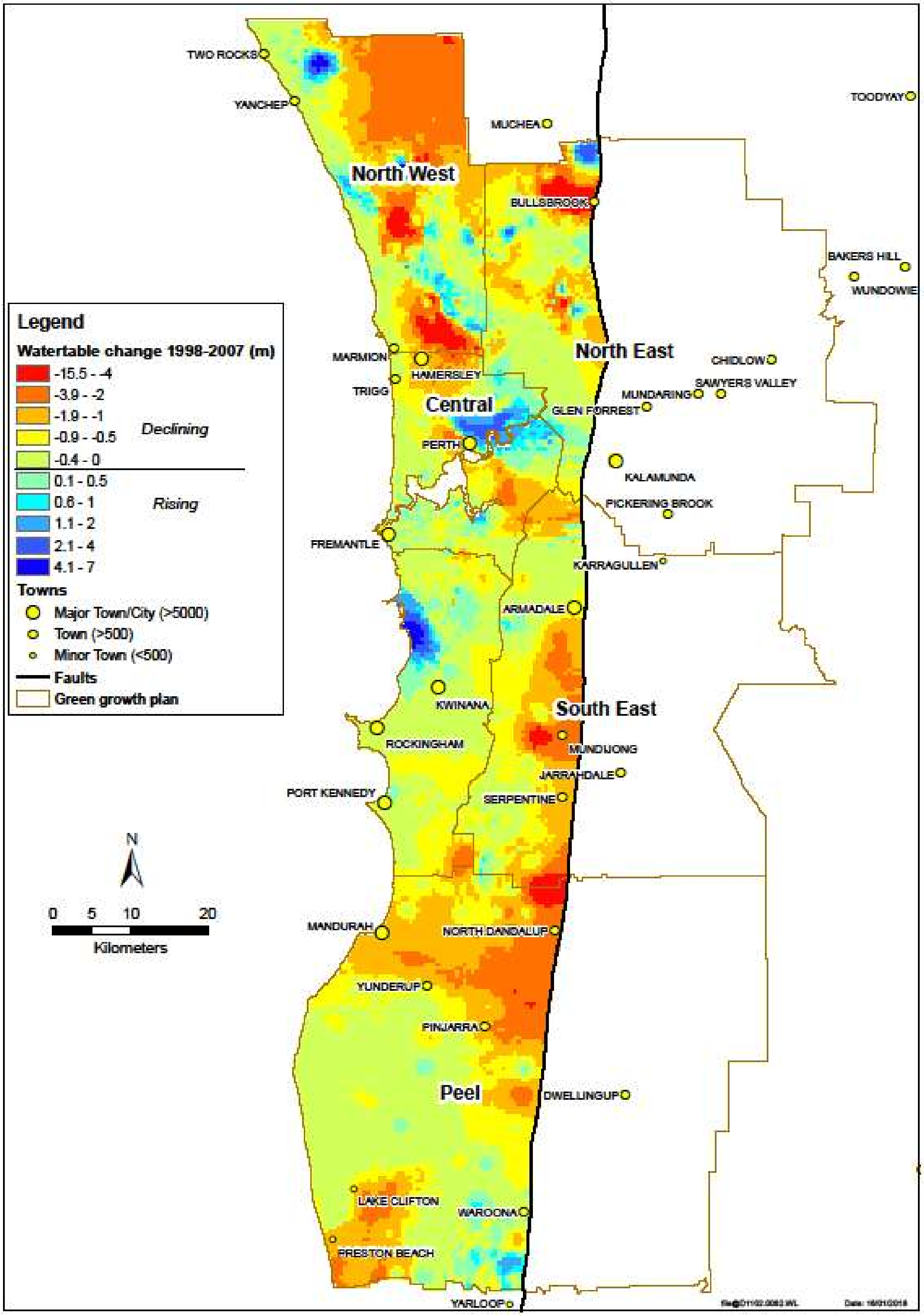

Figure 5-2. Change in watertable levels between 1998 and 2007 (Source: DWER)

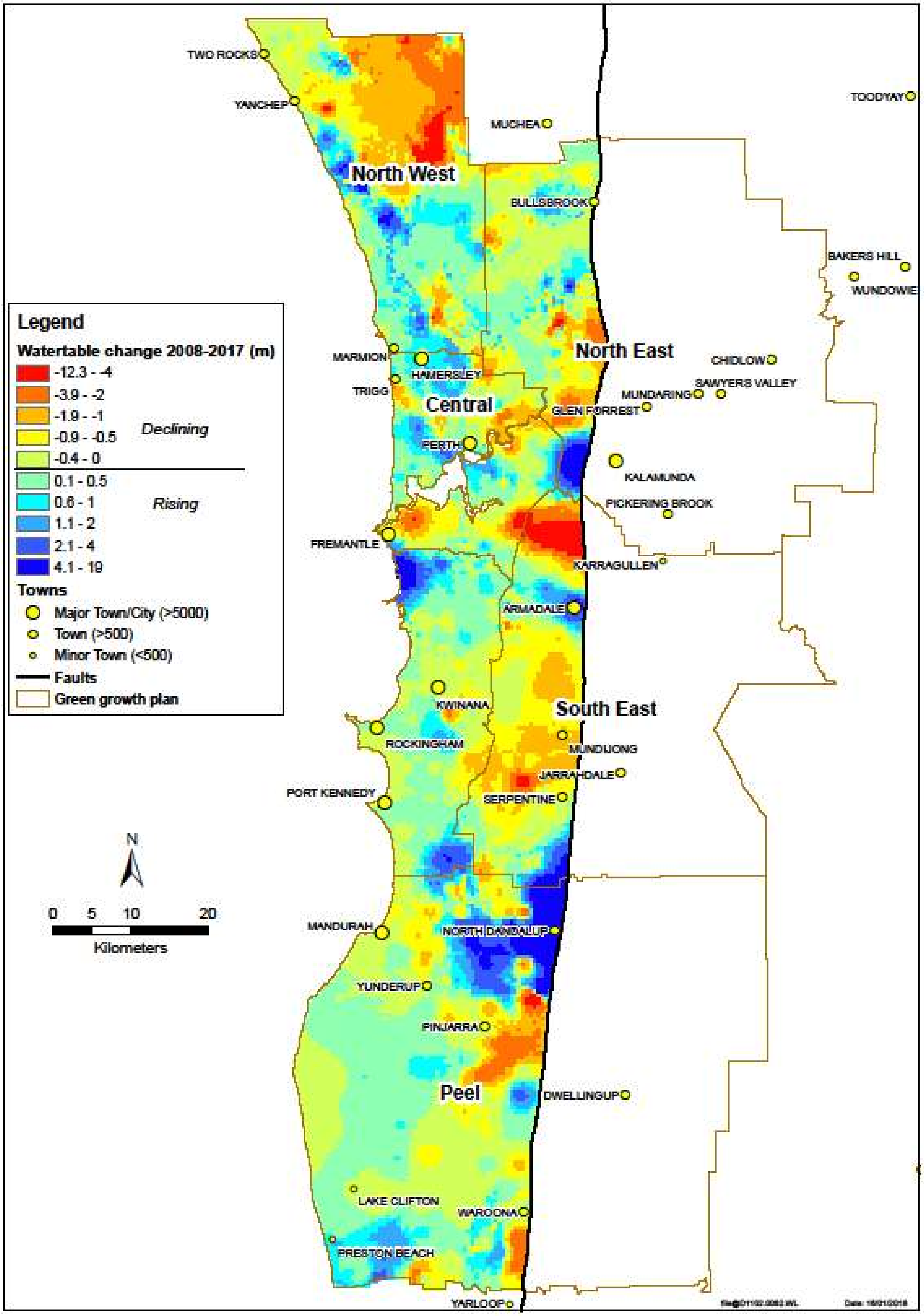

Figure 5-3. Change in watertable levels between 2008 and 2017 (Source: DWER)

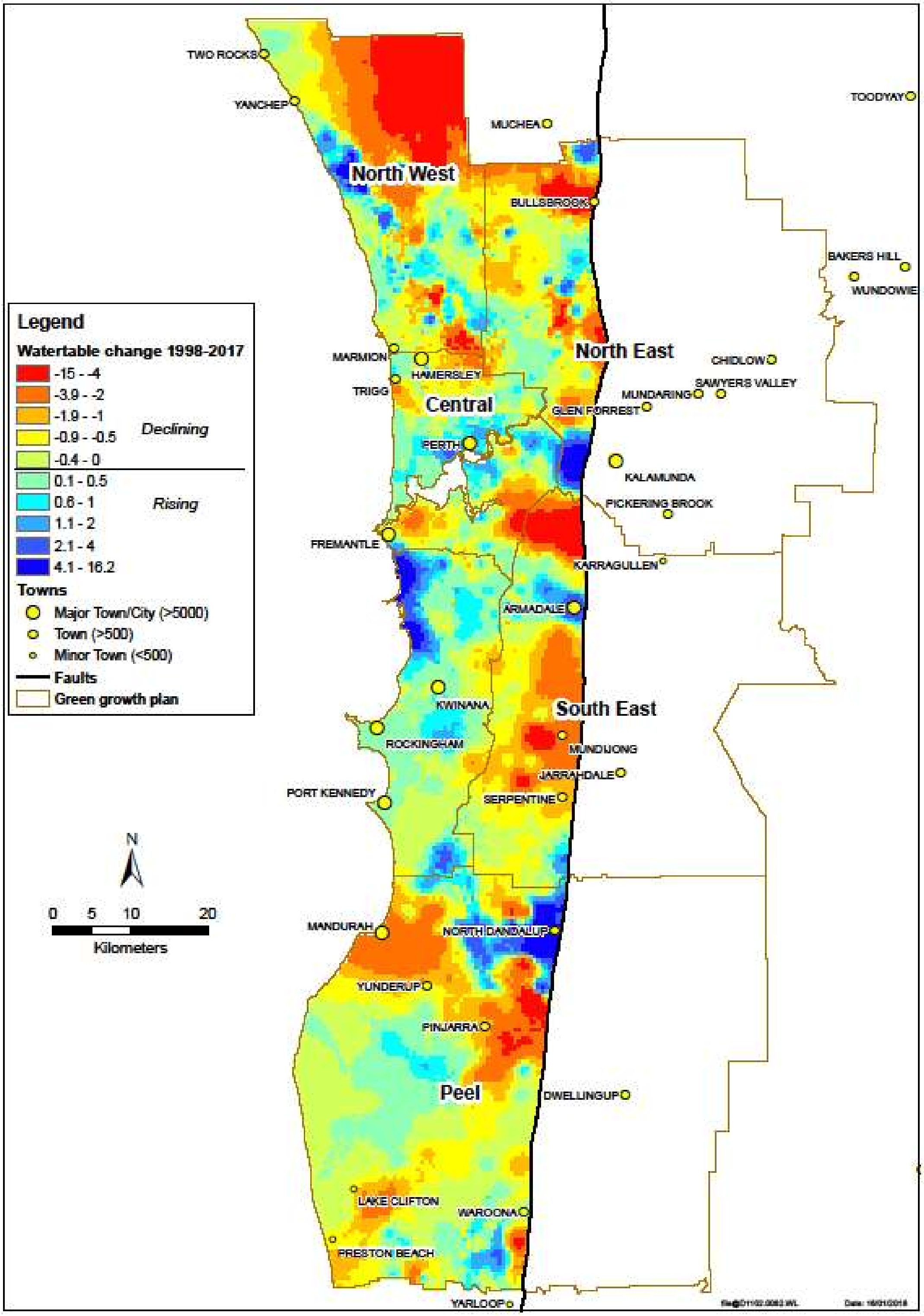

Figure 5-4. Change in watertable levels between 1998 and 2017 (Source: DWER)

6. Main Drains

6.1 Location of main drains

The location of main drains in the three northern sub-regions is shown in Figure 6-2 and in the three southern sub-regions in Figure 6-3. Gravity drains are closed pipes which flow under gravity; open channel drains also flow under gravity but are open to groundwater ingress (gaining streams) and egress (losing streams). Pressure main drains are closed pipes that only contain water when water levels in the intake exceed a minimum level which triggers pumps to start.

There are very few main drains in the North West sub-region (Figure 6-2), because most of this area has deep watertables (Figure 4-1) and highly permeable sands and Tamala Limestone capable of carrying water away (Figure 3-1). Some eastern areas with high watertables and Bassendean Sands are within the Gnangara Pine Plantation and Banksia woodlands, which don't require drainage.

Most main drainage in Perth and Peel is within the Central sub-region (Figure 6-2), partly because this sub-region is the most urbanised and cannot afford even short periods of inundation. There are two main reasons for drains being needed in the sub-region; geology and elevation.

The highly-transmissive Tamala Limestone or permeable Safety Bay Sands are the main aquifers west of the CBD and Bull Creek. Watertables are well below the surface apart from inter-dunal wetlands. Main drains in these western areas remove groundwater from swampy areas around wetlands, such as around Herdsman Lake and the Osborne Park industrial area, to enable them to be built up and not liable to inundation by elevated groundwater or flooded by stormwater. Some internally-drained wetlands in the west have main drain outlets to remove road runoff, which enters them during large rainfall events or in wet winters (e.g. Big Carine Swamp, Lake Jualbup, Perry Lakes, Frederick Baldwin Park and Booragoon Lake). North of the Swan River these drains discharge into the Indian Ocean at North Beach (Carine Drain), Floreat (Herdsman Drain) and Swanbourne (Subiaco Drain). South of the river they discharge into the Canning River at Bull Creek. Finally, there are short main drains in Fremantle, Freshwater Bay and the University of Western Australia, which are more like local street drains.

East of, and including, most of the CBD and Bull Creek, main drains discharge groundwater from areas with high watertables (Figure 4-1), often in Bassendean Sands or Guildford Formation alluvium (Figure 3-1), into the Swan and Canning estuaries (Figure 6-2). There is a main drain from the western suburbs that takes overflow from Jolimont Lake and Lake Monger to the Mounts Bay Drain between the Narrows interchange and Elizabeth Quay. However, most are gravity and open drains, which augment short drainage lines that discharge into more substantial natural drainages such as Bennett Brook, Claisebrook, Bull Creek and Bannister Creek. These drainages have been extensively studied for their nutrient loads as part of the Swan-Canning Water Quality Improvement Plan (Swan River Trust 2009).

GHD (2008) estimated median annual discharge of stormwater from the Perth and Peel metropolitan regions to be about 120 GL/year. Approximately 67% of flow came from the Swan-Canning catchment (exclusive of the Avon and Helena rivers; and the Ellen, Jane and Susannah brooks), 16% came from the coastal main drains (Carine, Herdsman and Subiaco) and 17% came from the Peel sub-region's main drains.

To realise the potential for stormwater harvesting of the drainage waters, GHD (2008) recommended:

- Continue implementation of the water sensitive urban design principle of 'infiltrate at source';
- Identification of suitable reaches along the Main (and Local) Drain network to raise invert levels and widen the channel;
- Extraction of winter and spring baseflows with injection (or infiltration) into the Superficial Aquifer; and

- Storage of stormwater events in detention basins with possible injection or infiltration into the Superficial Aquifer.

A reduction in main drain flows In the Mills Street Main Drain and Bayswater Brook was completely attributed to reduced groundwater inflow (Figure 6-1; Water Corporation and CSIRO 2012). This reflects the reduction in watertables between 1998 and 2007 (Figure 5-2).

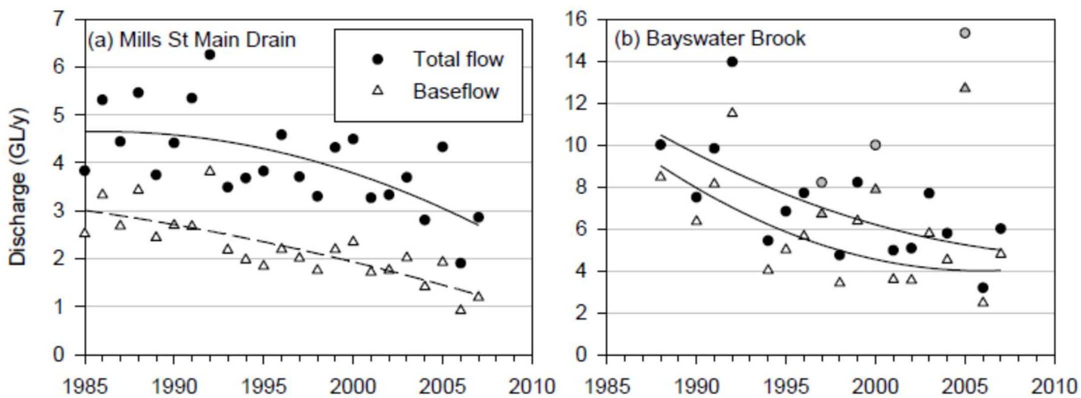

Figure 6-1. Changes in baseflow and total flows in the Mills Street Main Drain and in Bayswater Book (Water Corporation and CSIRO 2012)

The high value of land in the Central sub-region can make it worthwhile to improve the availability of non-potable water for irrigation and wetlands, but also makes implementing works that disrupt roads and buildings very expensive. The City of Perth is evaluating options to reduce its dependence on groundwater for irrigating public open space and trees in its jurisdiction (City of Perth 2018).

Increasing tree canopies provide shade, but much less cooling than if they are also irrigated. There therefore is an incentive to redirect water suitable for irrigation to reduce urban heat island temperatures by ten degrees or more in summer.

The location of the main drains mentioned in the following section is shown in Figure 6-4.

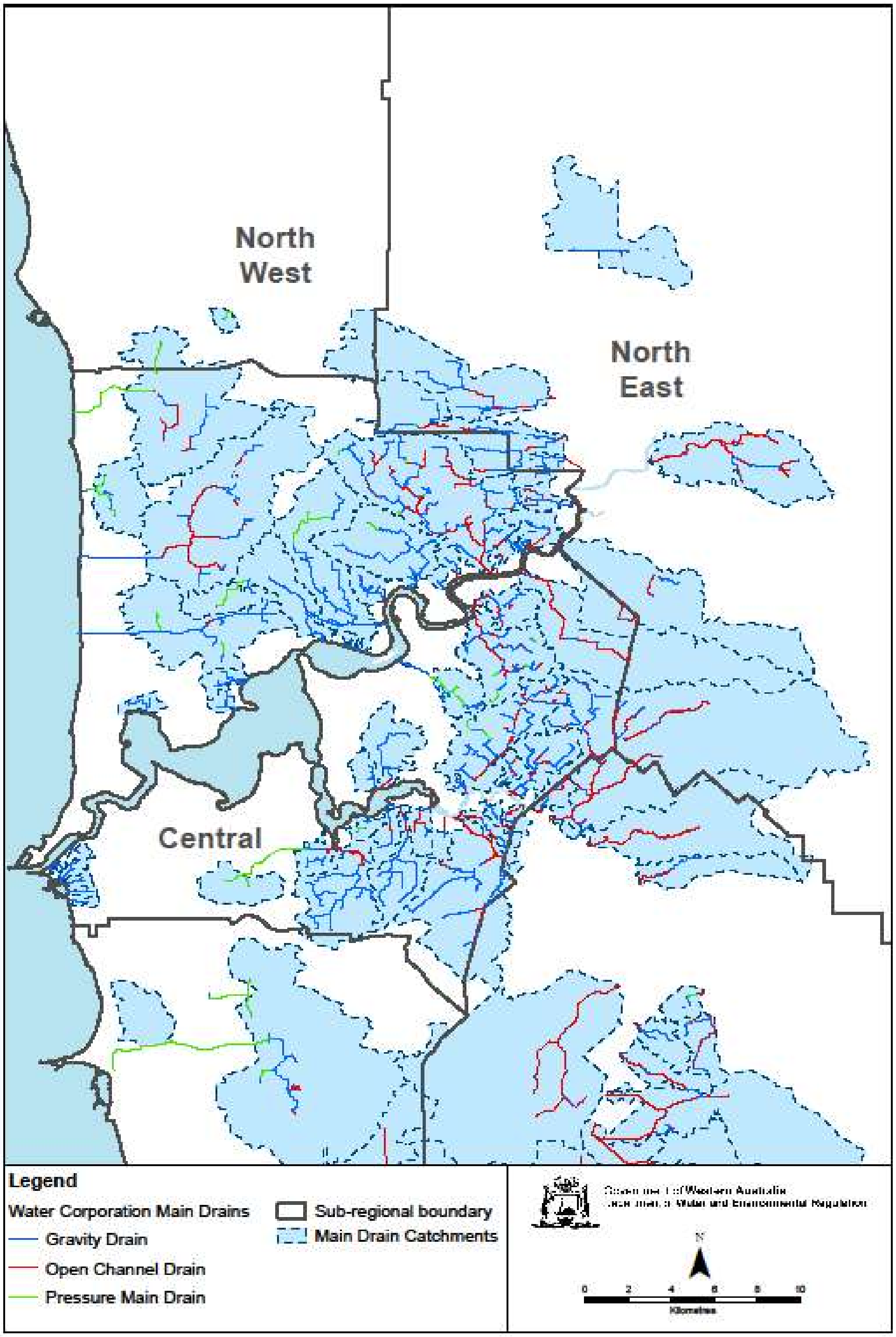

Figure 6-2. Main drains and their catchments on the three northern sub-regions

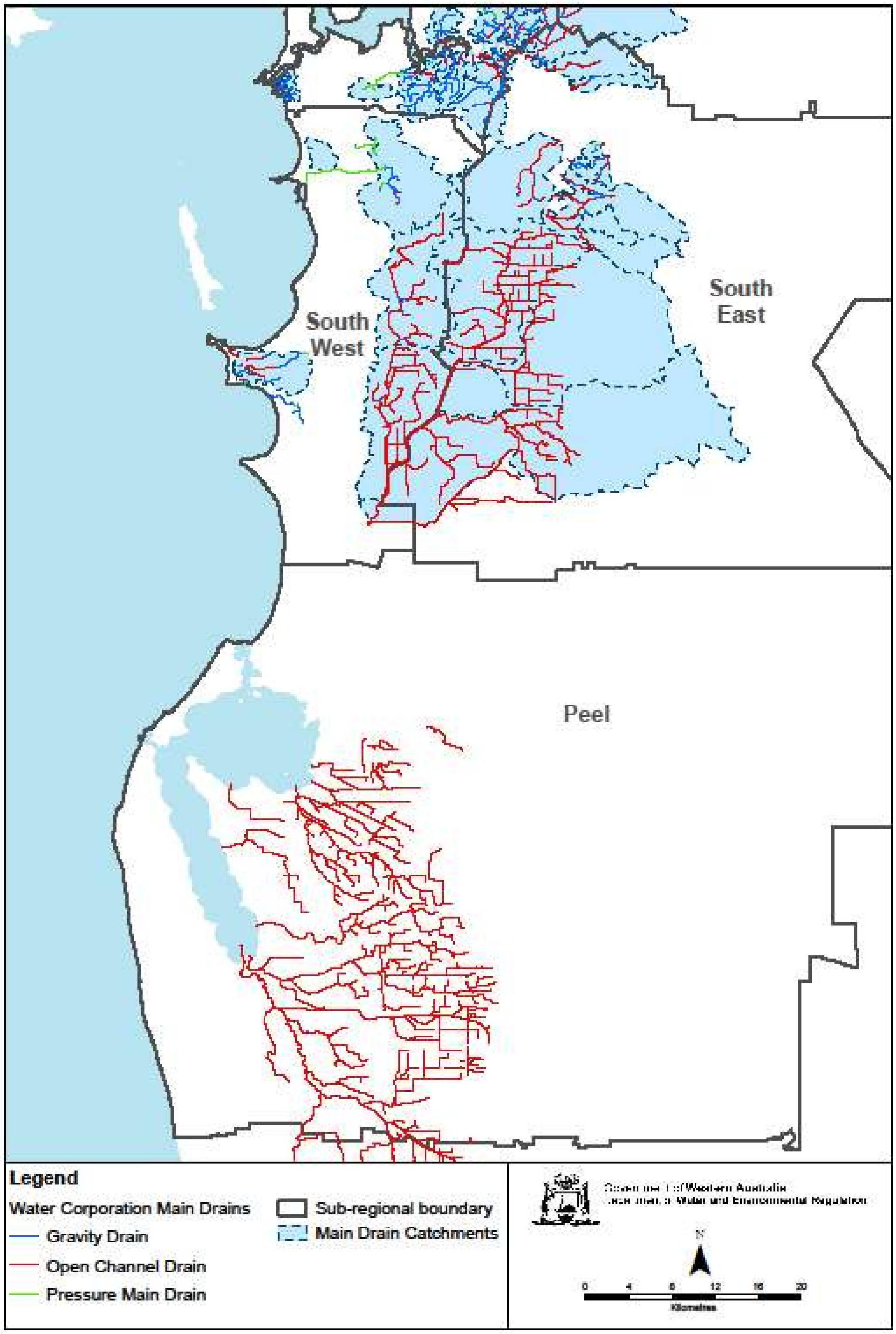

Figure 6-3. Main drains and their catchments in the three southern sub-regions

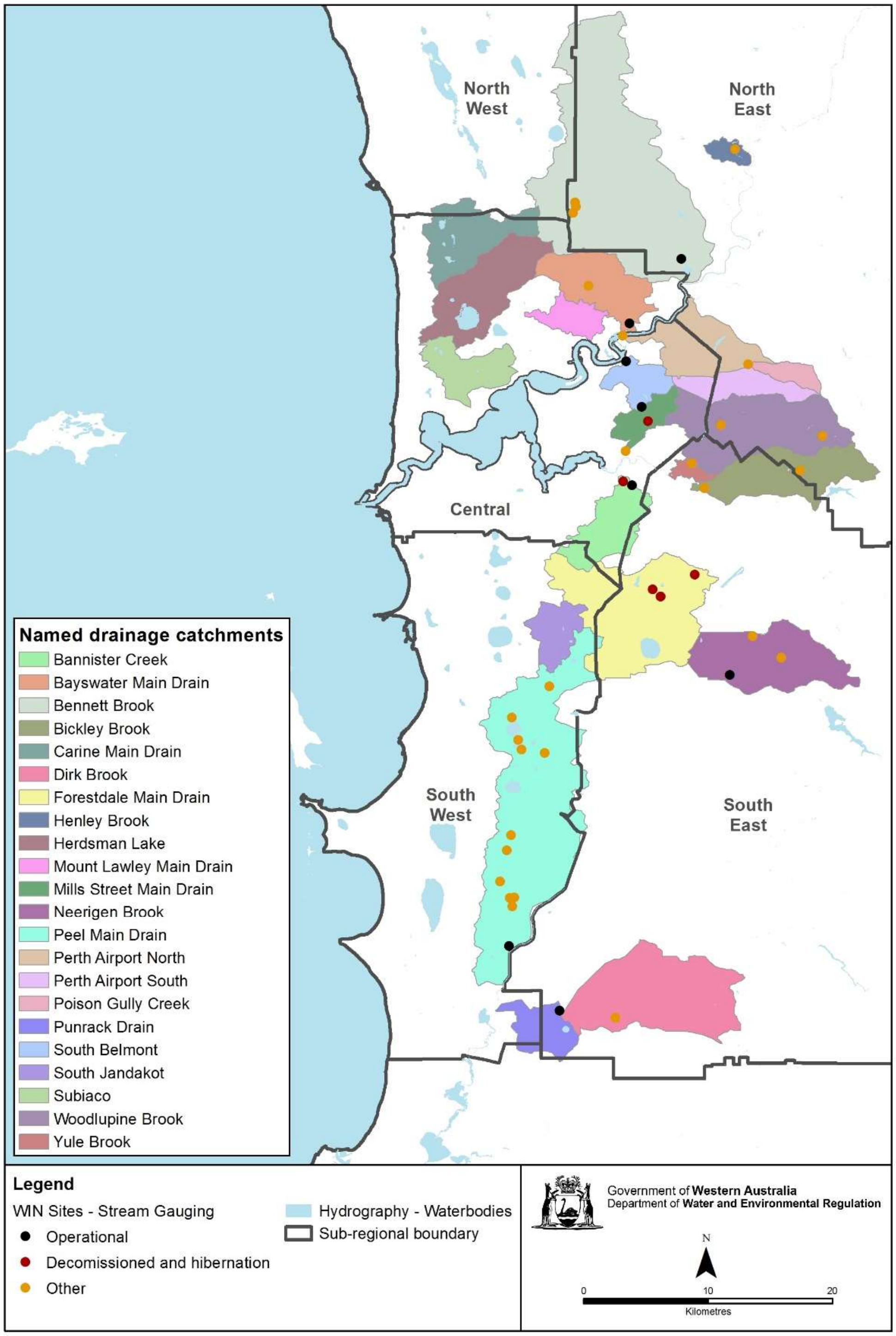

Figure 6-4. Location of named main drains in the Perth and Peel regions

6.2 Trends in main drain flows

The Water Corporation provided all flow data for their main drains as part of this investigation. Some drains are no longer monitored, and the records are of variable length. Where available, additional streamflow data was added from Department of Water and Environmental Regulation sources.

In the Bassendean Dunes and Guildford Formation (Figure 3-1Figure 3-2) there is a cross-over between main drain and natural drainages, which makes interpretation difficult. No major natural drainages were included in the following analyses because it is unlikely that they could be diverted for recharge purposes.

The Yule Brook Main Drain has occasionally very high flows including several in the past two years (Figure 6-5). However, the overall trend in daily flows is for a decrease. Yule Brook is the most eastern of all the main drains (Figure 6-4) and arises on the Darling Range (Department of Water 2016a).

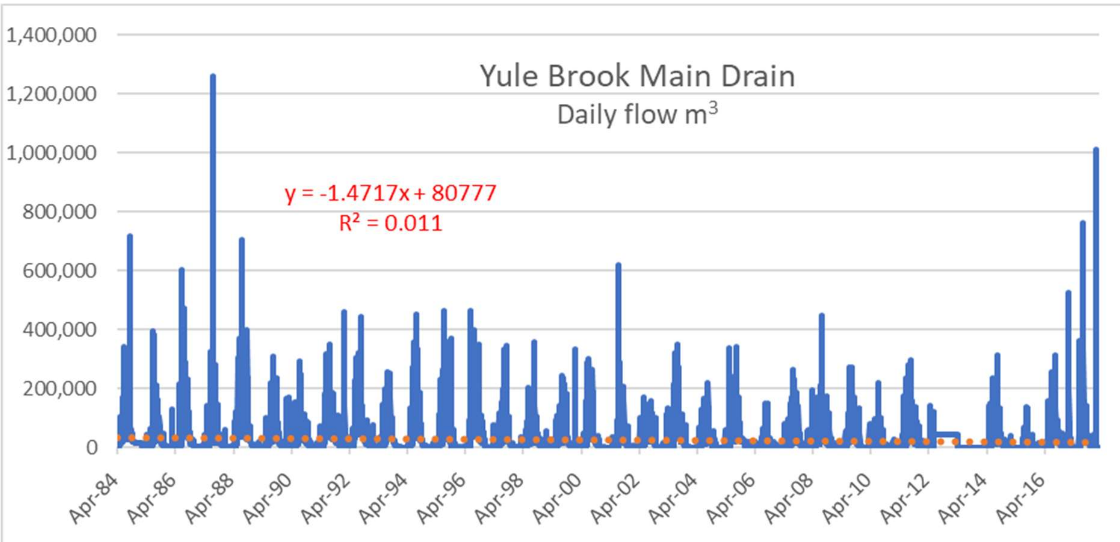

Figure 6-5. Daily flow data from Yule Brook Main Drain (Water Corporation data)

Poison Gully Creek also arises in the Darling Range and flows through less-developed areas before discharging to Munday Swamp at Perth Airport and then the Swan River. Its daily flow is very seasonal and has reduced similarly to Yule Brook (Figure 6-6), as have many natural drainages in the Darling Range.

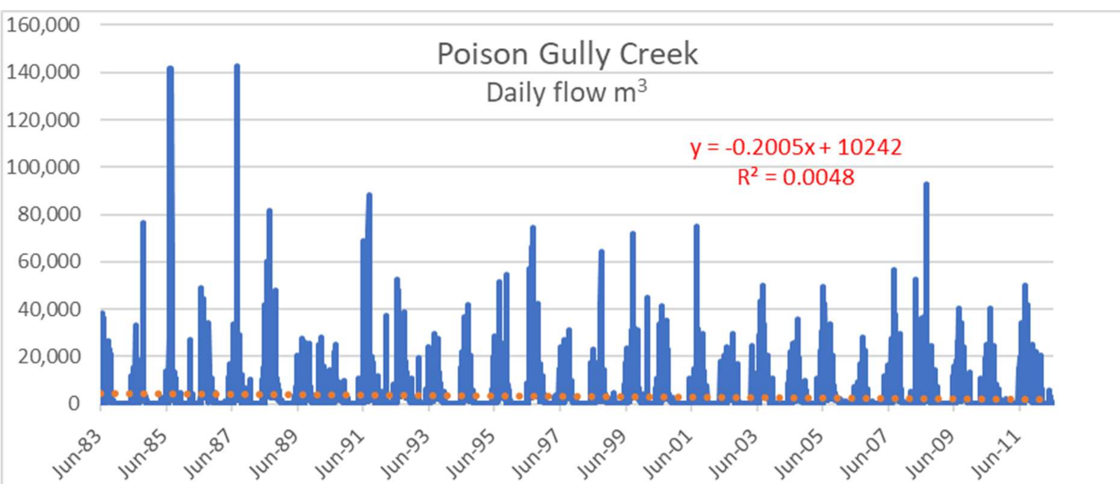

Figure 6-6 Daily flow data from Poison Gully Creek (Water Corporation data)

Flows in Woodlupine Brook have been studied because of its diversion to the Superficial Aquifer at Hartfield Park (City of Kalamunda 2018). While having a similar geographic setting to Yule Brook and Poison Gully, it has a slightly greater rate of fall, an estimate that is exacerbated by the period of missing record in 2013 and 2014 as shown in Figure 6-7.

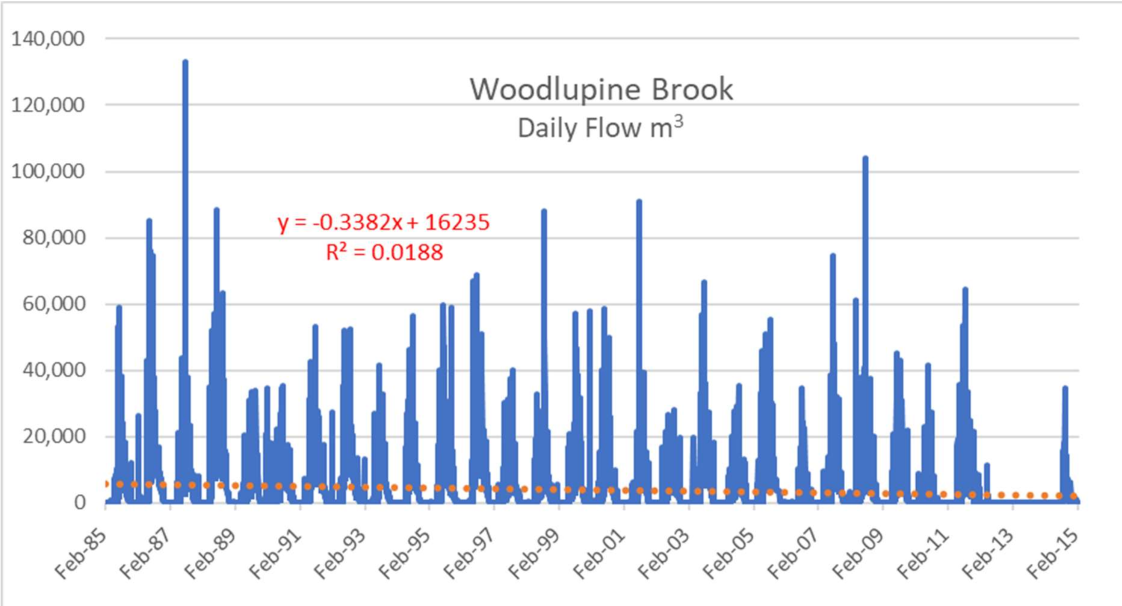

Figure 6-7. Daily flow data from Woodlupine Brook (Water Corporation data)

Like Yule Brook, Poison Gully, Bickley Brook and Woodlupine Brook, Neerigen Brook runs off vegetated parts of the Darling Range before entering urbanised areas and eventually the Canning River. It has experienced an even greater reduction in average daily flow than the others (Figure 6-8).

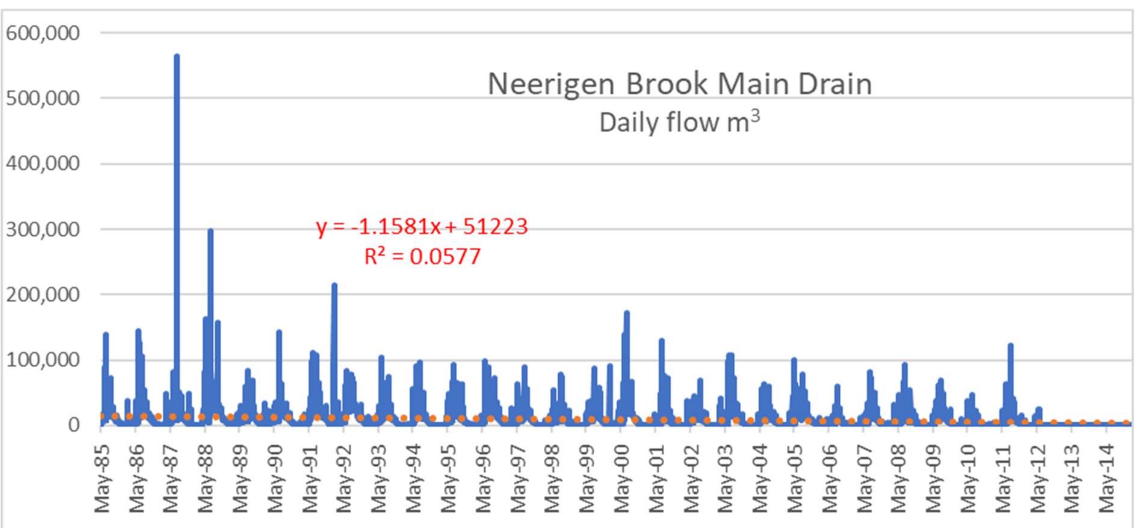

Figure 6-8. Daily flow data from Neerigen Brook Main Drain (Water Corporation data)

The Mill Street Main Drain, which also enters the Canning River, has a similar long-term downward trend in daily flows (Figure 6-9). The catchment is highly developed and has a high watertable within Bassendean Sands (Department of Water 2016b).

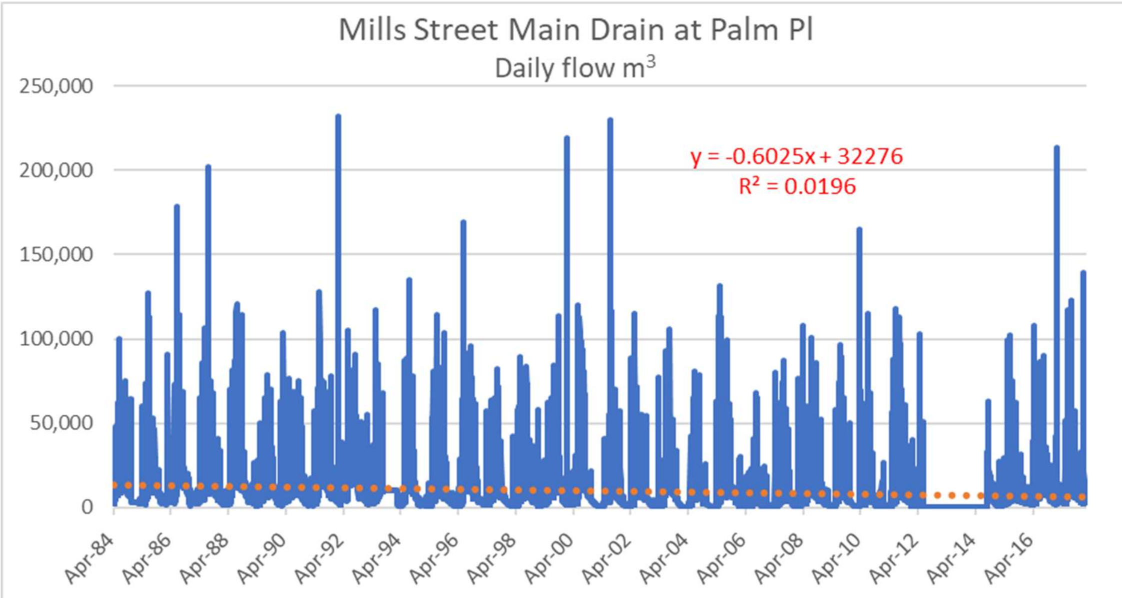

Figure 6-9. Daily flow data from Mill Street Main Drain (Water Corporation data)

Both average and peak flows in the Mount Lawley Main Drain have decreased since monitoring started in 1984 (Figure 6-10). Groundwater levels fell in this catchment between 1998 and 2007 (Figure 5-2), which covers the middle to latter parts of this period of record.

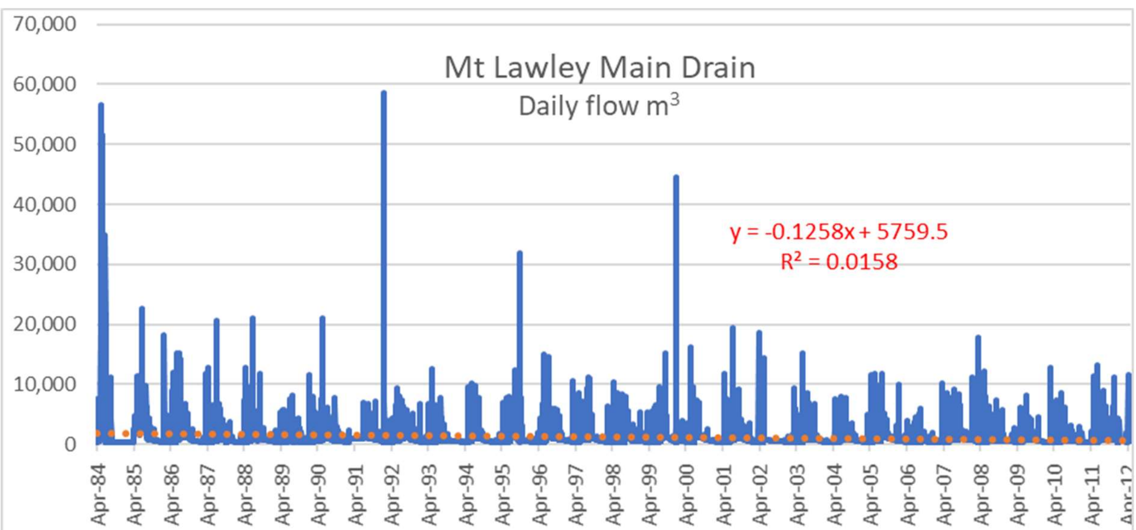

Figure 6-10. Daily flow data from Mount Lawley Main Drain (Water Corporation data)

Bickley Brook is a tributary of the Canning River and had a reservoir built in 1921. It is another drainage that originates in hills catchments and is experiencing a decline in flows (Figure 6-11). Peak flows have especially reduced as runoff in all Darling Range streams have declined, a trend most evident in inflows to Perth's metropolitan drinking water dams.

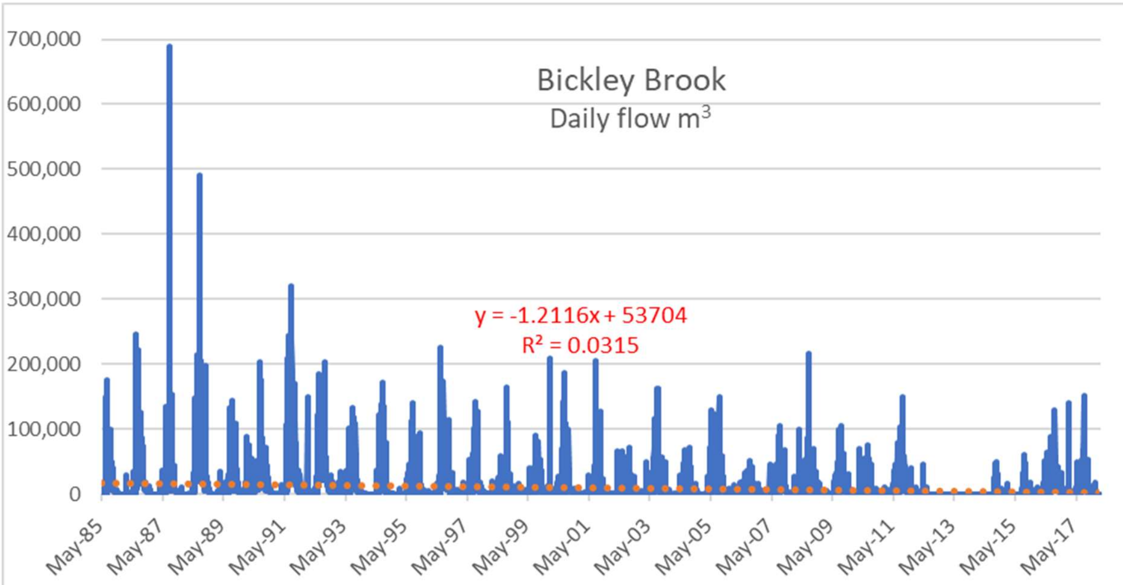

Figure 6-11. Daily flows in Bickley Brook (Water Corporation data)

Henley Brook arises on the eastern flank of the Gnangara Mound and discharges into the Upper Swan River. Its catchment is undergoing urbanisation at Ellenbrook. While flows are very small, they increased between 1995 and 2012 (Figure 6-12), possibly because of pine removal and urbanisation.

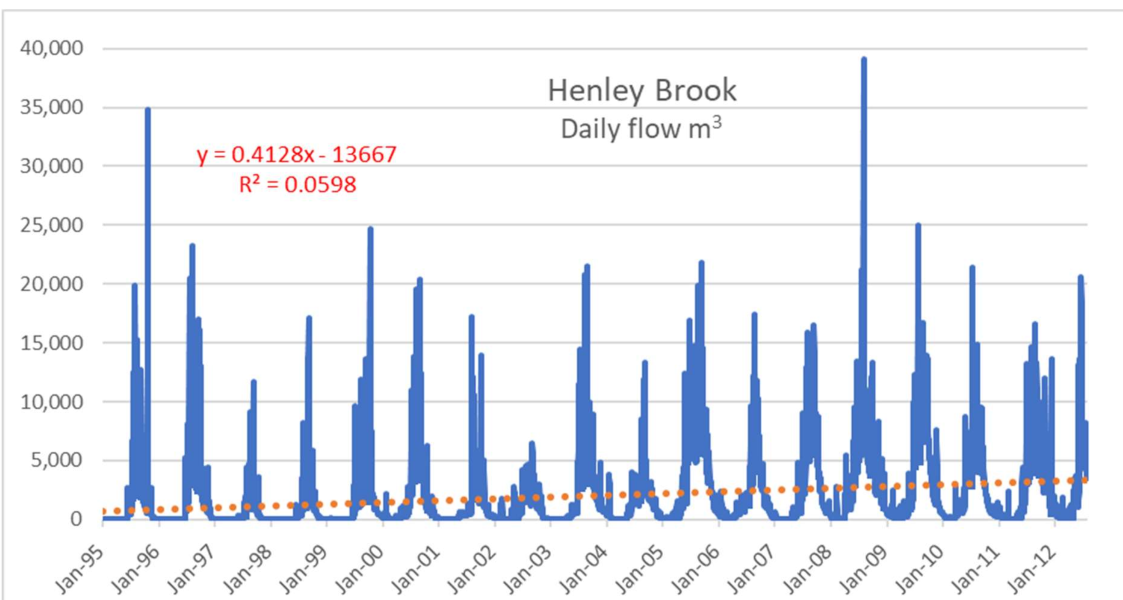

Figure 6-12. Daily flows in Henley Brook (Water Corporation data)

Like Henley Brook, the much larger Bennett Brook arises from the flank of the Gnangara Mound and discharges to the upper Swan. Daily flows have generally declined (Figure 6-13), along with groundwater levels in the Superficial Aquifer (Figure 5-4). Both Henley and Bennett brooks had high flows in late July- early August 2008 after a storm brought more than 60mm to Perth Airport. The trend is approximate given the missing data between 1993 and 2001.

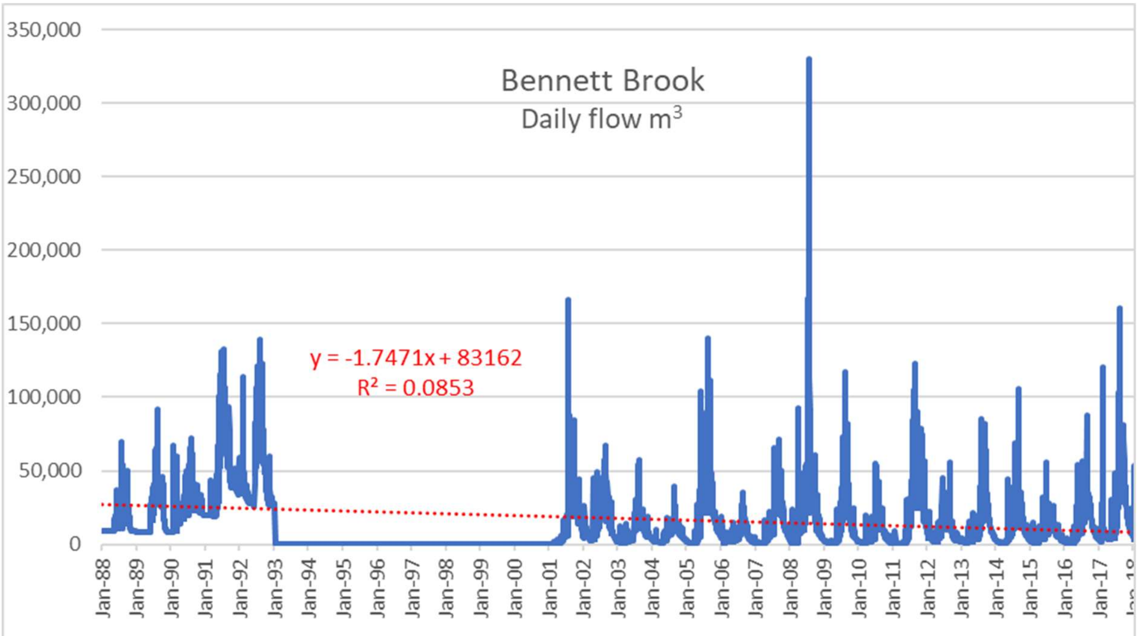

Figure 6-13. Daily flows in Bennett Brook (Water Corporation data)

The South Belmont Main Drain removes groundwater from urban areas underlain by Bassendean Sands and discharges it into the middle Swan Estuary (Department of Water 2016c). Flows have remained relatively constant between 1988 and 2010 (Figure 6-14).

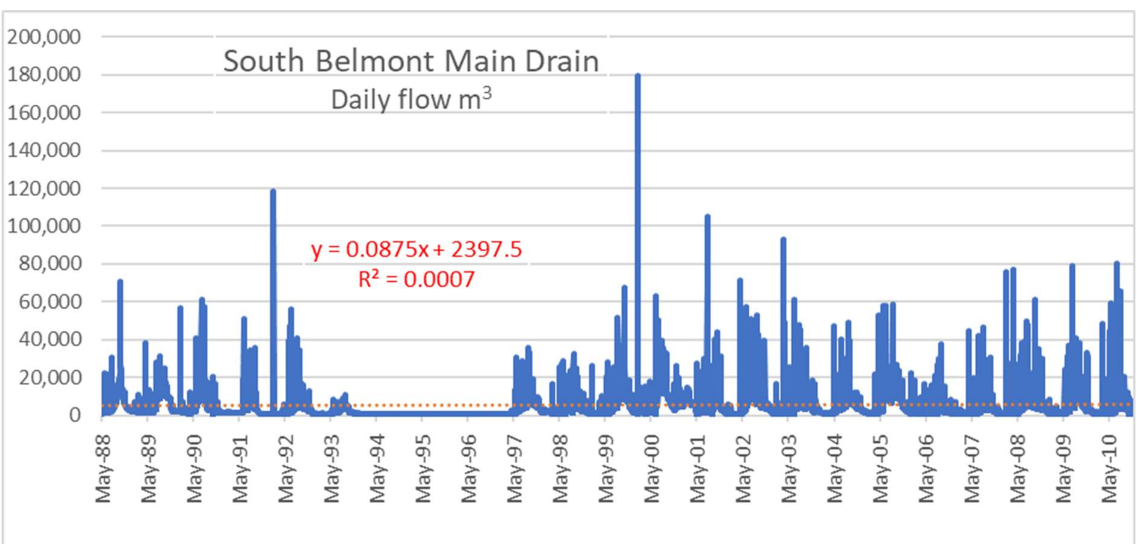

Figure 6-14. Daily flows in South Belmont Main Drain (Water Corporation data)

The Bayswater Main Drain contains sections that were once natural watercourses (Department of Water 2016d) before it discharges into the middle Swan Estuary. Flows have almost halved between 1988 and 2015 (Figure 6-15).

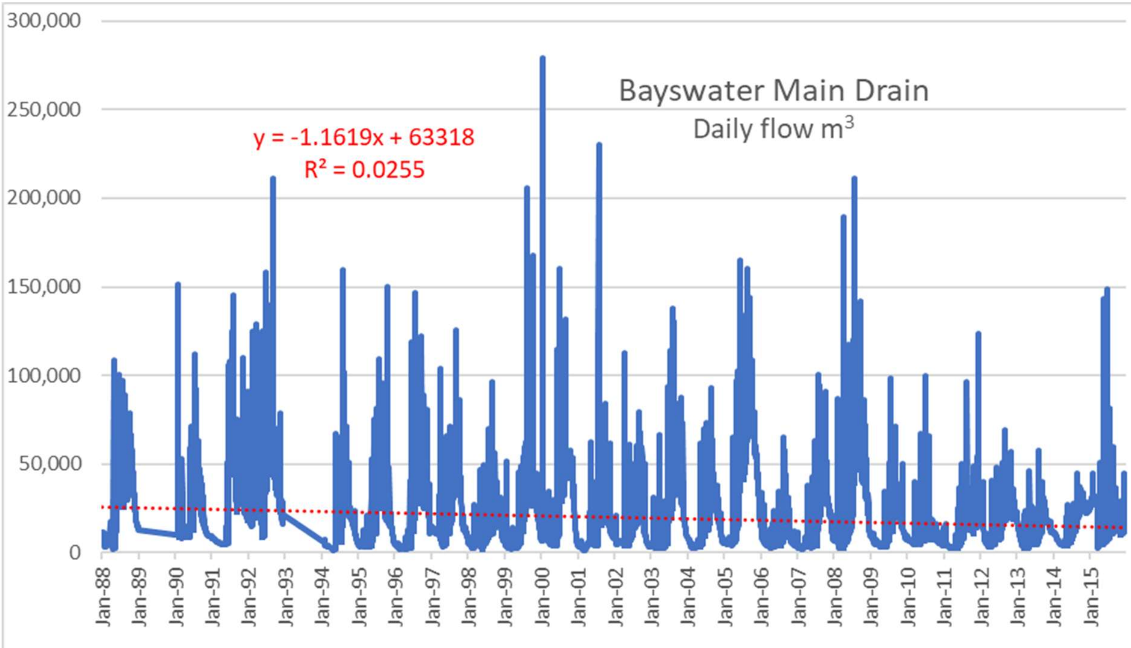

Figure 6-15. Daily flows in Bayswater Main Drain (Water Corporation data)

Increases in flow in the South Jandakot Drain are small in volume (0.02 GL/y), but large in percentage terms, because the flows are low (Figure 6-16). The increase correlates with rising groundwater levels (Figure 5-4), which may be the result of urbanisation in the catchment.

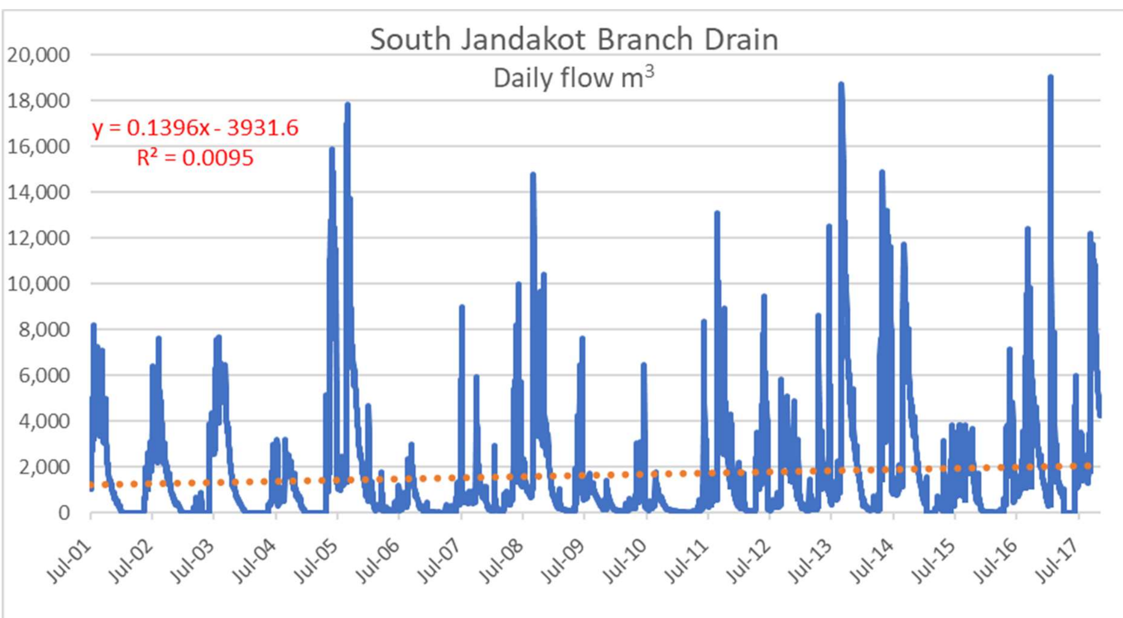

Figure 6-16. Daily flows in South Jandakot Branch Drain (Water Corporation data)

The Herdsman Main Drain lowers groundwater levels in the Osborne Park industrial area and includes water from Herdsman and Jackadder lakes. Interest in diverting the drain into either the Wembley Golf Course or Perry Lakes has resulted in it being re-monitored since February 2018. Flows decreased during the six-year period it was monitored in the later 1990s (Figure 6-17).

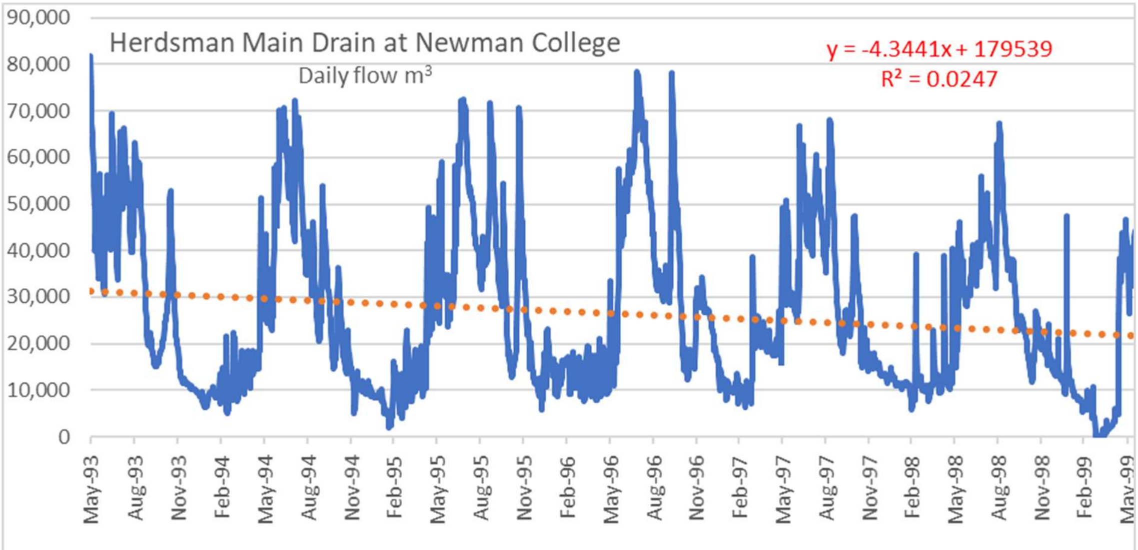

Figure 6-17. Daily flows in the Herdsman Main Drain at Newman College (Water Corporation data)

Slightly less than four years of data are available for the Peel Main Drain at Folly Pool. These show a rise in flows, almost all being in winter (Figure 6-18).

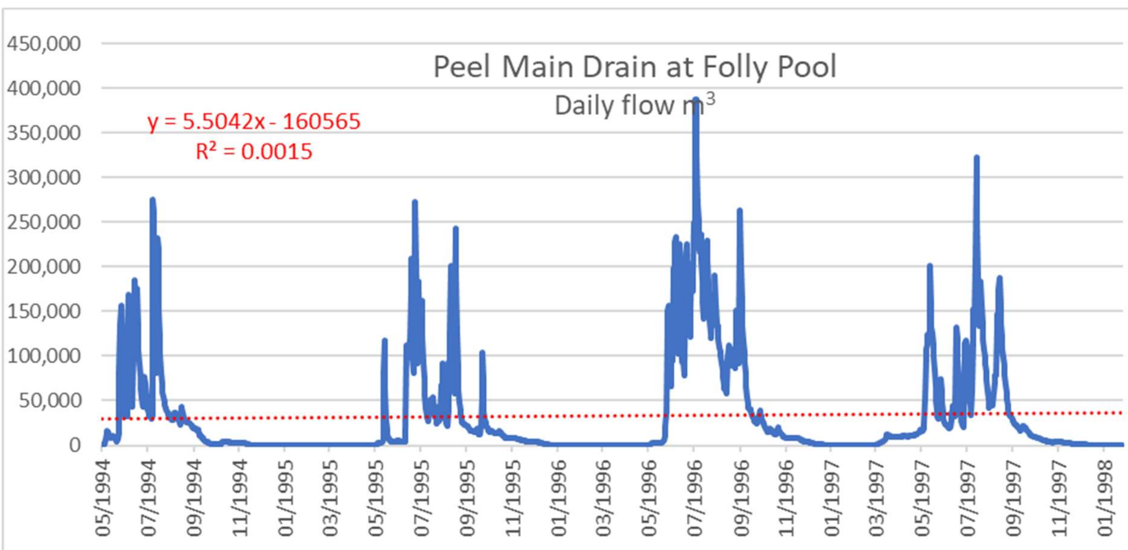

Figure 6-18. Daily flows in the Peel Main Drain at Folly Pool (Water Corporation data)

Annual flows in the Peel Main Drain at Karnup Road, which is further downstream from Folly Pool, show a decrease in flow between 2005 and 2015 (Figure 6-19). The Peel Main Drain starts in the north at Banjup Swamp, flows through Mandogalup Swamp, The Spectacles and Bollard Bulrush Swamp before reaching Folly Pool and Karnup Road. The 'drain' is a natural drainage line that has been modified. It eventually joins the Serpentine River.

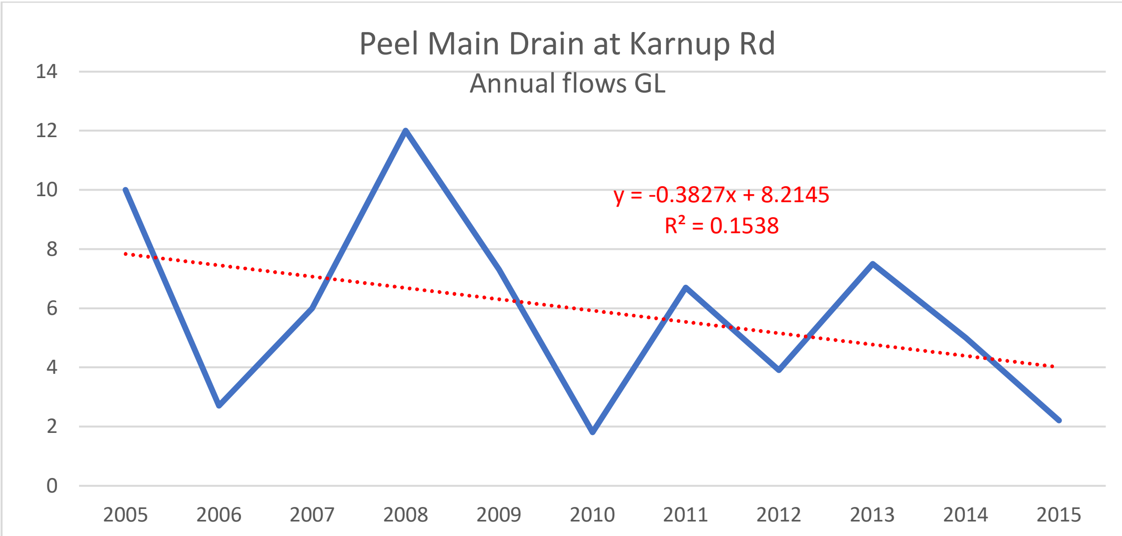

Figure 6-19. Annual flows in the Peel Main Drain at Karnup Road (Department of Water 2016c)

Dirk Brook arises on the Darling Plateau before flowing onto the Swan Coastal Plain, where it is later re-named Punrak Drain, before entering Lake Amarillo, one of the Serpentine lakes (Department of Water 2017). These eventually discharge into the Peel Inlet. Daily flows provided by Water Corporation for the period between 1971 and 2001 show a slight reduction (Figure 6-20).

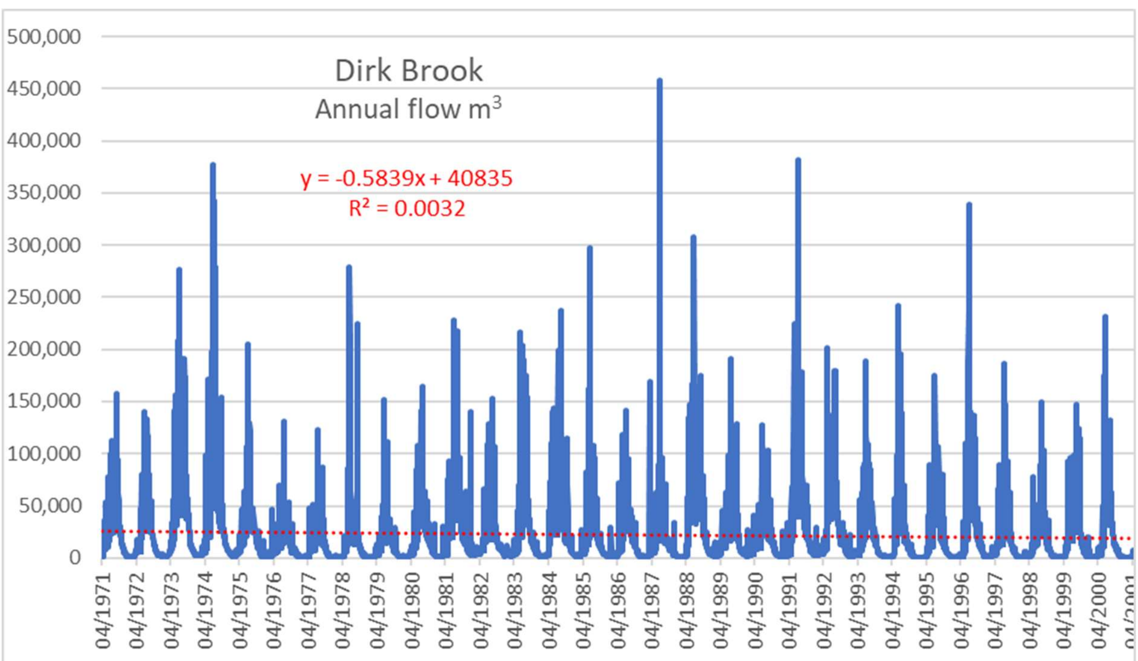

Figure 6-20. Daily flows in Dirk Brook (Water Corporation data)

Annual flow data for Dirk Brook at Punrak Drain show a more dramatic reduction in flows between 2003 and 2016 (Figure 6-21).

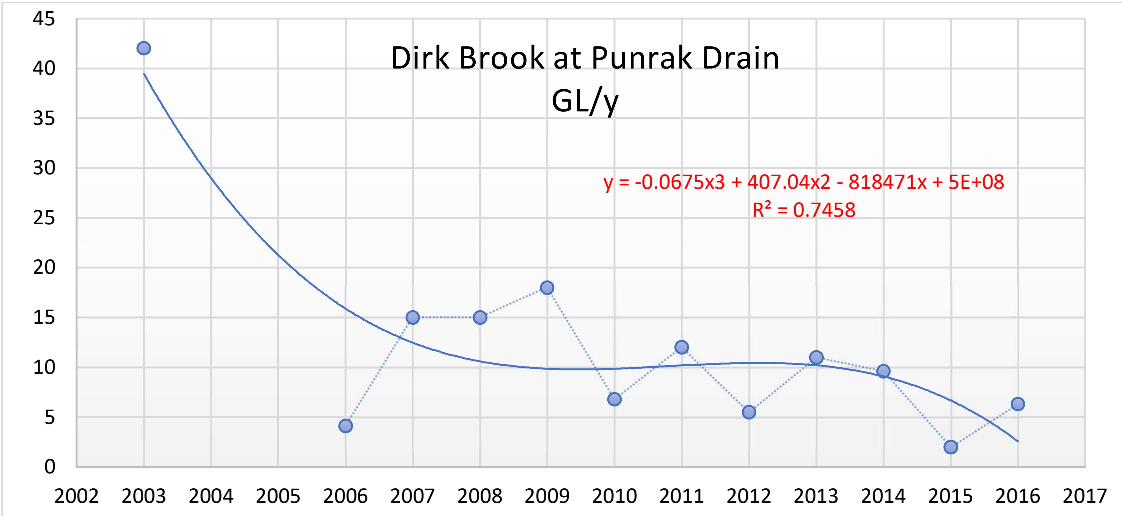

Figure 6-21. Annual flows in Dirk Brook at Punrak Drain (Department of Water 2017)

Summaries of the trends in flows are shown in Table 6-1. Thirteen of the seventeen drains have reductions in flow of between 0.8 and 6.5% per annum. This assumes a linear reduction, but reductions may also be slightly convex, or concave as was shown in Figure 6-1. Some early rates of fall must have reduced for records that do not extend to the present, or flows would have ceased or reversed by 2018. Flows in the Herdsman Main Drain have been monitored since February 2018 and five other drains may similarly be monitored in future (Suzanne Brown, pers. comm. 5th April 2018).

Four drains have recorded increased flows: Henley Brook, which lies west of Bennett Brook; the South Jandakot Branch Drain; the South Belmont Main Drain; and the Peel Main Drain, which was only monitored for 4 winters (Table 6-1). There were 0.1 to 0.5m rises in groundwater levels between 1998 and 2017 in the Henley Brook and South Belmont catchments (Figure 5-4), and both rises and falls around the South Jandakot Drain between 2008 and 2017 (Figure 5-2). The Peel Main Drain at Folly Pool (Figure 6-18) has a slightly increased flow, but flows further downstream within this drain have decreased (Figure 6-19). Some rises are due to land use changes (e.g. pine removal, urbanisation), but the overall trend is for reduced flow in main drains. While this may make them less reliable for managed aquifer recharge in future, there are rising groundwater levels in some urban areas between 2008 and 2017 (Figure 5-3). Because this period was not well gauged it is possible that drain flows may have stabilised or even increased, but this data has not been recorded.

Table 6-1 Trends in flow in selected monitored drains

Drainage	Period gauged	Start flow (GL/y)	End flow (GL/y)	Change (GL/y)	Change (%/year)
Yule Brook Main Drain	April 1984 – March 2018	12.96	6.29	-0.20	-1.5
Poison Gully Creek	June 1983 – June 2012	1.51	0.74	-0.02	-1.8
Woodlupine Brook	Feb 1985 – Feb 2012	2.09	0.74	-0.05	-2.1
Neerigen Brook Main Drain	May 1985 – May 2012	5.53	1.37	-0.15	-2.8
Mill Street Main Drain	April 1984 – March 2018	5.02	2.29	-0.08	-1.6
Mt Lawley Main Drain	April 1984 – April 2012	0.69	0.22	-0.02	-2.4
Bickley Brook	May 1985 – March 2018	5.83	0.50	-0.16	-2.8
Henley Brook	Jan 1995 – July 2012	0.24	1.20	+0.06	+23.3
Bennett Brook 616084	Jan 1988 – Jan 2018	9.86	2.87	-0.23	-2.3
South Belmont Main Drain 616087	May 1988 – Nov 2010	1.88	2.14	+0.01	+0.6
Bayswater Main Drain 616082	Jan 1988 – Dec 2015	9.48	5.14	-0.15	-1.6
Herdsman Main Drain	May 1993 – May 1999	11.52	8.05	-0.58	-5.0
South Jandakot Branch Drain	July 2001 – Nov 2017	0.45	0.76	+ 0.02	+4.1
Peel Main Drain Folly Pool 614096	June 1994 – Feb 1998	10.68	13.37	+2.69	+6.7
Peel Main Drain Karnup Rd 614121	2005-2015	7.9	4.0	-0.35	-4.4
Dirk Brook 614005	April 1971- April 2001	9.36	7.02	-0.08	-0.8
Dirk Brook at Punrak Drain	2003-2016	42.0	6.3	-2.75	-6.5

There are several patterns in the trends in flows shown in Table 6-1:

- Flows in drains emanating from the Darling Range south of the Swan River (Yule Brook, Poison Gully, Woodlupine Brook, Neerigen Brook) have been decreasing by 1.5 to 2.8% per annum, which is like that for runoff into the hills catchments' drinking water reservoirs;
- Drains from the eastern flanks on the Gnangara Mound (Bickley Brook, Bennett Brook, Belmont Main Drain) are similarly falling by between 1.6 and 2.8% per annum, except where changes in land use have increased groundwater levels and drain flows (Henley Brook, South Belmont Main Drain);
- Large reductions in drain flows have occurred in western areas (Herdsman Main Drain, Peel Main Drain at Karnup); even though urbanisation often results in increased flows (Peel Main Drain at Folly Pool). It is possible that these drains were not excavated far below the watertable and declines in groundwater levels have resulted in them being disconnected;
- Dirk Brook has the largest reduction in flows, possibly because it receives water from the Darling Scarp. In addition, groundwater levels in the catchment have fallen consistently between 1998 and 2017 (Figure 5-4). The reductions may result from lower rainfall, increased pumping and some urbanisation of the catchment.

6.3 Updated estimate of main drain flows

The data in the previous section relates to individual gauged drains. The last comprehensive published assessment of drainage flows to the Swan-Canning Estuary, Harvey-Peel Estuary and Indian Ocean were made by GHD (2008). No attempt was made at that time to assess trends in the flow data attributable to climate change (Jose Romero pers. comm. 2 May 2018).

For the Swan-Canning Estuary, simulation modelling using the Large-Scale Catchment Model (LASCAM) for the 1976 to 2000 period was used by GHD (2008). The area modelled was about 280 km^2 and included 75 drainage catchments ranging in size range from 0.2 to 27.8 km^2 (GHD 2008). The median discharge estimates totalled 80.7 GL/year and were derived from the catchments shown in Table 6-2. Estimates excluded natural flows from the Avon River above Millendon, Ellenbrook, Jane Brook and the Helena River.

GHD (2008) quote Water Corporation estimates of the three coastal main drains to be Carine (7 GL/year), Herdsman (8 GL/year) and Subiaco (3 GL/year). For the two Peel main drains the median annual discharge from 1971 to 2001 was estimated to be 8 GL for the Dirk Brook Main Drain at Kentish Farm and 12.6 GL for the Peel Main Drain at Folly Road. As shown in Table 6-2, the combined mean annual runoff for the Swan Canning Estuary (80.7 GL/year), Coastal (18 GL/year) and Peel main drains (20.6 GL/year) was estimated to be about 120 GL/year by GHD (2008).

Estimates of drain flows made by GHD (2008) have been updated (Table 6-2) by extending trends in drain flows (Table 6-1) and considering whether groundwater levels have been rising or falling between 2008 and 2017 (Figure 5-3),. These extrapolations are only approximate because they are aggregates of drains in areas. Estimates should be done individually where catchment areas, land uses and depths of the watertable are well known or have been modelled.

Table 6-2. indicates that about 100 GL/year of drain flows may be available for potential diversion. Open drains can have important environmental flows, or nearby residents prefer flowing water (social amenity), so this volume should be considered an upper limit. Ideally, monitoring should be carried out to provide data that will help us understand the potential volumes available for diversion or reuse. This monitoring is currently being undertaken for the Herdsman and Subiaco main drains and the data needs to be examined before a decision can be made by the Town of Cambridge about augmenting Perry Lakes.

Table 6-2. Main flows in 2008 (data provided by GHD 2018) and how they may have changed by 2018 (this report)

Catchment name	GHD (2008) estimated flow (GL/y)	Adjusted flow in 2017 (GL/y)	Comments
Upper Swan	1.8	1.6	Groundwater levels have fallen more than risen in these catchments and most monitored drain flows have been reducing so flows have been adjusted down by 11%
Perth Airport North	12.9	9.0	Drains arising in the Darling Scarp are especially reducing in flow and groundwater levels along the scarp have fallen so flows have been reduced by about 23%
Perth Airport South	10.7	8.5	Similar conditions to Perth Airport North so flows have been reduced by 21%
Maylands	5.3	4.0	Mt Lawley and Bayswater drains are reducing by about 2% per annum so drain flows have been reduced by 25% to reflect the much larger contribution by the Bayswater Drain
Belmont Central	1.1	1.2	Slight increase in South Belmont Drain
Claisebrook	3.0	3.5	Drain flows should increase following the rise in groundwater levels since 2008
CBD	3.9	4.5	Drain flows should reflect the rise in groundwater levels since 2008
South Perth	11.3	11.5	Flows should have remained similar or risen slightly with recent groundwater level changes
Bullcreek	16.9	15.0	South of the river has falling groundwater levels since 2008. There are no monitored drains to assess trends in this area
Lower Canning	1.7	1.6	Slight reduction possible (e.g. Mill Street Drain trend is down) but urbanisation may counter this impact.
Drains entering the estuary from the south downstream of the Canning River	5.0	4.0	South of the river has falling groundwater levels since 2008
Drains entering the estuary from the north downstream of the CBD	2.4	2.6	Slight rise in groundwater levels in urban areas since 2008
Total into estuary	**80.7**	**66.0**	
Coastal main drains	18.0	13.0	Very limited flow gauging but Herdsman was falling rapidly in the late 1990s. There has been limited urban infill to offset the reduction in rainfall.
Dirk Brook Main Drain	8.0	6.0	Extension of downward trend to 2001 with upwards adjustment for urbanisation and groundwater rise
Peel Main Drain at Folly Road	12.6	14.5	Urbanisation and rising groundwater levels in areas should offset falls
Total drainage flows	**ca. 120**	**ca. 100**	

6.4 Water quality of main and local drains

The impact of main and local stormwater drain discharge on Perth beaches was investigated by the Department of Water in 2007. The department found the beaches were mainly contaminated with microbes and heavy metals. Nutrients, petroleum hydrocarbons, organic chemical compounds and suspended solids were also present, but to a lesser extent.

Microbial quality was extremely poor with recordings of around 20 times the guideline value for secondary contact (i.e. fishing or boating) in six regions. Microbial quality in the swash zone, where swimming is most likely, was also poor with seven of the nine regions exceeding primary contact recreational guideline values for swimmers (ANZECC and ARMCANZ 2000). Rockingham, Safety Bay, Stirling and Cottesloe exceeded these guidelines by at least six-fold.

Total metal concentrations (aluminium, copper, iron and lead) in stormwater in Joondalup, Stirling, Scarborough and Cottesloe were consistently higher than other regions, exceeding the ANZECC and ARMCANZ (2000) environmental guidelines by up to 21-fold. Total metal concentrations in sediment were higher in three regions south of the Swan River.

While nutrient concentrations were generally low relative to the other contaminants, there were exceptions:

- Dissolved nutrient concentrations were high in Cambridge (nitrogen oxides by six-fold), Scarborough and Safety Bay (ammonia by four-fold); and Cottesloe (filterable reactive phosphorous by two-fold) relative to the relevant ANZECC and ARMCANZ (2000) guideline values. Total phosphorus concentrations in all regions except Cambridge, exceeded environmental guidelines by up to two-fold. This was mostly due to particulate phosphorous.
- Total petroleum hydrocarbons were particularly high in Joondalup, Stirling and Cottesloe.
- Sites of concern include one in Stirling that consistently exceeded the ANZECC and ARMCANZ (2000) guideline levels for petroleum hydrocarbons as well as heavy metals in stormwater (aluminium, copper, iron, and lead) and in sediment (copper); and the Herdsman Main Drain which flows continuously and where NOx levels exceeded the relevant ANZECC and ARMCANZ (2000) guidelines by six-fold.

Foulsham et al. (2009) conducted a baseline study of organic pollutants entering the Swan and Canning estuaries via constructed drains and natural drainage lines. Contaminants were detected in surface water in all sub-catchments. The passive samplers that were used adsorbed contaminants dissolved in water, but not those bound to suspended solids. The highest and most widespread organic contaminant levels were detected in the Bayswater, Southern River, Belmont South and Perth Airport South sub-catchments. Twenty-five pesticides were detected, with simazine, diuron and atrazine the most prevalent. Polycyclic aromatic hydrocarbons (PAHs) were detected in all sub-catchments, but none exceeded freshwater ecosystem trigger values. PAH values may have been higher in suspended solids, which were not analysed.

Nice et al. (2009) conducted a similar baseline study of contaminants in drainages entering the Swan and Canning estuaries in 2006, an exceptionally dry year. The sampling included both water and surface sediments within drains. PAHs were usually only found in drain sediments. They consistently exceeded the relevant ANZECC and ARMCANZ (2000) guidelines in the Helena River, Perth Airport South and the Central Business District (CBD). Organochlorine pesticides were detected mainly in sediments of the Bayswater Main Drain, Blackadder Creek, Central Belmont Main Drain, South Belmont Main Drain, Helena River, Maylands, Upper Swan, Mills Street Main Drain and Lower Canning sub-catchments. Neither organophosphorus pesticides nor polychlorinated biphenyls (PCBs) were detected in any of the drains within the limits used for analysis. Herbicides (mainly simazine and atrazine) were sporadically detected in the Bayswater Main Drain, Bennett Brook, Blackadder Creek, Central Belmont Main Drain, Helena River, Jane Brook, Maylands, St Leonards Creek, Upper Swan, Bannister Creek, Bickley Brook, Helm Street Main Drain, Lower Canning, Mills Street Main Drain and Yule Brook sub-catchments. All 14 metals that were analysed were detected in both sediment and surface water samples except for mercury, which was only detected in sediment samples. The Bayswater Main Drain, Blackadder Creek, Bannister Creek, Mills Street Main Drain and Upper Canning sub-catchments had significantly higher concentrations of metals. Both faecal coliforms and enterococci were detected, and Primary Contact Recreational Guidelines were exceeded for either one or both parameters in all sub-catchments. Secondary Contact Recreational Guidelines were also exceeded for either one or both parameters in the Blackadder Creek, CBD, Helena River, Henley Brook, Maylands, Perth Airport North, Perth Airport South, Bannister Creek, Bickley Brook, Lower Canning River, Mills Street Main Drain and Upper Canning River sub-catchments. Three drains had low pH (acidic) water: St Leonards Creek, Susannah Brook and South Perth. Dissolved oxygen levels were generally low in most sub-catchments.

Foulsham (2009) carried out a snapshot of contaminants in drains from four Perth industrial areas: Osborne Park/Herdsman Lake, Bayswater Drain, Bickley Brook and Bibra Lake. Surfactants and metals were consistently detected at all sites. Total petroleum hydrocarbons (TPH) concentrations were highest in sediments at one of the Herdsman Lake sites, Bibra Lake and both the Bickley Brook sites. Herdsman Lake was identified by Foulsham (2009) to have the highest level of contaminants of the four locations with polychlorinated biphenyls (PCBs), ethinylestradiol and a range of other contaminants. Bayswater had an elevated concentration of ethinylestradiol detected on one occasion and its total aluminium concentrations in surface waters were consistently above environmental trigger values. The Bibra Lake sump had high concentrations of polycyclic aromatic hydrocarbons (PAHs), with trigger values in the relevant ANZECC and ARMCANZ (2000) guidelines exceeded on several occasions. Other than industry, contaminants were thought to come from septic tanks, road runoff, bushfires and fertiliser application on residential properties, and in parks and reserves.

Methods to improve main drain water quality were examined by Barron et al. (2010). They found:

- storm runoff delivers 20 to 60% of annual loads of predominantly particulates and organic nutrients during May to October;
- low baseflow in November to April delivered less than 15% of annual loads of predominantly particulate and organic nutrients and $PO_{4,}$ when the Swan-Canning is particularly sensitive to nutrient inputs; and
- high baseflow in the wet season between June and October delivers 20-60% of annual nutrient loads.

The following issues were considered by Barron et al. (2010) to be important when selecting best management practices (BMPs) for main drains:

- no single BMP will treat all nutrient forms (dissolved, particulate etc), but vegetated systems may provide better control than non-vegetated BMPs;
- badly planned BMPs can become a source of nutrients, because of nutrients introduced during construction, the seasonal release of accumulated biomass and eutrophication;
- there are limited options for in-situ treatments of groundwater and for organic nutrients;
- assessing BMPs is difficult; and
- the efficiency of BMPs may reduce in time if not maintained.

The studies mentioned above show that receiving surface water bodies and beaches may already be impacted by drainage waters that enter them. Diverting some of this water through soils and aquifers may improve its water quality, as has been shown for treated wastewater additions at both disposal (Donn et al. 2017) and research sites (Bekele et al. 2011). However, the risk of contaminating soils and aquifers needs also to be investigated on a site-by-site basis.

The studies reviewed above are relevant to current conditions, but they are also largely consistent with historical, but less detailed, measurements, which indicate that conditions may have been relatively stable. McFarlane (1983), Newman and Bishaw (1983) and JDA (2007) all found that the quality of street drainage water in Perth was better than that reported from eastern states cities. The Institute of Engineers Australia (2005) estimates the nutrient loads from Australian urban areas to average about 20 kg Total Nitrogen (TN)/ha/year and 1 kg Total Phosphorous (TP)/ha/year. However, JDA's (2007) measurements in WESROC catchments range between 2.1 and 2.7 kg TN/ha/year and 0.4 to 0.8 kg TP/ha/year. Compared with the surrounding groundwater, JDA (2007) found stormwater had lower levels of Total Dissolved Solids (TDS), electrical conductivities and TN, and higher TP and metals. It is possible that the differences in water quality are due to the low contribution of soil runoff from Perth's sandy soils, so the pollutants come almost totally from the roads rather than the catchments.

6.5 Drain water storage options

Because main drains are designed to lower groundwater levels, they are usually not well located to direct excess water into aquifers unless water is diverted from the drain area. GHD (2008) considered the following options:

1. Water Sensitive Urban Design (WSUD), including infiltration basins and swales, as well as lot-scale infiltration via soakwells;
2. Managed Aquifer Recharge (MAR) to the Superficial Aquifer;
3. Underground storage systems to store main drain runoff either from winter/spring baseflow or from episodic stormwater events;
4. Above ground storage systems to be used in a similar manner as the underground storage systems; and
5. Drainage channel modification, whereby the invert levels (i.e. base levels) of the main drains are elevated to drain less of the local groundwater stores and widened to maintain hydraulic capacity.

WSUD is now standard in new developments. A few examples of MAR opportunities are provided below, with regional opportunities summarised in an accompanying report (McFarlane 2018b). Underground and above ground storage can be very expensive, especially if land is required in high-value areas. Drain channel modification has been considered in areas of over-drainage, but experiences have not been documented.

The best documented diversion of main drain water to an aquifer is the Woodlupine Main Drain diversion to the Superficial Aquifer for irrigating Hartfield Park (City of Kalamunda 2018). Low infiltration rates at the surface meant the water must be injected into the aquifer. Concerns about aquifer clogging have required that the water is filtered and treated with activated carbon to avoid biofilms forming. Flows in the main drain, which come from the Darling Scarp, are also decreasing (Figure 6-6).

Water levels in Jackadder Lake have been revived by connection to the Osborne Park Branch Drain within the Herdsman main drain system (ENV Australia Pty Ltd 2008). Flows had to be reduced to lessen the incidence of algal blooms and midge infestations.

Two options for diverting the Herdsman to Floreat Main Drain into the Wembley Golf Course have been investigated. The first is a simple diversion of water from an open channel through a dive structure under a road to enter a depression on the golf course. This would cost about $220K (capital expenditure) and zero operating costs to divert about 2 GL/year, depending on the impact on flooded gums (*Eucalyptus rudis*) around the depression (GHD 2010). A later evaluation involved pumping water into large infiltration basins on the golf course, the cheapest of which cost $648K (capital expenditure) and $117K in operating costs for 1.7 GL/year (GHD 2011). Currently an evaluation is being undertaken by the Town of Cambridge to divert water from this drain to replenish both the golf course and Perry Lakes.

The Subiaco Main Drain could also be considered for diversion to Perry Lakes. This drainage system is already connected by a branch drain to Perry Lakes Reserve. The Subiaco drain water quality is likely to be better than in the Herdsman Drain, because there are no industrial areas or large, drying wetlands in the catchment. However, flows would be highly seasonal and may not be able to maintain levels in dry seasons and years.

Diversion of the main drain on Bay View Terrace, Claremont, to a series of underground infiltration cells in Claremont Park has been considered by JDA (2017). Depending upon the design chosen, between 12 and 53 ML/year of drainage water could be infiltrated to the Superficial Aquifer at a cost of $1.11 to $1.39 per kL. For comparison, drinking water consumption charges are $ 1.782 /kL for the first 150 kL, $2.375/kL for the next 449 kL, and $4.442/kL for any additional usage (https://www.watercorporation.com.au/my-account/your-bill-and-charges, accessed 16/10/18).

7. Street drains

7.1 Drain volumes

Street drainage or stormwater is mainly the responsibility of local government although as was shown earlier (Figure 6-2) there are some short drains in the Town of Claremont and the City of Fremantle that are managed by the Water Corporation. The cheapest way to remove stormwater is in local absorption- and compensation-basins, which may also be wetlands that are common in sandy parts of the Perth-Peel region. Only local governments with direct or indirect access to the Swan-Canning Estuary or the ocean, discharge to anything other than the Superficial Aquifer.

In the western suburbs, the ubiquity of deep sand means that only streets located close to the river or ocean discharge runoff into these water bodies. Local drains extend for only a kilometre or two from the river (JDA 2017) and the presence of coastal sand dunes along most of the coast means that little local stormwater drainage reaches the ocean. In the Upper Swan and Ellenbrook areas the watertable is higher, and surface drainages exist in riverine areas, making the removal of street runoff to the estuary more viable.

The value of recharging the Superficial Aquifer with stormwater has only become apparent in recent decades as watertables have declined. Detailed water balances calculated in the early 1980s showed that roads comprised 9.6% of the land surface in Nedlands-Dalkeith, a low urban density catchment, and 65-70% of rainfall on this surface recharged the Superficial Aquifer (McFarlane 1984). About 13.1% of Subiaco-Shenton Park, a medium-density urban catchment comprised of road surfaces, and about 90% of rainfall that fell on these roads recharged the aquifer at Lake Jualbup. Stormwater contributed more than three times the water extracted to irrigate areas of public open space in these catchments (McFarlane 1984). Stormwater recharge was not enough to offset private bore extraction, but recharge from roofs was enough.

The road area contributing to runoff has been accurately mapped for the area underlain by the Kings Park Formation using the Urban Monitor method (McFarlane and Caccetta 2017). The method takes account of trees that overhang roads as interception losses in tree canopies can significantly reduce road runoff in light storms (Figure 7-1). The figure shows how relatively small the area of road surface exposed to direct rainfall is in many urban areas. Some rain falling on tree canopies extending over roads will reach the road surface, but losses are likely to be about 40% or higher for small rainfall events. Showers interspersed with sunny and/or windy periods are increasingly common in Perth and Peel, which is likely to increase interception losses.

As a result, about 30% of rain that falls directly onto road surfaces was assumed by McFarlane and Caccetta (2017) to be lost to recharge, because of evaporation from the road surface and delivery system, and losses at the discharge point, especially for absorption basins located above the watertable.

Despite most road runoff already recharging the Superficial Aquifer (especially in western areas), there have been efforts to divert stormwater currently entering the river and ocean to the Superficial Aquifer to increase water available for irrigation. The Town of Mosman Park diverted its stormwater to the aquifer to prevent seawater intrusion with initial beneficial results (Figure 7-2, Glover 2002). More groundwater salinity readings would be required before the impact can be shown to persist. The Town of Cottesloe subsequently diverted its street drainage into absorption basins and a plan for enhanced stormwater infiltration has been prepared to the WESROC area (JDA 2017).

Replacing closed infiltration pits with soak wells in roads that drain to the river in the Claremont and Nedlands local government areas could divert about 32 ML/year at a cost of $1.03 to $3.05/kL over a ten-year planning period (JDA 2017). Whether these diversions would be enough to reverse or stabilise salt water interfaces would need to be monitored or modelled.

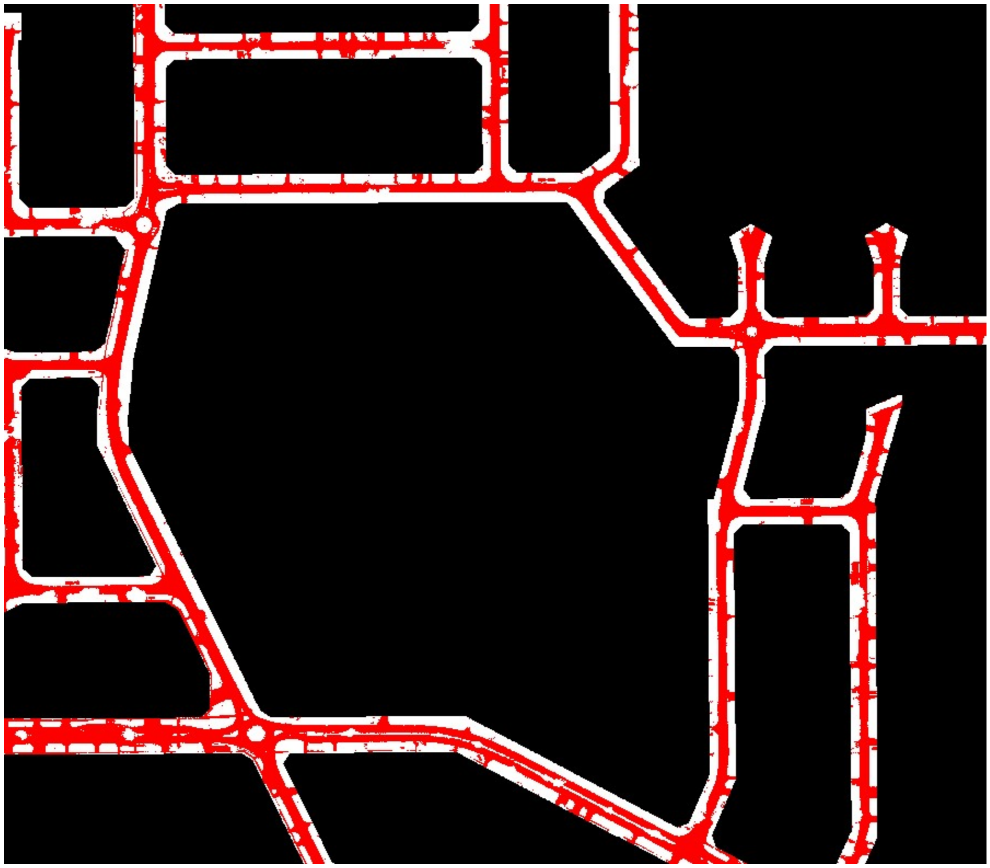

Figure 7-1. Road reserve refined by impervious surface classification. The impervious surface (red) within the road reserve (white) was identified by spectral classification of aerial photographs. The impervious surface estimate includes road surfaces, paving and driveway cross overs within the reserve. Impervious surfaces that are obscured by tree canopy are not included in the estimate (McFarlane and Caccetta 2017).

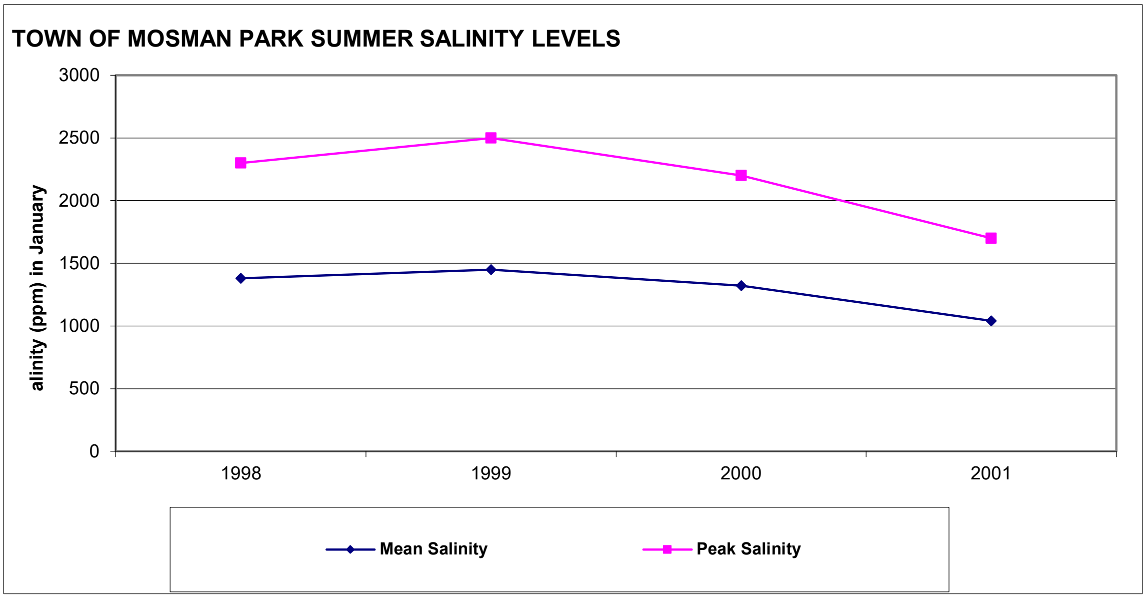

Figure 7-2. Groundwater salinity after stormwater was diverted to the Superficial Aquifer in 1999 at Mosman Park (Glover 2002).

7.2 Stormwater impacts on the Superficial Aquifer

The water quality of main and local drains was reviewed in the previous chapter. There have been several analyses of the impact of adding street drainage (stormwater) to wetlands that are expression of the Superficial Aquifer. McFarlane (1983) examined the water quality of street runoff and within the Superficial Aquifers around wetlands receiving the stormwater in Nedlands-Dalkeith and Subiaco-Shenton Park. The quality of the stormwater was judged at that time to be better than that reported from Sydney and Melbourne, and suitable for irrigation use. Organic matter was higher in the first flush levels after summer, and from less swept streets. The low salinity stormwater lowered the surrounding aquifer salinity. The main impacts on groundwater quality arose from interactions between the stormwater and the wetland sediments rather than from pollutants in the stormwater itself. Summer runoff into aerobic organic-rich wetlands inundated nearby soils containing iron, resulting in its mobilisation into down-gradient water. It was concluded that stormwater at that time was a valuable source of high-quality recharge to the Superficial Aquifer and it provides recharge even in small rainfall events.

Appleyard (1993) examined the impact on the Superficial Aquifer of runoff from a light industrial area, a medium-density residential area, and a major arterial road. He reported a marked reduction in salinity and an increase in dissolved oxygen concentrations in the aquifer downgradient of the infiltration basins. Concentrations of toxic metals, nutrients, pesticides, and phenolic compounds in groundwater near the infiltration basins were low and generally well within the existing Australian drinking water guidelines. He found sediment in the base of the infiltration basin, which drained the major road, contained more than 3500 ppm of lead. Phthalates were detected in all but one bore, which may have been a sampling artefact, but may also be from plastic litter that accumulated in the infiltration basins. As for McFarlane (1983), Appleyard (1993) found high iron concentrations occurring where dissolved oxygen concentrations are low around the basins.

A snapshot of groundwater quality around three drying wetlands, two of which receive stormwater, was made by Tennent (2017). The lakes have mainly lost connection with the underlying aquifer. The stormwater additions appear to mobilise mineralised nitrogen that accumulates when the lake beds dry over summer. Total Dissolved Nitrogen levels are raised down-gradient of the lakes, especially in the one that has been dry for the longest. High nitrogen levels in groundwater down-gradient of The Spectacles wetlands have similarly been reported by Bekele et al. (2015).

Dryland wetland sediments can therefore be a source of nutrients in aquifers and keeping them submerged is one way to prevent nutrient release. Appleyard et al (2005) recorded the development of acidic conditions in urban wetlands that dried out in the City of Stirling. Reduced rainfall, increased pumping and the exposure of sediments during construction contributed to the problem. Levels of heavy metals, including arsenic and aluminium, rose in down-gradient groundwater, causing the death of irrigated vegetation and posing a risk to human health if the vegetation was consumed.

In summary, the main impact of adding stormwater to wetlands arises from the interactions between the runoff and the lake sediments, rather than what is contained in the stormwater itself. The low salinity of road runoff can reduce groundwater salinity, while its oxygenated nature can cause iron to be released into down-gradients areas. Nitrogen that is slowly released from drying wetlands can be mobilised and potentially transformed by the added stormwater. Allowing wetlands to dry increases the risk of acidification and the release of toxic metals.

8. Sub-surface drains

Areas in the North East and South East sub-regions are difficult to urbanise because of high watertables (Figure 4-1 and Figure *4-2*), clayey soils (Figure 3-1 and Figure *3-2*) and low slopes. In addition to main drains, these areas can require sand infill and/or sub-surface drainage such as buried drain coil or slotted pipes to manage any rise in watertables that may follow urbanisation.

Subsoil drainage is becoming an increasingly common method to control groundwater levels in developments in these sub-regions (Brad Degens pers. comm. 30th April 2018). Sub-surface drainage is especially needed when local governments adopt policies to retain as much stormwater on-site as possible through infiltration. Where the principles of water sensitive urban design have been adopted, infiltration is the primary means of retaining stormwater on site. Infiltration of roof runoff via soak wells is enough to require subsoil drains even without policies of local retention of stormwater.

There has been interest in diverting this drainage water for use in irrigating public open space in the Wungong Urban Water development by the Armadale (now Metropolitan) Development Authority, and in Nambeelup in the Shire of Murray (Russell Martin pers. comm.) after it is urbanised.

A feasibility study of sub-surface drains at six sites was conducted by RPS (2017) for the Department of Water and Environmental Regulation. Bennett Springs, Brabham, Henley Brook and the Upper Swan sites were identified by RPS as being suitable for sub-surface drainage harvesting. These sites have shallow depth to groundwater and/or clayey soils occurring close to the land surface.

Lexia has high depths to groundwater making sub-surface drainage unsuited and often unnecessary. Substantial uncertainty exists for sub-surface drainage at Bullsbrook, because of variable land slope, soil permeability and urban drainage strategies (RPS 2017). MAR from subsoils is likely to be limited to localised schemes and depend a lot on the local hydrogeology of the Superficial Aquifer (Brad Degens pers. comm. 31st July 2018). There likely to be localised opportunities for MAR where subsoil drains are used with urbanisation on the Guildford formation.

Table 8-1 shows that the likely yield of sub-surface drains in these six sites is estimated by RPS (2017) to be about 2 GL/year. While appearing significant, the cost of collecting, possible treatment, storage and use of the water may be higher than alternative water sources. The drainage water will be low in the landscape and therefore may require pumping to an aquifer with sufficient storage. Where the drainage water could result in adverse environmental impacts on receiving water bodies, its collection and removal may be warranted to avoid these impacts.

DWER have discharge monitoring data spanning four years at six points (including two outlets) in a subsoil drainage network in Southern River as part of a trial using Iron Man Gypsum amendment around the drains to retain phosphate (Brad Degens pers. comm 30th April 2018). This is complemented with shallow groundwater monitoring that captures the changes in quality following urbanisation. Yield estimation from sub-soil drains is mainly modelled rather than measured at this stage.

Over the entire Perth-Peel region, the volumes from sub-surface drains are very small when compared with main drains and street drain volumes, because they occupy a very small area. However, the volumes may be comparable on a per-hectare basis, given all drains must deal with runoff from roofs and roads. The water is also mainly available in areas with extensive high watertables making it difficult to identify storage sites, unless these are created by heavy pumping over summer or unless the drainage water is recharged to a deeper aquifer.

There is an opportunity to use subsoil drainage yields from areas with high watertables where the Guildford formation occurs in the Superficial aquifer. The local confining effect of the aquifer can be potentially be used to store water like the Hartfield Park MAR (Brad Degens pers. comm. 31st July 2018). This scheme relies on the local confining effect of the Guildford formation for MAR storage without causing surface flooding. To date the emphasis has been on avoiding detrimental impacts of poor drain water quality and this is likely to remain the focus until the volumes increase or local water shortages become acute.

Table 8-1. Area suitable for subsurface drainage and likely yields in the North East Corridor (RPS 2017)

Site	Site area (ha)	Area suited to subsurface drainage (ha)*	Area suited to subsurface drainage (%)*	Suitability for subsurface drainage harvesting	Subsurface drainage volume (ML/y)
Bennett Springs	161	132	82-100	Suitable	321
Brabham	341	313	92-100	Suitable	762
Bullsbrook	775	Uncertain	Uncertain	Uncertain	Uncertain
Henley Brook	295	283	96	Suitable	690
Lexia	378	-	0	Unsuitable	-
Upper Swan	147	100	100	Suitable	244
Total	**2,097**	**828**	**Na**	**Na**	**2,016**

* Site area with land surface within 3 m of the Annual Average Maximum Groundwater Level

9. Discussion of potential future diversions of drainage water to aquifers

9.1 North West sub-region

There are very few main drains in the North West sub-region (Figure 6-2), so the only drain diversion options relate to street drains from which stormwater may be diverted and infiltrated in strategic locations to help prevent seawater intrusion into the Superficial Aquifer. This diversion of drainage water occurs near beach-side car parks where inter-dunal swales can accept local road runoff.

9.2 Central sub-region

Most of the options to divert main drains exist in this sub-region (Figure 6-2). The three drains with the greatest potential are the Subiaco, Herdsman and Carine main drains, because they cross areas with enough depth to the watertable and soils with high water transmissivities (McFarlane 2018b).

Main drains could prevent about 50 GL/year from entering aquifers and street surfaces in this sub-region (Table 6-2). There are also some local government areas with river or ocean frontages that are yet to divert their street drainage into the Superficial Aquifer.

Reductions in licenses to extract water from the Superficial Aquifer may trigger investigations to divert drain water (e.g. City of Perth 2018). Such diversions could improve the water quality of receiving water bodies as shown by investigations of the quality of water on both beaches and within the drains. Open drains may have significant environmental and cultural values so not all water could be diverted.

Most of this sub-region is developed and is also undergoing infill development, so there is less scope to incorporate water sensitive urban design methods and managed aquifer recharge than in greenfield developments. However, the value of land and public open space is very high in this sub-region so expensive retrofits may be cost effective.

This sub-region is likely to be most impacted by urban heat island (UHI) effects, so effort to maintain or increase the area of greenspaces is needed despite the lack of available groundwater. The most intensively urbanised areas produce the most stormwater as well as capture the most heat, so there may be opportunities for managed aquifer recharge during wet periods to provide evaporative cooling over summer.

9.3 North East sub-region

This sub-region has some main and natural drainage associated with the eastern flank of the Gnangara Mound (e.g. Henley Brook) as well as flows from the Darling Scarp (e.g. Yule Brook) (Figure 6-2). Urbanisation can increase drain flows, but generally drain flows are decreasing. Given that this sub-region is far from coastal wastewater treatment plants, drainage water represents an important resource for improving non-potable water availability. Sub-surface drainage may become important as areas with high watertables associated with developments in the sub-region become urbanised. However, the volumes are unlikely to be significant and reuse may be more local than regional.

The drying climate in south-west WA has dramatically reduced natural runoff and the Swan Canning estuary is now poorly flushed of nutrients and salt each winter. Reducing nutrient inputs from drains through diversion into aquifers may offer benefits in addition to supplementing non-potable water supplies on adjacent land.

9.4 South West sub-region

The Peel Main Drain, which connects inter-dunal wetlands, represents the main opportunity for diversion in this sub-region (Figure 6-3). Urbanising parts of this catchment are increasing drainage flows, but the drying climate is reducing flows in rural and native bush areas (Table 6-1 and Table *6-2*). It is possible that there is redistribution of main drain water from areas where groundwater enters the drain (when groundwater levels are higher than the drain invert) to reaches where it is lower and water is lost from the drain to the aquifer.

Innovative ways of integrating natural and constructed water drainage networks may exist in the Perth Peel region. For example, a small main drain catchment exists in the Woodman Point area, close to both the Woodman Point Wastewater Treatment Plant and the Ramsar-listed Thomson Lake, which has been severely impacted by dropping groundwater levels. Using the main drain to carry treated wastewater to sand and limestone quarries to act as infiltration points near the lake is one example of how systems could be better integrated to address the effects of the drying climate.

9.5 South East sub-region

The Dirk Brook – Punrak Drain is the main modified drainage in this sub-region (Figure 6-3). Not yet affected by urbanisation, flows are generally decreasing, most likely because of reduced rainfall and rising temperatures. Groundwater levels in this sub-region are falling faster than in others (Figure 5-3), indicating that there may be capacity to divert water into the resulting freeboard if desirable to do so. This sub-region has extensive natural drainages associated with the Serpentine River, which have not been considered for diversion, but there may be opportunities where natural drainage flows affect receiving water bodies such as the Harvey Estuary.

9.6 Peel sub-region

This sub-region is dominated by agricultural main drains (Figure 6-3). While gazetted, the rural drainage rate was removed over twenty years ago so management is limited unless there is a designated Community Service Obligation. The Water Corporation now receives an Operating Subsidy (previously called a Community Service Obligation) to maintain gazetted rural drains.

Whether water removal from these drains can be regulated by DWER depends on whether they have been proclaimed as water resources that require licensing. Permission from the Water Corporation is required to access the water within these drains because of their management responsibilities. The Water Corporation is required to remove inundation within 72 hours and third-party access may affect this role. Whether environmental flows are required to be maintained in the drains is unclear. The drains are known to contribute to nutrient loads in the Harvey Estuary – Peel Inlet and their diversion may reduce downstream eutrophication problems.

There is interest in diverting some of this drainage water, along with freshened Wellington Dam water, into the Superficial Aquifer to be used in the Myalup Irrigation Area.

Clarity as to who owns the water in these drains, who is responsible for improving its water quality, and who can regulate access if they are unproclaimed, is not clear under existing legislation. A new Water Resource Management bill is being prepared, which will replace several acts of parliament to do with water and waterways management in Western Australia. It will also provide clarity on managed aquifer recharge, a practice not considered when existing legislation was drafted.

10. Conclusions

Main drains represent the most promising source of drainage water that could augment existing recharge to the Superficial and Leederville aquifers. The volume removed by main drains, which can sometimes be hard to separate from natural drainage, is in the order of 100 GL/year. The Carine, Herdsman and Subiaco main drains are probably the most promising main drains for diversion, because they cross areas with available storage and the aquifer has a high transmissivity, which would reduce the risk of the added water expressing at the surface.

Most of the water discharged from main drains enters the Swan and Canning Rivers, often in urban areas, which can make it expensive to divert to areas with available aquifer storage. While the water quality of main drains is usually suitable for non-potable uses, its recharge and passage through an aquifer will almost certainly improve its quality further. The improvement of water quality in ocean and estuarine areas after drain waters are diverted through the aquifer provides additional benefits and may make diversion cost-effective. Methods for improving water quality within main drain channels are likely to be less effective than MAR.

Most stormwater arising from rain falling on roads and roofs in Perth and Peel already enters the Superficial Aquifer through soak wells, absorption and compensation basins, the latter often being urban wetlands. The sandy aeolian soils over most of the coastal plain make on-site infiltration the most cost-effective disposal method. Such indirect recharge almost certainly exceeds direct recharge in urbanised areas.

After main drains, street drainage that is still being discharged into the estuary and ocean represents the next most promising source of drainage water for recharge. While the volumes may be small, street drain additions are made where immediately upgradient of the salt-water interface, making them prospective for reducing salt-water intrusion. More studies of the cost-effectiveness of diverting the street drainage are needed.

Street- and in some cases main-drains could be valuable water sources if diverted into an aquifer for summer irrigation in intensively urbanised areas experiencing high summer temperatures because of the urban heat island effect. The cost of diverting this water may be high given high land values making engineering works difficult to build, but the resulting benefits may justify the cost.

Studies of the impact of street drainage water added to throughflow wetlands on the down-gradient groundwater have shown that most of the water quality effects arise though interactions of the fresh and oxygenated runoff with the peat and sediments in the lake bottoms (releasing mainly iron and nutrients), rather than from any pollutants in the stormwater itself. Allowing urban wetlands to dry increases the risk of nutrient release, acidity and heavy metals so there may be multiple benefits from augmenting these wetlands and/or the Superficial Aquifers that surround them.

Agricultural drains in the Peel area are a potential source of recharge for both the environment and for irrigated agriculture, while reducing nutrient loads entering estuaries. Their potential for MAR is being investigated as part of the Myalup-Wellington project.

Sub-surface drainage in new urban areas with high watertables is currently the smallest amount of drainage for diversion. However, it is a growing resource and it may help solve local watering needs in areas with high watertables.

11. Recommendations

The flows and trends in many main drains are poorly known, affecting consideration of their usefulness for diversion to the Superficial Aquifer in particular. A flow device has been installed by Water Corporation in the Herdsman Main Drain and others are being planned. Once enough data are collected, modelling of flows may be feasible to infill missing data and to predict the impact of management and climate change.

Beneficial and detrimental impacts of adding drainage water to the Superficial Aquifer need to be better understood, especially for those main drains that are yet to be properly investigated. The effect of wetland drying on downgradient groundwater quality needs to be studied in more urban wetlands to understand the risks of doing nothing in a drying climate.

Environmental flows in drains need to be better defined so that the relative impacts of allowing drainage water to enter estuaries or beaches can be compared with in-situ values of water in drains. Ideally drainage water will be treated in-situ, or more likely, by diversion through an aquifer before it enters disposal points.

Finally, the roles, responsibilities and rights of access to drainage water need to be clarified in modern legislation that takes account of new practices such as recycling drainage water, managed aquifer recharge and issues such as climate change.

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