Government of **Western Australia**
Department of **Water and Environmental Regulation**

Gnangara

groundwater allocation plan

draft methods report

Water resource allocation
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Department of Water and Environmental Regulation
Prime House, 8 Davidson Terrace
Joondalup, Western Australia 6027
Locked Bag 10 Joondalup DC WA 6919

Phone: 08 6364 7000
Fax: 08 6364 7001
National Relay Service 13 36 77

dwer.wa.gov.au

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For more information about this report, contact: gnangara.planning@dwer.wa.gov.au

WATER WISE PERTH

Action Plan

This report is a companion to the *Gnangara groundwater allocation plan,* part of the State Government's 2019–2021 *Waterwise Perth Action Plan* which sets the direction for Perth's transition to a waterwise city. Our ambition is for Perth to be cool, liveable, green and sustainable – a place where people want to live, work and spend their time.

The *Gnangara groundwater allocation plan* helps deliver Action 14 of the *Waterwise Perth Action Plan*: Review groundwater allocation plans for Gnangara, Perth South and Jandakot, Cockburn and Serpentine to manage groundwater levels for wetlands, urban trees and irrigation of green spaces. The plan also contributes to achieving the 2030 target of 10 per cent less groundwater use across the region.

The Department of Water and Environmental Regulation acknowledges the Whadjuk and Yued Noongar peoples as the traditional owners and custodians of the lands and waters covered by this plan. We pay our respects to their elders past and present.

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Summary

Climate change means Perth must become even more waterwise. Our city needs to adjust to using less groundwater to achieve the same productivity and amenity benefits we are used to. The amount of water being taken from the Gnangara groundwater system exceeds the amount of water recharging the system. Reducing abstraction will protect important wetlands and native bushland by making them more resilient to climate change, prevent further declines in water quality and help ensure the long-term sustainability of the groundwater resource.

The Department of Water and Environmental Regulation has created this plan to address this water imbalance and secure the Gnangara groundwater system as a long-term sustainable water resource that supports a healthy environment for Perth.

What is this report?

This report is a companion to the draft *Gnangara groundwater allocation plan* (DWER 2021a). The draft plan details how the Department of Water and Environmental Regulation will manage, licence and monitor groundwater in the Gnangara groundwater system. This report explains how we developed the draft plan and details the hydrogeological, environmental, cultural and community information that underpinned our decision-making.

What does this report include?

In line with our approach to allocation planning in the guideline *Water allocation planning in Western Australia* (DoW 2011e), this report has three main parts:

- Part A: describes the information we assessed to develop the draft plan
- Part B: outlines how we set the plan's objectives and the methodology for deciding on the scale of reductions to abstraction
- Part C: describes our management approach to meet the plan's outcomes and objectives.

For more information about the draft plan, send an email to gnangara.planning@dwer.wa.gov.au and see the References section for a list of technical documents.

1 Introduction

1.1 Plan area and location

The Gnangara plan covers about 2,200 km^2 of the Swan coastal plain, extending north from the Swan River (Derbarl Yerrigan) in Perth, Western Australia. The plan area is bound by the Swan River (Derbarl Yerrigan) to the south, the Moore River and Gingin Brook to the north, the Darling Scarp to the east, and the Indian Ocean to the west (Figure 1).

1.2 The Gnangara groundwater allocation plan

The Department of Water and Environmental Regulation issues licences under the *Rights in Water and Irrigation Act 1914* (WA) to regulate and manage groundwater abstraction in the plan area.

It is intended that the *Gnangara groundwater allocation plan* (DWER 2021a) when finalised will replace the *Gnangara groundwater areas allocation plan* (DoW 2009a). Key features of the draft plan are:

- new groundwater level and water quality objectives
- a more sustainable allocation regime for groundwater across the system
- a pathway to reduce the amount of groundwater being used over the next decade.

The draft plan sets out how we will use water licensing and other mechanisms to ‘rebalance’ the Gnangara system to:

- reduce groundwater abstraction to better match declining water availability under climate change
- stabilise or recover groundwater levels in some areas with long-term declines to protect important wetlands and bushland from the effects of groundwater abstraction
- help safeguard the long-term, sustainable use of the groundwater system as a resource for Perth’s community.

This report describes how we determined the necessary reductions to the volume of abstraction, and how these reductions will be shared by water users.

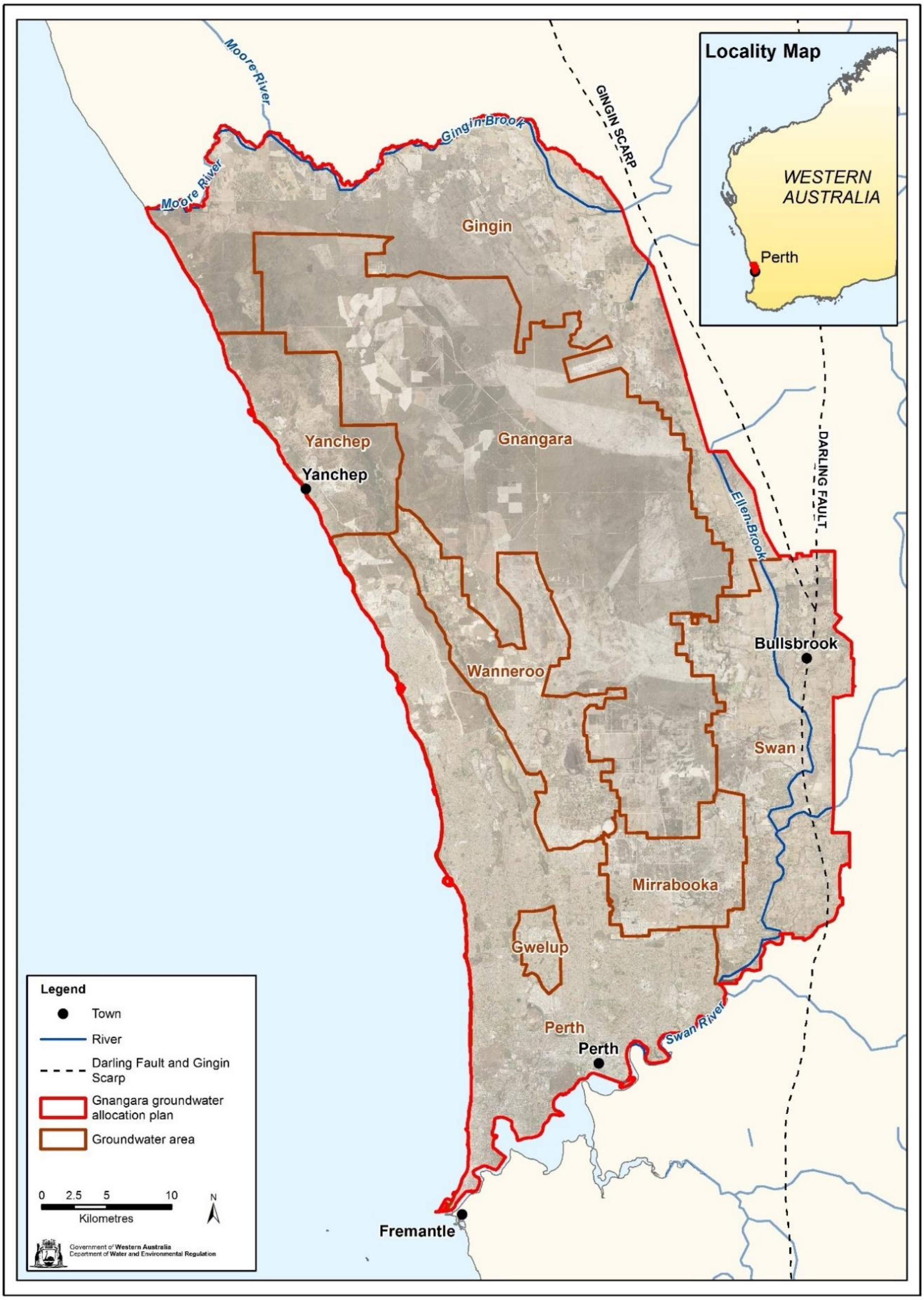

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Figure 1 The Gnangara groundwater allocation plan area

1.3 Our process for allocation planning

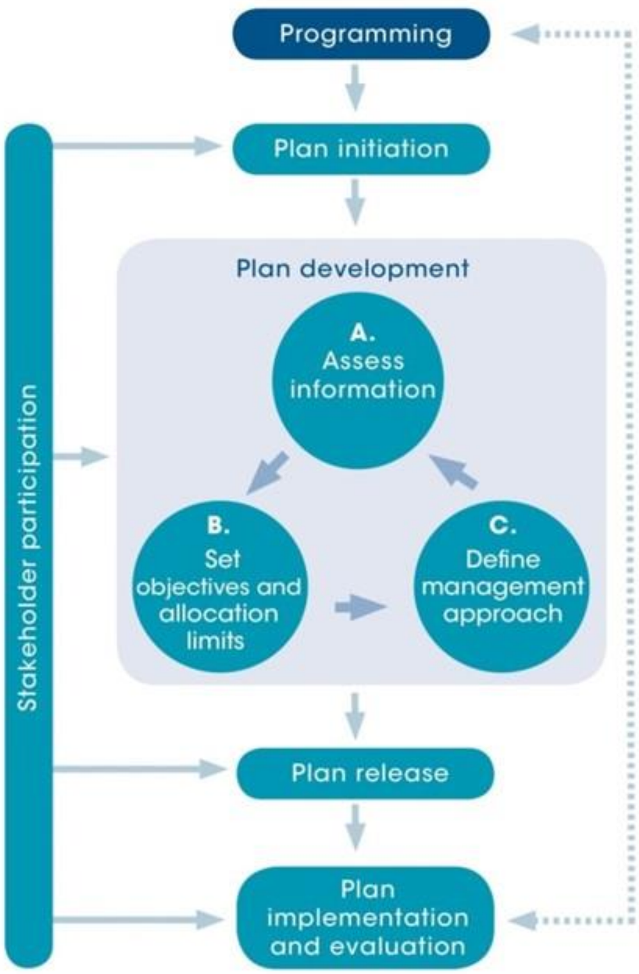

Figure 2 Our water allocation planning model for Western Australia

We developed the draft Gnangara plan using our standard allocation planning model (Figure 2). This report describes:

- Part A – Our assessments of climate, groundwater use, water resource trends, impacts to values that groundwater supports, new hydrogeological research, and modelling.
- Part B – The objectives and method we used to decide on the scale of reductions to abstraction using future climate projections.
- Part C – Our approach to sharing the reductions across all water users and managing the groundwater resource as climate change continues.

For more information about allocation planning, see *Water allocation planning in Western Australia: a guide to our process* (DoW 2011e).

1.4 Working with water users and other stakeholders

To develop the draft Gnangara plan, we held more than 100 workshops and meetings with groups and individuals across different water use sectors, including the Water Corporation, local governments, agricultural organisations and environmental groups. The consultation followed three main phases:

1. *Science update* – beginning in 2016 we shared the latest science and research with stakeholders, including groundwater modelling of the past effects and future projections of groundwater abstraction, climate and land use change.
2. *Licensing strategy* – we then asked representatives from the major water use sectors for their input, including how they thought their industry would respond to reduced groundwater availability.

3. *Option assessment* – from late 2017 onwards our discussions with representatives from the major water use sectors, other agencies and groups interested in Gnangara groundwater planning began to focus on potential water allocation options and underlying licensing approaches.

Our stakeholders raised a variety of issues during the consultation phases. They asked about or pointed to:

- the necessity, costs and benefits of reducing abstraction
- the implications for public open space, agriculture and businesses
- low water levels at lakes and wetlands, and protecting banksia woodlands
- licensees having enough time to adapt to reduce their groundwater use
- which sector/s were responsible for causing the groundwater level declines
- future land use and water demands, including groundwater availability in urban growth areas, and the potential need for alternative water supplies
- ways to target inefficient and wasteful water use
- how reductions should be spread across different water use sectors
- opportunities to trade water
- the high number of garden bores and their potential impact on the groundwater system over time.

To keep water licensees and the wider community informed, in May 2018 we released the brochure *Our groundwater future in Perth: Securing Gnangara groundwater and adapting to climate change* (DWER 2018a) and launched the Gnangara groundwater website <gnangara.dwer.wa.gov.au>.

The brochure was posted to 2,600 individual licensees in 2018 with a letter to advise them that Gnangara planning work was underway. The letter also described the likely changes to their groundwater licences and let them know they could formally comment on the draft plan during a three-month public comment period.

Since 2019 we have worked with key stakeholders and agencies to consider approaches for each sector to transition and adapt to reduced water use because of climate change. These discussions have informed several State Government initiatives to help groundwater users adjust to using less water – see Chapter 11 for more information.

1.5 Waterwise Perth Action Plan

In October 2019, the State Government released the *Waterwise Perth Action Plan* as part of its response to climate change. The plan sets the groundwork for a 10-year program to ensure Perth remains beautiful, green and liveable by becoming a leading waterwise city (Government of Western Australia 2019). The action plan has 38 actions to achieve nine targets by 2030, one of which is to reduce groundwater use by 10 per cent across the Perth-Peel region. Delivery of a new *Gnangara groundwater allocation plan* is action 14 under the *Waterwise Perth Action Plan*.

Part A — Assessing information

In Part A of the plan development process, we assessed:

- past climate trends and future climate projections
- land use change impacts on recharge and groundwater use
- groundwater use, aquifer trends and impacts on water quality
- the ecological, community and cultural values that groundwater supports
- new hydrogeological research and groundwater modelling.

Key points from Part A:

- Climate change has led to a decline in rainfall and recharge to groundwater across south-west Western Australia since the 1970s. There is high confidence in global climate models, coupled with future emissions projections, that the Gnangara plan area will have a warmer and drier climate in the future.
- Urban growth and other land use change will result in changes to groundwater recharge and how water is used in parts of the plan area.
- Levels in the Superficial aquifer have generally declined in the past 40 years due to climate change, abstraction and pine plantations (which limit recharge).
- Hydraulic pressure in the Leederville and Yarragadee aquifers has declined since the 1980s as groundwater abstraction from those aquifers, mostly for public water supply, has increased.
- Pumping from the Leederville and Yarragadee aquifers can directly affect the Superficial aquifer where they are connected. This impacts on groundwater-dependent ecosystems and other groundwater users.
- Rising salinity associated with abstraction has been recorded in Yanchep, Quinns, on the Cottesloe-Mosman peninsula and along the Swan River (Derbarl Yerrigan) in the Swan Valley.
- Declines in water levels have exposed acid sulfate soils in the Superficial aquifer, causing shallow groundwater acidification over more than 15 per cent (380 km^2) of the plan area including around some abstraction bores and in sensitive areas such as Mussel Pool in Whiteman Park.
- More sites no longer comply with environmental water level criteria in *Ministerial Statement no. 819* compared with the 2009 Gnangara plan.
- Preventing further degradation of groundwater-dependent ecosystems is as important for the community of Perth as it is for our wildlife.
- New hydrogeological studies, such as the Perth Regional Confined Aquifer Capacity (PRCAC) study, the Perth shallow groundwater systems investigations and a major update of the Perth Regional Aquifer Modelling System (PRAMS) have improved how we manage abstraction from the Gnangara system.

2 Climate

2.1 Past climate trends

Gnangara groundwater aquifers are recharged by rainfall, primarily in winter and spring. Climate change has caused a significant reduction in Perth's average rainfall, which in turn is impacting on these aquifers, and the values they support.

Average annual rainfall has declined 15 per cent since 1975 at the Perth Airport station, from 841 mm/year (1945–1974) to 708 mm/year (1975–2020). Most of the reduction in average annual rainfall is because of less rain falling between April and July each year. As a result, recharge to the groundwater system often starts later in the year and is now much less than it was.

Over the same time periods there was nearly a 1°C increase in annual average maximum temperature, with the six hottest years on record for Perth Airport station occurring in the past eight years. Higher temperatures increase evapotranspiration loss from groundwater, and people use more water when it is hotter.

When we developed the 2009 *Gnangara groundwater areas allocation plan*, average annual rainfall at Perth Airport station had fallen to 729 mm/year (1975–2008). Since 1990, the average has been 699 mm/year, with three of the driest years recorded: 483 mm in 2010, 578 mm in 2015 and 525 mm in 2019 (Figure 3).

Figure 3 Annual rainfall at the Perth Airport rainfall station 9021 from 1975–2020

2.2 Future climate projections

Modelling for the plan is based on a climate projection to 2030 that is consistent with the trend in declining rainfall experienced in Perth over the past two decades (Figure 4). Under this projection, the average annual rainfall at 2030 is 663 mm (Perth Airport rainfall station).

The climate projection used in the modelling for this plan falls within the range of climate change projections for Australia (Figure 4) released in 2015 by the Australian Government, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation – see <www.climatechangeinaustralia.gov.au>.

The climate change in Australia projections used global climate models as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5) which were also used as inputs to the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) released in 2013. A new CMIP6 ensemble of models is being used to assess climate change processes as part of the sixth IPCC assessment report (AR6). The first instalment of AR6 was release on 9 August 2021 and will be completed in 2022.

Under both CMIP5 and CMIP6 models there is a high confidence that the future climate for south-west Western Australia will be warmer and drier. CMIP6 rainfall projections are similar to CMIP5 but have a narrower range of rainfall change for Southern Australia (Grose et al. 2020).

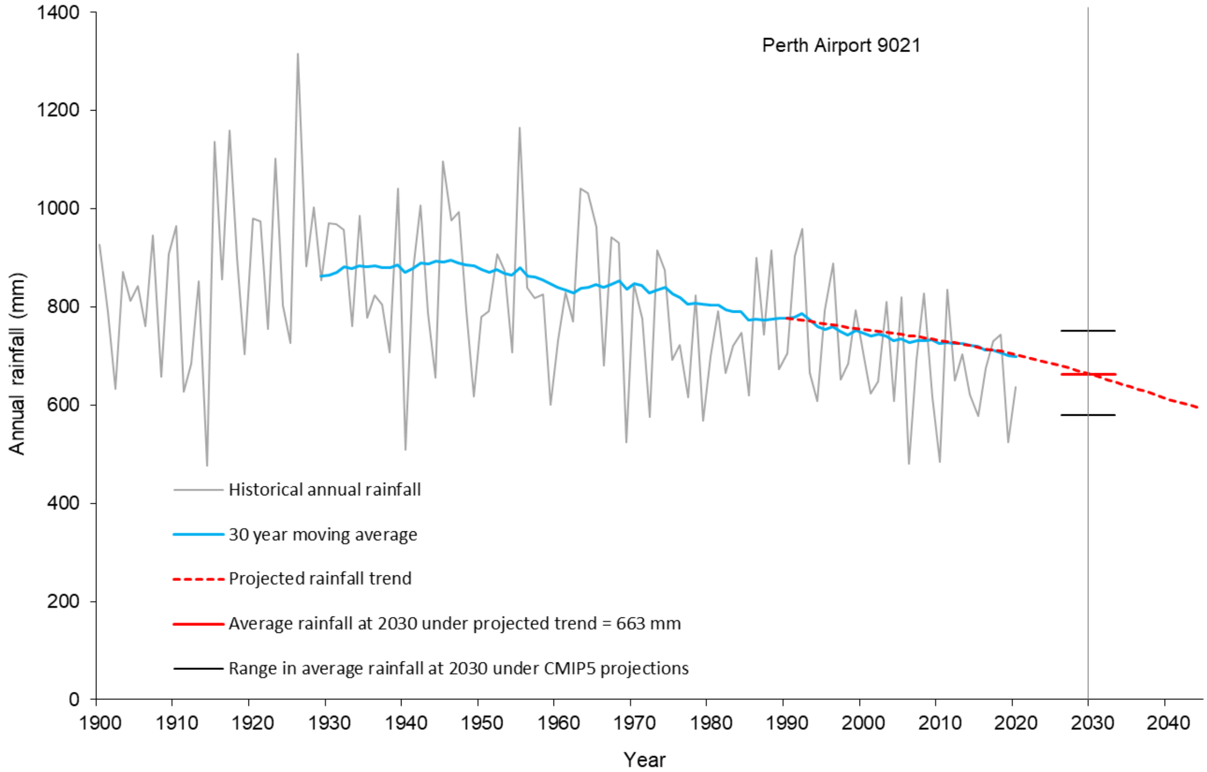

Figure 4 Historical and projected rainfall at the Perth Airport rainfall station 9021

3 Land use change

3.1 Impacts of land use change on groundwater recharge

The plan's groundwater modelling scenarios (see Chapter 9) predict the changes in recharge to groundwater that will result from:

- all planned urban and industrial growth likely to occur by 2030, as outlined in the *Perth and Peel @3.5 million* land use planning and infrastructure frameworks (DPLH and WAPC 2018a)
- expected changes to land use and groundwater recharge in the Gnangara, Pinjar and Yanchep pine plantations.

Urban and industrial growth

Land use influences the amount of rainfall that recharges shallow groundwater systems. Urban development on the Swan coastal plain typically causes higher groundwater recharge rates compared with pre-development land use (Davies et al. 2017). The higher recharge rates are caused by lower evapotranspiration compared to pre-development rates and increased rainfall-runoff from hardstand (or paved) areas (Davies et al. 2017).

The State Government's *Perth and Peel @3.5 million* (DPLH and WAPC 2018a) land use planning and infrastructure frameworks give a strategic view of where new homes and jobs will be located to make best use of existing and proposed infrastructure, while also considering how important environmental assets will be protected. The North West, North East and part of the Central subregional frameworks cover the Gnangara plan area.

Pine plantations

Dense pine plantations intercept and transpire much more water than grassland and open native Banksia woodland. Numerous studies have found that recharge to groundwater under dense pine plantations is negligible (Xu et al. 2008). When pine plantations are thinned or cleared and replaced with grassland or open Banksia woodland, then recharge to groundwater increases (Xu et al. 2008). The department, Water Corporation and CSIRO have extensively modelled and researched the Gnangara, Pinjar and Yanchep pine plantations. This work has shown the plantations must be harvested to ensure the ongoing sustainable use of groundwater from the Gnangara system, and to protect the environmental, community and cultural values it supports.

Together with the Department of Biodiversity, Conservation and Attractions (DCBA) and the Forest Products Commission, we are looking at post-harvest land use options for the 23,000 hectares of pine and ex-pine plantations in the plan area. This work aims to balance and support multiple objectives, which are to:

- meet existing forestry commitments under the *Wood Processing (Wesbeam) Agreement Act 2002*
- conserve important food sources for the endangered Carnaby's cockatoo
- maximise recharge to the Gnangara groundwater system.

Work to date, including groundwater modelling, shows we can balance these competing objectives by having a mixture of replanted pines, pine wildings (pine trees that regrow naturally), low native shrubs and grassland, and banksia and other native revegetation areas. We will continue working with DBCA to identify revegetation and carbon farming opportunities as part of the Carbon for Conservation Initiative.

Figure 5 shows the likely mix of post-harvest land use in the Gnangara, Pinjar and Yanchep pine plantations including:

- the areas where pines have been replanted to provide habitat and food for the Carnaby's cockatoo
- Dick Perry Reserve, which is being retained for its old growth pines and for recreational purposes
- the areas where a mix of pine wildings, open Banksia woodland and low native shrub and grassland will be managed to provide habitat and food for the Carnaby's cockatoo while maximising groundwater recharge, especially in the priority recharge areas:
  - to the east of the North Wanneroo horticultural precinct to support ongoing groundwater use in the precinct
  - to the east of Lake Pinjar to support remnant wetlands in the area
  - to the north of Whiteman Park to help support the Park's groundwater-dependent environmental and community values.
- urban and industrial investigation areas as outlined in the *Perth and Peel@3.5 million* land use planning and infrastructure frameworks (DPLH and WAPC 2018a).

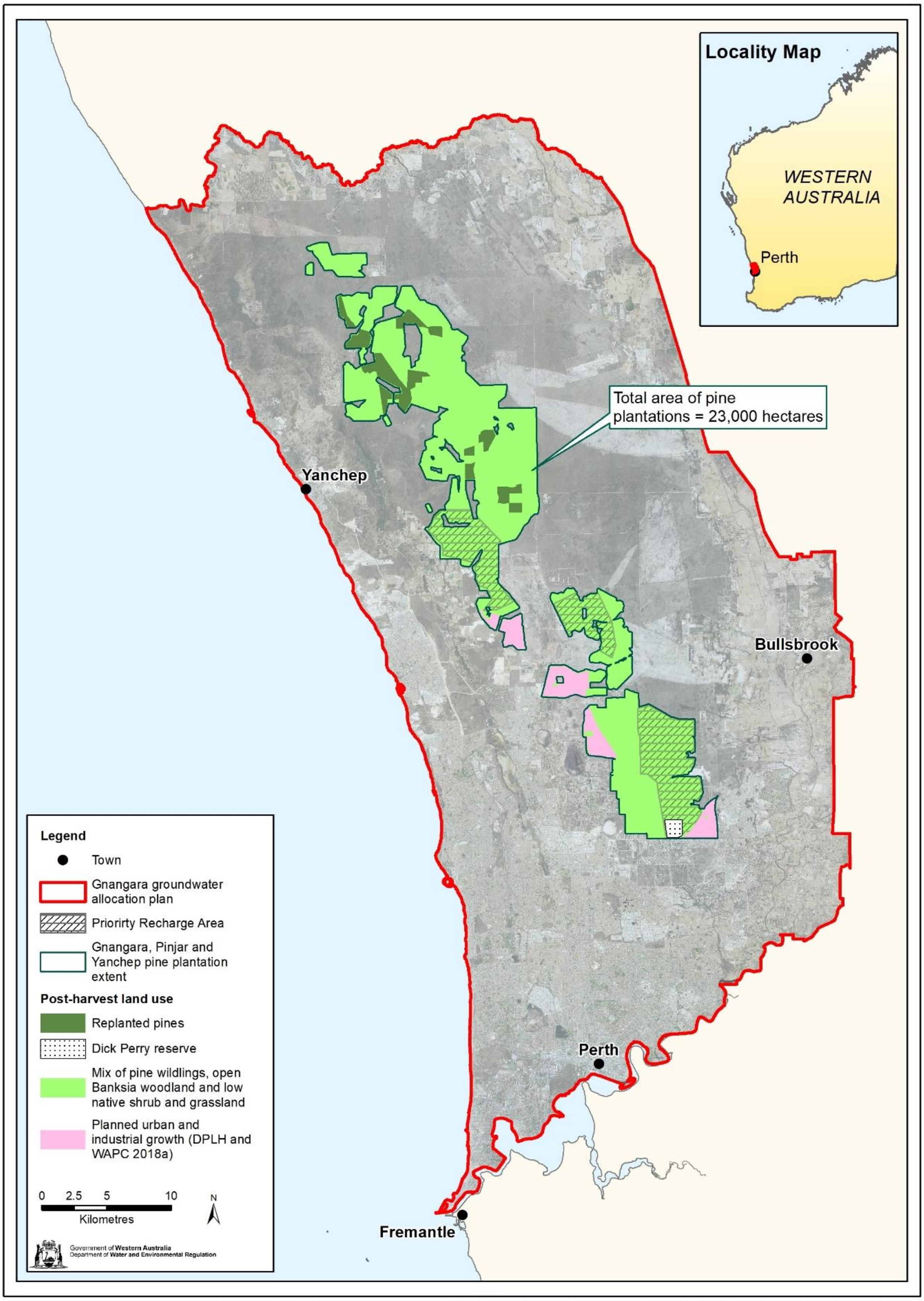

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Figure 5 Likely post-harvest land use in the Gnangara, Pinjar and Yanchep pine plantations

3.2 Impacts of land use change on groundwater use

In some parts of the plan area, land use change will affect how groundwater is used in the future. Understanding these changes has been an important part of our groundwater modelling and assessment process (see Chapter 9) and allowed us to account for:

- less groundwater abstraction resulting from planned urban expansion that will replace areas of horticulture in East Wanneroo
- water that planned greenfield development in the North West urban growth corridor will need for:
  - public water supply and public open space (Quinns, Eglinton and Yanchep subareas)
  - new public open space (Beechboro subarea)
- water for dust suppression and extraction of essential basic raw materials in the Reserve and Wanneroo Wellfield subareas to support urban and industrial development
- water that new domestic garden bores in urban growth areas will use.

See Appendix A and B and the abstraction datasets in Chapter 9 for more details about the volumes associated with these future uses.

4 Groundwater use and resource trends

The Gnangara groundwater system is made up of layers of water-holding sands and gravels interspersed with clays. The aquifer system stores Perth's largest source of good quality water: it provides almost half of all the water used in the metropolitan area each year.

Groundwater is taken from the system's four main aquifers (Figure 7):

- the shallow, unconfined Superficial (watertable) aquifer known as the Gnangara Mound
- the shallow, semi-confined Mirrabooka aquifer[1]
- the deep, partially confined Leederville aquifer
- the deep, mostly confined Yarragadee aquifer.

The general hydrogeology of these aquifers, their use and trends over time are described below.

In 2019–20, we allocated a total of 275 gigalitres (GL) of water from the Gnangara groundwater system, for both licensed use (such as public water supply and irrigated agriculture) and for purposes exempt from licensing (such as garden bores). See Figure 6 for the volumes of groundwater used across the system's aquifers.

The Water Corporation uses about 40 per cent of the groundwater abstracted from the Gnangara system to supply the Integrated Water Supply Scheme (IWSS). The IWSS services most of the households and businesses in the Perth and Peel regions, as well as Kalgoorlie. The other 60 per cent is abstracted by licensed self-supply users and unlicensed stock and domestic garden bore users.

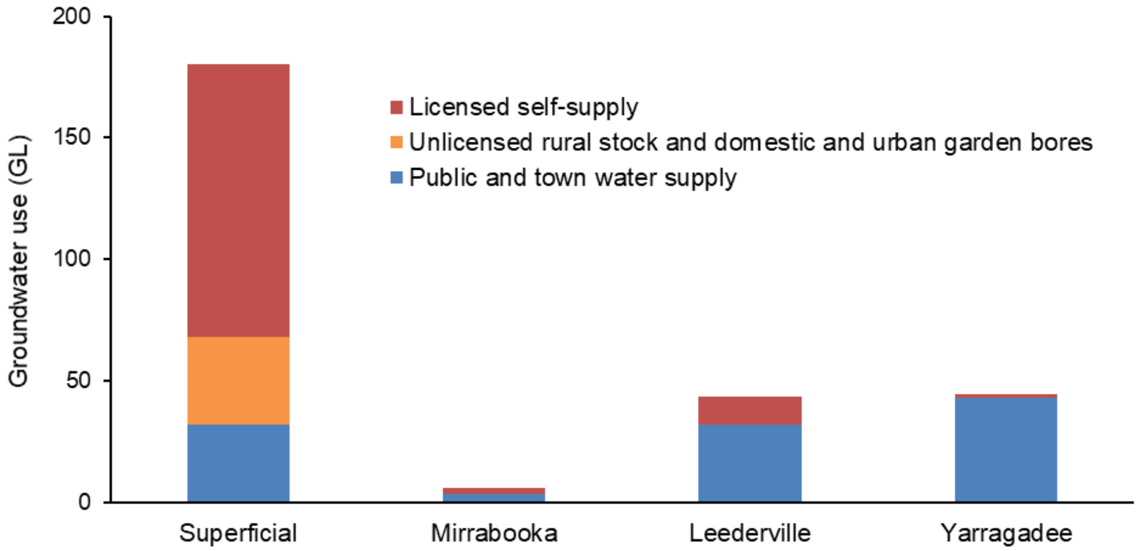

Figure 6 Groundwater use from the Gnangara system 2019–20

[1] The Mirrabooka aquifer is not illustrated on the cross section shown in Figure 7 as it is found in localised areas only.

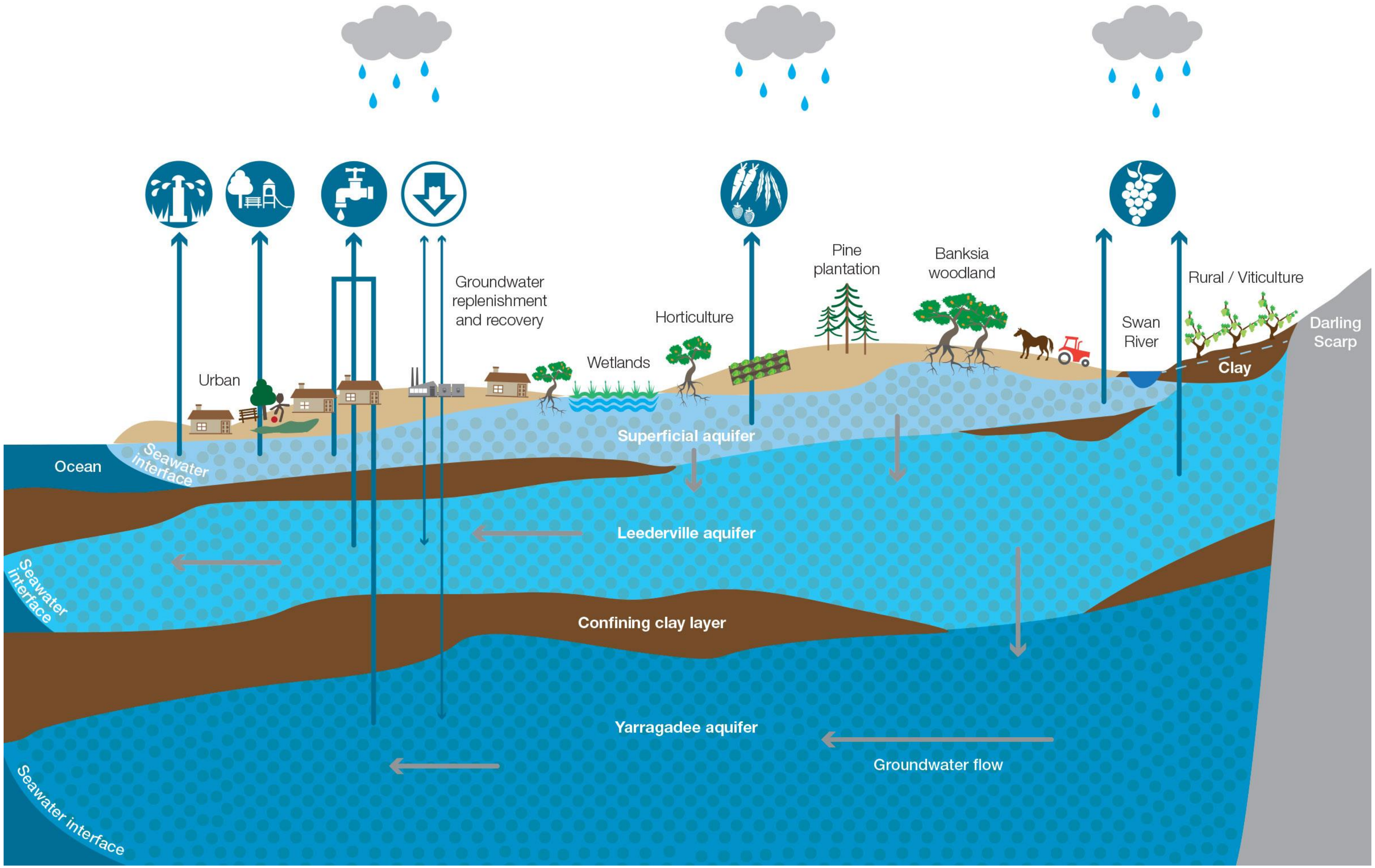

Figure 7 *Cross-section showing the structure of the Gnangara system, layering of major aquifers and confining units, connection between aquifers, directions of groundwater movement, the saltwater interface and Darling Fault*

4.1 Superficial and Mirrabooka aquifers

Superficial aquifer

The Superficial aquifer is a major unconfined aquifer that exists across the entire plan area (except in some parts along its eastern boundary, close to the Darling Fault). The Gnangara Superficial aquifer is commonly called the ‘Gnangara Mound’.

Water levels in the Superficial aquifer support wetlands and other groundwater-dependent ecosystems and keep underground seawater at the coast from moving inland. The aquifer has a maximum saturated thickness of about 70 metres in the central part of the Gnangara plan area to the west of Bullsbrook.

At present about 180 GL/year is taken from the Superficial aquifer. The aquifer provides most of the groundwater abstracted by self-supply bore owners and almost one-third of the groundwater abstracted by the Water Corporation for the IWSS (Figure 6).

Mirrabooka aquifer

The Mirrabooka aquifer is present in some parts of the Gnangara groundwater system, but it is not as extensive as the other aquifers. It sits below, and in parts is connected to the Superficial aquifer. A relatively small amount of groundwater (about 6 GL/year) is taken from this aquifer compared with other aquifers in the system.

Water level declines

Water levels in the Superficial aquifer have generally been in decline for the past 40 years because of decreasing rainfall, continued use of groundwater, and pine plantations limiting recharge. The largest declines of about 10 metres are in the northern and central part of the Gnangara plan area (Figure 8). The decline in water levels represents the loss of more than 1,000 GL of storage from the Superficial aquifer since 1980 (Figure 9).

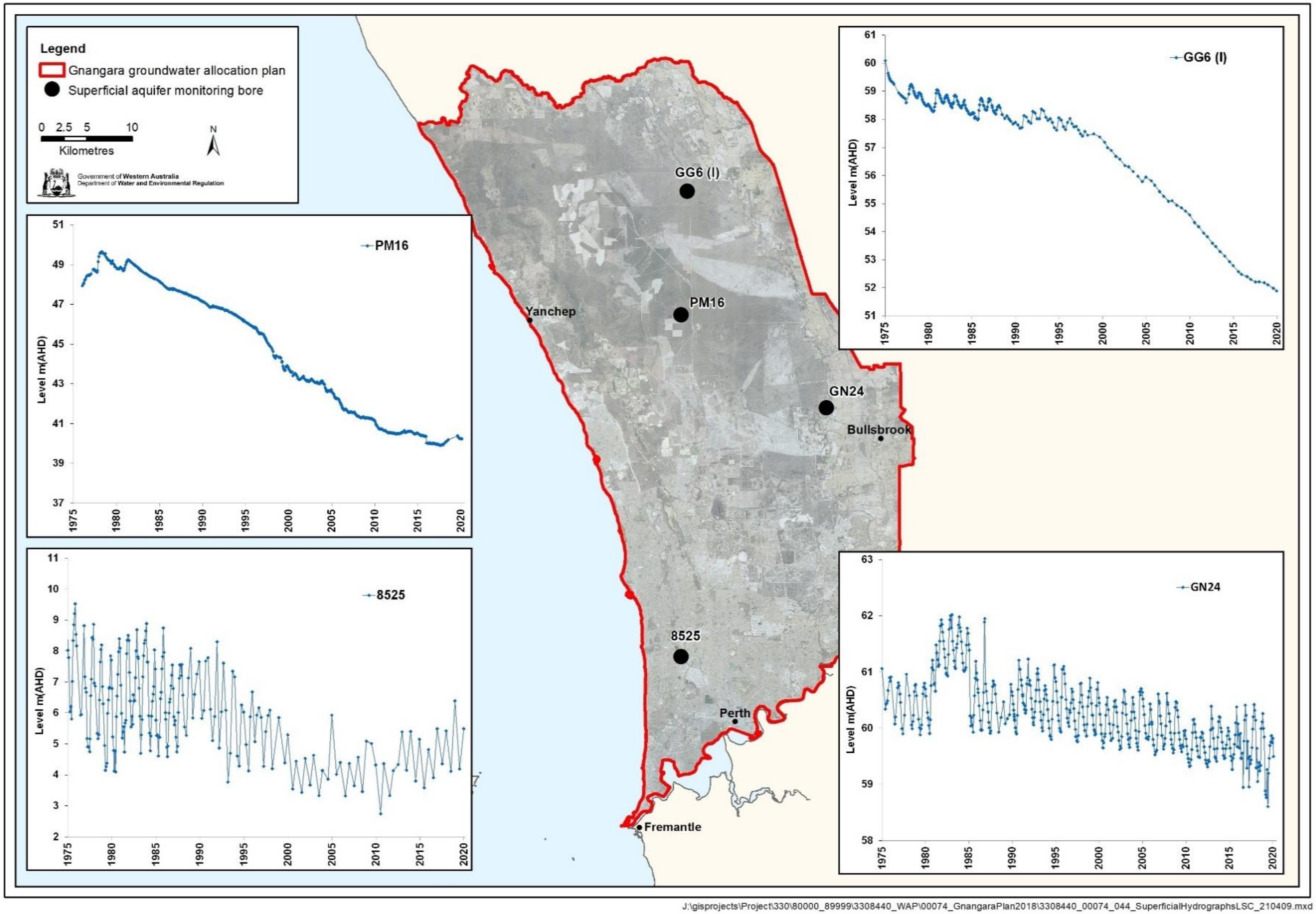

Figure 8 Trends in Superficial aquifer levels

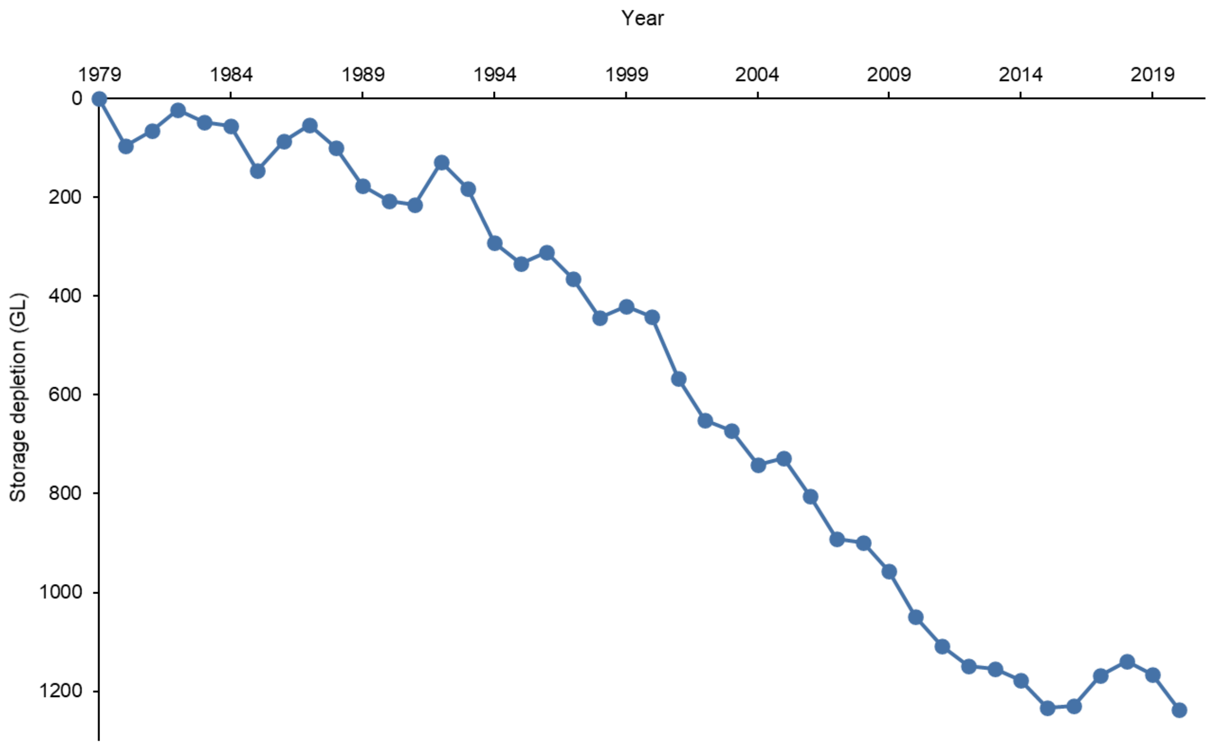

Figure 9 *More than 1,000 gigalitres of groundwater storage has been lost from the Superficial Aquifer since 1980*

4.2 Leederville and Yarragadee aquifers

The Leederville and Yarragadee are ‘semi-confined’ or ‘mostly confined’ aquifers. Where they are confined, shale units (aquitards) above them prevent water moving between the aquifers and water pressure builds up within them. At present about 90 GL/year of groundwater is abstracted from these aquifers combined, mostly by the Water Corporation to supply the IWSS (Figure 7).

Leederville aquifer

The Leederville is a major semi-confined aquifer, with an estimated maximum thickness of 550 metres. It is present across the entire Perth region except where incised by the Kings Park Formation across the central Perth area (Figure 10, light green area).

While often referred to as a confined aquifer, the Leederville is connected to a large area of the Superficial aquifer in the northern part of the Gnangara groundwater system (Figure 10, dark green area). It is disconnected from the Superficial aquifer by the Kardinya Shale aquitard across the southern half and northern coastal parts of the Gnangara system (Figure 10).

Where connected, pumping from the Leederville can directly affect the Superficial aquifer, groundwater-dependent ecosystems and other groundwater users.

Yarragadee aquifer

The Yarragadee is a major, mostly confined aquifer, ranging in size up to more than 2,000 metres thick. It is found across the entire Gnangara system.

The Yarragadee is largely disconnected from the shallower Leederville aquifer by the South Perth Shale aquitard. However, in the north of the Gnangara groundwater system there are areas where the confining shale layer is absent and the Yarragadee and Leederville aquifers are connected (Figure 10 and Figure 11, dark blue area).

There is also a small area at Yeal Nature Reserve in the north-eastern part of the system where the Yarragadee aquifer is directly connected to the Superficial aquifer (Figure 11, pink area). Where it is connected to the Leederville or Superficial aquifer, pumping from the Yarragadee can directly affect these aquifers and the values they support.

Water pressure declines in the Leederville and Yarragadee aquifers

Declines in hydraulic pressure in the Leederville and Yarragadee aquifers (measured as pressure head in mAHD) has accelerated since the 1980s as groundwater abstraction from them, mostly for public water supply, has increased (Figure 12).

In the Leederville aquifer, the largest declines of about 30 metres are in the central northern and south-western parts of the plan area (Figure 12).

In the Yarragadee aquifer, the largest declines of more than 40 metres are in the south-western part of the plan area (Figure 12).

Where the deep aquifers are connected to the Superficial aquifer, the reduced pressures have exacerbated declines in Superficial aquifer levels.

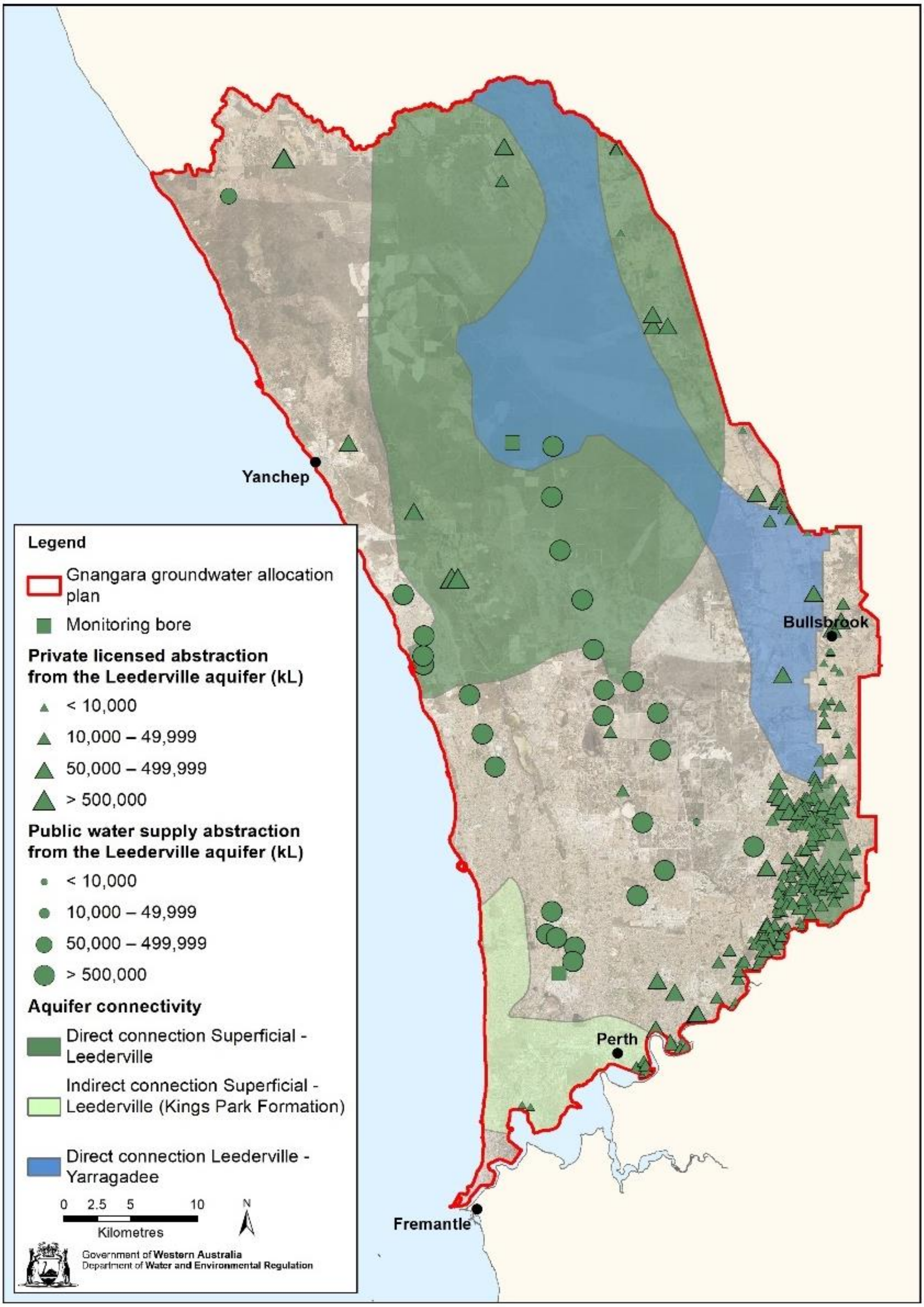

Figure 10 Groundwater connectivity of the Leederville aquifer, with abstraction locations and volumes

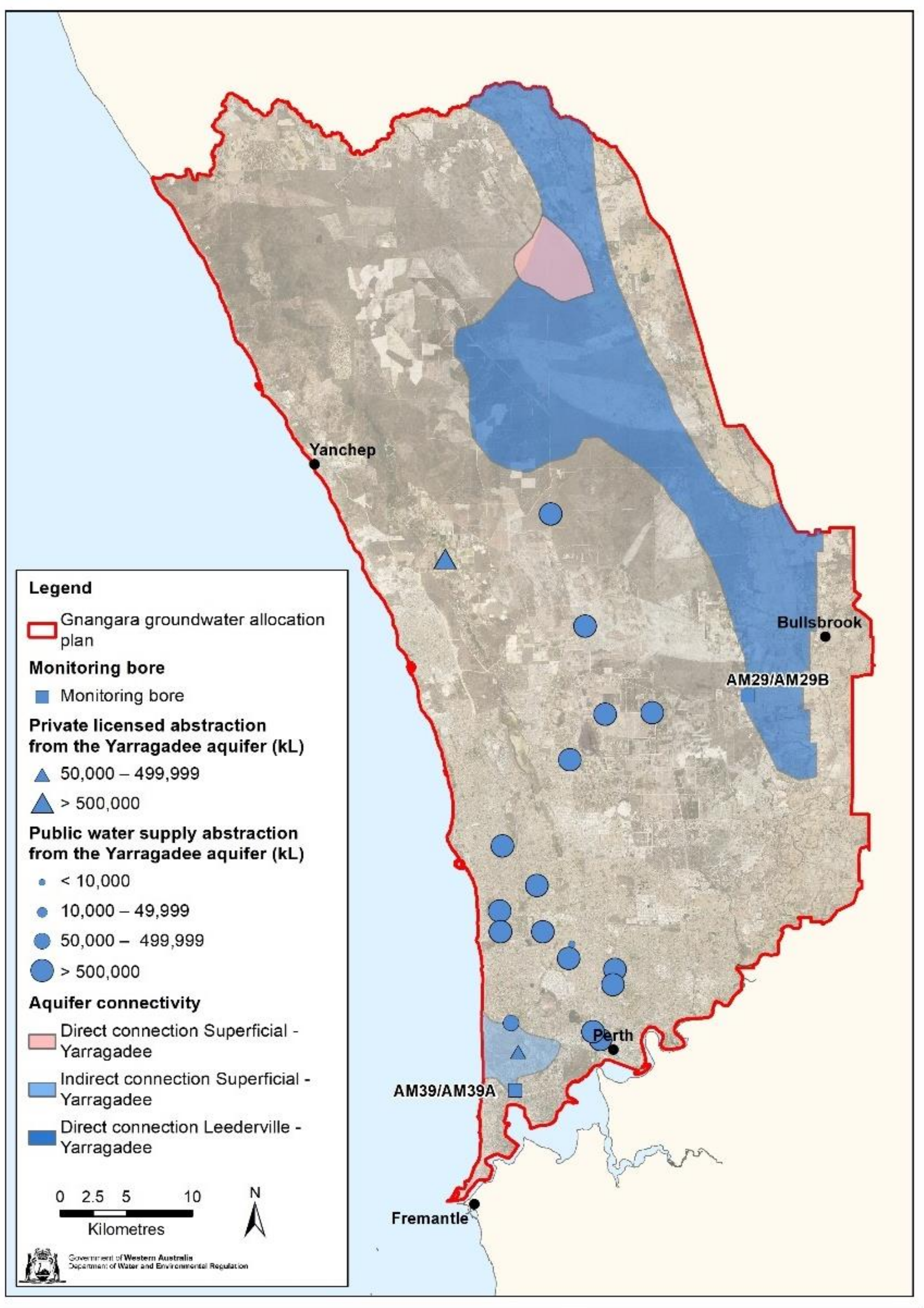

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Figure 11 Groundwater connectivity of the Yarragadee aquifer, with abstraction locations and volumes

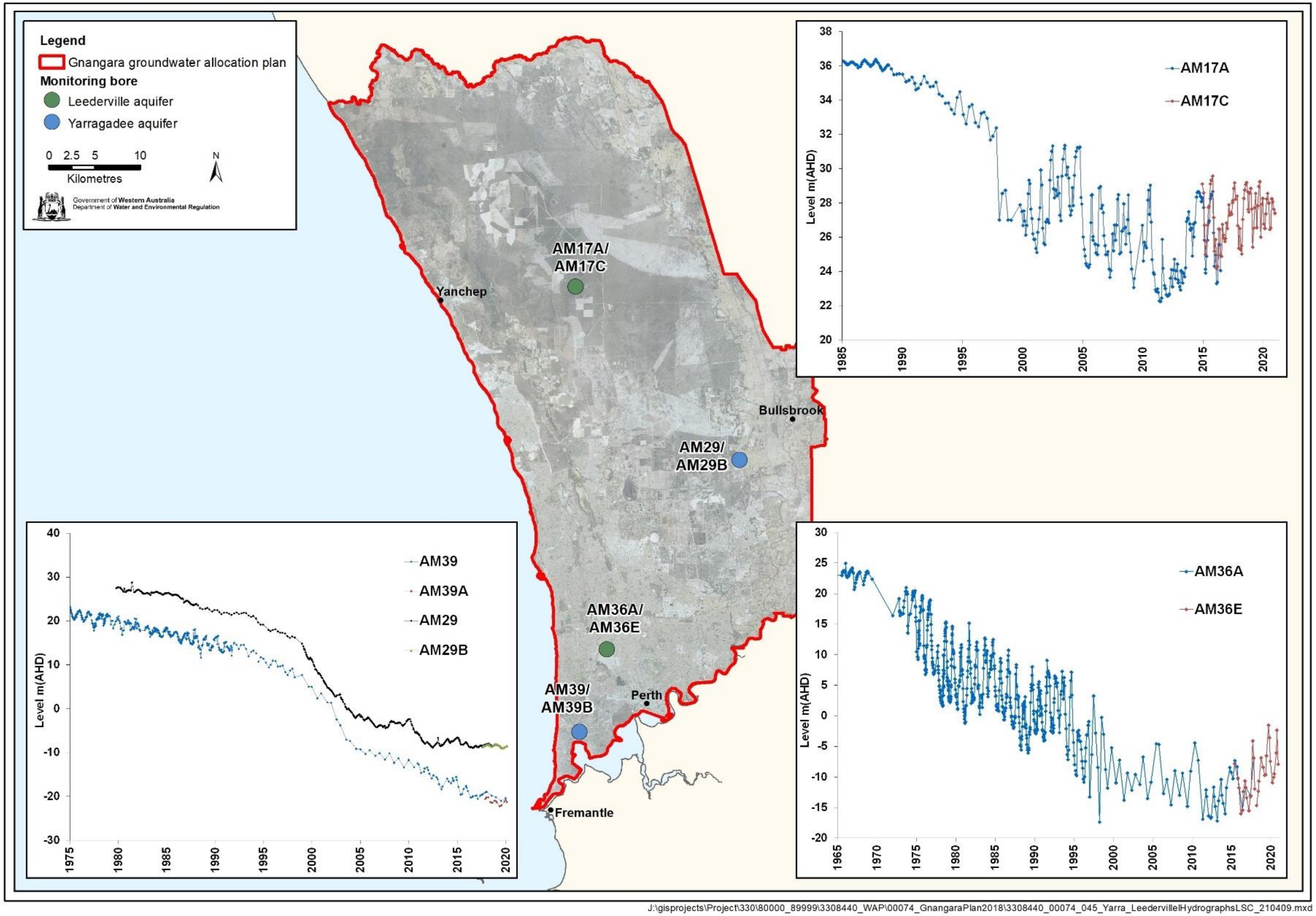

Figure 12 Trends in pressure heads in the Leederville aquifer and Yarragadee aquifer

5 Water quality

5.1 Seawater interface

Groundwater flowing through the Superficial aquifer and discharging to the Indian Ocean maintains the seawater interface and good groundwater quality by stopping saline water intruding along the coast (Figure 13). Some saline intrusion is a natural property of aquifers that discharge to the ocean. The seawater interface in the deeper, Leederville and Yarragadee aquifers is located further offshore (Figure 7).

The inland position of the seawater interface is influenced by groundwater recharge, tidal fluctuations, and climatic and seasonal variability in rainfall and sea levels. This causes a natural ebb and flow of the seawater interface along the coastline.

Groundwater abstraction near the coast can draw saline water further inland, affecting the quality of groundwater pumped from bores near the coast. Groundwater abstraction along the river can also draw saline water from the river into groundwater and affect the quality of groundwater pumped near the river.

Rising salinity has been recorded adjacent to the coast in Yanchep, Quinns, the Cottesloe-Mosman peninsula and along the Swan River (Derbarl Yerrigan) in the Swan Valley (Figure 14).

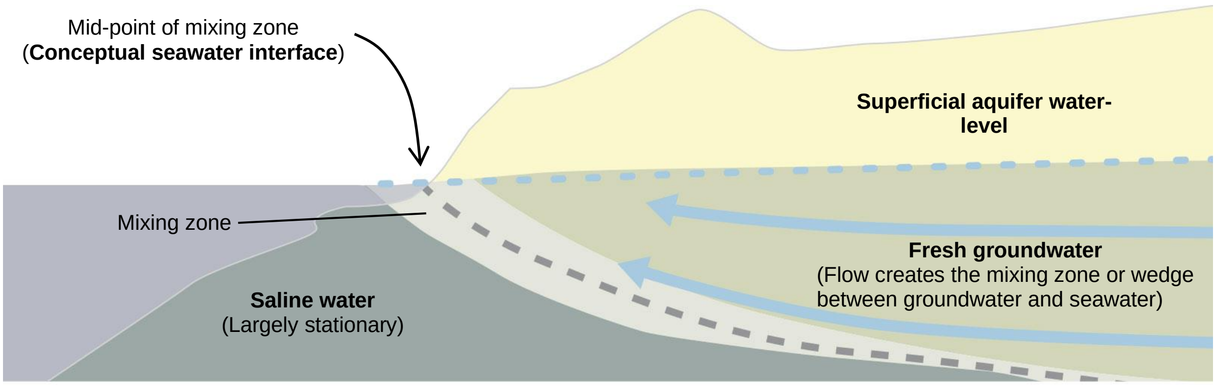

Figure 13 Conceptual representation of fresh groundwater interacting and mixing with saline water in a coastal aquifer

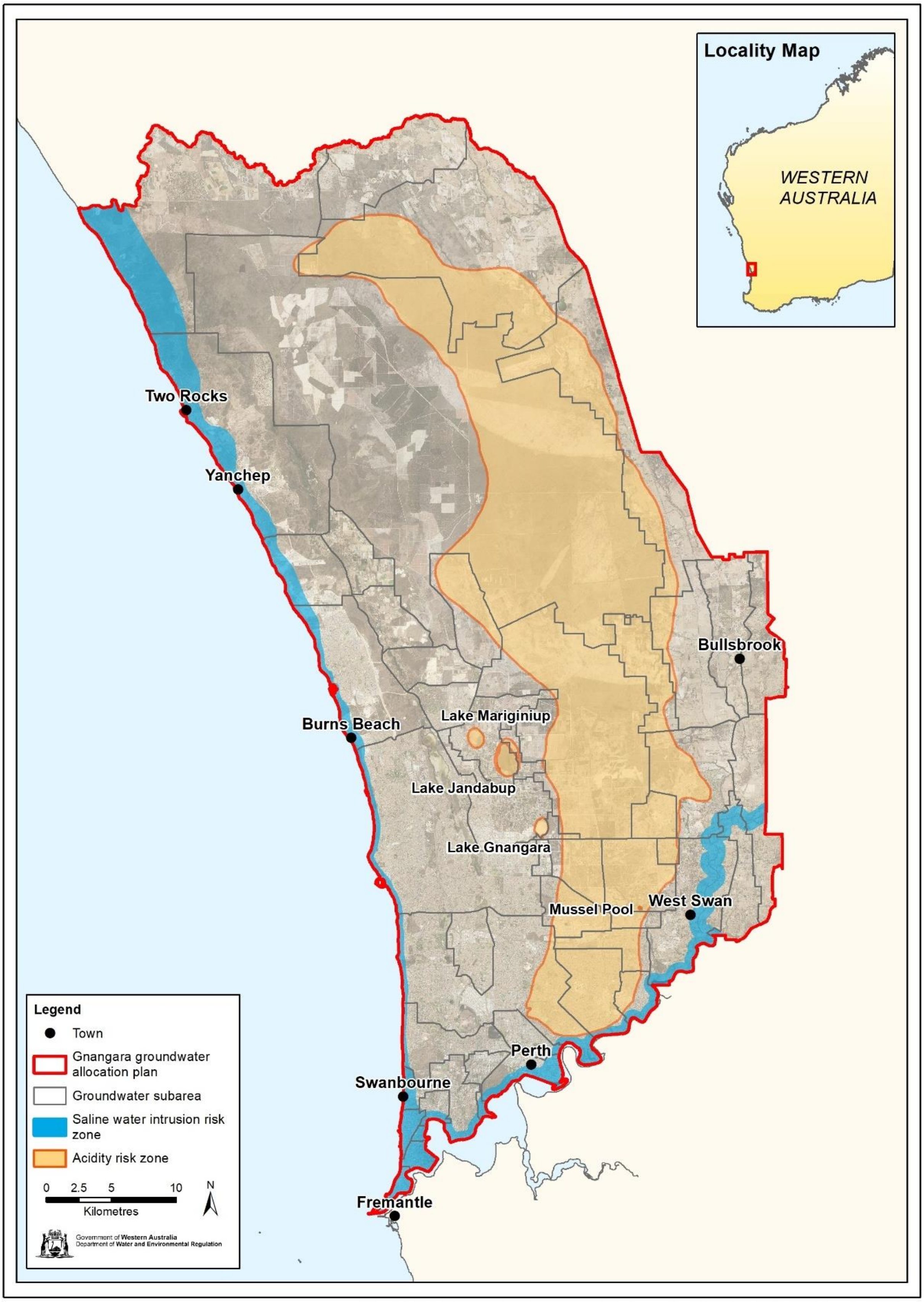

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Figure 14 Saline water intrusion and acidity risk zones

5.2 Acid sulfate soils

Water quality can also deteriorate if abstraction draws the watertable down to expose naturally occurring pyritic soils, commonly referred to as acid sulfate soils. These are soils that contain iron sulfide, which remain safe and harmless if they are kept saturated with water and undisturbed (Figure 15). Acid sulfate soils are commonly concentrated around wetlands but in the inland parts of the Gnangara groundwater system, are also widespread as layers between wetlands.

When the watertable is drawn down and the soils begin to dry and aerate, oxygen reacts with minerals in the soils and forms sulfuric acid, causing groundwater to become acidic. Low groundwater levels have already caused acidified soils and impacted on ecology at some of the wetlands that we monitor. Lake Gnangara and Lake Mariginiup have become acidic. Lake Jandabup has experienced intermittent acidification (Sommer & Horwitz 2009) but has recovered after supplementation improved water levels at the lake. Mussel Pool in Whiteman Park is also being impacted by acidity.

Declines in the watertable between wetlands has exposed acid sulfate soils in parts of the Superficial aquifer. This has caused acidification of shallow groundwater across 380 km^2 (>15 per cent) of the Gnangara plan area (see Figure 14, Degens & Thornton 2018). This could eventually limit the use of shallow groundwater in these areas.

Figure 15 shows a conceptual representation of how watertable decline and exposure of acid sulfate soils can lead to acidity in groundwater.

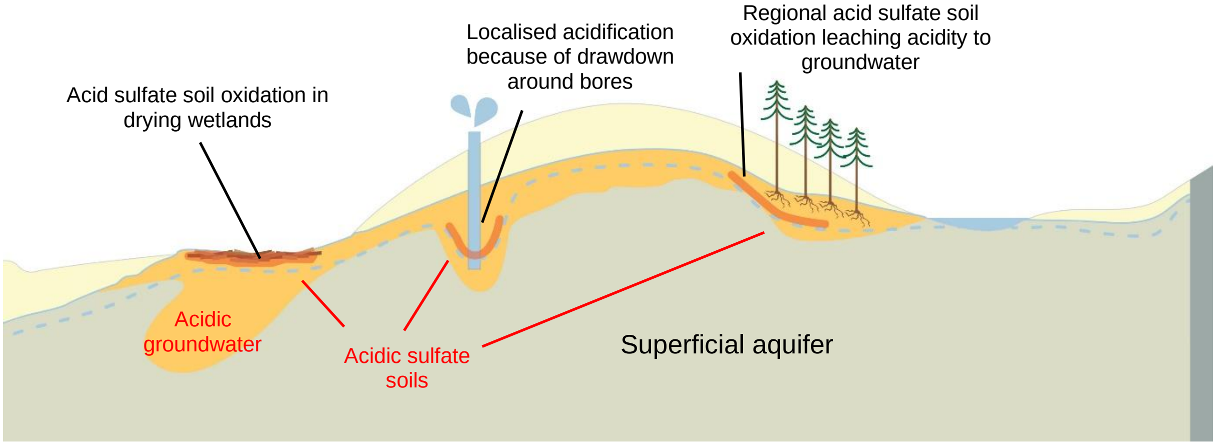


Figure 15 Conceptual representation of acid sulfate soils and water level declines leading to acidity in groundwater

Pumping from deeper bores can draw the acidic shallow water deeper into an aquifer – this has occurred in the Mirrabooka borefield (Appleyard & Cook 2008).

Declining groundwater levels have led to greater drying of peat in and around wetlands in the Gnangara plan area, leaving them at increased risk of fire. Peat fires are difficult to extinguish and can burn underground for weeks or even months.

Drying out of these organic soils can leave deep cracks in the sediments and accelerate the oxidation of acid sulfate soils, which then release acid upon rewetting, in turn mobilising metals and salts from the soil into the shallow groundwater system. In late 2019 an intense fire broke out in Yanchep National Park, burning through large areas of bushland and wetland, including Lake Yonderup and Loch McNess (Wagardu).

The bushfire at Yanchep National Park in late 2019 resulted in the loss of organic sediments and exposed large cracks over one metre deep (Photographer: Pierre Horwitz, ECU.)

The fire resulted in a massive loss of organic sediments and exposed cracks of more than a metre deep in some areas. Monitoring water chemistry at the two wetlands showed an increase in acidity and a decrease in alkalinity in surface waters in the winter of 2020, as groundwater levels rose for the first time after the fire (Blake et al. 2021). Climate change and unabated groundwater abstraction will accelerate acidification in organic soils in the Gnangara plan area, while declining groundwater levels will leave sediments more vulnerable to desiccation and fire.

6 Ecological, community and cultural values

6.1 Groundwater-dependent ecosystems

During the past 200 years most of the native bushland and more than 80 per cent of the original wetlands on the Swan coastal plain have been lost through clearing and draining. This means the natural areas that remain are critically important.

The Gnangara groundwater system sustains valuable natural areas that include wetlands, mound springs, cave systems and large areas of bushland that lie over shallow groundwater (Figure 16). These areas are highly likely to depend on groundwater for some or all their water needs where water levels in the Superficial aquifer are within 10.5 metres of the surface (Sommer & Froend 2010). However, some large, deep-rooted trees can access deeper groundwater up to 20 metres below the surface (Eamus et al. 2006).

Many of the groundwater-dependent features on the Gnangara system have conservation significance, and are recognised and protected under state and federal legislation.[2] They are also some of the most biologically diverse and ecologically productive parts of the environment and support most wildlife in the Gnangara plan area.

Lake Yonderup in Yanchep National Park (Photographer: Renée Rowling, DWER.)

[2] In 2016 the 'Banksia Woodlands of the Swan Coastal Plain' ecological community was listed as 'endangered' under Australia's national environment law, the *Environment Protection and Biodiversity Conservation Act 1999*. As most of the groundwater-dependent native vegetation in the Gnangara plan area is Banksia woodland, this listing effects a significant increase in the level of legal protection for much of the area shown in Figure 16. Banksia woodlands provide vital habitat for more than 20 nationally threatened species, including the Carnaby's black cockatoo.

As described in Section 4.1, during the past 40 years groundwater levels in the Superficial aquifer have fallen across most of the Gnangara plan area. These declines have had a visible and measurable impact on groundwater-dependent ecosystems.

Ministerial Statement no. 819 environmental water level criteria

In managing the Gnangara groundwater resources, we are responsible for meeting conditions set under the *Environmental Protection Act 1986* (WA). *Ministerial Statement no. 819*, published on 4 December 2009, sets water level criteria for 30 representative wetland and bushland sites in the Gnangara plan area (Figure 16).

Water level criteria are minimum water level thresholds set at staff gauges or monitoring bores at wetlands or in bushland areas. The criteria are scientifically based and designed to protect key ecological and community values for groundwater-dependent ecosystems at an acceptable level of risk (WAWA 1995).

Environmental conditions and commitments were first set for Gnangara groundwater in *Ministerial Statement no. 21* (published on 8 March 1988). This followed an Environmental Protection Authority (EPA) assessment of a proposal from the Water Authority (now Water Corporation) to expand public water supply borefields in Pinjar and self-supply groundwater use in the Wanneroo area (EPA 1987).

Since then, the conditions and commitments have been revised several times. One of these revisions came after a major study in 2004 that re-evaluated ecological values and water requirements, recognising the cumulative impacts of historic abstraction, climate and land use change on groundwater levels (Froend et al. 2004). The most recent revision, *Ministerial Statement no. 819*, removed seven sites and amended the water level criteria at three sites (EPA 2009).

Water level criteria are just one part of a range of environmental conditions in the statement. They sit with a broader objective to ‘minimise environmental and/or significant impacts of abstraction and to manage the resource sustainably’.

We report annually to the EPA on compliance with water level criteria and other environmental conditions in the statement.

The water level criteria in *Ministerial Statement no. 819* and those preceding it have played an important role in managing the Gnangara system. The water level criteria:

- have driven the development of a comprehensive network of water level monitoring sites and a series of long-term ecological monitoring programs
- have supported the creation of large datasets of scientific information that have been used to develop critical tools, such as the Perth Regional Aquifer Modelling System
- have helped instigate hydrogeological investigations to better understand how the various aquifers interact with one another and support surface ecosystems, and to identify the drivers of groundwater decline in different locations

- have provided an important foundation for management decisions about where (which bores) and how the Water Corporation takes its annual licensed groundwater quota from the Gnangara system
- have given legal protection to significant groundwater-dependent ecosystems and, through our annual reporting commitments, have raised public awareness of the impacts of groundwater abstraction on these systems.

We used the water level criteria to assess the ‘reduced abstraction’ options underpinning our allocation limit decision for the new Gnangara allocation plan. We ran a range of modelled groundwater abstraction scenarios and assessed these against the water level criteria to see how each scenario performed against them.

One of our initial objectives was to reduce groundwater use enough to meet all the water level criteria in *Ministerial Statement no. 819*. However, as the groundwater modelling progressed, it became clear that 100 per cent compliance was impossible to achieve under the projected dry climate scenario, even with very large reductions to groundwater use.

The modelling helped us develop proposed new water level criteria (or thresholds) at some of the existing representative wetland and bushland sites. At these sites, modelled projections showed that existing criteria could not be met under a drier climate, even with large reductions to groundwater abstraction (see Section 9.4).

Non-compliance with environmental conditions and impacts to ecosystems

Since the release of the 2009 Gnangara allocation plan, the number of sites that have not been compliant with their absolute end-of-summer minimum or spring-peak water level criteria increased from 12 in 2009–10 to a maximum of 18 in 2015–16. Since 2015–16, two highly unusual summer rainfall events in 2017 and 2018 contributed to increased groundwater levels at some sites, resulting in non-compliance decreasing to 14 sites in 2019–20 (Figure 16).

Breaches of water level criteria indicate that groundwater levels are not high enough to adequately meet the water requirements of the ecosystem, and point to an increased risk of significant impacts to ecosystem values. The results of our ecological monitoring programs show that water level declines and breaches of criteria have led to:

- drying and terrestrialisation of wetlands, which can be seen at Loch McNess (Wagardu) and Lake Wilgarup in Yanchep National Park
- an increased risk of wetland peat fires, such as those in the Yanchep National Park wetlands in December 2019
- declines in vegetation health and loss of species that require wetter conditions, which can be seen at Lake Nowergup where many mature fringing melaleucas have died
- groundwater acidification at half of the monitored wetlands, which at lakes Jandabup and Mariginiup has altered the macroinvertebrate fauna communities, and at Whiteman Park has caused acidification of Mussel Pool

- frogs disappearing from some wetland areas, such as the reduced species and population numbers at Lexia wetlands
- loss of the Yanchep Caves Aquatic Root Mat threatened ecological community.

Our long-term water level and ecological monitoring datasets have been invaluable for providing key information about the relationship between water levels and ecosystem health. During the past two decades this monitoring data has been a critical driver of management actions.

The observed loss of wetland and bushland values (associated with falling water levels) is clear evidence that we must reduce abstraction impacts on these already stressed ecosystems. This will be critical to preserving their health as the climate continues to change.

The department's ecological monitoring program has found that frogs are disappearing from some wetland areas (Photographer: Grant Buller, ECU.)

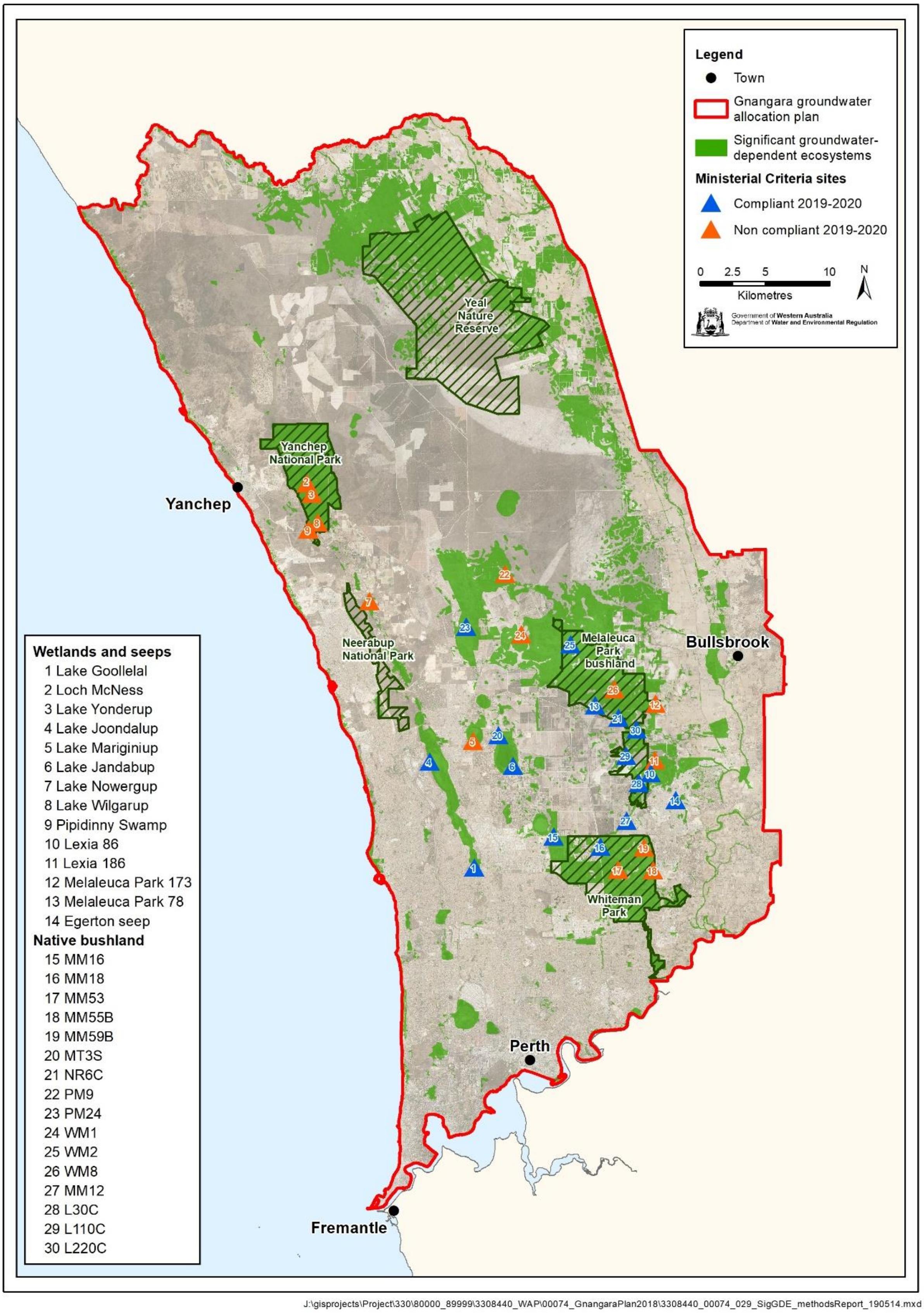


Figure 16 Significant groundwater-dependent ecosystems supported by the Gnangara groundwater system

6.2 Community and cultural values

Community values of groundwater

Groundwater has economic value to the community when it is abstracted. It also has many *in situ* or ‘in place’ values that the community benefits from. One of the most important is that it sustains large areas of bushland and wetlands north of Perth.

These groundwater-dependent ecosystems provide attractive places for the community to visit and enjoy. They provide important recreational, aesthetic, educational and therapeutic values and for many people; being in and around these places is essential for their physical, mental and spiritual wellbeing.

In a city where residential block sizes are decreasing, and traditional suburban backyards are disappearing, our groundwater-dependent natural areas are becoming increasingly valuable spaces for recreation and community interaction.

Beckwith (2006) studied the *in situ* social values of the groundwater-dependent ecosystems of the Gnangara system using in-depth interviews with 26 stakeholder representatives and a three-hour workshop.

The study found significant social values for the following eight groundwater-dependent features (participants gave these the highest rating):

- Loch McNess (Wagardu)
- Crystal Cave
- Lake Monger (Galup)
- Herdsman Lake (Ngurgenboro)
- Perry Lakes
- Lake Joondalup
- Star Swamp
- Bennett Brook

The participants rated a further 22 sites or group of sites as important. Some of the primary values were found to be:

- aesthetic
- Aboriginal and European heritage
- birdwatching/nature observation
- recreational (such as walking, running, cycling, picnicking)
- education and research
- complementary land use (such as parks and pathways).

Very few groundwater-dependent ecosystems in the 2006 Beckwith study received a low social-value rating, and those that did tended to be poorly known features such as the Pinjar wetlands.

In addition to social values, wetlands and waterways provide important ecosystem services to the community, such as retaining nutrients from drainage, mitigating floods and measurably cooling hot urban areas. These cooling benefits are becoming more critical in a city where domestic gardens are shrinking and where climate change is causing warmer temperatures and less rainfall.

The Perth community values groundwater-dependent ecosystems. Research for the 2009 *Gnangara sustainability strategy* (DoW 2009b) found the community expected some changes to wetlands as a result of climate change. However, wetland losses as a result of human impacts, such as over-abstraction, were viewed as unacceptable. The community did not support high-value wetlands drying out (Government of Western Australia 2009).

Gnangara groundwater and its significance to the Noongar people

The Whadjuk and Yued Noongar peoples are the traditional custodians of the land covered by the Gnangara plan area (Figure 17). This is recognised in the *South West Native Title Settlement 2019* and the *Noongar (Koorah, Nitja, Boordahwan) (Past, Present, Future) Recognition Act 2016.* Most of the plan area is Whadjuk country from Two Rocks down to the Swan River (Derbarl Yerrigan). Yued country is north of Two Rocks to the northern extent of the plan area (Gingin Brook).

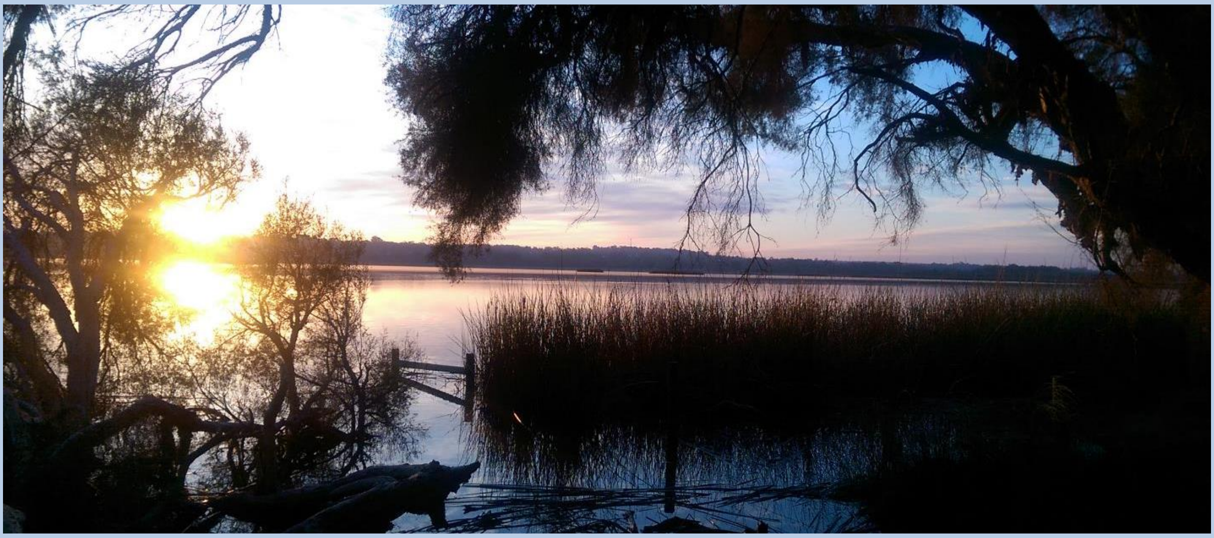
Spiritual connection to groundwater

The Waugal, the giver of life and creator of fresh water sources, is the central spirit in Noongar beliefs. Noongar creation stories describe the Waugal as a great, serpent-like being, moving through the earth, creating the lakes and wetlands in places where it came up or stopped to rest, forming the curves and contours of the land with its body, and leaving *wirrin* (spirits) behind to look after the earth. The Waugal is said to inhabit most deep waterholes, lakes and pools, and sometimes the hills and rocks or the sea. If the Waugal is disturbed or angered, the fresh water sources may dry up and disappear, and so care must be taken to respect the places where the Waugal resides (SWALSC 2021).

The Waugal may be thought of as the caretaker of the rivers, wetlands and springs while the Noongar people are the caretakers of the land, both working together to care for country (Wooltorton et al. 2019).

The unbreakable connection between land and water (including underground water) and the relationship between the environment, the Noongar people and the Waugal are woven through all the creation stories, demonstrating how important groundwater and groundwater-dependent ecosystems are to Noongar people and culture.

The creation of Pinjar Joondalup



Long ago, as the Waugal moved through the land, creating the lakes, a tall spirit woman with long, white hair that cascaded down her back, the Charnock woman, travelled about in the darkness of the Dreamtime collecting spirit children.

The Charnock woman didn't want to part with the spirit children, so she kept them in her long, white hair.

One day she realised keeping the spirit children was wrong, and so she shook her long hair to release them. The spirit children were flung into the air and became the stars. Sometimes the children returned to the earth in the form of meteor showers to become spirit adults, the carers of everything.

On a full moon, the reflection of the Charnock woman's long, white hair can be seen in the waters of Pinjar Joondalup (Lake Joondalup). The name Joondalup means place of the long, white hair, or place of the water that glistens. The shape of the lake is the shape of the Charnock woman's footprint, made as she stepped across the land collecting the spirit children.

Based on the story as told by Whadjuk Noongar Elder Dr Noel Nannup, retrieved from the Water Corporation's Walk with the Waugal videos.

Heritage values for groundwater

Many Gnangara lakes, wetlands and springs have Aboriginal heritage values and are registered as sites under the *Aboriginal Heritage Act 1972*. These places hold historical and contemporary values for Noongar people and are used for a range of activities and purposes, including hunting, gathering and performing ceremonies. They are also used as campsites, burial sites, birthplaces and totemic places. Indigenous artefacts have been found at several wetland sites.

A cultural values study by Estill & Associates (2005) focused on the Gnangara plan area. A key outcome of the study was the Noongar representatives unanimously calling for wetlands to be maintained and flows to be restored wherever possible. The study noted that:

> *‘Any degradation to groundwater features constitutes a cultural impact whether that degradation is caused by natural climatic cycles, climate change or over-exploitation of the groundwater resource.’*
>
> *‘Any actions government take to reverse the degradation of groundwater-related features and associated ecological processes, and to restore these to their natural state, will have the support of Aboriginal people.’*

The study identified many groundwater-dependent cultural sites that were a priority for protection (Figure 17). Note that this list is not exhaustive, as there are many more areas of significance to Aboriginal people. Overall, the study emphasised the importance of Aboriginal people being included in the ongoing management of Gnangara groundwater resources (Estill & Associates 2005).

Bidi (pathways)

The Gnangara wetlands are important *bidi* (pathways) to Noongar people. Historically, family groups moved between the hills in winter, across to the foothills *Gyunning* (Ellen Brook) area on the eastern side of the Gnangara groundwater system, and then to the western wetlands in summer. Many Noongar place names in these areas include words meaning ‘feet’ (*jen*, *gyn*, *gin*, *chan*), marking their significance as part of a walking route.

The chain of wetlands from Yanchep to *Galup* (Lake Monger) form part of an important *bidi* that provided vital sources of food, water and materials to the Noongar people in the summer seasons of *Birak* and *Bunuru* (December to March).

The significance of a wetland area for a particular resource can often be found in its Noongar place name. For example, Yanchep – *janjidi-up* means place of *Typha*, or bullrush, Lake Wilgarup – *wil-gar-up* means place of the ochre hole, and Lake Mariginiup – *mar-marin-gin-ni-up* means place of vegetables gathered by hand and foot.

Source: Wooltorton et al. 2019

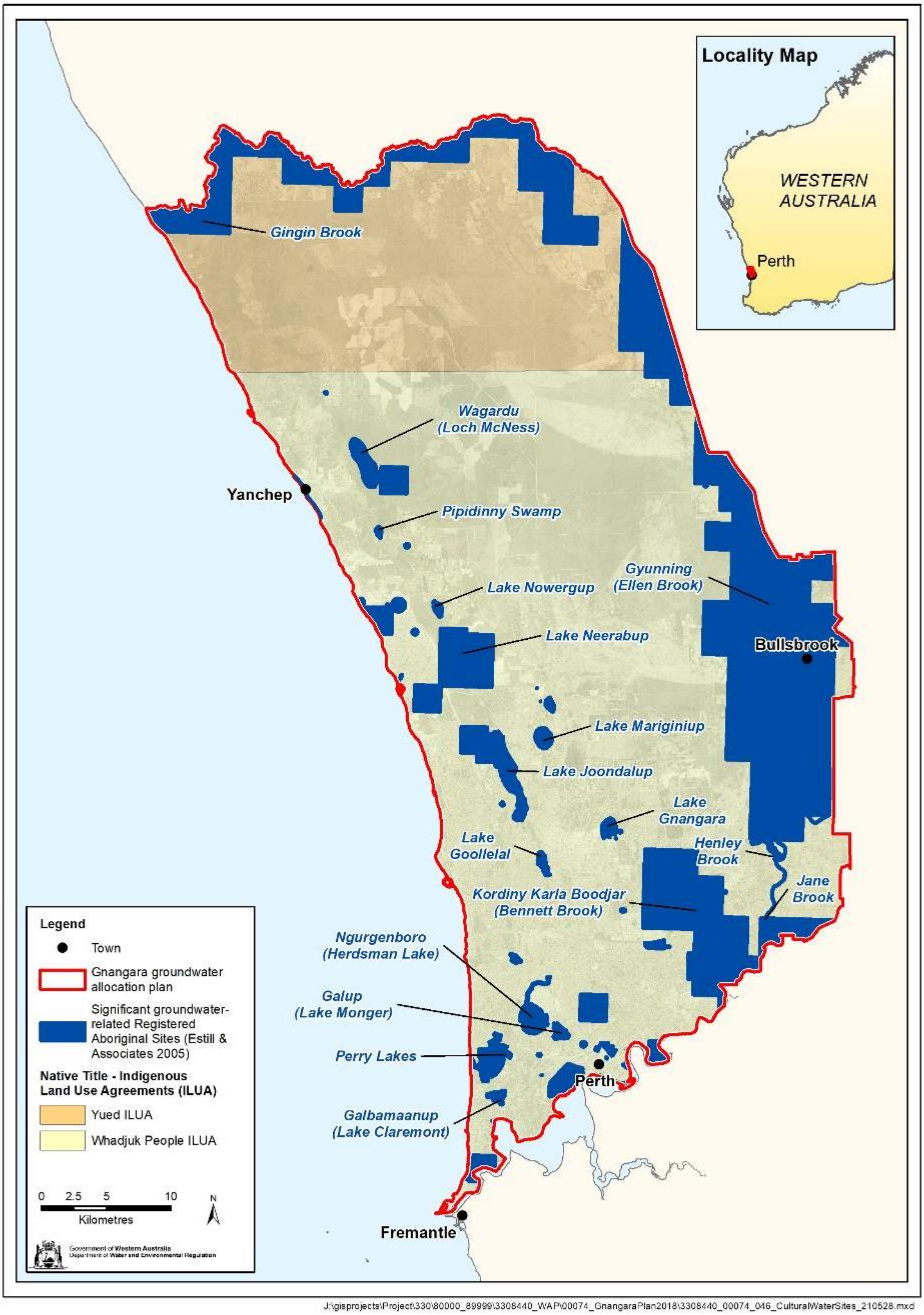


Figure 17 Significant groundwater-related Registered Aboriginal Sites as described by Estill & Associates 2005

See Appendix D for a complete list of mapped sites.

7 New hydrogeological research and modelling

Since the 2009 *Gnangara groundwater areas allocation plan* was released, the Department of Water and Environmental Regulation has completed several major studies to help manage abstraction from the Gnangara system. These include:

- the Perth Region Confined Aquifer Capacity (PRCAC) study
- the Perth shallow groundwater systems investigations
- studies into the causes of water level declines at Loch McNess (Wagardu) and Lake Nowergup
- a major update of the Perth Regional Aquifer Modelling System (PRAMS).

7.1 Perth Region Confined Aquifer Capacity study

The PRCAC study (DWER 2021b) used robust and established science, coupled with innovative research, to improve our understanding of the deep Leederville and Yarragadee aquifers in the Perth region. Recommendations from the study that supported our allocation planning for the Gnangara system included:

- reduce the volume of deep aquifer groundwater abstraction over time in targeted locations – this will contribute significantly to rebalancing the Gnangara groundwater system
- focus the abstraction reductions in parts of the deep aquifers near where they are connected to the Superficial aquifer

7.2 Perth shallow groundwater systems investigations

We completed multiple shallow groundwater systems investigations at wetlands prioritised for ecological significance, management issues and geomorphic setting. The wetlands studied included:

- Lake Mariginiup (Searle et al. 2010)
- Lake Yonderup (DoW 2011a)
- Loch McNess (Wagardu) (DoW 2011b)
- Lexia wetlands (DoW 2011c)
- Tangletoe Swamp (DoW 2011d)
- Egerton Seepage (McHugh et al. 2011)
- Lake Nowergup (Searle et al. 2011)
- Lake Gwelup (Clohessy 2012)
- Lake Muckenburra (Degens et al. 2012)
- North Yeal wetlands (Degens et al. 2021).

These investigations set out to improve our understanding of the hydrogeology of wetlands and to determine the interactions and connectivity between the surface water, surrounding shallow groundwater, and regional groundwater. The findings supported our interpretation of the modelling results and our assessment of the modelled changes in regional groundwater levels and how these would affect wetland hydrology and ecosystem health.

The shallow groundwater system investigations generally confirmed that surface water levels and the ecological health of most of the studied wetlands directly depend on groundwater levels in the regional Superficial aquifer. This means the ecological health of those wetlands is driven by groundwater levels in the Superficial aquifer. This includes abstraction from the regional Superficial aquifer and from deeper aquifers in areas where they are connected to the Superficial aquifer.

The exceptions were Lake Muckenburra and Tangletoe Swamp. These wetlands are supported by shallow groundwater systems that sit above the Superficial aquifer and are not affected by groundwater abstraction.

The investigation at North Yeal wetlands found that the regional Superficial aquifer supported the ecological health of Quin Brook wetland and Quin Swamp, but not Yeal Lake, which was disconnected from the regional Superficial aquifer (Degens et al. 2021).

7.3 Causes of historic water level decline at Loch McNess (Wagardu) and Lake Nowergup

Lake Nowergup and Loch McNess (Wagardu) are two highly valued wetlands where falling water levels have led to drying and significant declines in ecological health. Lake Nowergup is artificially supplemented by groundwater pumped from the Leederville aquifer. We recently studied why water levels were declining at both important lakes.

At Loch McNess (Wagardu) (see Figure 18) we found the watertable decline to 2012 (to the east of the lake) was mostly caused by abstraction for public water supply from the Leederville aquifer. The remaining watertable declines were attributed to reduced rainfall (Kretschmer & Kelsey 2016).

To the west of the lake, declines were attributed to abstraction from the Superficial aquifer, including for public water supply and self-supply, as well as reduced rainfall because of climate change (Kretschmer & Kelsey 2016).

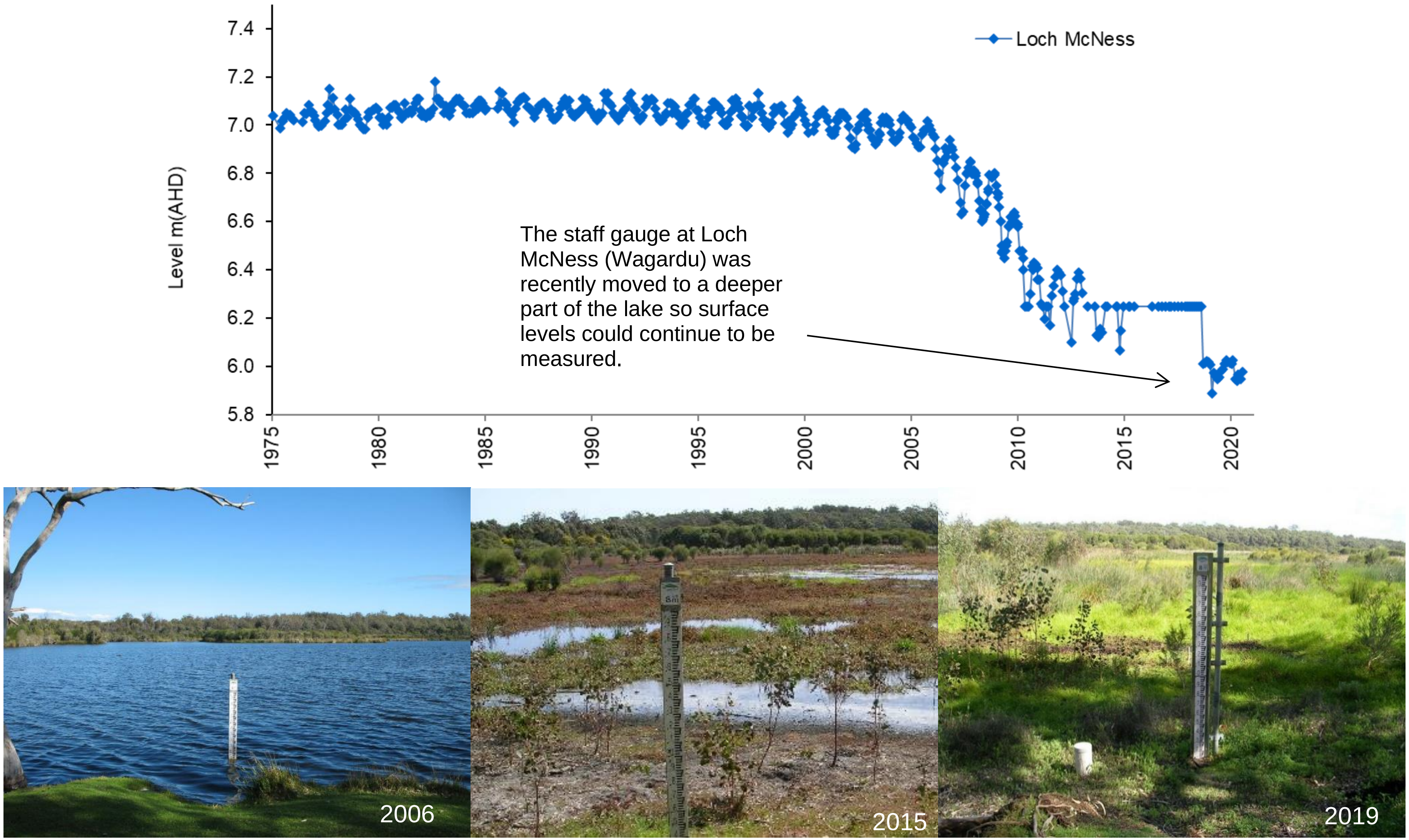


Figure 18 Groundwater level declines have led to drying and terrestrialisation of Loch McNess (Wagardu) in Yanchep National Park (Photographers: DWER and ECU.)

The study at Lake Nowergup ranked the contribution of climate and groundwater abstraction on the watertable changes at the lake since 1973. The study found that use of the local Superficial aquifer for horticulture had caused the greatest impact on lake levels, followed by reduced rainfall, then Leederville aquifer pumping for public water supply from the Quinns and Pinjar borefields (Global Groundwater 2015).

The findings of these studies informed the reduced abstraction options described in Chapter 9. The modelled options reduce abstraction in targeted areas to identify how particular changes would support improved water levels at these lakes and other groundwater-dependent ecosystems.

Groundwater level declines at Lake Nowergup have reduced the area of open water at the lake and caused fringing melaleucas to die (Photographer: Craig Stott, DWER.)

7.4 Groundwater modelling

Modelling of the Gnangara groundwater system was completed using the Perth Regional Aquifer Modelling System (PRAMS) version 3.5. PRAMS is a sophisticated numerical groundwater flow model that simulates the responses of Perth aquifers to changes in climate, land use and abstraction (CyMod Systems Pty Ltd 2014).

The model has been improved since it was developed in the early 2000s, with PRAMS 3.5 including updated geological, abstraction, climate and land use information. These updates have improved the model's capacity to project the effect of changes to climate and land use on rainfall recharge and groundwater levels.

The updated model meets the calibration targets and performance criteria in the *Australian groundwater flow modelling guidelines* (Barnett et al. 2012). This enables the model to provide consistent and reliable water balance calculations and projections of relative water levels. The calibrated model has been independently reviewed (HydroAlgorithmics 2014). The review found the model was fit to:

- estimate the impact of abstraction on water levels and pressure head in all aquifers
- provide quantitative estimates of the water resources of the Perth region
- evaluate how future land use management would affect groundwater levels of the Perth region
- evaluate the impacts of climate change.

We recently completed a post-audit of PRAMS 3.5, which further demonstrated the model's reliability and effectiveness as a groundwater management tool. For the post-audit we:

- assessed the performance of the calibrated model parameters (for the 2000–13 calibration period) with updated datasets of land use, abstraction and climate, using measured data to 2019
- compared the rainfall and land use datasets used in the predictive modelling against measured data from 2013 to 2019.

Updating PRAMS 3.5 with measured data to 2019 had a very minor impact on the previous calibration statistics (Table 1). This indicates the PRAMS 3.5 model calibration is robust and supports the validity of its predictive capabilities.

Table 1 Calibration statistics for PRAMS 3.5 for the original calibration period compared with the statistics with measured data to 2019

Aquifer	Original calibration period (2000–13)	Calibration updated with measured data to 2019
	Model SRMS[3] values	
Superficial	3.20%	3.22%
Mirrabooka	2.64%	3.35%
Leederville	7.75%	7.38%
Yarragadee	10.59%	10.13%

To test our predictive rainfall and land use datasets, we compared the predictive data to observed data from 2013 to 2019. Rainfall from the dry climate scenario that we used for plan modelling closely matched observed rainfall data since 2013 across each climate zone in PRAMS (Figure 19). Satellite imagery from 2013 to 2019 shows land use change is tracking closely to the future land use dataset we used in plan modelling.

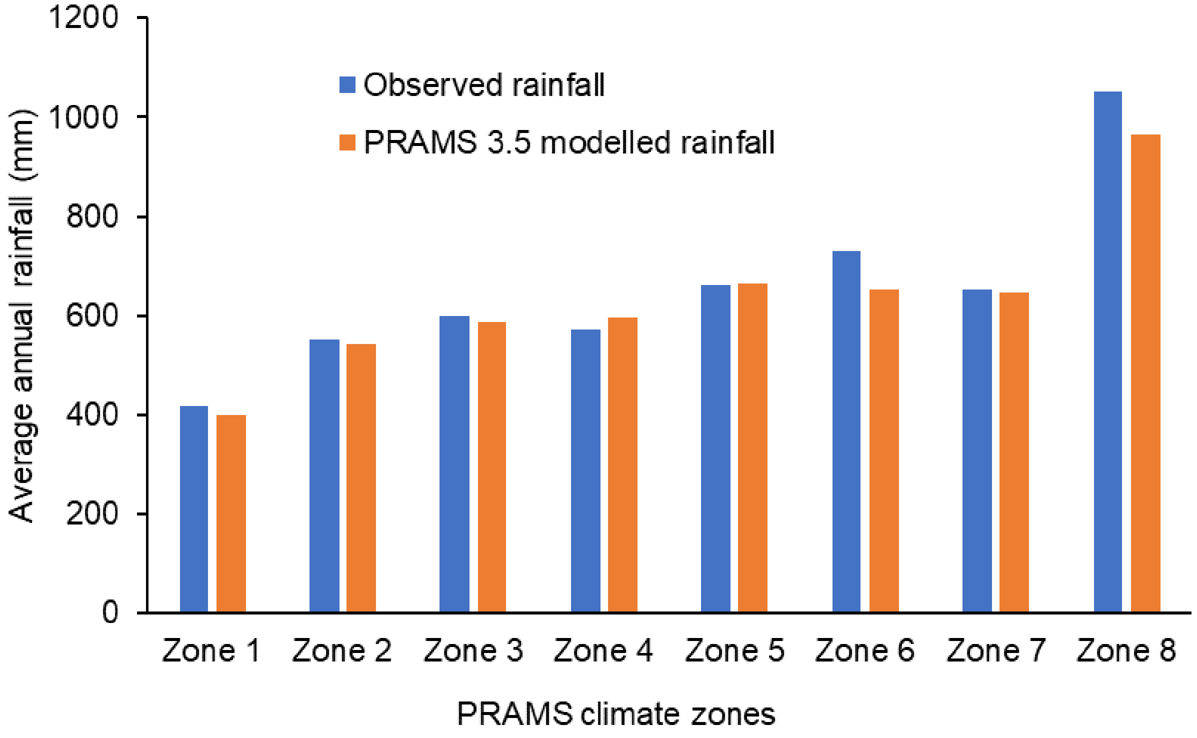


Figure 19 PRAMS 3.5 modelled rainfall verses observed rainfall (2013 to 2019)

[3] Scaled Root Mean Squares (SRMS) is a statistic commonly used in assessments of model calibration.

Part B — Setting objectives and deciding on the scale of reduced abstraction

In Part B of this report we define the:

- expected outcomes from the allocation plan
- water resource objectives
- reduced abstraction options for assessment
- results of the modelling we used to assess the abstraction options
- reduced abstraction decision (scale of reduction).

Key points from Part B:

- We set the plan's outcomes and objectives consistent with the aims of the 2009 Gnangara plan to reduce total groundwater use and protect the quality and environmental values of the resource.
- The objectives align with our legislative requirements and consider climate change and stakeholder feedback.
- We completed more than 100 modelled scenarios, as well as innovative modelling research, to understand how the Gnangara groundwater system might respond to future changes in climate, land use and abstraction. We used this modelling to develop and assess four 'reduced abstraction' options.
- We selected the department's future dry climate scenario as the basis for the modelling of options for this plan to 2030. This scenario reflects Perth's declining rainfall trend during the past two decades.
- The modelling included future land use changes to 2030, including forecast urbanisation and consideration of post-harvest land use options for the 23,000 hectares of pine and ex-pine plantations in the plan area (see Section 3.1).
- We assessed the modelling results of the four 'reduced abstraction' options and a 'no intervention' reference scenario against the water resource objectives and water level criteria set in *Ministerial Statement no. 819*.
- We compared the results of this work against the past impacts on the resource and the environment and found that abstraction must be reduced by 54 GL/year to meet the plan's water resource objectives.

8 Setting outcomes and resource objectives

8.1 Outcomes

The outcomes we expect to see from implementing the Gnangara plan are:

1. Groundwater abstraction from the Gnangara groundwater system is reduced to be more **secure and sustainable** in the long term.
2. Perth's unique groundwater-dependent **wetlands and bushlands are healthier and more resilient** to climate change.
3. Groundwater users and state and local government are **optimising how the Gnangara groundwater system is used** for water supply, storage and reuse.
4. Groundwater users, infrastructure and the environment are **safer from deteriorating water quality**.

Achieving these outcomes will help implement the *Waterwise Perth Action Plan* (Government of Western Australia 2019) and be an important part of Perth's transition to a leading waterwise city with:

- water used sustainably in our homes and gardens
- liveable, green and resilient communities
- sustainably maintained public open space.

The *Gnangara groundwater allocation plan* when finalised will help deliver Action 14 of the *Waterwise Perth Action Plan*: Review groundwater allocation plans for Gnangara, Cockburn, Perth South and Jandakot and Serpentine to manage groundwater levels for wetlands, urban trees and for irrigation of green spaces.

8.2 Water resource objectives

The plan's water resource objectives reflect the aims of the 2009 *Gnangara groundwater areas allocation plan* to manage the Gnangara system in line with the effects of climate change across south-west Western Australia.

The objectives align with our legislative responsibilities under the:

- *Rights in Water and Irrigation Act 1914*, particularly the following:
  - Part III, Div. 1, section 4: Objects of the Act:

    'a) To provide for the management of water resources, and in particular –

    i. for their sustainable use and development to meet the needs of current and future users *ii. for the protection of their ecosystems and the environment in which water resources are situated, including by the regulation of activities detrimental to them.*

   b) To promote the orderly, equitable and efficient use of water resources.'

  - Division 3D – Plans for management of water resources under section 26GX.
  - Schedule 1, Division 2, clause 7(2).
- *Water Agencies Powers Act 1984*, in particular the following*:*
  - Part II, Division 1, section 9 (1a – d) and section 9 (4).
- *Ministerial Statement no. 819: Gnangara Mound groundwater resources [including East Gnangara Shire of Swan]*, under Part IV of the *Environmental Protection Act 1986*:
  - manage public and private groundwater abstraction to:
    - minimise environmental and/or significant impact to Yanchep Caves and phreatophytic[4] vegetation
    - meet water level criteria (in *Ministerial Statement no. 819*)
  - to minimise environmental and/or significant impacts of abstraction and to manage the resource sustainably.
- *Environment Protection and Biodiversity Conservation Act 1999* (Cth) to protect Matters of National Environmental Significance (e.g. Banksia Woodlands of the Swan Coastal Plain ecological community).

The plan's water resource objectives are specific to different aquifers and locations (Table 2). They are based on achieving the results shown in the projected modelling as the climate continues to change.

The objectives take into account that further declines in groundwater levels are likely to be unavoidable in some areas where climate has an overriding influence. We are not aiming to reverse declining groundwater level trends in all areas, nor return the system to a pre-abstraction state.

In some areas, where modelling shows that changes to groundwater abstraction is likely to affect Superficial aquifer water levels, the objective is to maintain or increase those levels to avoid or reverse adverse impacts on water quality and environmental health at important locations.

In areas where climate change is the overriding influence, the objective is to reduce the rate of groundwater level decline.

[4] Phreatophytic vegetation uses groundwater to meet at least part of its water needs.

We considered the status of the resource in developing the water resource objectives, including:

- historical rainfall trends (see Section 2.1)
- water level trends in each aquifer (see Section 4)
- allocation status and estimated levels of groundwater use (see Section 4)
- evidence of impacts on water quality or on groundwater-dependent ecosystems, obtained through monitoring results (see sections 5 and 6)
- reports of changes in water quality or environmental impacts from licensees (see *Figure* 22).

In addition, we considered the potential impacts of:

- future climate change (see Section 2.2)
- likely land use changes, including urbanisation and consideration of post-harvest land use options for the 23,000 hectares of pine and ex-pine plantations in the plan area (see Section 3.1)
- groundwater demand for future strategic purposes, such as new public open space irrigation, public water supply and basic raw materials extraction (see Section 3.2)
- the predicted growth in garden bore installation and use (see Section 3.2).

We developed the final water resource objectives (see Table 2) using an iterative process that involved assessment of water level and ecological monitoring trends, extensive stakeholder engagement and many rounds of groundwater modelling and assessment of results.

Using PRAMS 3.5 we modelled and assessed several ‘reduced abstraction’ options, including a ‘no intervention’ option (no active reductions to abstraction). These enabled us to assess the impacts of reduced groundwater use by estimating the effect on regional groundwater levels and risks to the environment and water supply.

Through this process we worked to find a reduced abstraction scenario that:

- maximised the groundwater response in the right locations – where groundwater users or the environment had experienced/are experiencing negative impacts because of declining groundwater levels
- minimised the impact of reductions to abstraction on licensees, particularly on self-supply water users, who have limited opportunities to access alternative water sources
- allowed groundwater users enough time to adapt before the reductions to groundwater use become compulsory, but still achieved the desired resource outcomes within the plan period.

The following chapter describes the inputs to the modelling, and the scenarios we generated and simulated to come to the final reduced abstraction decision.

Table 2 Water resource objectives for the Gnangara allocation plan

Objective	Site-specific details
Water levels	
1. Maintain or increase groundwater levels in the Superficial aquifer:	
a. To maintain a reliable supply to groundwater users.	Maintain groundwater levels at modelling reference bores across the plan area (see Appendix F of the plan for bore locations).
b. To maintain or improve the health of groundwater-dependent ecosystems (proposed threshold levels for specific sites are given in Table 11 in Part C).	Maintain groundwater levels at: • Yellagonga Regional Park wetlands (Lake Joondalup and Lake Goollelal) • Egerton Seepage • Eastern Gnangara wetlands (Lexia 86 and 186) • Lexia bushland • Lake Pinjar.
	Increase groundwater levels at: • Loch McNess (Wagardu), Lake Yonderup, Lake Wilgarup and Pipidinny Swamp in Yanchep National Park • Lake Nowergup • Lake Mariginiup • Lake Jandabup • Lake Gnangara • Whiteman Park.
2. Manage declines in Superficial groundwater levels at a rate and magnitude that presents a lower risk of critical declines in ecological condition.	Reduced rate of decline in groundwater levels at: • some of the Eastern Gnangara wetlands (Melaleuca Park 173 and Melaleuca Park 78) • northern Melaleuca Park bushland • Pinjar bushland.
3. Increase groundwater pressure heads in the Leederville and Yarragadee aquifers, especially in and near areas connected to the Superficial aquifer:	

Objective	Site-specific details
a. To support groundwater-dependent ecosystems.	Increase deep aquifer pressure heads to help meet objectives at groundwater-dependent ecosystems: • increase water levels in Yanchep National Park wetlands. • increase water levels at Lake Nowergup. • limit groundwater level declines at Quin Brook, Gingin Brook and areas of groundwater-dependent Banksia woodland in the Yeal Nature Reserve.
b. To minimise impacts on water users.	Increase deep aquifer pressure heads to support: • Superficial aquifer users in the North Wanneroo horticultural area • Superficial and Leederville aquifer users in the Swan Valley area.
Water quality	
4. No significant inland movement of saline water along the coast and the Swan River (Derbarl Yerrigan) to maintain suitable water quality for use.	Salinity risk areas: • along the coast including at Two Rocks, Yanchep, Eglinton and Quinns • along the Swan River (Derbarl Yerrigan) to Caversham • the Mosman, Cottesloe and Nedlands peninsula area.
5. Changes in acidity in the Superficial aquifer in potential areas of acid sulfate soils have little or no adverse impacts on significant environmental values and groundwater users.	Acidification risk areas: • at and around wetlands including lakes Jandabup and Mariginiup, as well as Egerton Seepage • dunes between wetlands, particularly in the localities of Banksia Grove, Jandabup, Mariginiup, Gnangara, Whiteman, Ellenbrook, Melaleuca and west Bullsbrook and the urban areas spanning Bayswater to Ballajura and Dianella to Bassendean.

9 Modelling and assessment of reduced abstraction options

Our modelling using PRAMS 3.5 provided groundwater level changes over a 30-year predictive period from 2013 to 2043, centred around the year 2030. The three major variables or 'stressors' in the scenario modelling were climate, land use and groundwater abstraction.

9.1 Input data consistency

Climate and land use input data were the same for all predictive modelling scenarios, but we varied the abstraction volumes (other than future abstraction associated with the land use changes outlined below) so we could assess the relative differences between abstraction patterns and their impact on groundwater levels.

Climate change

We chose a 'future dry' climate scenario, centred around the year 2030, for the modelling scenarios because it matched closely with actual rainfall trends during the past two decades (Section 2.2). Using the dry climate scenario (rather than a wetter scenario) to develop and assess the reduced abstraction options helped:

- increase the reliability of a secure supply of water for users into the future
- give more confidence that sufficient water will be maintained in the Superficial aquifer to support groundwater-dependent ecosystems as the climate changes.

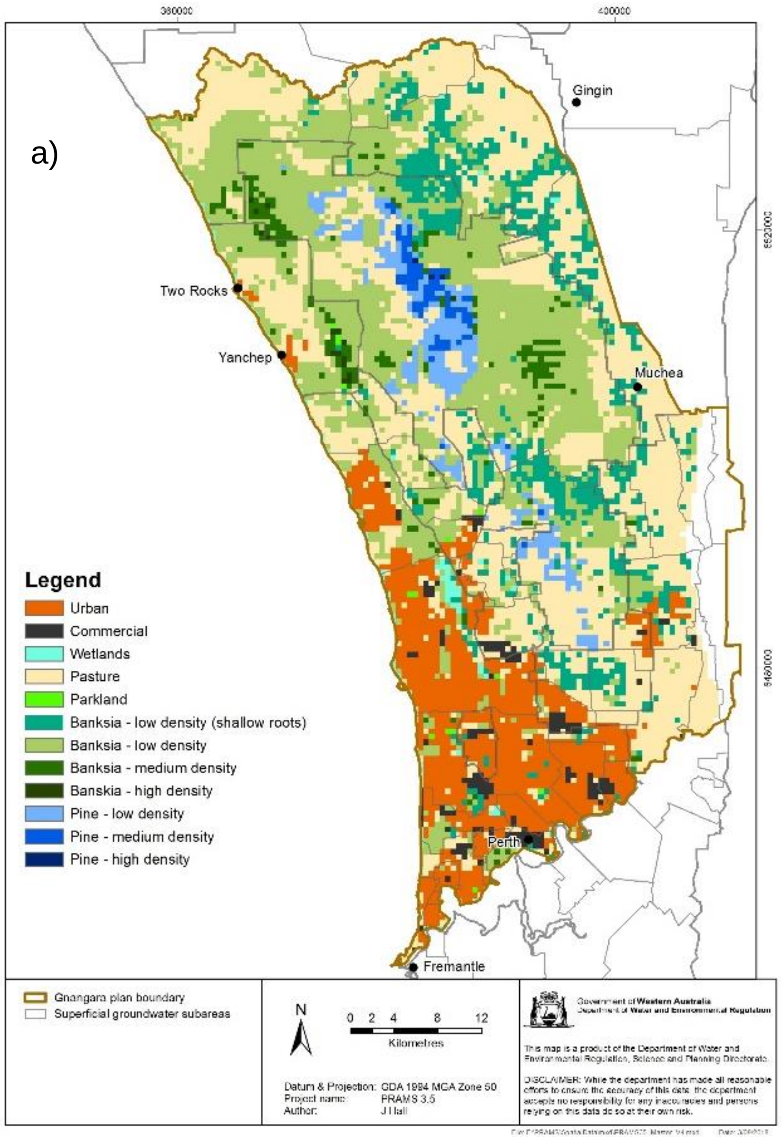
Land use change

The modelling scenarios predict the changes in recharge to groundwater that will result from land use change to 2030 (see Section 3). Figure 20a shows current land use and Figure 20b shows expected land use to 2030 that will result from:

- planned urban and industrial growth, as outlined in the *Perth and Peel@3.5 million* land use planning and infrastructure frameworks (DPLH and WAPC 2018a)
- expected changes to land use and groundwater recharge in the Gnangara, Pinjar and Yanchep pine plantations.

Future groundwater abstraction

We kept the abstraction inputs associated with land use changes, as described in Section 3.2, the same for all options. See Appendix A and B for the volumes associated with these future groundwater uses.



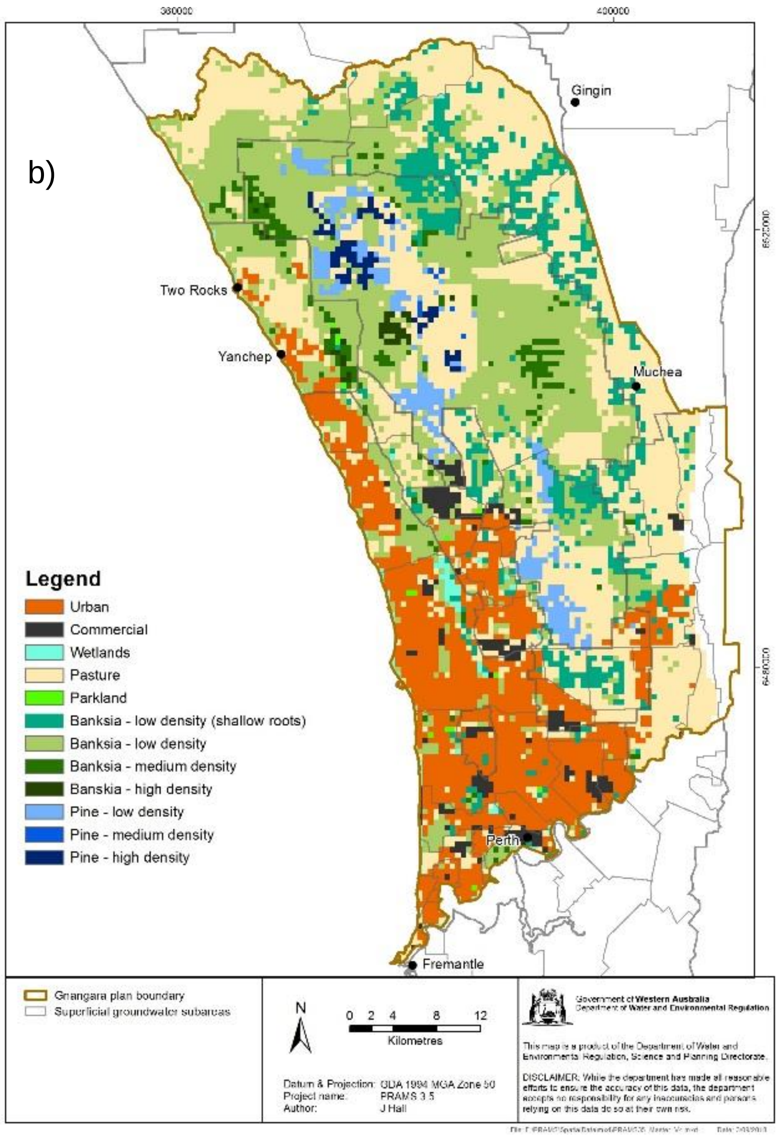


Figure 20 Model input data for current land use (a) and future land use at 2030 (b)

9.2 Reduced abstraction options

We modelled various options to reduce abstraction and assessed the relative benefits of these against the water resource objectives. We developed the 'reduced abstraction' options by carrying out the following process:

1. broadly assessing the water balance of the whole system
2. testing different regional scale scenarios
3. refining the regional scale scenarios based on more localised assessments of risks to the resource and environment.

The first step in the process was to assess the whole water balance of the Gnangara groundwater system. To do this, we broadly calculated the total water inputs and outputs of the resource from modelled water balances. Using this information, we assessed the rates of historic storage loss in the Superficial aquifer – this is influenced by abstraction from the Superficial aquifer as well as from the deep aquifers where they are connected to the Superficial. We were then able to determine the broad scale of reductions, ranging from 20 to 60 GL/year, for 'rebalancing' the Gnangara system.

Using this assessment, we modelled a selection of regional scenarios across this range of reductions in abstraction, starting at 20 GL/year, to about 40 GL/year, and up to more than 60 GL/year. We assessed the outputs to gain an understanding of:

- where groundwater levels could be improved and how this changed as the volume of reductions increased
- the magnitude of improved groundwater levels that might be expected and how much this increased with larger reductions to abstraction
- whether the rate of improvement declined, as the volume of reductions increased, or alternatively, whether a certain magnitude in the volume of reductions was needed to make measurable improvements in water levels in key locations
- whether targeting different aquifers for reductions could make a significant difference to where and by how much water levels improved.

The final step was to refine the scenarios by assessing the risk to subareas based on local impacts to the resource and environment (Figure 22). From this we developed four final 'reduced abstraction' scenario options and a 'no intervention' reference scenario.

We used groundwater modelling to assess the likely risk of not meeting the water resource objectives and the water level criteria set in *Ministerial Statement no. 819* for each of the 'reduced abstraction' options.

See Figure 21 and Table 3 for the reduced abstraction inputs to the 'no intervention' scenario and the four 'reduced abstraction' options. See Appendix B for the abstraction volumes by component (use category) and aquifer.

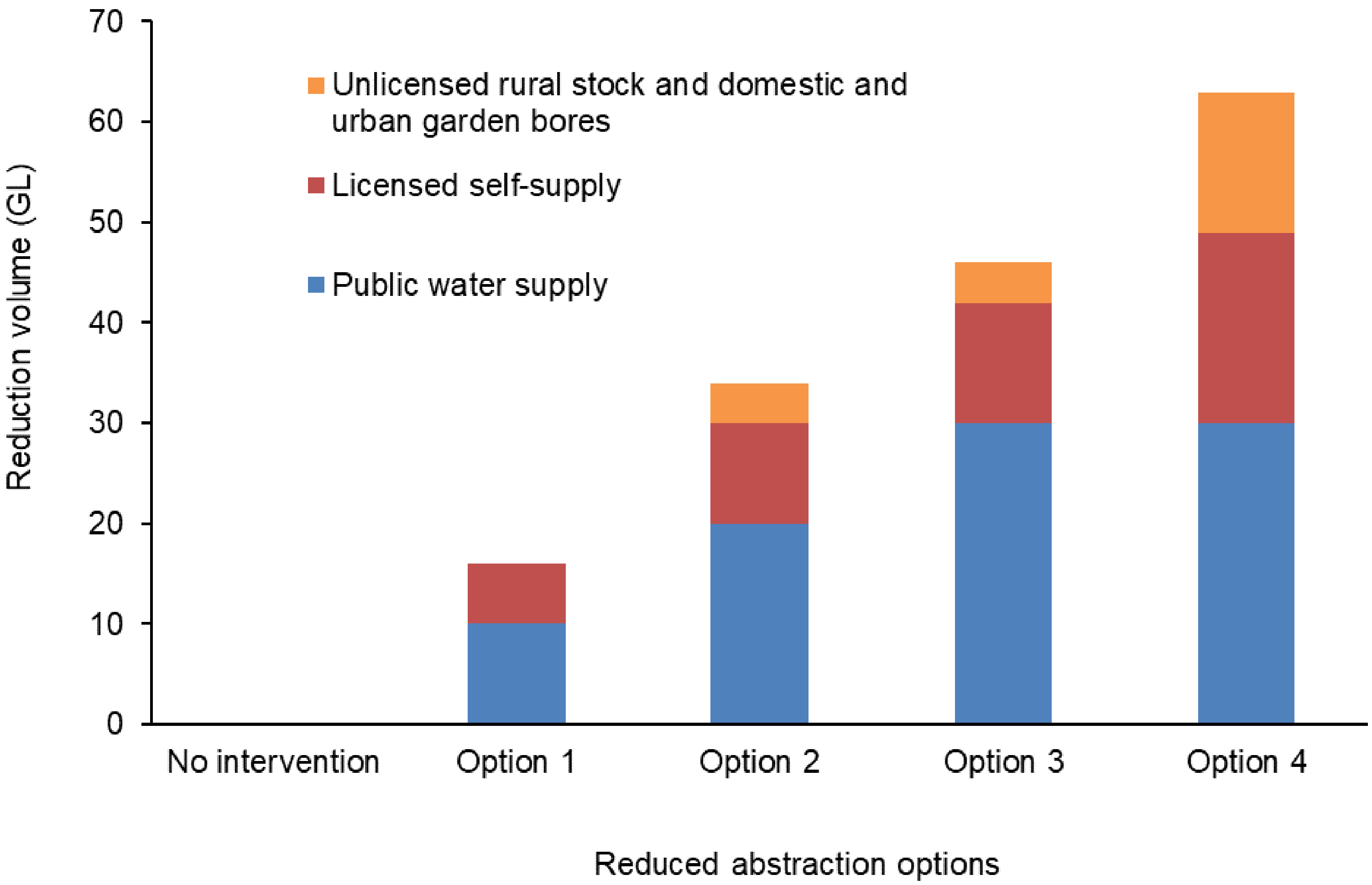


Figure 21 Scale of reduced abstraction under different allocation options

Table 3 Summary of reduced abstraction options

Type of use	No intervention scenario	Option 1	Option 2	Option 3	Option 4
Public water supply	No reduction	10 GL/year reduction (9% reduction)	20 GL/year reduction (18% reduction)	30 GL/year reduction (27% reduction)	30 GL/year reduction (27% reduction)
Licensed self-supply	No reduction	0% reduction in Superficial and Mirrabooka abstraction in lower-risk subareas; 10% reduction in Superficial and Mirrabooka abstraction in higher-risk subareas	10% reduction in Superficial, Mirrabooka and Leederville abstraction in all subareas	10% reduction in Superficial, Mirrabooka and Leederville abstraction in all areas and 25% in Carabooda and Nowergup subareas	10% reduction in Superficial, Mirrabooka and Leederville abstraction in lower-risk subareas and 25% reduction in all higher-risk subareas
Unlicensed rural stock and domestic and urban garden bores	No reduction	No reduction	10% reduction in all subareas (education campaign)	10% reduction in all subareas (education campaign)	Change to garden bore sprinkler roster to align with scheme users
Total reduction	**0 GL/year***	**16 GL/year**	**35 GL/year**	**46 GL/year**	**64 GL/year**

The ‘no intervention’ scenario

We simulated the ‘no intervention’ scenario to project the likely resource and environmental outcomes if the plan did not apply any active reductions to groundwater abstraction from the Gnangara system. This meant we could compare the ‘reduced abstraction’ options with the ‘no intervention’ scenario to understand the likely difference in water levels from changes to abstraction, rather than the combined effects of land use, climate and abstraction.

Under the ‘no intervention’ scenario, we set public water supply abstraction at the current baseline volume of 110.65 GL/year and assumed self-supply abstraction would remain at 2013 volumes (the start of the modelled period), except for:

- reductions in Superficial aquifer abstraction because of land use changes in the East Wanneroo area
- increases in Superficial aquifer abstraction along the North West corridor associated with the activation of water reserved for public water supply and public open space
- increases in Superficial aquifer abstraction associated with dust suppression for the extraction of basic raw materials
- increases in domestic garden bore abstraction as new bores continue to be installed.

We also applied the changes to abstraction described in the first three dot-points above to each of the four ‘reduced abstraction’ options described in the following subsections (garden bore abstraction varied between the options).

See Appendix A for more information about the assumptions in this scenario and Appendix B for more information on the abstraction datasets used for modelling the ‘no intervention’ scenario.

Reduced abstraction options

The climate change and future land use data were common to all options. The key differences in the options were the reductions to groundwater abstraction we applied across the three main categories of water use:

- public water supply abstraction
- licensed self-supply abstraction
- unlicensed domestic garden bore abstraction.

Public water supply abstraction

We worked closely with the Water Corporation to develop details of three groundwater reduction options: 10, 20 and 30 GL/year[5].

The geographic and 'by aquifer' distribution of these reduction options was informed by the Water Corporation's scheme operational constraints and by an optimised modelling approach achieved through collaboration with the University of Western Australia (DWER 2021b).

Licensed self-supply abstraction

For licensed self-supply, the reduction options ranged from 0 to 25 per cent of licensed entitlements and were informed by a risk assessment of all groundwater subareas. Applying this, we classified subareas as 'lower' or 'higher' risk based on current known or likely impacts to the resource and environment, and made larger reductions to higher-risk subareas (Figure 22*).*

Domestic garden bore abstraction

For domestic garden bore abstraction, inputs to the allocation options were informed by assumptions of:

- overall abstraction volumes increasing by one per cent per year to account for continued growth in the number of bores installed as Perth expands (Appendix A)
- reductions in groundwater use by bore owners because of:
  - an education campaign to encourage water efficiency targeting a 10 per cent reduction in garden bore use[6]; or
  - a change in the garden bore sprinkler roster to reduce the number of watering days permitted in autumn, spring and summer from three to two days per week, the same as scheme users.

5 30 GL was the assumed groundwater reduction by 2030 in Water Forever (Water Corporation 2009).

6 See our Be groundwater wise website.

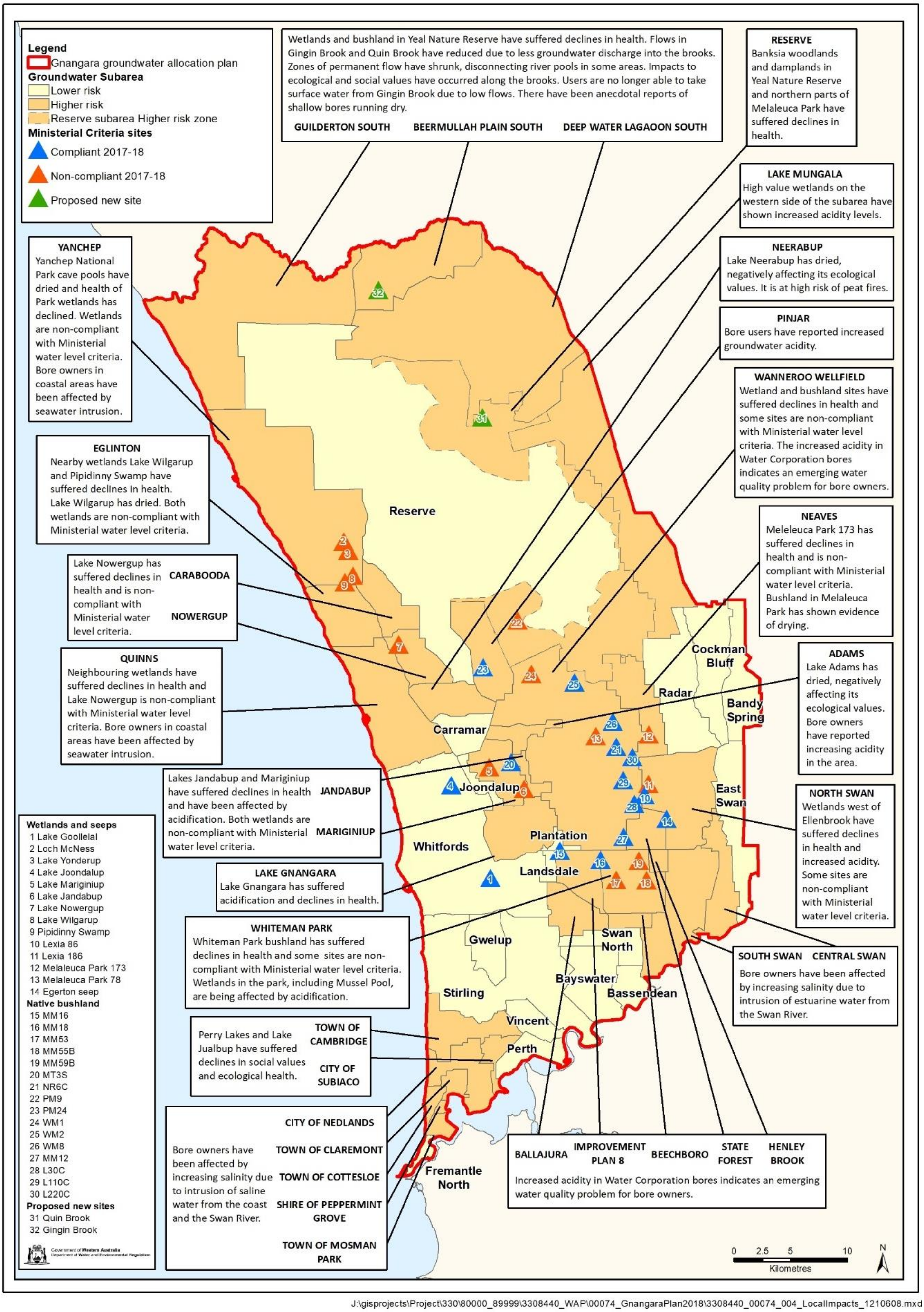


Figure 22 Lower- and higher-risk subareas based on assessment of local impacts to the resource and environment

9.3 Assessment against water resource objectives

See Table 4 for a summary of how we assessed the modelling results for each 'reduced abstraction' option and for the 'no intervention' scenario against the plan's water resource objectives.

Water level objectives

The drawdown maps in part a) of Figure 23 to Figure 33 show spatially how groundwater levels in each of the aquifers are likely to respond under 'no intervention' and to the range of reductions to abstraction in the four options.

Drawdown maps informed our assessment of the rate and magnitude of water level change in the Superficial aquifer at groundwater-dependent ecosystems, including wetlands and bushland reserves (objectives 1 and 2 in Table 4, Figure 23 to Figure 27). They also helped us assess deeper aquifer trends (objective 3 in Table 4, Figure 28 to Figure 33).

The difference maps in parts b) and c) of Figure 23 to Figure 33 allowed direct comparison between two alternative options. They show the relative difference in water level changes across the plan area by putting one option in place compared with another option. These maps helped us assess how well each of the 'reduced abstraction' options met objectives 1, 2 and 3 in Table 4 compared with one another.

Under the 'no intervention' scenario and future dry climate, modelled levels in the Superficial aquifer are predicted to decline across most of the northern, eastern and southern parts of the Gnangara plan area. The largest declines are seen near the crest of the Gnangara Mound in the Reserve subarea to the west of Muchea (Figure 23). However, to the east of Yanchep, Superficial aquifer water levels are projected to rise because of increased recharge associated with pine plantation clearing. In East Wanneroo, rises are projected because of a combination of increased recharge from urbanisation and reduced abstraction as agricultural land uses begin to move out of the area.

The percentage of the Gnangara plan area that shows stable or improved water levels increases from 35 per cent under the 'no intervention' scenario to 62 per cent under 'reduced abstraction' Option 4 (Figure 23, Figure 24a, Figure 25a, Figure 26a, Figure 27a).

For groundwater-dependent ecosystems supported by the Gnangara system, the modelling projects stable or improved water levels and ecological condition across 22 per cent of ecosystem area under the 'no intervention' scenario. This is mainly in the areas of land use change described in Figure 20. By reducing abstraction, the projected results of the modelling show that improved water levels can increase to 33 per cent under Option 1, and up to 44 per cent under Option 4 (Figure 24a, Figure 25a, Figure 26a, Figure 27a).

The modelling predicts that water levels in the Superficial aquifer improve progressively with each ‘reduced abstraction’ option. However, water levels in some parts of the plan area improve more than others. The differences in modelled levels in the Superficial aquifer under each option are summarised as follows:

- Water levels in Option 1 are predicted to be higher over much of the plan area compared with the ‘no intervention’ scenario, but the greatest improvements occur to the west of Ellenbrook and in the northern Pinjar area (Figure 24b).
- Water levels in Option 2 are predicted to be higher over much of the plan area compared with Option 1, but the greatest improvements occur in Perth’s northern suburbs in the Mirrabooka area (Figure 25c).
- Water levels in Option 3 are predicted to be higher in the central part of the plan area compared with Option 2, but the greatest improvements are west of Ellenbrook and in the northern Pinjar area (Figure 26c).
- Water levels in Option 4 are predicted to be higher in the southern half of the plan area compared with Option 3, with the greatest improvements in the Bayswater area, and east of Guilderton close to Gingin Brook (Figure 27c).

For the Leederville and Yarragadee[7] aquifers, the modelled area where pressure heads rise, is 56 per cent for the Leederville aquifer and 6 per cent for the Yarragadee aquifer under the ‘no intervention’ scenario. This increases to 81 per cent and 97 per cent respectively under Option 4 (Figure 33).

[7] Modelled levels for the Yarragadee aquifer in the southernmost part of the Gnangara plan area show the influence of abstraction from a Water Corporation production bore in the Yarragadee aquifer in the Jandakot groundwater area. Abstraction from the bore began in 2013–14. It currently contributes about 6 GL/year to the IWSS.

Table 4 Summary of the model results for each reduced abstraction option assessed against the plan's objectives

Water resource objective	No intervention	Option 1	Option 2	Option 3	Option 4
Water levels					
1 a) Maintain or increase groundwater levels in the Superficial aquifer to maintain a reliable supply to groundwater users.	Water levels are maintained or increase across 35% of the plan area relative to 2013* levels (Figure 23).	Water levels are maintained or increase across 45% of the plan area (Figure 24).	Water levels are maintained or increase across 53% of the plan area (Figure 25).	Water levels are maintained or increase across 56% of the plan area (Figure 26).	Water levels are maintained or increase across 62% of the plan area (Figure 27).
1 b) Maintain or increase groundwater levels in the Superficial aquifer to maintain or improve the health of groundwater-dependent ecosystems.	Water levels are maintained or increase at 22% of dependent ecosystems relative to 2013 levels (Figure 23).	Water levels are maintained or increase at 33% of dependent ecosystems (Figure 24).	Water levels are maintained or increase at 37% of dependent ecosystems (Figure 25).	Water levels are maintained or increase at 41% of dependent ecosystems (Figure 26).	Water levels are maintained or increase at 44% of dependent ecosystems (Figure 27).
2. Manage declines in Superficial groundwater levels at a rate and magnitude that presents a lower risk of critical declines in condition.	17% of dependent ecosystems are at risk of critical declines (Figure 23).	13% of dependent ecosystems are at risk of critical declines (Figure 24).	10% of dependent ecosystems are at risk of critical declines (Figure 25).	9% of dependent ecosystems are at risk of critical declines (Figure 26).	8% of dependent ecosystems are at risk of critical declines (Figure 27).
3. Increase pressure heads in the Leederville and Yarragadee aquifers, especially in and near areas where the aquifers are connected to the Superficial aquifer.	Leederville aquifer pressure heads increase across 56% of the plan area relative to 2013 levels (Figure 28).	Leederville aquifer pressure heads increase across 65% of the plan area (Figure 29).	Leederville aquifer pressure heads increase across 75% of the plan area (Figure 29).	Leederville aquifer pressure heads increase across 80% of the plan area (Figure 30).	Leederville aquifer pressure heads increase across 81% of the plan area (Figure 30).
	Yarragadee aquifer pressure heads increase across 6% of the plan area relative to 2013 levels (Figure 31).	Yarragadee aquifer pressure heads increase across 29% of the plan area (Figure 32).	Yarragadee aquifer pressure heads increase across 82% of the plan area (Figure 32).	Yarragadee aquifer pressure heads increase across 97% of the plan area (Figure 33).	Yarragadee aquifer pressure heads increase across 97% of the plan area (Figure 33).

Water resource objective	No intervention	Option 1	Option 2	Option 3	Option 4
Water quality					
4. No significant inland movement of saline water along the coast and the Swan River (Derbarl Yerrigan) to maintain suitable water quality for use.	Saline water risk to 2.1 GL of licensed use along the coast (Figure 23).	Saline water risk to 2.0 GL of licensed use along the coast (5% less than 'no intervention') (Figure 24).	Saline water risk to 1.9 GL of licensed use along the coast (10% less than 'no intervention') (Figure 25).	Saline water risk to 1.8 GL of licensed use along the coast (14% less than 'no intervention') (Figure 26).	Saline water risk to 1.7 GL of licensed use along the coast (19% less than 'no intervention') (Figure 27).
5. Changes in acidity in the Superficial aquifer in potential areas of acid sulfate soils have little or no adverse impacts on significant environmental values and users.	Acidity risk to 11 GL of licensed and garden bore use (Figure 23).	Acidity risk to 9.7 GL of licensed and garden bore use (12% less than 'no intervention') (Figure 24).	Acidity risk to 4.4 GL of licensed and garden bore use (60% less than 'no intervention') (Figure 25).	Acidity risk to 4.0 GL of licensed and garden bore use (64% less than 'no intervention') (Figure 26).	Acidity risk to 0.7 GL of licensed and garden bore use (94% less than 'no intervention') (Figure 27).

* *The year 2013 was the starting year of the predictive sequence in the modelling*

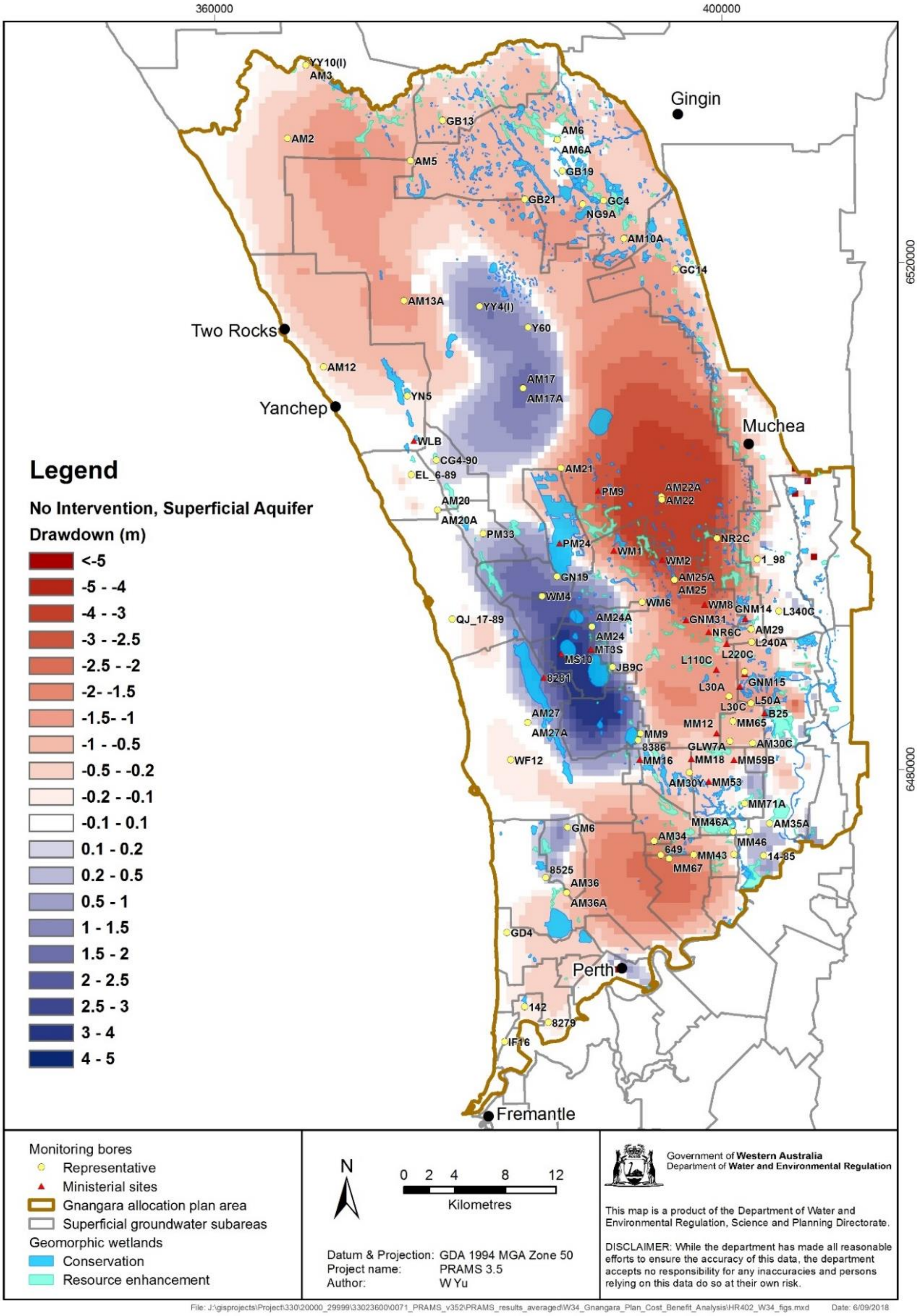


Figure 23 Water level change in the Superficial aquifer under the 'no intervention' scenario

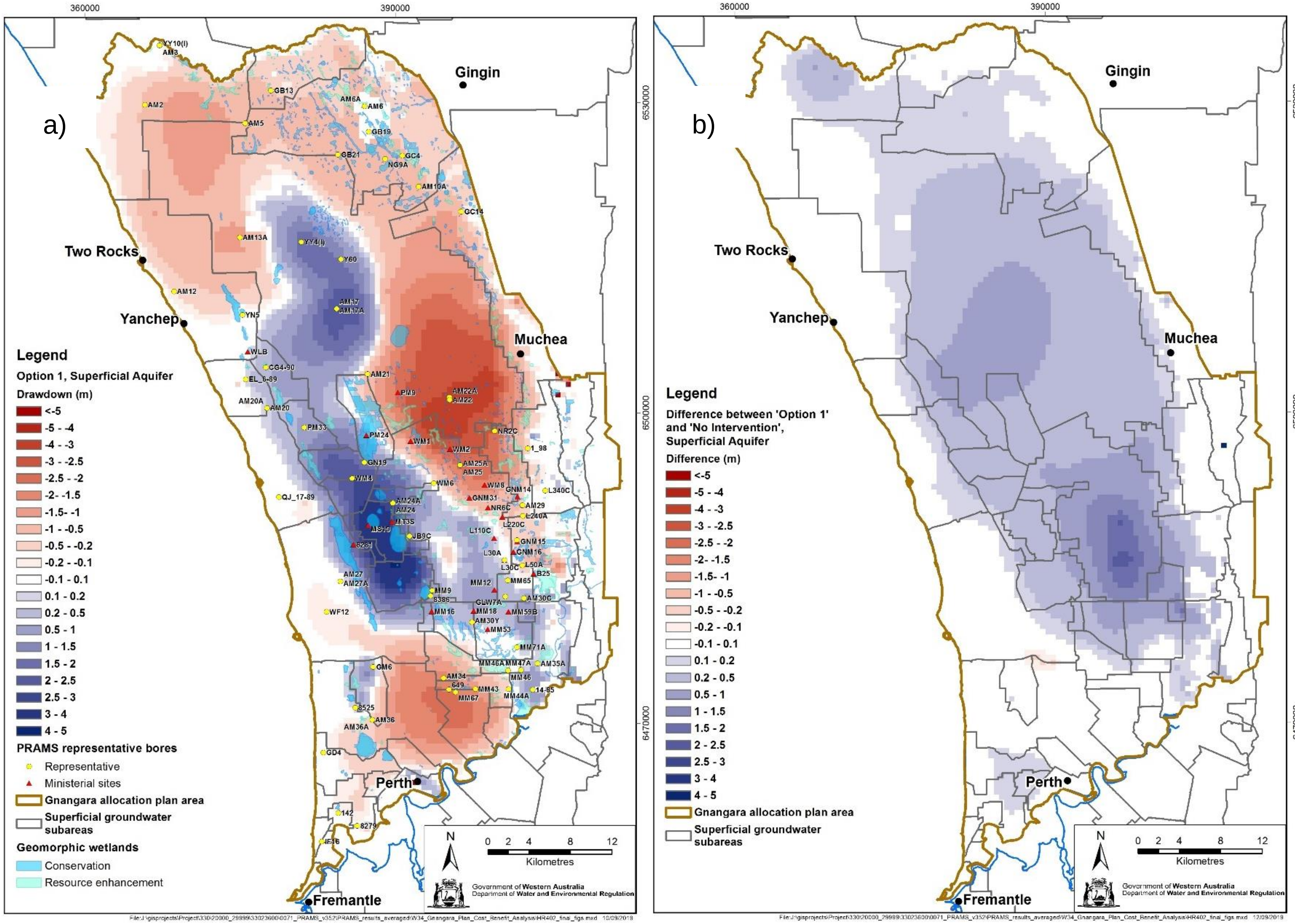


Figure 24 Water level change in the Superficial aquifer under Option 1 (a) and difference in levels compared with 'no intervention' (b)

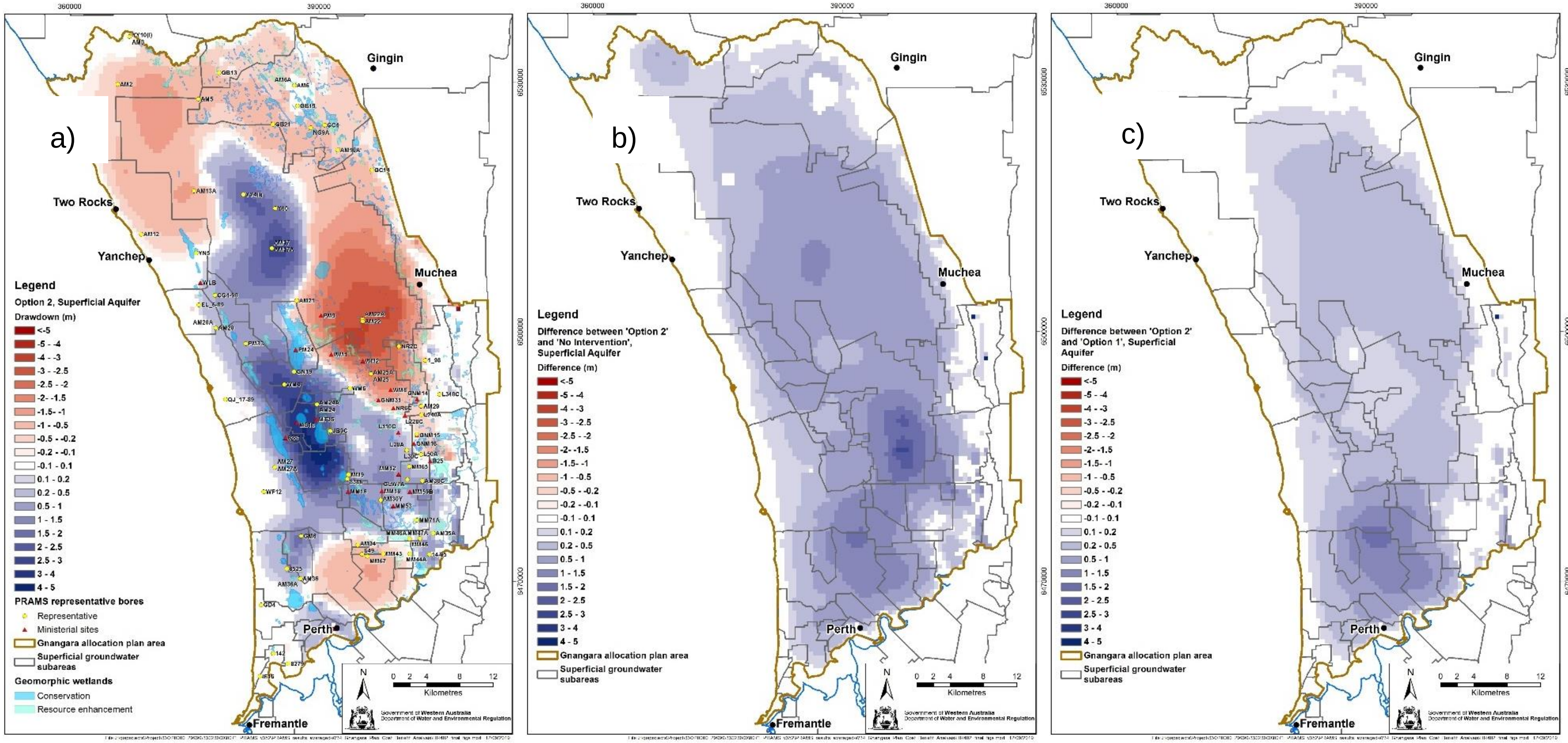


Figure 25 *Water level change in the Superficial aquifer under Option 2 (a), difference in levels compared with 'no intervention' (b) and difference in levels compared with Option 1 (c)*

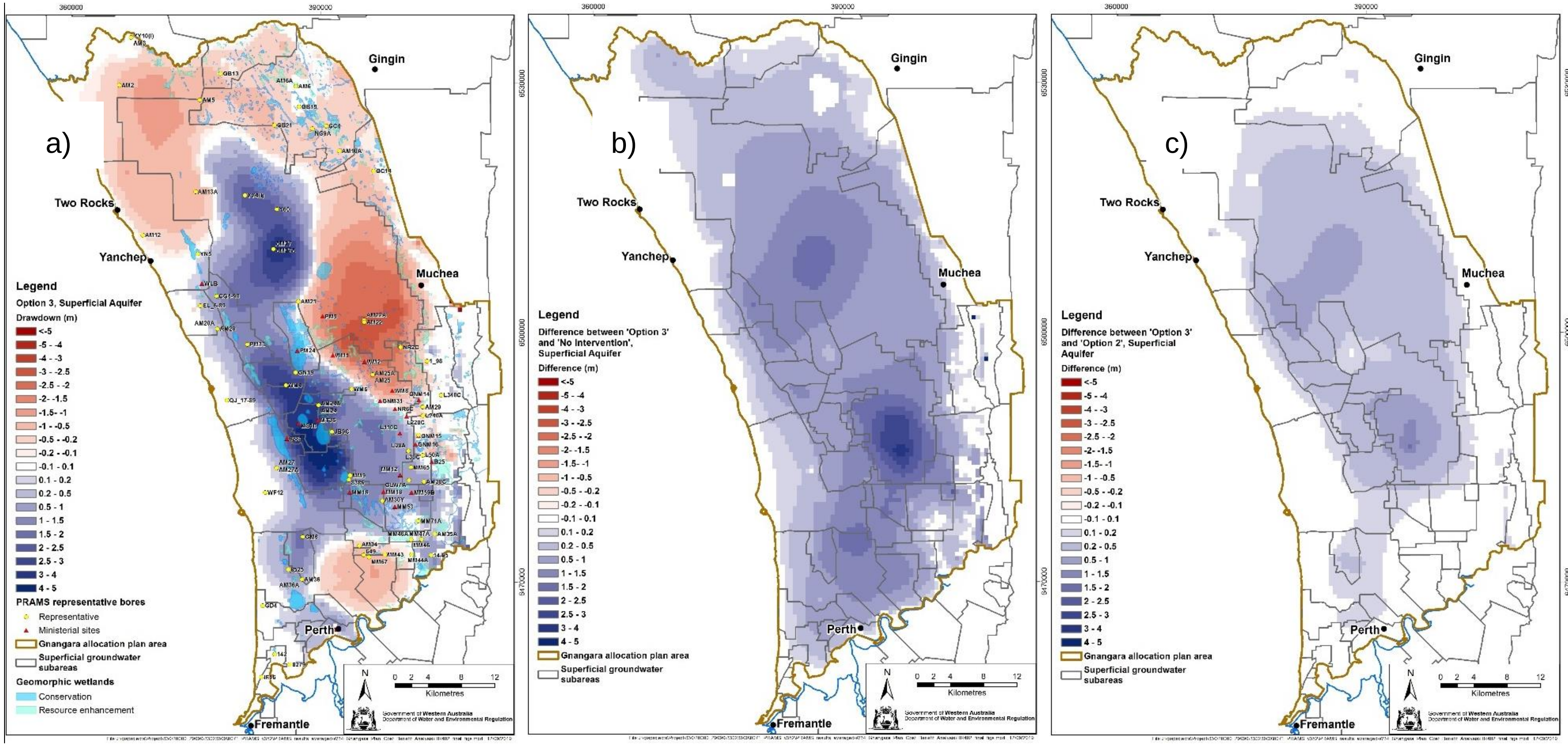


Figure 26 Water level change in the Superficial aquifer under Option 3 (a), difference in levels compared with 'no intervention' (b) and difference in levels compared with Option 2 (c)

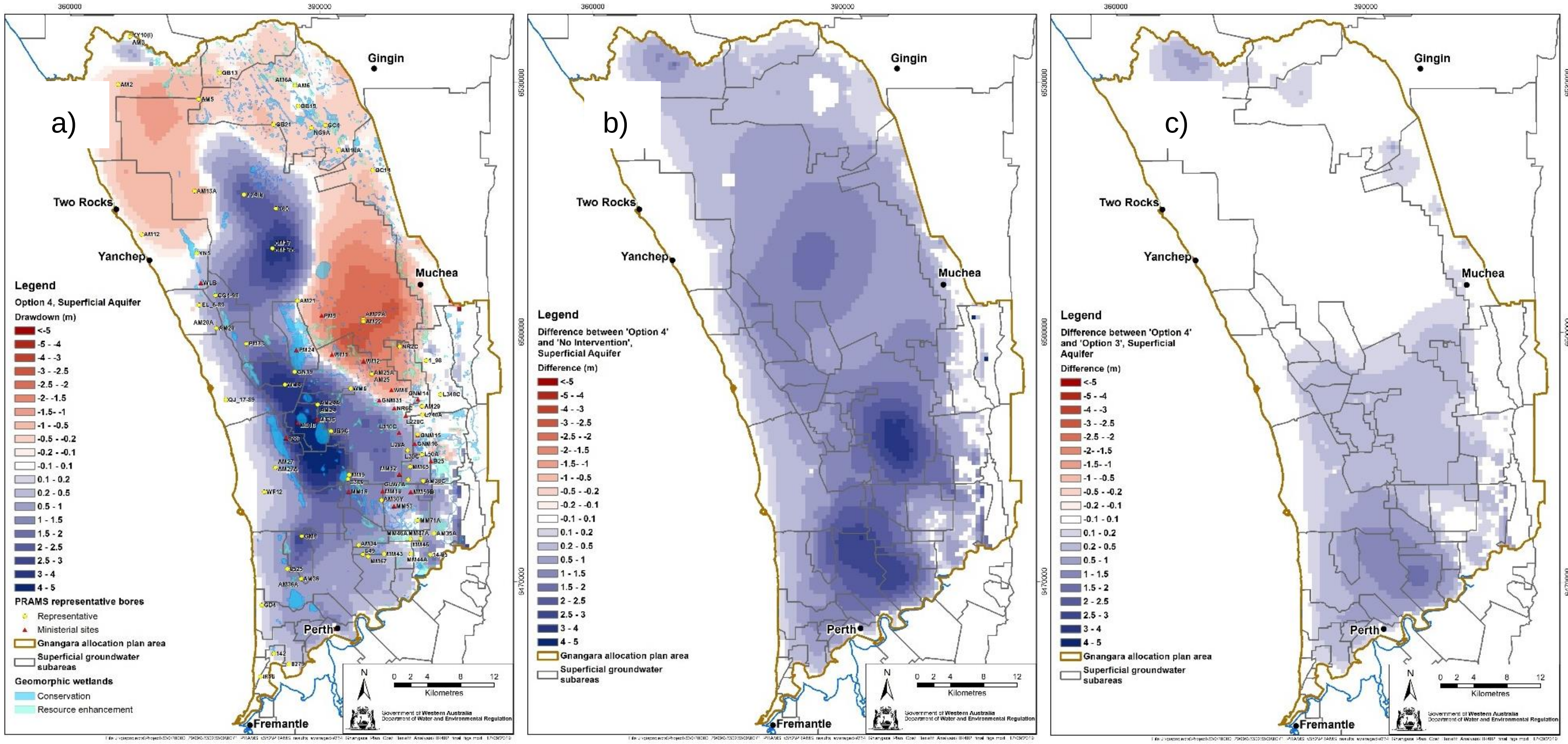


Figure 27 Water level change in the Superficial aquifer under Option 4 (a), difference in levels compared with 'no intervention' (b) and difference in levels compared with Option 3 (c)

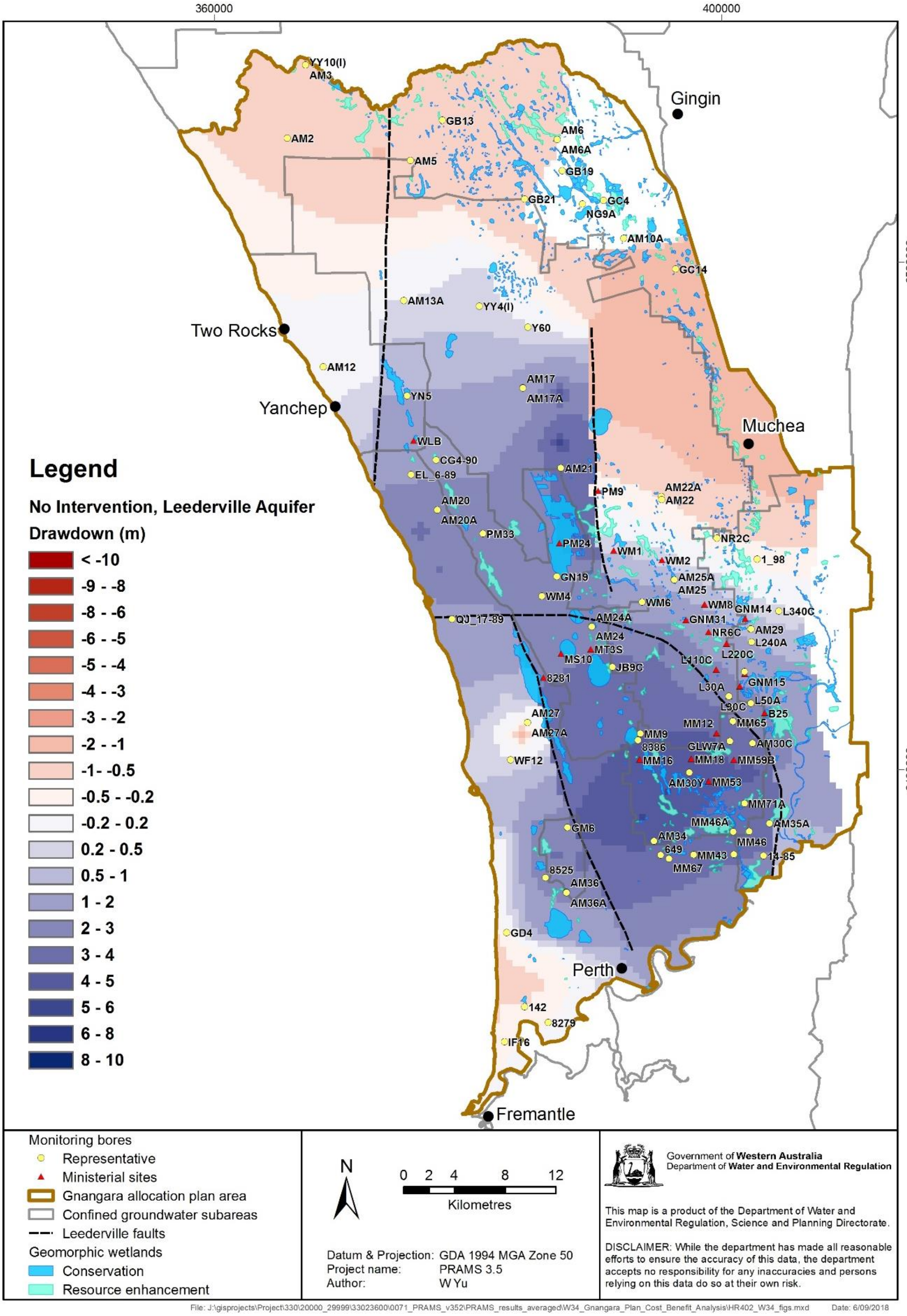


Figure 28 Pressure head change in the Leederville aquifer under the 'no intervention' scenario

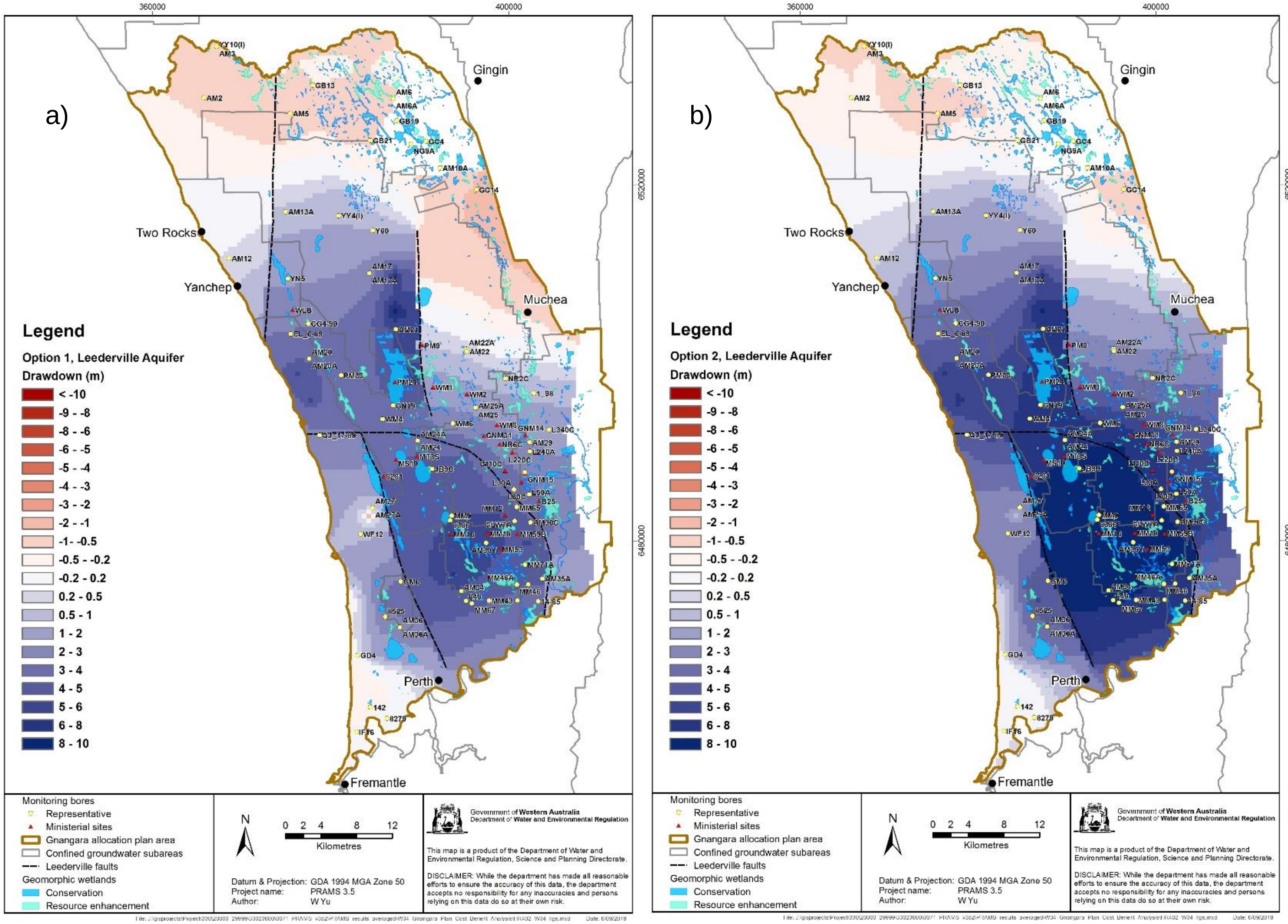


Figure 29 Pressure head change in the Leederville aquifer under Option 1 (a) and Option 2 (b)

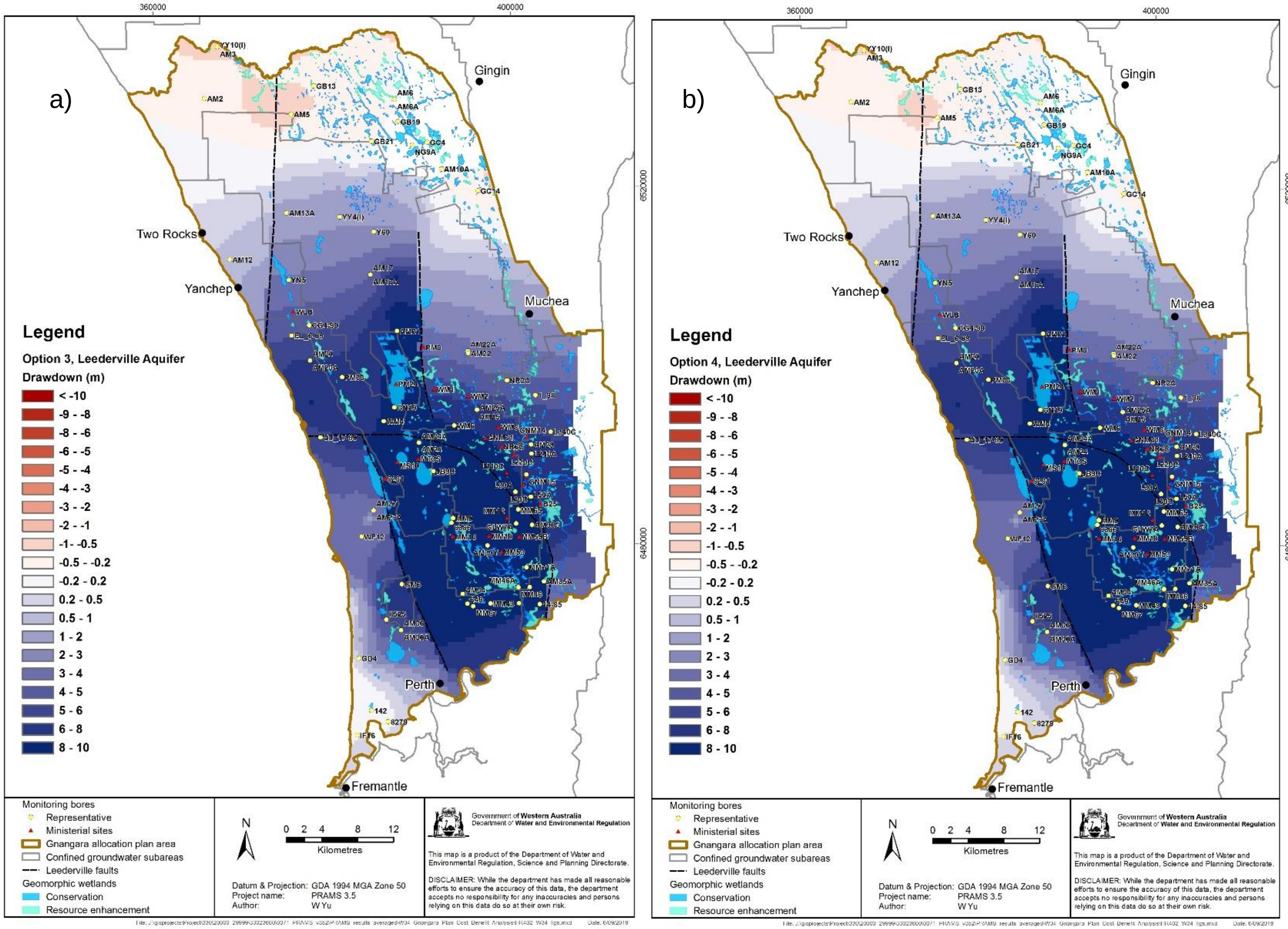


Figure 30 Pressure head change in the Leederville aquifer under Option 3 (a) and Option 4 (b)

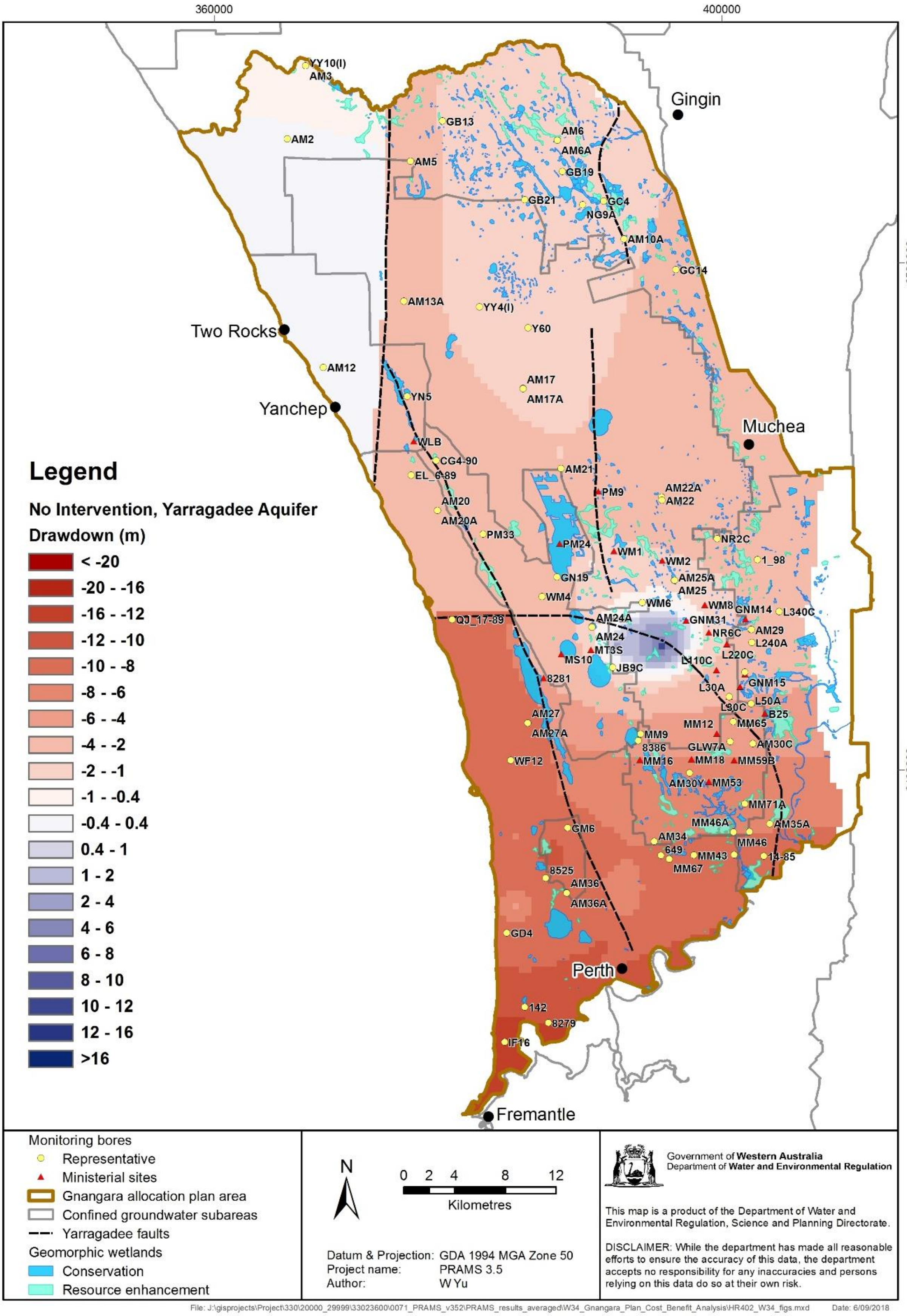


Figure 31 Pressure head change in the Yarragadee aquifer under the 'no intervention' scenario

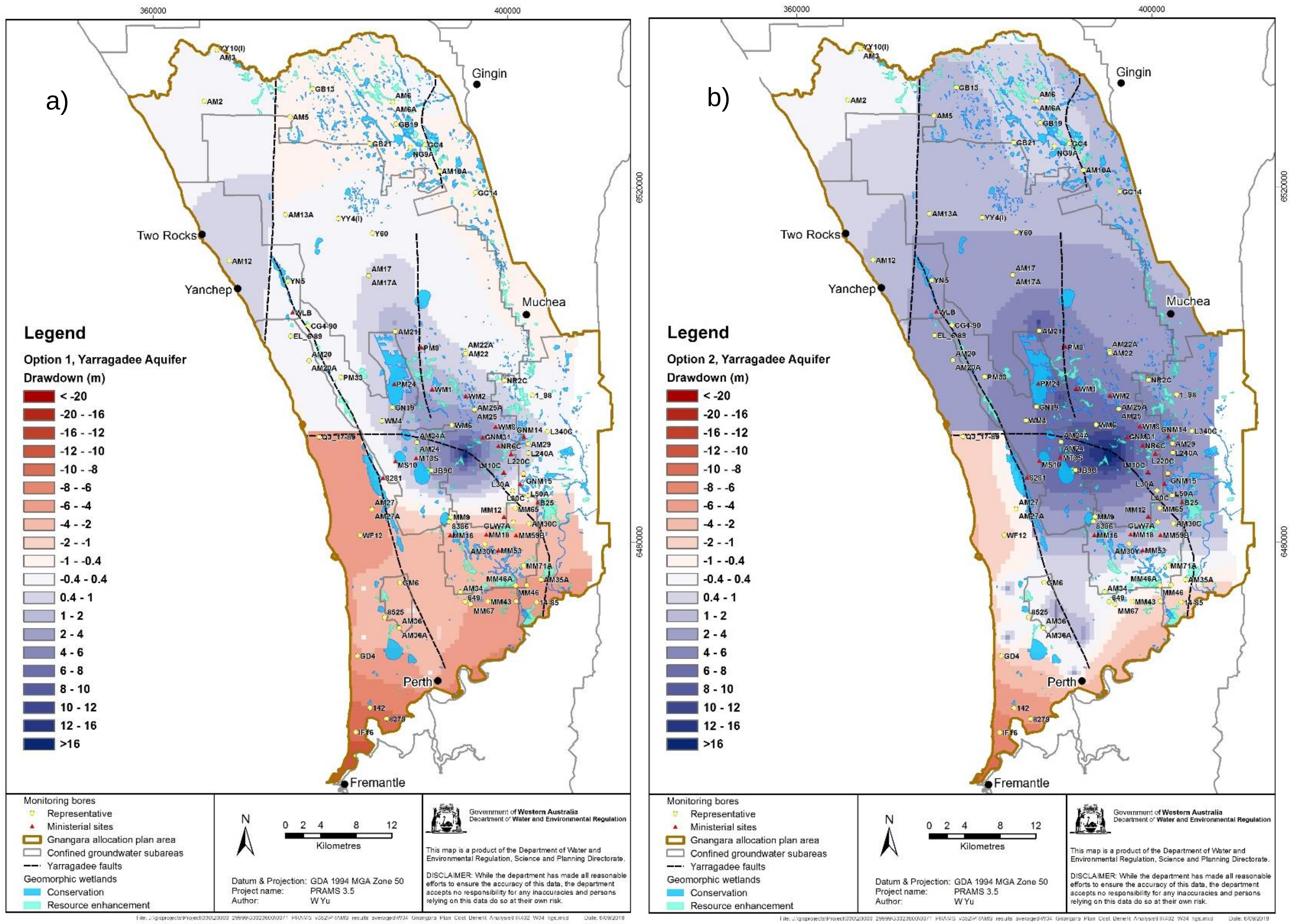


Figure 32 Pressure head change in the Yarragadee aquifer under Option 1 (a) and Option 2 (b)

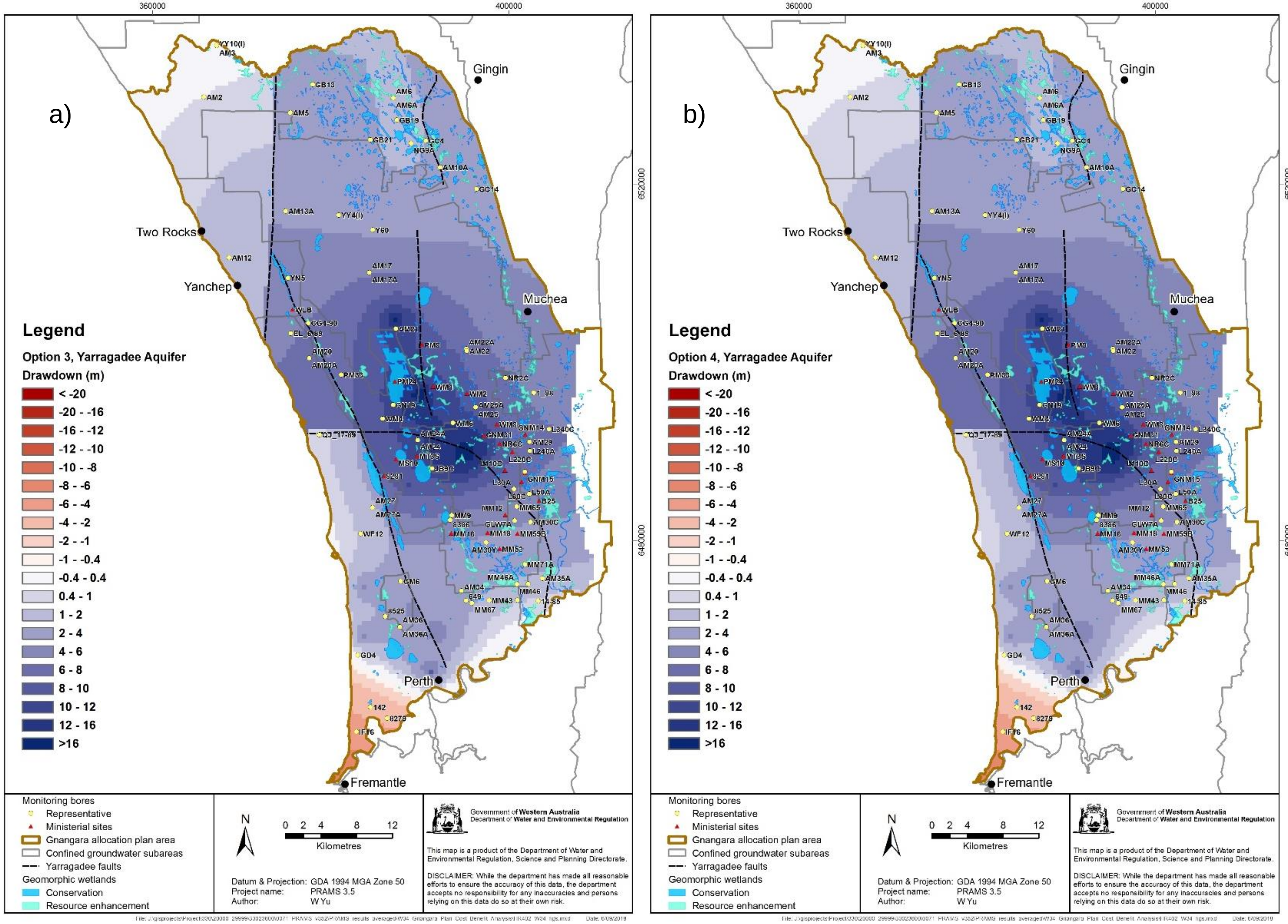


Figure 33 Pressure head change in the Yarragadee aquifer under Option 3 (a) and Option 4 (b)

Water quality objectives

Salinity risks

The position of the seawater interface along the coastline moves in toward the land or out toward the ocean depending on the volume of groundwater flowing out of the system (the water balance). We used PRAMS to predict the position of the seawater interface in the Superficial aquifer for each of the 'reduced abstraction' options and for 'no intervention' based on the water balance of each scenario.

Where the seawater interface intercepted existing Superficial aquifer bore drawpoints, we calculated the total licensed volume taken from these drawpoints, and this became the volume at risk of increasing salinity from saline intrusion for each scenario. In 2013, we estimated 1.5 GL of licensed annual abstraction was at risk of water quality problems associated with saline water intrusion.

Under the 'no intervention' scenario, the seawater interface was estimated to intrude (relative to 2013) more than 1000 metres further inland in the area north of Yanchep because of the new public water supply abstraction for the growing North West corridor (Degens 2019).

We will carefully manage the risks of saline water intrusion associated with any new public water supply abstraction in this area. New abstraction will be developed incrementally and have operational requirements for close monitoring of the seawater interface to ensure existing groundwater use in the area is not put at risk of salinity impacts.

In most subareas south of Whitfords, we predict the movement of seawater interface would generally be less than 40 metres inland. The increased intrusion relative to 2013 causes the volume of licensed annual abstraction at risk to increase by 0.6 to 2.1 GL (Table 5).

Under the 'reduced abstraction' options 1 to 4, the inland movement of saline water relative to 2013 progressively reduces, except in the northern part of the Yanchep subarea. This is because the activation of public water supply reserves for the North West corridor is the same for all options.

The risk of salinity impacts to the volume of licensed abstraction decreases by 0.1 GL for each progressive reduced abstraction option. Under Option 1 the volume at risk is projected to be 2.0 GL (or 0.1 GL less than the 'no intervention' scenario), while under Option 4 the volume at risk reduces to 1.7 GL.

Table 5 Summary of model results for the 'no intervention' scenario and 'reduced abstraction' options assessed against water resource objective 3.

Water resource objective	No intervention	Option 1	Option 2	Option 3	Option 4
3. No significant inland movement of saline water along the coast and the Swan River (Derbarl Yerrigan) to maintain suitable water quality for use.	Movement of the seawater interface (SWI) was mostly prevented in Town of Cambridge and Eglington. Intrusion in Yanchep up to 1.2 km, Quinns to Whitfords of up to 60 m and Nedlands and Cottesloe up to 240 m. Risk to licensed use increased by 0.6 GL relative to 2013 with overall 2.1 GL at risk.	Movement of the SWI was mostly prevented in Quinns, City of Stirling and Town of Cambridge. Intrusion in Yanchep up to 1.2 km. Intrusion in Nedlands and Cottesloe up to 110 m, amplifying risk to users. Minor intrusion and impacts in Eglington and Whitfords (<60 m). Risk to licensed use increased by 0.5 GL relative to 2013 with overall 2.0 GL at risk.	Movement of the SWI was mostly prevented along the coast from Quinns to Town of Nedlands with reduced impacts to users in this area. Intrusion in Yanchep up to 1.2 km. Minor intrusion (<50 m) and impacts in Cottesloe and Eglinton. Risk to licensed use increased by 0.4 GL relative to 2013 with overall 1.9 GL at risk.	Movement of the SWI was mostly prevented along the coast from Eglington to Town of Nedlands with reduced impacts to users in this area. Intrusion in Yanchep up to 1.1 km. Very minor intrusion (<30 m) and impacts in Cottesloe. Risk to licensed use increased by 0.3 GL relative to 2013 with overall 1.8 GL at risk.	Movement of the SWI was mostly prevented along the coast from Eglington to Cottesloe with reduced impacts to users in this area. Intrusion in Yanchep up to 1 km. Risk to licensed use increased by 0.2 GL relative to 2013 with overall 1.7 GL at risk.

Acidification risks

We assessed acidification risks using spatial outputs that showed where and by how much water levels fell below potential acid sulfate soil layers across the plan area (objective 5 in Table 4). The modelling also enabled us to calculate the volume of groundwater use in the Superficial aquifer that could be affected by acidification under each ‘reduced abstraction’ option (Degens & Thornton 2018). This was done by estimating how much water was being pumped by licensed and exempt users in the acidification risk areas.

Under the ‘no intervention’ scenario, projected water level declines result in an increased risk of acidification impacts to groundwater users in many inland subareas of the Gnangara plan area. At least 11 GL of groundwater, abstracted mostly by self-supply users, is at risk of impacts from poor water quality caused by acid sulfate soils drying out and oxidising.

The overall volume of groundwater remaining in the aquifer that would be affected by increased acidity is likely to be at least 10 times greater than the abstracted volumes (Degens & Thornton 2018). This underlies more than 20 per cent (500 km^2) of the Gnangara plan area.

The reductions to abstraction included in options 1 to 4 progressively lower the risks of acid sulfate soils to groundwater users and the area of aquifer acidified. Option 4, in which garden bore use was reduced by one third (a 10 per cent reduction was included in options 2 and 3), overall reduces the volume of acidity-affected groundwater by more than 10 GL in both urban and semi-rural subareas (Table 6). Other options with lesser reductions to garden bore use do not lower risks in urban subareas as much as Option 4 does.

Table 6 Summary of assessment of the 'no intervention' scenario and 'reduced abstraction' options against water resource objective 4.

Water resource objective	No intervention	Option 1	Option 2	Option 3	Option 4
4. Changes in acidity in the Superficial aquifer in potential areas of acid sulfate soils have little or no adverse impacts on significant environmental values and groundwater users.	Increased risk of impacts on 11 GL of pumping. Greatest impacts (>8.2 GL) are in urbanised subareas (Bayswater, Ballajura Bassendean, Stirling and Shire of Swan North) affecting up to 15,500 bores. Extensive impacts of 1.9 GL in rural subareas such as Reserve, Neaves, North Swan and Lake Mungala affecting up to 350 bores.	Increased risk of impacts on 9.7 GL of pumping. Greatest impacts (>7.8 GL) are in urbanised subareas (Bayswater, Ballajura Bassendean, Stirling and Shire of Swan North) affecting up to 13,000 bores. Extensive impacts of 1.4 GL in mostly rural subareas of Reserve, Neaves, North Swan and Lake Mungala affecting up to 260 bores.	Increased risk of impacts on 4.4 GL of pumping. Greatest impacts (>3 GL) are in urbanised subareas (Bayswater, Bassendean, Stirling and Shire of Swan North) affecting up to 6,000 bores. Extensive impacts of 1.1 GL in mostly rural subareas of Reserve, Neaves, North Swan and Lake Mungala affecting up to 211 bores.	Increased risk of impacts on 4.0 GL of pumping. Greatest impacts (>1 GL) are in urbanised subareas (Bayswater, Bassendean, Stirling and Shire of Swan North) affecting up to 5,700 bores. Impacts of 0.8 GL in mostly rural subareas of Reserve, Neaves, North Swan and Lake Mungala affecting up to 180 bores.	Increased risk of impacts on 0.7 GL of pumping. Greatest impacts of 0.7 GL in mostly rural subareas of Reserve, Neaves, North Swan and Lake Mungala affecting up to 130 bores. No impacts in urbanised subareas.

9.4 Assessment against water level criteria in *Ministerial Statement no.819*

For the representative wetland and bushland sites with water level criteria set in *Ministerial Statement no. 819* (see Section 6.1), we used the modelling to project likely changes in water levels under each ‘reduced abstraction’ option and the ‘no intervention’ scenario.

We also used the modelling to assess changes in water levels at three other representative wetlands:

- Quin Brook in the Yeal Nature Reserve
- Gingin Brook
- Lake Gwelup.

We selected these three ecosystems to improve the spatial distribution of the representative wetlands in Ministerial Statement no. 819. Studies such as the *Perth Regional Confined Aquifer Capacity study* (DWER 2021b, see Section 7.1) and the *Perth shallow groundwater systems investigations* (see Section 7.2) helped to confirm their groundwater dependence and identify them as appropriate sites to add to our monitoring network of representative ecosystems.

The initial rounds of the groundwater modelling we used to develop the water resource objectives listed in Table 2, attempted to find a groundwater reduction scenario that would improve water levels at the representative sites. This was to lower the risk of any non-compliance with the water level criteria set *in Ministerial Statement no. 819*.

During the modelling process it became apparent that under the dry future climate scenario, achieving full compliance with the water level criteria at all sites was very unlikely, even with very large (greater than 60 GL/year) reductions to abstraction. In recognition of this, we worked to refine the water resource objectives for the 30 representative sites.

For the non-compliant sites, our primary goal was to achieve compliance, but if this was not possible, we applied the following secondary objectives based on the following hierarchy:

1. Increase water levels to improve ecological health
2. Maintain water levels (no further decline in water levels and ecological health)
3. Reduce the rate or magnitude of decline in water levels for sites where water level decline was primarily climate driven.

For sites currently compliant with water level criteria, our objective was to maintain compliance.

We assessed the model projections for each of the four ‘reduced abstraction’ options and the ‘no intervention’ scenario against the water resource objectives for the 30 representative sites and calculated:

- the number of sites where modelling showed a low risk that future levels would breach the water level criteria (see Table 7).
- the number of non-compliant sites where water levels were projected to increase (see Table 8).
- the number of currently compliant sites where modelling showed a high risk that future levels would breach the water level criteria (Table 9).

See Table 7, Table 8 and Table 9 for a summary of the assessment results.

Ecological water requirement surface

We also used the water level criteria to help create an ‘ecological water requirement surface’. We used this to assess whether each scenario could meet the water requirements of groundwater-dependent vegetation more broadly across the Gnangara system (not just at the water level criteria sites).

The ‘ecological water requirement surface’ is a spatial dataset that specifies a groundwater level pass/fail line in the Superficial aquifer. It uses a digital elevation model and applies water level criteria from *Ministerial Statement no. 819* and historical, measured groundwater levels (from the year 2001[8]), to create a two-dimensional ‘surface’ in the Superficial aquifer under groundwater-dependent ecosystems.

When the modelled groundwater levels were above the ‘ecological water requirement surface’, this showed the ecosystem had enough groundwater to keep it healthy (a pass). If levels fell below the ‘ecological water requirement surface’, then the ecosystem did not have enough groundwater to meet its needs and its health would decline (a fail).

We ran the ‘no intervention’ scenario and ‘reduced abstraction’ options using PRAMS 3.5 to assess the change in area of groundwater-dependent ecosystems that either passed or failed the ‘ecological water requirement surface’. We compared the change in area under each scenario to the baseline year of 2013 (which was the start of the predictive modelling sequence) to estimate the relative increases in area of healthy groundwater-dependent ecosystems in the plan area under each ‘reduced abstraction’ option.

[8] We used 2001 minimum groundwater levels in the surface as this was the year when levels were last sufficient to meet most of the water level criteria in *Ministerial Statement no. 819*.

Modelling results

'No intervention' scenario

The modelling showed that 10 additional sites were at risk of becoming non-compliant under the 'no intervention' scenario compared with the start of the modelling period (Table 7). The sites likely to be compliant under the 'no intervention' scenario are all located in the East Wanneroo area, where urbanisation and associated reductions in agricultural groundwater use are projected to result in rises in groundwater levels.

The model predicted that water levels would continue to decline at most currently non-compliant sites, which would likely result in a further deterioration in ecological condition at those sites.

Urbanisation and associated reductions in groundwater use in East Wanneroo under the 'no intervention' scenario are predicted to increase water levels at lakes Mariginiup and Jandabup, alleviating acidification risks at the lakes. Higher water levels will help improve the lakes' current ecological condition and enhance their visual appeal in an urbanising area, adding to their overall value to the community.

Artificial supplementation of Lake Jandabup, which the Water Corporation undertakes at present, would be reduced and likely ceased. Modelling predicted the ecological condition of Lake Gwelup would also be maintained under the 'no intervention' scenario. But in other areas under the 'no intervention' scenario, the modelling predicted there would be risks of:

- continued declines in levels at wetlands Loch McNess (Wagardu), Lake Yonderup, Lake Wilgarup and Pipidinny Swamp in Yanchep National Park, causing further drying, potential acidification, and loss of ecological, cultural, community and tourism values
- artificial supplementation needed indefinitely, and in increasing volumes, to protect the ecological, cultural and social values of Lake Nowergup
- acidification and proliferation of nuisance midges at Lake Goollelal, negatively affecting the lake's ecological, cultural and community values, as well as outrage levels
- drying and acidification of the threatened mound spring community at Egerton Seepage
- continued loss of wetland vegetation and frog habitat west of Ellenbrook at Lexia and Melaleuca Park wetlands
- continued reductions to the contribution of groundwater to Quin and Gingin brooks, leading to reduced flow and declines in ecological health.

Under the 'no intervention' scenario, the 36 per cent less area where levels pass the 'ecological water requirement surface' would result in declines in ecological condition across large sections of the remaining healthy groundwater-dependent ecosystems the Gnangara system supports.

Table 7 Risk of non-compliance with water level criteria

Assessment	No intervention	Option 1	Option 2	Option 3	Option 4
The number of sites where modelling showed there was a low risk of breaching current Environmental Protections Act criteria.	6 (criteria possibly met at 4 more sites)	12 (criteria possibly met at 1 more site)	13 (criteria possibly met at 3 more sites)	15 (criteria possibly met at 1 more site)	16 (criteria possibly met at 1 more site)
The wetlands and bushland sites where modelling showed there was a low risk of non-compliance with water level criteria (red text indicates a new site for that option compared with the previous option).	*Wetlands*				
	Lake Joondalup Lake Mariginiup Lake Jandabup	Lake Joondalup Lake Mariginiup Lake Jandabup Egerton Seepage	Lake Joondalup Lake Mariginiup Lake Jandabup Egerton Seepage Lake Goollelal	Lake Joondalup Lake Mariginiup Lake Jandabup Egerton Seepage Lake Goollelal Lexia 86	Lake Joondalup Lake Mariginiup Lake Jandabup Egerton Seepage Lake Goollelal Lexia 86
	Bushland sites				
	MM16 MT3S PM24	MM16 MT3S PM24 MM18 MM12 L30C L110C L220C	MM16 MT3S PM24 MM18 MM12 L30C L110C L220C	MM16 MT3S PM24 MM18 MM12 L30C L110C L220C NR6C	MM16 MT3S PM24 MM18 MM12 L30C L110C L220C NR6C MM55B

Table 8 Non-compliant sites where water levels were projected to increase

Assessment	No intervention	Option 1	Option 2	Option 3	Option 4
The number of non-compliant sites where water levels were projected to increase.	4	7	8	10	11
Non-compliant sites where water levels were projected to increase.	*Wetlands*				
	Lake Joondalup Lake Mariginiup Lake Jandabup	Lake Joondalup Lake Mariginiup Lake Jandabup Lake Wilgarup	Lake Joondalup Lake Mariginiup Lake Jandabup Lake Wilgarup Pipidinny Swamp	Lake Joondalup Lake Mariginiup Lake Jandabup Lake Wilgarup Pipidinny Swamp Loch McNess (Wagardu) Lake Yonderup	Lake Joondalup Lake Mariginiup Lake Jandabup Lake Wilgarup Pipidinny Swamp Loch McNess (Wagardu) Lake Yonderup Lexia 186
	Bushland sites				
	MM55B	MM55B MM53 MM59B	MM55B MM53 MM59B	MM55B MM53 MM59B	MM55B MM53 MM59B

Table 9 Risk of currently compliant sites becoming non-compliant

Assessment	No intervention	Option 1	Option 2	Option 3	Option 4
The number of currently compliant sites where modelling showed a high risk that future levels would breach water level criteria.	10	4	3	1	1
Sites where the modelling showed a high risk that future levels would breach water level criteria.	*Wetlands*				
	Lake Goollelal Lexia 86 Melaleuca Park 78 Egerton Seepage	Lake Goollelal Lexia 86 Melaleuca Park 78	Lexia 86 Melaleuca Park 78	Melaleuca Park 78	Melaleuca Park 78
	Bushland sites				
	MM18 MM12 NR6C L30C L110C L220C	NR6C	NR6C		

Reduced abstraction options

Overall risk of non-compliance, compared with the baseline year of 2013, is predicted to reduce under Options 3 and 4. Under these modelled options groundwater level rises are likely at over half the non-compliant sites, including Loch McNess (Wagardu) and Lake Yonderup in Yanchep National Park, which would help to maintain or improve current ecological and community values at these sites.

Compared with the number of compliant sites at the start of the modelling period, the results found that one additional site was at a high risk of becoming non-compliant under both Option 3 and Option 4 (Table 7).

The likely ecological outcomes for the representative sites listed in *Ministerial Statement no. 819* improve progressively under each 'reduced abstraction' option. Compared with the 'no intervention' scenario, the modelled increases in groundwater levels under Option 1 would have a positive impact on two of the wetlands described above under 'no intervention':

- past impacts at Lake Wilgarup in Yanchep National Park caused or exacerbated by declining water levels would be alleviated, enabling a transition to a more stable ecohydrological state and reduced risk of acidification
- perennial flow would likely be maintained at Egerton Seepage, limiting acidification risks and helping to protect the unique organic mound spring threatened ecological community.

Compared with Option 1, the groundwater levels predicted under Option 2 reduce risks at three more representative sites in *Ministerial Statement no. 819* by:

- helping to protect the waterbird habitat, unique macroinvertebrate assemblages and rare or priority flora at Pipidinny Swamp in Yanchep National Park
- alleviating risks of acidification and proliferation of nuisance midges at Lake Goollelal, helping to protect the lake's ecological, cultural and community values
- maintaining conditions to support the diverse wetland vegetation and frog habitat at Lexia 86, west of Ellenbrook.

Compared with Option 2, the modelled groundwater levels under Option 3 reduce the risks at three additional wetlands in *Ministerial Statement no. 819* by:

- helping to restore and protect the ecological, community and tourism values of Loch McNess (Wagardu) and Lake Yonderup
- maintaining conditions to support the diverse vegetation and frog habitat at Lexia 186.

Compared with Option 3, the modelled groundwater levels under Option 4 reduce the risks at two additional wetlands in *Ministerial Statement no. 819* by:

- likely restoring Lake Nowergup to a permanent flow-through lake and protecting the habitat it provides for waterbirds, macroinvertebrates and turtles without the need for any supplementation
- maintaining conditions to support the diverse vegetation and frog habitat at Melaleuca Park Dampland 78.

Under Option 4, which included a greater than 60 GL/year reduction to abstraction, our modelling predicted that groundwater levels would continue to decline at one of the wetlands in *Ministerial Statement no. 819* and the two additional sites in the plan area's north that were assessed – Quin Brook and Gingin Brook. These declines would contribute to:

- the likely loss of surface water and terrestrialisation at Melaleuca Park 173
- continued reductions to the contribution of groundwater to Quin and Gingin brooks, leading to reduced flow and declines in ecological health.

While the modelling predicted that groundwater levels could neither be maintained nor improved at these sites under the 'reduced abstraction' volumes modelled, the declines were progressively less under each successive option, with Option 4 having the least ecological risk.

Under Option 1 the percentage area of groundwater-dependent ecosystems where the 'ecological water requirement surface' would be achieved increases significantly and progressively improves with each successive option. However, all options modelled still result in a reduction in healthy groundwater-dependent ecosystems compared with the 2013 baseline year.

Under Option 2 the area of healthy groundwater-dependent ecosystems decreases by 15 per cent compared with the baseline year; for Options 3 and 4 the decrease is limited to 10 per cent or less (Figure 34).

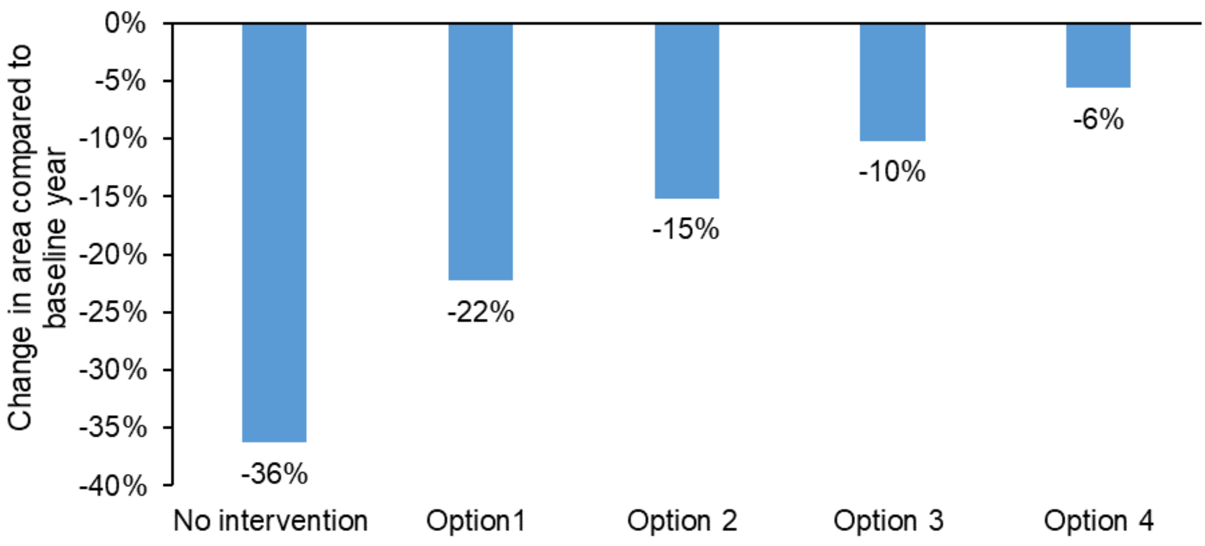


Figure 34 Change in area that meets the 'ecological water requirement surface' compared with the baseline year

10 Deciding the scale of reductions to abstraction

The assessments described in Chapter 9 demonstrate that:

- the more abstraction is reduced, the lower the risks to Gnangara's groundwater-dependent ecosystems, with the highest reductions (Option 4) representing the least risk compared with 'no intervention'
- the more abstraction is reduced, the smaller the volume of pumped groundwater at risk of salinisation and acidification, with Option 3 and Option 4 having the lowest risks to groundwater quality
- abstraction must be reduced by more than 16 GL/year (Option 1) for benefits to some of the groundwater system and its dependent environments
- the reductions to garden bore abstraction included in Option 4 are needed to reduce risk of water level declines and increased acidity in groundwater in urban subareas, and deliver benefits to urban wetlands including Perry Lakes, Herdsman Lake (Ngurgenboro) and Carine Swamp.
- a total volume of reduced abstraction between 46 and 64 GL/year (between Option 3 and Option 4) can deliver benefits across the aquifer system compared with 'no intervention'.

After considering all the information (e.g. input from stakeholder groups and individuals, and modelling results), we found that while Option 4 provided the most benefit to the environment, a reduction of 54 GL/year (a volume in between the reductions included in options 3 and 4) could still meet the water resource objectives with less cost to the community.

Option 4 included a reduction in garden bore use to align with the 2 day a week roster for scheme users. Modelling showed that this was required to reduce risks of water level decline and increased acidity in groundwater in urban subareas.

Option 4 included a 25 per cent reduction to licensed, self-supply abstraction in the higher risk subareas, including Carabooda, Nowergup and Neerabup, where groundwater use is particularly intensive and close to high-value ecosystems such as Lake Nowergup and Yanchep National Park. After the State Government considered the North Wanneroo Agriculture and Water Taskforce's report (NWAWT 2018) it confirmed that only a 10 per cent reduction to groundwater use for North Wanneroo growers would be proposed in the draft Gnangara plan (Kelly 2019). This decision lessens the overall reduction from 64 GL/year (as modelled in Option 4) to 54 GL/year but means the reductions in the North Wanneroo area (Carabooda, Nowergup and Neerabup subareas) will be consistent with other licensed self-supply users across the plan area.

Modelling showed these reductions to garden bore and licensed self-supply use, combined with a 30 GL/year reduction to Water Corporation abstraction (27 per cent) and increased recharge from planned land use changes, is likely to achieve the plan's water resource objectives.

Implementing a reduction to abstraction of 54 GL/year will deliver considerable benefits across most of the Gnangara system, improving environmental values and reducing groundwater quality risks. It will improve the condition of some, but not all groundwater-dependent ecosystems that are currently experiencing significant stress.

The reductions to abstraction will:

- reduce the risk that the number of non-compliant water level criteria sites will go up, compared with the current level of compliance
- reduce the risks of declines in groundwater levels and help maintain wetlands in Whiteman Park, Ellenbrook and the North West corridor – including Loch McNess (Wagardu) and Lake Yonderup within Yanchep National Park – at a similar or slightly improved condition compared with their current state
- result in a relatively small area of currently healthy groundwater-dependent ecosystems being at risk of a decline in health, compared with 36 per cent at risk under the ‘no intervention’ scenario
- reduce the risks of declines in water levels and increased acidity in groundwater in urban subareas and provide environmental benefits to wetlands including Perry Lakes, Herdsman Lake (Ngurgenboro) and Carine Swamp.

Smaller reductions in abstraction are unlikely to prevent declining groundwater levels and further impacts to the northern and urban wetlands. Larger reductions, while resulting in improved environmental outcomes, would be significantly more costly for licensed self-supply groundwater users.

See Part C for further details about how the reductions in groundwater use will be shared across the water use sectors.

Table 10 Reduction decision compared with the other tested options

Consideration	Reduced abstraction options, including the decided option					
	No intervention scenario	**Option 1**	**Option 2**	**Option 3**	**Reduction decision**	**Option 4**
Total annual reduced abstraction	No reduction	16 GL	35 GL	46 GL	54 GL	64 GL
Sites where modelled levels are improved compared with 'no intervention'		Bushland areas in Whiteman Park and west of Ellenbrook	Pipidinny Swamp, Lake Goollelal, Lexia wetlands	North west wetlands like Loch McNess (Wagardu) and Lake Yonderup	Urban wetlands such as Herdsman Lake (Ngurgenboro) and Perry Lakes	Lake Nowergup
Number of sites where modelling showed there was a low risk of breaching the current *Environmental Protection Act* criteria (currently 16 out of 30 compliant) (Table 7)	6	12	13	15	16	16
Area of healthy groundwater-dependent ecosystems compared with now (Figure 34).	36% less	22% less	15% less	10% less	10% less	6% less

Part C – Defining the management approach

In Part C of the allocation planning process, we define our management approach to meet the plan's outcomes and objectives.

Part C explains how we developed the main strategies to meet the groundwater resource objectives. It supports the water licensing approach outlined in Chapter 4 of the *Gnangara groundwater allocation plan* (DWER 2021); that is, how we will use water licences and the provisions of the *Rights in Water and Irrigation Act 1914* to reduce the volume of groundwater that licensees abstract to more sustainable levels.

Key points from Part C:

- A reduction in groundwater use is required to meet the water resource objectives set for the Gnangara groundwater resources.
- Groundwater reductions will be shared across user groups fairly and equitably.
- A 30 GL/year (27 per cent) reduction to abstraction for the IWSS is needed because this abstraction affects most of the Gnangara system and the groundwater-dependent ecosystems it supports.
- A 10 per cent reduction to licensed self-supply use is needed to achieve local improvements in groundwater levels and to contribute to achieving environmental outcomes.
- Implementing groundwater reductions to licensees from 2028 gives users adequate time to make business and behavioural changes and, for larger operations, to scope, plan for, invest in and build new infrastructure.
- Schools and hospitals will be excluded from reductions in abstraction, and an enhanced Waterwise Schools program will focus on water use efficiency for school grounds.
- Where possible we have reserved water to meet strategic future needs, including for public water supply and irrigation of public open space.
- To reduce domestic garden bore use, the bore sprinkler roster will be aligned with the two day a week scheme water roster in the Perth/Mandurah area.
- We will support groundwater users to adjust to the reductions by encouraging efficient use of water and water entitlement transactions where possible. We will also continue to support investigations of alternative water sources.
- We have proposed new water level thresholds for some of the representative sites that have criteria set in *Ministerial Statement no. 819*.
- We will use the monitoring network for the sites to assess against the water resource objectives and water level thresholds, and we will use the assessment outcomes to review and adapt our management approach.

11 Plan strategies

There are four main strategies in the draft Gnangara plan to manage groundwater to meet water resource objectives:

1. Reduce groundwater abstraction over the next decade
2. Encourage efficient use of water, water trading and where appropriate, alternative water sources
3. Set aside groundwater for the future strategic needs of Perth where it is available and appropriate to do so
4. Use our monitoring network to review our management.

This chapter explains what we considered to develop and decide on these strategies.

11.1 Reduce groundwater abstraction over the next decade

Part B of this report describes how we decided on the volume of reductions required. Below we explain when the reductions will be put in place and how they will be shared across water users.

Timing of reductions

Adequate time to adjust to less water was one of the main constraints raised by licensees when we consulted with different interest groups. It takes time to make business and behavioural changes and, for larger operations, to scope, plan for, invest in and build new infrastructure.

Some stakeholders said that with adequate notice, they could bring the need to reduce their water use into their current asset and fund planning processes. Some also suggested that more time before the licence changes were made, allowed for new technologies to become more affordable and available. This had the potential to make it cheaper and easier for licensees to update their infrastructure and irrigation practices.

We took on this advice and proposed the reductions to licences would start from 1 July 2028. By starting the conversation with stakeholders in 2016 and sending letters to all licensees and key stakeholders in May 2018, we have given significant notice that groundwater use needs to reduce and changes to licences may be required. The draft *Gnangara groundwater allocation plan* (DWER 2021) confirms the proposed timing and licence changes.

Sharing reductions

In the draft plan, we have proposed to share the total 54 GL/year reduction across water users in the following way:

- most of this reduction will come in 2028 from changes to public water supply abstraction for the IWSS totalling 30 GL/year across all aquifers (a 27 per cent reduction in their current licences)
- from 2028, 10 per cent less will be taken by most self-supply licensees (totalling about 10.2 GL/year), including water for:
  - agriculture and horticulture sectors (5.4 GL/year)
  - irrigating parks, gardens and other recreational green space (3.4 GL/year)
  - most other licensed water use, such as industry and mining (1.4 GL/year).
- a 13.6 GL/year reduction to groundwater taken from domestic garden bores, to be achieved by aligning the garden bore sprinkler roster with the two day a week scheme water roster to remove the additional watering day for households with garden bores in the Perth/Mandurah area.
- no reductions will apply to schools and hospitals, as well as a small number of other specified purposes and locations.

The draft allocation plan aims to reduce groundwater abstraction by 54 GL/year to rebalance the Gnangara groundwater system:

- Most of this reduction will come from changes to Water Corporation licences in 2028 totalling 30 GL/year across all aquifers.
- Self-supply licensed use will be reduced by about 10.2 GL/year from the Superficial, Mirrabooka and Leederville aquifers.
- A further 13.6 GL/year will come from reductions in water use from domestic garden bores.

Public water supply share

We have proposed a 27 per cent (30 GL/year) reduction in the Water Corporation’s licensed allocation, compared to the current baseline of 110 GL/year, from 2028. This is a significantly larger reduction when compared to the 10 per cent for self-supply users and will achieve regional scale improvements in groundwater levels and to help meet the plan’s objectives.

Unlike self-supply groundwater users who have limited alternatives to shallow groundwater, the Water Corporation has the flexibility to adapt its water supply sources to changing circumstances due to its extensive network of bores and its capacity to build alternative water sources.

Additionally, public water supply abstraction affects almost the whole Gnangara groundwater system, and the reduction will mostly benefit the health of groundwater-dependent ecosystems. Given these ecosystems are public assets with important aesthetic, recreation and conservation values, it's appropriate that as a state-government (publicly) owned entity, the Water Corporation account for a significant portion of the reduction.

It's important to note that following the previous *Gnangara groundwater areas allocation plan* (DoW 2009a) and the commissioning of a second desalination plant in 2013, the Water Corporation have already made reductions to the amount of groundwater they abstract.

We continue to work closely with the Water Corporation to assess options to meet demand for the IWSS and reduce the pressure on Gnangara water resources. A portfolio of additional supply sources is part of the Water Corporation's long-term planning that anticipates the effects of climate change and population growth.

Self-supply licensees share

The 2009 *Gnangara groundwater areas allocation plan* capped growth in licensed self-supply groundwater abstraction through new allocation limits but did not require direct reductions to water licence entitlements.

With climate change and abstraction continuing to affect water levels across the Gnangara system, it is now necessary to reduce self-supply water use in line with reduced rainfall to help rebalance the system.

The 10 per cent reduction to licensed self-supply use is needed to contribute to improvements in groundwater levels and to help meet the plan's objectives. Reductions to public water supply abstraction alone are not enough to provide benefits to water users and the environment across the whole system.

Extensive consultation with self-supply groundwater users found many licensees could likely achieve a 10 per cent reduction by changing their water use practices (see Section 11.2) and that the proposed reduction was reasonable and achievable. The long lead time before the reductions are implemented will enable users to adopt water saving technologies or management practises.

Even though the state of the water resource varies across the Gnangara system, just as the impact of individual licensees on the environment varies, an equitable cut for self-supply licensed users is a fair, reasonable and practical way of sharing the reduction. An uneven approach would not pass the fairness test and would be very difficult to implement and administer across 2,600 licences in the plan area.

Domestic garden bore users share

The reduction to domestic garden bore use will be achieved by aligning the garden bore sprinkler roster with the two day a week scheme water roster, removing the additional watering day for households with garden bores in the Perth/Mandurah area. This reduction is needed because:

- although individual bores have a negligible impact on the groundwater resource, collectively the estimated 70,000 garden bores across the Gnangara plan area represent a major use sector that measurably affects groundwater levels

- domestic bore ownership continues to grow as new areas are developed, thus the impact of this sector on the groundwater system is continually increasing
- various estimates of residential water use over the last decade, when comparing similar-sized properties, have consistently found that on average households with a garden bore use 3 to 4 times more water on lawns and gardens than households using scheme water. In part, this is a consequence of the extra watering day that garden bore users have under the current sprinkler restrictions.

Deciding on exceptions to reductions

The following groundwater users will not have reductions to their licensed abstraction in 2028.

Primary and secondary schools with groundwater licences for irrigating school grounds

To avoid negatively affecting outdoor education and recreation, we will exclude all schools from a reduction in groundwater take. Instead, we will encourage schools to increase water use efficiency to support a more sustainable level of local and total abstraction (targeting a 10 per cent reduction in use by 2030).

We will work with the Department of Education (the licensee for most public schools) and the private school sector to build efficiency into watering programs for grounds. The approach will be rolled out gradually, through an enhanced Waterwise Schools program which the *Waterwise Perth Action Plan* has initiated.

Hospitals irrigating hospital grounds and gardens

The seven groundwater licences for hospitals total 0.3 GL/year. This volume is insignificant in terms of its impact on nearby ecosystems, thus the benefits of reducing it are negligible.

Licensees in the North West urban growth corridor taking groundwater to develop and irrigate new public open spaces

In 2014, we reviewed allocation limits in the Quinns, Eglinton and Yanchep subareas, adjusted down the groundwater available and established the *North West corridor water supply strategy* (DoW 2014). All new licensing in the corridor since 2014 has been managed in line with this strategy, which accounts for climate change, increased recharge from urbanisation, and use of best-practice design and irrigation standards for new public open space development.

Any pre-2014 licensed use in these subareas, such as for agriculture, other commercial uses and existing public open space, is still subject to the 10 per cent reductions from 2028.

Licensees in the area identified as urban expansion in East Wanneroo

We expect groundwater levels to rise in East Wanneroo as urban expansion causes increases in recharge and decreases in local abstraction after the area transitions from rural agriculture to urban land use. The urban expansion area partially covers five groundwater subareas – Adams, Mariginiup, Jandabup, Joondalup and Lake Gnangara. Licensees in the area zoned as urban expansion are exempt from reductions because the water resource objectives will be achieved through the expected rise in water levels. Outside the urban expansion area, licensees will need to reduce their groundwater use by 10 per cent from 2028.

To manage the risk that local groundwater level rises will impact on wetlands and future urban form in the area, the *East Wanneroo district water management strategy* (Urbaqua 2021) proposes a concept to control groundwater via subsoil drains and a pumping scheme to remove water from the area. The concept will need to go through further pre-feasibility and feasibility studies (Urbaqua 2021). The controlled groundwater level is likely to limit the influence of groundwater rises within the area on groundwater levels outside it.

Self-supply Yarragadee aquifer licences

The small volume of groundwater licensed from the Yarragadee aquifer to self-supply users is mostly for geothermal heating purposes and is reinjected back into the aquifer.

Temporary licences, such as for dust suppression and dewatering

These licences are temporary and cannot be renewed or transferred. There will always be demand for the temporary use of groundwater for purposes such as dewatering and dust suppression during construction of roads and buildings. Once the work is completed, the water is no longer needed and is returned to the system. Reducing temporary use is not required.

All licences for fractured rock and coastal saline aquifers

Fractured rock aquifers are typically located on the Darling Scarp and are not connected to the Gnangara groundwater system. Reducing use from these licences will not benefit the Gnangara system. There is one licence from the coastal saline aquifer in the Whitfords subarea used for aquaculture research.

Gingin groundwater use

We will defer any reductions to groundwater abstraction from the Superficial and Leederville aquifers in the Guilderton South, Beermullah Plain South, Deepwater Lagoon South and SA3 South subareas until we complete a new Gingin water allocation plan. This is because there is abstraction outside of the Gnangara plan area that influences the health of Gingin Brook and Moore River Estuary.

11.2 Encourage efficient use of water

The draft plan's long lead time for making the reductions to groundwater should give groundwater users enough time to achieve a 10 per cent reduction in groundwater use without negatively affecting productivity. Most users will be able to achieve this through improving their water efficiency and irrigation practices.

In developing the draft plan, we considered recent work on water use efficiency and worked closely with different groundwater use sectors to advance research and build capacity in this area. See below for a summary of this work and of ongoing programs that are supporting improved water use efficiency.

Agriculture

Research using economic farm modelling by the University of Western Australia (Iftekhar & Fogarty 2017) found the impact of reduced licensed use can be largely mitigated through changes in the cropping mix and use of more efficient irrigation technologies.

The North Wanneroo Agriculture and Water Taskforce reported on options for water efficient horticulture and recommended ways we could support efficiency and ensure groundwater was not being wasted (NWAWT 2018).

In 2019, the Department of Primary Industries and Regional Development (DPRID) set up two demonstration sites showing water efficient techniques and best-practice irrigation. DPIRD commissioned Irrigation Australia to assess the irrigation efficiency of 22 on-farm systems. The results found opportunities for growers to become significantly more water efficient by modernising their irrigation systems and other means.

Following on from the taskforce report, in 2021 the State Government established a $600,000 water efficiency infrastructure and technology grants program to support adaptation. The program will help growers improve the design of water systems, implement soil and crop sensor technology, and apply soil amendments to increase soil-moisture holding capacity. The government has also committed $150,000 to support the City of Wanneroo's local planning processes to maintain and protect agriculture in North Wanneroo consistent with the taskforce's recommendations.

Parks, gardens and recreational spaces

We worked with the City of Wanneroo to establish the *North West corridor water supply strategy* (DoW 2014). The strategy provides enough groundwater, based on waterwise irrigation rates, for essential public parkland (such as active turf areas for sport and recreation). It also seeks to minimise water use on non-active open space areas such as verges and streetscapes.

We are continuing to work with the Water Corporation to extend the Waterwise Councils, Golf and Schools programs under the current and future Waterwise action plans. These programs support improved water efficiency and resilience to climate change by focusing on training, waterwise design such as hydro-zoning and eco-zoning, efficiency upgrades to irrigation infrastructure, water budgeting, soil management and good maintenance of irrigation systems.

Our work with agencies such as the Department of Local Government, Sport and Cultural Industries and the Water Corporation, as part of the *Waterwise Perth Action Plan,* is showing that in most cases, waterwise practices will mean existing groundwater supplies will be adequate to meet green space irrigation demand.

We will continue to work with the City of Swan to develop the North East Corridor integrated water strategy and advise developers on options to meet green space watering requirements in new urban developments. We will encourage them to make water savings through redesign and efficiency improvements to existing public open space areas.

Domestic garden bore use

Water Corporation will assist householders to make their gardens more waterwise through initiatives including smart irrigation sprinkler rebates and spring sprinkler system check-ups.

Awareness-raising campaigns aimed at garden bore owners began in Spring 2019. Recent campaigns include a Spring 2021 campaign and the launch of the Be groundwater wise website as part of the *Waterwise Perth Action Plan*. More campaigns will be run over the next five years to drive behaviour change and improve garden bore efficiency.

We are working with Irrigation Australia to offer Waterwise Garden workshops to the Perth community to increase awareness and provide practical education to ensure garden bore users are waterwise in their gardens.

11.3 Encouraging water entitlement transactions

Trades, transfers and agreements allow existing licensees to expand their operations as well as adapt to changing circumstances. We expect that the clear picture of water scarcity and reduced groundwater availability described in the draft Gnangara plan will drive increased interest in water transactions. Importantly, over time, this will mean that the productive value of groundwater is being maximised.

People seeking water transactions can find details about current water licences and contact details for existing licensees at our online Water Register.

We will assess all trades, transfers and agreements using our normal processes (see *Policy: Water entitlement transactions for Western Australia* (DWER 2020)[9] and those described in Section 4.3 of the draft plan.

For water entitlement transactions near groundwater-dependent ecosystems, we may ask for additional information to complete our assessment of the licence

9 Formerly operational policy 5.13

application and apply licence conditions to minimise the risk to these environments. Water entitlement transaction applications that increase risk of abstraction impacts to groundwater-dependent ecosystems may be refused.

We have defined a priority agricultural trading zone in the new Swan Valley subarea. The following trading rules apply in this area:

- water can be traded into the trading zone
- water can be traded within the trading zone
- water cannot be traded out of the trading zone.

When we assess any trade in the priority agricultural zone, we will consider the proximity of abstraction to the river and potential water quality impacts.

11.4 Alternative source options

The timeframe for reductions set out in the draft plan gives licensees time to explore water efficiency measures before considering more costly alternative source options. Time is also needed to plan for alternative source options and ensure they are practical and economically viable.

Work under the *Waterwise Perth Action Plan* has generally shown that waterwise practices will mean existing groundwater supplies will be adequate to meet green space irrigation demand. In some cases, alternative water sources such as rainwater harvesting, subsurface drainage, stormwater harvesting, recycled wastewater or scheme supply may be needed. Throughout the draft plan's development we supported several investigations on potential alternative source options including:

- An evaluation of water supply options for green space watering with WESROC and the Town of Cambridge (DWER 2018b). Preliminary cost estimates from the study showed that while more expensive than direct groundwater abstraction, recycled wastewater and drainage water options are cheaper than water supplied from the IWSS. The study also found that using groundwater more efficiently could delay or avoid the need to move to alternative sources.
- An economic and financial viability assessment of non-potable water supply options for the North East urban growth corridor (Synergies 2018).
- A preliminary assessment of the availability of subsurface drainage as a potential recycled water source in the North East urban growth corridor (RPS 2018). This assessment found several land development areas in the North East corridor were likely suitable for subsoil drainage harvesting.
- An assessment of water options for intensive agricultural use in North Wanneroo (WGA 2018).

We will continue to:

- Supply local governments and other stakeholders with up-to-date water availability information and advice to:

  - make planning for public open spaces more compatible with reduced groundwater abstraction from the Gnangara system
  - identify alternative water sources to local groundwater if required.
- Work with the Water Corporation to identify where a strategic approach to alternative water supply options might be needed for future non-drinking water sources.
- Advise the City of Swan on an integrated water management strategy for the North East urban growth corridor that considers alternative water source options.
- Advise the agricultural sector on potential options for alternative water supplies into the future.

New hydrogeological investigation in the North East corridor

To inform future groundwater management in the North East corridor (and Swan Valley) we have funded a project through the State Groundwater Investigation Program to conduct further hydrogeological studies in the corridor. The project aims to:

- determine the degree to which the Wanneroo and Serpentine faults affect groundwater flow in the Leederville aquifer
- define areas of connectivity between the Superficial, Mirrabooka and Leederville aquifers
- assess the causes of falling groundwater levels in the Swan Valley
- determine the source and the hydrogeological factors causing the reported increased groundwater salinity in the Swan Valley
- provide a regional scale guide to facilitate potential managed aquifer recharge proposals for water supply in the North East corridor
- update conceptualisation of key hydrogeological features for the project area.

The investigation involves airborne geophysical survey, drilling and installing groundwater monitoring bores, groundwater chemistry and isotope sampling, and analysis of data to develop a conceptual model of the study area.

11.5 Water for future strategic needs

To account for different water uses and administer water licensing, we divide allocation limits into different components. In the Gnangara plan area, we have six components (Figure 35). Five of the components are used for water licensing and one accounts for unlicensed use (water uses exempt from licensing such as from domestic garden bores).

We licence the recovery of groundwater injected through managed aquifer recharge operations (such as Water Corporation’s groundwater replenishment scheme) under a 'managed aquifer recharge component' that is outside the allocation limit. The volume and locations of groundwater licensed under this component are linked to the volume and locations of the injected water (DWER 2021c).

We assessed demand for water to meet strategic needs such as for public open space in planned urban areas, basic raw materials extraction and future public water supply, and where possible set aside groundwater to meet these demands in relevant components of the allocation limit.

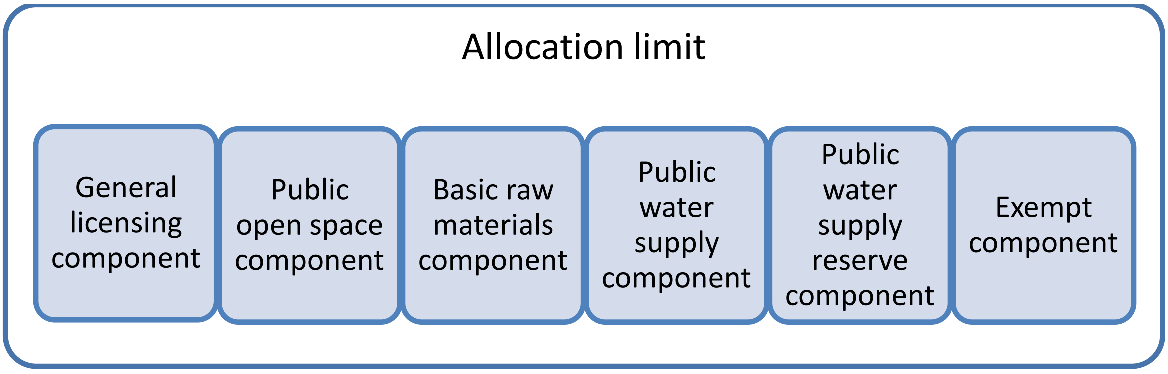


Figure 35 Components of the allocation limits for the Gnangara plan area

The allocation limits for each subarea and aquifer across the Gnangara plan area and their components are detailed in the draft *Gnangara groundwater allocation plan* (DWER 2021a).

Public open space

The public open space component is the volume of water for licensing the irrigation of new public open spaces in specified locations. We applied this component in subareas for the three main growth areas on the Gnangara system – the North West and North East urban growth corridors and the East Wanneroo area.

Water from this component is or will be allocated to land developers, schools and local governments to establish and irrigate new parks and gardens, sports ovals and public open spaces. The component volume is based on the water required once turf and garden areas are established (long-term requirements).

Any licence issued for temporary establishment of turf and garden areas will have a reduced licence tenure and include conditions that mean the licence cannot be transferred to other uses, or water users, and will not be renewed.

Basic raw materials

The basic raw material component is the volume of water set aside for licensing dust suppression required under the *Environmental Protection Act 1986* during the extraction of basic raw materials, such as limestone and sand.

This component is set for the Superficial aquifer in subareas that overlap areas identified:

- as a high priority area shown in the 2018 North East, North West, and Central subregional planning frameworks as part of the *Perth and Peel @ 3.5 million* (DPLH and WAPC 2018a)
- as priority resource locations in draft *State Planning Policy 2.4 – Basic raw materials policy and guidelines* (DPLH and WAPC 2018b and 2018c).

Public water supply reserves

Public water supply reserves are the volume of water set aside for planned public water supply needs. These reserves were initially established in the 1980s and 90s in the Gnangara groundwater area and have now either been allocated or impacted by climate change. These reserves were largely removed from the Gnangara groundwater area as part of setting allocation limits for the draft plan.

The department and the Water Corporation reassessed public water supply reserves in the Superficial aquifer along the North West urban growth corridor. We considered climate change, planned urban developments and risks to wetlands in Yanchep National Park and to Lake Nowergup. The total volume reserved was decreased from 23.1 to 18.1 GL/year, and most of this volume is only available in the most northern parts of the Yanchep subarea where there is minimal development and where there are few competing uses. Access over time, with continued climate change, may be limited and will be subject to stringent assessment requirements.

11.6 Using our monitoring network to review our management

Chapter 7 of the draft Gnangara plan describes:

- the monitoring program for the Gnangara groundwater system
- how we will use the monitoring to review the plan’s water resource objectives.

We operate an extensive network of more than 700 monitoring bores and 30 staff gauges to monitor the Gnangara groundwater system and the ecosystems that depend on it. We regularly take measurements at these sites to assess changes in groundwater levels, hydraulic pressure and, in some cases, water quality (salinity). We also undertake specific monitoring, including ecological monitoring, under environmental conditions in *Ministerial Statement no. 819*.

We will assess the results of the monitoring program against the performance indicators detailed in Chapter 7 of the plan to determine whether the objectives are being met. We will continue to comply with reporting requirements related to *Ministerial Statement no. 819* or a revised statement following an assessment under Section 46 of the *Environmental Protection Act 1986* (see below for more information on this process).

Proposal to change some of the current water level criteria set in *Ministerial Statement no. 819*

The environmental impacts on groundwater-dependent ecosystems that we have documented through our monitoring program, together with ongoing groundwater declines and increasing non-compliance with water level criteria, are clear signs that the Gnangara groundwater resources are stressed, and groundwater abstraction must be reduced to bring the system back into balance.

Part B of this report describes how we used groundwater modelling to assess how much to decrease groundwater use to sufficiently improve the system's health. The water level criteria for the representative groundwater-dependent ecosystems listed in *Ministerial Statement no. 819* were important inputs into the model. We used these to assess each 'reduced abstraction' scenario.

As described in Section 9.3, one of our initial objectives was to reduce groundwater use enough to meet all the water level criteria in *Ministerial Statement no. 819*. However, as the groundwater modelling progressed, it became clear that 100 per cent compliance was impossible to achieve under the projected dry climate scenario, even if groundwater use was reduced by greater than 60 GL/year.

Knowing, in some cases, that existing criteria would not be achieved despite major reductions in groundwater use, we are proposing new water level criteria (or thresholds) at some representative wetland and bushland sites. These are in line with what is achievable under a drier climate and the reductions to groundwater abstraction outlined in Part B of this report.

To determine the proposed water level thresholds, we considered:

- past and current water levels and the relationship between water levels and ecological health
- ecological water requirements
- the hydrogeology of wetlands and the interactions and connectivity of surface waterbodies and groundwater informed by the Perth shallow groundwater systems investigations
- modelled projections of what water resource outcomes can likely be achieved once reductions to abstraction are in place
- consultation with key stakeholders, including DBCA, on site management objectives
- a review of the draft thresholds by the Centre for Ecosystem Management at Edith Cowan University (Kavazos et al. 2020).

We will submit our proposed changes to the EPA with the outcomes of the public comment period for the draft Gnangara plan. The review by Edith Cowan University will support this submission.

The EPA will assess the environmental acceptability of the changes under Section 46 of the *Environmental Protection Act 1986* and report on its inquiry into the proposed changes to the Minister for Environment. For administrative reasons the EPA may also decide to review other conditions in *Ministerial Statement no. 819* as they may be out of date, duplicated, or not enforceable.

Table 11 describes water level ‘thresholds’ proposed for the draft plan. The thresholds are the equivalent of the minimum water level criteria in *Ministerial Statement no. 819* and, if the EPA accepts them, will become the water levels that we report compliance against.

We have also proposed preliminary threshold levels at two new sites (Quin Brook and Gingin Brook). We will confirm these levels as part of the next Gingin water allocation plan.

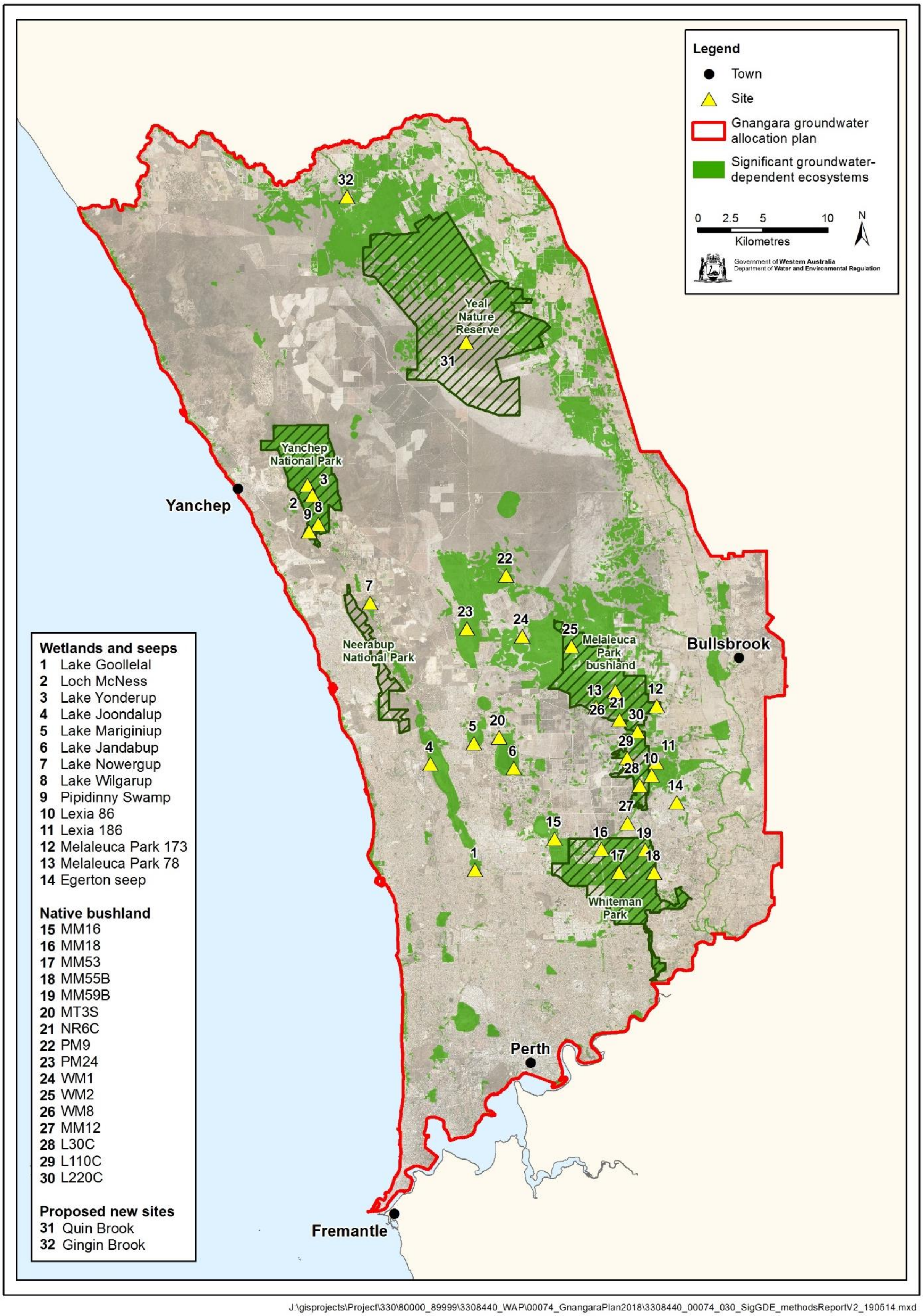


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Figure 36 Location of sites in the Gnangara plan area with existing and proposed water level thresholds

*Table 11 Proposed ecological threshold levels at groundwater-dependent ecosystems in the plan area**

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Proposed Threshold level mAHD	Notes [i]
Lake Goollelal	*1b) Maintain health* Maintain groundwater levels to: • maintain permanent surface water for fauna habitat and visual amenity • maintain fringing vegetation • minimise risk of acidification and nuisance midge proliferation.	6162517 (staff 459)	26.9	26.0	26.4	Monitoring shows that managing water levels to the existing minimum criterion will not meet site management objectives and that the criterion should be raised to reduce risk of acidification and nuisance midge proliferation. Levels have been above the proposed threshold since 2017 and modelling projects the threshold can continue to be met through the management outlined in the plan.
Loch McNess (Wagardu)	*1b) Improve health* Improve groundwater levels to: • increase surface area of permanent water for fauna habitat and visual amenity • maintain healthy, intact fringing vegetation • maintain diverse habitat types and excellent water quality.	6162564 (staff 8754)	<6.1 (dry at staff)	6.95	6.2	Modelling projects only small rises are possible in Yanchep National Park under the planned reduced abstractions – not enough to meet existing water level criteria. However, the modelling was not able to fully assess potential local management approaches in the Yanchep area so the threshold level will be further investigated within the life of the plan. The ECU review of threshold levels recommended the current criterion of 6.95 mAHD be retained and that the proposed threshold level should increase if assessments of local management strategies suggest it is possible to meet a higher level.
Lake Yonderup	*1b) Improve health* Improve groundwater levels to: • increase surface area of permanent water for fauna habitat • maintain intact, undisturbed fringing vegetation • maintain diverse habitat types and excellent water quality.	6162565 (staff 8780)	5.5	5.9	5.7	Modelling projects only small rises are possible in Yanchep National Park under the planned reduced abstractions – not enough to meet existing water level criteria. However, the modelling was not able to fully assess potential local management approaches in the Yanchep area so the threshold level will be further investigated within the life of the plan.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Proposed Threshold level mAHD	Notes [i]
Lake Joondalup	*1b) Maintain health* Maintain groundwater levels to: • maintain permanent water for fauna habitat and for visual amenity • maintain diverse aquatic plants and fringing vegetation • minimise risk of acidification.	6162572 (staff 8281) 61610661 (bore 8281)	16.7	15.8	16.2	Monitoring shows that managing levels to the existing minimum criterion will not meet the site management objectives and that the criterion should be raised to reduce risk of acidification. Current levels are above the proposed threshold and modelling projects the threshold level can continue to be met through the management outlined in the draft plan. Threshold to be measured at the staff gauge.
Lake Mariginiup	*1b) Improve health* Improve groundwater levels to: • increase wading bird habitat • maintain the rich aquatic macroinvertebrate community • reduce lake acidity to beneficial levels for fauna.	6162577 (staff 1943) 61610685 (bore MS10)	41.2	41.5 (minimum peak)	42.1 (minimum peak)	Water levels are currently below the existing minimum peak criterion but modelling projects levels will rise at Lake Mariginiup because of land use change and associated reductions in local abstraction. These rises mean that meeting the existing preferred minimum peak will likely be achievable. Threshold to be measured at the staff gauge.
Lake Jandabup	*1b) Improve health* Improve groundwater levels to: • increase wading bird habitat • maintain the rich aquatic macroinvertebrate community • minimise risk of acidification.	6162578 (staff 1944)		44.2 (minimum peak)		Lake Jandabup is artificially maintained by the Water Corporation. Water levels are currently below the existing absolute minimum criterion but modelling projects levels will rise as a result of land use change and associated reductions in local abstraction to the extent that artificial maintenance may no longer be required within the plan period.
		6162578 (staff 1944)	44.3	44.3	44.3	The minimum peak criteria should be removed as this is too low to meet the water quality objectives of minimising risk of acidification. Threshold to be measured at the staff gauge.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Threshold level mAHD	Notes [i]
Lake Nowergup	*1b) Improve health* Improve groundwater levels to: • increase area of permanent deep-water habitat for fauna • maintain fringing vegetation to support macroinvertebrate diversity and nutrient retention.	6162567 (staff 8756)	<16.0 (dry at staff)	16.8 (minimum peak)	16.0 (absolute minimum)	Modelling projects levels will rise at Lake Nowergup, but the increase will not likely be enough to meet existing criteria, even with continued artificial maintenance by the department.
		[616145 (telemetry site) Note – both staff gauge and telemetry site measure lake levels.	16.6		18.0	
Lake Wilgarup	*1b) Improve health* Improve groundwater levels to maintain soil moisture and minimise risk of acidification.	61618500 (Wilgarup Lake bore)	3.0	4.5	3.2	Modelling projects small increases in groundwater levels are possible in Yanchep National Park under the reduction in abstraction. This will reduce risks to existing wetland values but will not be enough to meet the existing water level criterion. Note – a resurvey of Wilgarup Lake bore found the historic data had an incorrect datum applied.
Pipidinny Swamp	*1b) Improve health* Improve groundwater levels to: • increase area of water habitat for fauna • maintain fringing vegetation to support a range of habitat types for macroinvertebrates.	6162624 (staff) 61611872 (bore PIP_C)	0.5	1.6	1.1	Modelling projects small increases in groundwater levels are possible in Yanchep National Park under the reduction in abstraction. This will reduce risks to existing wetland values but will not be enough to meet existing water level criterion. Threshold to be measured at the staff gauge.
Lexia 86	*1b) Maintain health* Maintain groundwater levels to maintain fringing vegetation to support a range of habitat types for macroinvertebrates and vertebrates.	61613215 (bore GNM16)	47.1	47.0	47.0	Water levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Threshold level mAHD	Notes [i]
Lexia 186	*1b) Maintain health* Maintain fringing and wetland vegetation to support a range of habitat types.	61613214 (bore GNM15)	46.7	47.2	47.0	Modelling projects the reduction in abstraction can likely maintain water levels at Lexia 186 but that the existing water level criterion is unlikely to be achieved.
Melaleuca Park 173	*2) Manage declines in groundwater levels to reduce risk to ecological health* Limit declines in health of fringing and wetland vegetation to support a range of habitat types.	61613213 (bore GNM14) 6162628 (staff)	48.8	50.2	49.0	Modelling projects the reduction in abstraction will likely reduce, but not fully arrest further water level declines at Melaleuca Park 173, and ecological values associated with the presence of surface water, such as macroinvertebrates and frogs, may decline. Threshold to be measured at bore GNM14.
Melaleuca Park 78	*2) Manage declines in Superficial groundwater levels to reduce risk to ecological health* Limit declines in health of wetland vegetation.	61613231 (bore GNM31)	65.0	65.1	65.5 (minimum peak)	Modelling projects the reduction in abstraction will likely reduce, but not fully arrest further water level declines at Melaleuca Park 78, most likely leading to progressive encroachment of dryland vegetation species into the wetland.
Egerton Seepage	*1b) Maintain health* To maintain the mound spring threatened ecological community (EG01), intact fringing vegetation and invertebrate habitat.	61618607 (bore B25) 61672233 (B25A – replacement bore for B25)	39.9	39.3	39.3	Current levels are above the existing criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
MM16 Whiteman Park West	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and threatened Banksia woodland community (SCP 20a).	61610835 (bore MM16)	40.0	38.8	38.8	Current levels are above the existing criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
MM18 Whiteman Park Central	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61610918 (bore MM18)	39.4	38.6	38.6	Current levels are above the existing criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Threshold level mAHD	Notes [i]
MM53 Whiteman Park Central	*1b) Improve health* Improve groundwater levels to improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61610493 (bore MM53)	33.2	33.3	33.3	Modelling projects levels will rise in this area under the reduction to abstraction and that the current water level criterion can likely be met beyond 2030, but may not be met in the short term.
MM55B Whiteman Park East	*1b) Improve health* Improve groundwater levels to improve the condition of dependent Melaleuca woodland.	61610559 (bore MM55B)	29.5	29.5	29.5	Modelling projects levels will rise in this area under the reduction to abstraction and that the current water level criterion can likely be met beyond 2030, but may not be met in the short term.
MM59B Whiteman Park East	*1b) Improve health* Improve groundwater levels to improve the condition of dependent vegetation and potential Banksia woodland threatened community.	61611025 (bore MM59B)	35.7	36.3	36.2	Modelling projects water levels will rise in this area because of the reduction to abstraction, but that the rises may not be sufficient to meet the current water level criterion.
MT3S East Wanneroo	*1b) Maintain health* Maintain groundwater levels to maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61610745 (bore MT3S)	44.1	43.0	43.0	Modelling projects water levels will rise in this area because of land use change and associated reductions in local abstraction and that the current water level criterion can be met.
NR6C Melaleuca Park	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61610982 (bore NR6C)	59.0	58.5	58.5	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
PM9 Pinjar North		61610804 (bore PM9)	Bore dry	56.3	–	Groundwater levels have dropped to greater than 10 m below the ground surface and vegetation at PM9 is considered no longer groundwater-dependent. Model results indicate the proposed reductions in abstraction will not arrest further water level declines at PM9. We will propose to remove PM9 as a criteria site.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Threshold level mAHD	Notes [i]
PM24 Lake Pinjar	*1b) Maintain health* To maintain or improve the condition of regionally significant bushland, including Pinjar vegetation complex.	61610697 (bore PM24)	41.2	40.5	40.5	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
WM1 Pinjar	*2) Manage declines in Superficial groundwater levels to reduce risk to ecological health* To avoid significant impacts to habitat values of the Banksia woodland community as it transitions to be less groundwater-dependent	61610833 (bore WM1)	54.9	55.7	53.7	Modelling projects the reduction in abstraction will be able to reduce, but not fully arrest further water level declines at WM1.
WM2 Melaleuca Park North	*2) Manage declines in Superficial groundwater levels to reduce risk to ecological health* To avoid significant impacts to habitat values of the Banksia woodland community as it transitions to be less groundwater-dependent	61610908 (bore WM2)	66.7	66.5	64.7	Modelling projects the reduction in abstraction will be able to reduce, but not fully arrest further water level declines at WM2.
WM8 Melaleuca Park	*2) Manage declines in Superficial groundwater levels to reduce risk to ecological health* To avoid significant impacts to habitat values of the Banksia woodland community as it transitions to be less groundwater-dependent	61610983 (bore WM8)	65.0	64.8	63.7	Modelling projects the reduction in abstraction will be able to reduce, but not fully arrest further water level declines at WM8.
MM12 Lexia	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61610989 (bore MM12)	42.9	42.0	42.0	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.

Site name	Site management objectives	Bore or staff gauge where criteria and threshold are measured	2018 summer minimum (or spring peak) mAHD	Current absolute minimum/ minimum peak criteria set under EP Act mAHD	Threshold level mAHD	Notes [i]
L30C Lexia	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community	61611010 (bore L30C)	47.8	47.2	47.2	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
L110C Lexia	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61611011 (bore L110C	57.3	55.7	55.7	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
L220C Melaleuca Park South	*1b) Maintain health* Maintain or improve the condition of intact dependent vegetation and potential Banksia woodland threatened community.	61611018 (bore L220C)	53.3	52.2	52.2	Groundwater levels are currently above the existing water level criterion and modelling projects levels under the reduction to abstraction will likely continue to meet this level.
Quin Brook	To be confirmed in the Gingin water allocation plan (draft expected before 2025).	61710060 (bore GC11)	53.8		55.0	Proposed new site. Threshold to be confirmed in the draft Gingin water allocation plan.
Gingin Brook	To be confirmed in the Gingin water allocation plan (draft expected before 2025).	61710078 (bore GB13)	37.4		37.3	Proposed new site. Threshold to be confirmed in the draft Gingin water allocation plan.

i Descriptions of modelling results refer to the modelling of the ‘reduction to abstraction’ run with land use changes and a future dry climate.

** Sites with proposed changes to current water level criteria set under the* Environmental Protection Act 1986 *are shown in red text.*

Appendices

Appendix A — Abstraction assumptions for the 'no intervention' scenario

Under the 'no intervention' scenario, licensed groundwater abstraction was generally assumed to remain at 2013 levels, except for:

- increases in Superficial aquifer abstraction along the North West corridor associated with the activation of water reserved for public water supply (+18.1 GL) and public open space (+2.9 GL)
- reductions in Superficial aquifer abstraction because of land use changes in the East Wanneroo area (-7.9 GL)
- increases in Superficial aquifer abstraction associated with dust suppression for the extraction of basic raw materials (+0.4 GL).

Projected increases in domestic garden bore abstraction associated with new urban areas was also included in the 'no intervention' scenario (+7 GL).

North West corridor water supply

The North West urban growth corridor is a 9,000 hectare area for future urban development located along the coast from Quinns Rocks to Yanchep. It requires water to meet public water supply and public open space needs.

In 2014, the *North West corridor water supply strategy* (DoW 2014) outlined an approach for the orderly and equitable allocation of groundwater for public water supply, developers and future licensees (primarily the City of Wanneroo) in the corridor. In developing the strategy, groundwater allocation limits along the corridor were reviewed.

The review involved the use of groundwater flow cells to estimate groundwater throughflow and accounted for the drying climate and increased recharge from planned urbanisation. The review recommended that less water be made available in the Quinns and Eglinton subareas. It also found that allocation limits in the Yanchep subarea could be raised significantly because of the projected increases to recharge from urbanisation.

Most of the additional groundwater made available at the time of the 2014 review was reserved for public water supply, intending that it would be progressively allocated to meet demand as the urban front expanded northward.

As part of developing the draft Gnangara plan, the department worked with the Water Corporation to re-investigate the North West corridor allocation limits for the reserves set in the 2014 review. This was to reduce any unacceptable risks on important wetlands in Yanchep National Park and surrounds.

We found it was necessary to reduce the public water supply reserves down to a total of 18.1 GL across the Quinns, Eglinton and Yanchep subareas, to reduce the risks of further drawdown to wetlands in the Yanchep National Park (Table 12). This reduced public water supply reserve is what was modelled as part of the future demand requirements in all scenarios as part of the options assessment for the draft plan (see Chapter 9).

Access to the reserves will be staged with urban development and follow the usual rigorous licence assessment process.

The re-investigation also found that current volumes of public water supply abstraction from bores YB3 and YB4 (~1 GL per year) to the west of Loch McNess (Wagardu) represented a risk to recovering water levels at the lake, which were already drawn down by abstraction and climate.

In consultation with the Water Corporation, we developed a plan to step-down abstraction from these bores to a volume of 0.21 GL/year by 2025. This will reduce the risk of further drawdown at Loch McNess (Wagardu), while still meeting local demand for public water supply.[10]

The modelling of the 'reduced abstraction' options and the 'no intervention' scenario (described in Chapter 9) also included activation of 2.9 GL/year of water reserved for irrigation of public open space along the North West corridor.

This public open space reserve was not re-assessed after the 2014 review as the volume was originally calculated based on design criteria which:

- included hydro-zoning principles
- minimised irrigated areas
- applied a best-practice irrigation rate to all irrigated areas.

Table 12 Public water supply reserves along the North West corridor (GL)

Subarea	Aquifer	Current public water supply reserves (2014 review)	Public water supply reserves in draft plan
Quinns	Superficial	2.5	2.3
Eglinton	Superficial	5.3	4.2
Yanchep	Superficial	15.3	11.5
Total		**23.1**	**18.1**

[10] The reductions at YB3 and YB4 were included in all the modelled allocation options and counted as part of the 10, 20 and 30 GL reductions in each respective scenario.

East Wanneroo

Large areas of land currently used for agriculture will be urbanised in the East Wanneroo area (DPLH 2019). In three subareas in East Wanneroo the volume of water currently licensed for agricultural purposes exceeds the volume needed for future irrigation of public open space, once the area is urbanised. This will result in an estimated reduction in local groundwater use in the area by 7.9 GL. This reduction was included in all modelled scenarios (Table 13).

Table 13 Likely reductions in abstraction in East Wanneroo because of land use change (GL)

Subarea	Aquifer	Current agricultural licensed entitlement volume	Volume for the future irrigation of public open space	Reduced volume
Lake Gnangara	Superficial	7.1	2.3	4.8
Mariginiup	Superficial	4.2	1.1	3.1
Joondalup	Superficial	0.8	0.7	0.1
Total		**11.3**	**3.8**	**7.9**

Basic raw materials

When we developed the reduced abstraction options, we accounted for future water needs associated with the extraction of basic raw materials. The extraction of basic raw materials such as limestone and sand require water for dust suppression under the *Environmental Protection Act 1986*.

We estimated future water needs for basic raw materials for subareas that overlap areas identified as priority resource locations in *State Planning Policy 2.4 – Basic raw materials* (DPLH and WAPC 2018b) and as a high priority area in the North West, North East and Central subregional planning frameworks under *Perth and Peel @ 3.5 million* (DPLH and WAPC 2018a). The volumes estimated are in Table 14.

Table 14 Estimated future water needs for basic raw material extraction (GL)

Subarea	Aquifer	Volume required for dust suppression for basic raw materials extraction
Reserve	Superficial	0.2
Wanneroo Wellfield	Superficial	0.2

Garden bores

In the ‘no intervention’ scenario, use of domestic garden bores was projected to increase as a result of continued growth in the number of bores installed as Perth expands. The projected 1 per cent annual growth rate resulted in a 7 GL/year increase in modelled garden bore use by 2030.

This growth rate was based on 2012 data from the Australian Bureau of Statistics and the Water Corporation. This data showed that following the introduction of the three-day-a-week sprinkler ban and the end of the domestic bore rebate scheme, there was a marked slowing of bore installation to a growth rate of 1.37 per cent. We assumed the growth rate will continue to slow under these conditions and adjusted the rate of 1.37 per cent from the 2012 data to a 1 per cent growth rate.

Appendix B — Abstraction volumes by component and aquifer for scenarios of options assessed

Allocation limit component and aquifer*	Abstraction volumes GL/year				
	No intervention	Option 1	Option 2	Option 3	Option 4
General licensing					
Superficial aquifer	95.4	89.5	86.6	85.0	77.7
Mirrabooka aquifer	2.3	2.1	2.1	2.1	1.8
Leederville aquifer	10.9	10.9	9.8	9.8	9.8
Yarragadee aquifer	0.7	0.7	0.7	0.7	0.7
Total	**109.3**	**103.2**	**99.1**	**97.5**	**89.9**
Public open space					
Superficial aquifer	2.9	2.9	2.9	2.9	2.9
Total	**2.9**	**2.9**	**2.9**	**2.9**	**2.9**
Basic raw materials					
Superficial aquifer	0.4	0.4	0.4	0.4	0.4
Total	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Public water supply – Integrated Water Supply Scheme baseline licences					
Superficial aquifer	31.3	28.2	27.0	24.5	24.5
Mirrabooka aquifer	1.1	1.1	1.0	1.0	1.0
Leederville aquifer	33.1	30.4	25.8	21.8	21.8
Yarragadee aquifer	45.2	41.0	36.9	33.5	33.5
Total	**110.7**	**100.7**	**90.7**	**80.7**	**80.7**
Public water supply – Woodbridge Town Supply					
Superficial aquifer	0.0	0.0	0.0	0.0	0.0
Leederville aquifer	0.1	0.1	0.1	0.1	0.1
Total	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
Public water supply reserve					
Superficial aquifer	18.1	18.1	18.1	18.1	18.1
Total	**18.1**	**18.1**	**18.1**	**18.1**	**18.1**
Total licensed abstraction					
Superficial aquifer	148.1	139.1	134.9	130.8	123.5
Mirrabooka aquifer	3.4	3.2	3.1	3.0	2.7
Leederville aquifer	44.1	41.4	35.7	31.7	31.7
Yarragadee aquifer	45.8	41.6	37.5	34.1	34.1
Total	241.5	225.4	211.3	199.7	192.1
Exempt					
Superficial aquifer	43.3	43.3	38.9	38.9	29.2
Total	**43.3**	**43.3**	**38.9**	**38.9**	**29.2**
Grand Total	**284.8**	**268.7**	**250.2**	**238.6**	**221.3**

* *Where an aquifer is not shown there is no abstraction from it for that component.*

Appendix C — Map information

Datum and projection information

Vertical datum: Australian Height Datum (AHD)
Horizontal datum: Geocentric Datum of Australia 94
Projection: MGA 94 Zone 50 Spheroid: Australian National Spheroid

Disclaimer

These maps are a product of the Department of Water and Environmental Regulation. These maps were produced with the intent that they be used for information purposes at the scale as shown when printed. While we have made all reasonable efforts to ensure the accuracy of this data, we accept no responsibility for inaccuracies and persons relying on the data do so at their own risk.

Sources

We acknowledge the following datasets and their custodians in the production of these maps:

Aboriginal Sites and Heritage Places – DPLH 2021

Acidity Risk Zone – DWER 2018

Allocation plan areas – DWER 2016

Aquifer Connectivity – DWER 2015

Bush Forever – DPLH 2018

Cadastre – Landgate 2018

Darling Fault – DWER 2005

DBCA Legislated Lands and Waters – DBCA 2018

Faults – DWER 2018

Geomorphic Wetlands – DBCA 2018

Gnangara Jandakot Significant GDEs – DWER 2018

Groundwater monitoring bores – DWER 2018

Groundwater areas – DWER 2018

Groundwater subareas – DWER 2018

Imagery – Landgate 2016

Modelled water level change – DWER 2017

Native Title – Indigenous Land Use Agreements (ILUA) – Landgate 2021

Regional Parks – DBCA 2017

Rivers – Geoscience Australia 2001

Saline Water Intrusion Zone – DWER 2018

Sprinkler Restrictions – Water Agencies (Water Use) Bylaws – DWER 2012

Towns – Western Australia – DWER 2013

Urban expansion area – DPLH 2018

WA Coastline – DWER 2000

Water level change data – DWER 2019

WIN Sites – DWER 2018

WIN Sites – Ministerial Criteria – DWER 2005

Yeal Nature Reserve Banksia TEC reserve – DWER 2017

Appendix D — Significant groundwater-related sites listed under the Aboriginal Heritage Act 1972 (after Estill 2005)

Site ID	Site Name	Site ID	Site Name
1018	Doogarch (Coogee Swamp)	3572	Smith's Lake/Dajanberup
3186	Yonderup Cave	3573	Stone's Lake
3742	Loch McNess, Wagardu Spring	3585	Herdsman Lake (Ngurgenboro)
17450	Nowergup Lake	3593	Gudinup
17451	Pipidinny Lake	3596	Rocky Bay
17596	Limestone Reef	3694	Claisebrook Camp
17597	Emu Cave	3735	Perry Lakes
17599	Yanchep Beach	3736	Jolimont Swamp (Mabel Talbot Reserve)
19589	Muchea Unnamed Lake (Mu5)	3738	Dog Swamp
20008	Gingin Brook Waggyl Site	3754	Mt Eliza Waugal
21614	Airfield Road Wetlands	3755	Loreto Convent, Claremont
682	Gnangara Lake SW 1	3762	Lake Claremont
3169	Gnangara Lake SE	3788	Lake Monger
3319	Gnangara Lake SW 1	3791	Matilda Bay
3396	Lake Adams	3792	Hyde Park
3503	Honey Possum Site	3800	King's Park
3504	Joondalup Waugal Egg	17848	Weld Square
3509	Karli Spring	17849	Robertson Park
3525	Ellen Brook: Upper Swan	18936	King's Park
3532	Joondalup Caves	19387	Boodjemalup
3567	Mindarie Waugal	19863	King's Park Women's Site
3583	KI-IT Monger Brook	20178	Bold Park
3640	Lake Joondalup South-West	21253	Mosman Park
3693	Lake Neerabup	21537	TC/01-Waterway
3739	Lake Goollelal	21538	Stirling Wetlands
3740	Lake Joondalup	552	Lord Street North 2
3741	Lake Mariginiup	3487	Bennett Brook: Eden Hill R
3742	Emu Swamp	3488	Bennett Brook: Rosher Park
3772	Gnangara Lake	3489	Bennett Brook: Lord St 1
4102	Lake Joondalup North-West	3490	Bennett Brook Lord St 2
4404	Orchestra Shell Cave	3536	Swan River/Derbal Yerrigan
15118	Henley Brook	3620	Bassett Road
15979/ 3536	Avon River, Swan/Avon Rivers	3622	Turtle Swamp
17319	Ellen Brook Tributary	3692	Bennett Brook *in toto*
17498	Waugal Cave, Neil Hawkins Park	3720	Blackadder & Woodbridge Ck

Site ID	Site Name	Site ID	Site Name
17590	Edgewater Burial Site	3743	Emu Lake
20596	Butler - FS01	3745	Mussell Pool
20765	SBJ01	3757	Success Hill
20769	SBJ02	3758	Helena River
20772	Jindalee	3753	Perth? (Maylands Peninsula/ Minjelungin Swamp)
21588	Kinsale	3759	Jane Brook
21589	Rosslare Soak	3796	Blackadder Ck and Swan River
435	Moonderup	3840	Bennett Brook: Camp Area
3318	Lake Monger (Galup) NW and W	17037-41	Pyrton Sites A1-A5
3323	Lake Monger (Galup) Velodrome	20030	Ancient Well
3339	Minim Cove	21392	NOR/03 – Creek
3393	Lake Gwelup	21393	NOR/02 – Lightning Swamp
3500, 3501	Lake Gwelup	21432	Marshall Pool Wetlands

Shortened forms

AHD	Australian height datum
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DPC	Department of Premier and Cabinet
DPLH	Department of Planning, Lands and Heritage
DWER	Department of Water and Environmental Regulation
DoW	Department of Water (now DWER)
EPA	Environmental Protection Authority
IWSS	Integrated Water Supply Scheme
PRAMS	Perth Regional Aquifer Modelling System
WAPC	Western Australian Planning Commission
WAWA	Water Authority Western Australia
WIN	Water Information Network
WRC	Water and Rivers Commission

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 Megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 Gigalitre	(GL)

Glossary

Commonly used terms in relation to water resource management are listed below:

Abstraction	Withdrawal of water from any surface water or groundwater source of supply.
Acid sulfate soil	Waterlogged soils at wetlands and at the top of the Superficial aquifer naturally containing strong acidity (sulfuric acid) stored as iron pyrite that can be released to leach into groundwater if dried out by watertable decline.
Allocation limit	Annual volume of water set aside for use from a water resource.
Aquifer	An underground layer of saturated rock, sand or gravel that absorbs water and allows it to pass freely through pore spaces.
Basic raw materials	Sand (including silica sand), clay, hard rock, limestone (including metallurgical limestone), gravel and other construction and road building materials.
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
Ecological water requirement	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
Evapotranspiration	The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants.
Groundwater area	The boundaries proclaimed under the Rights in Water and Irrigation Act 1914 (WA) and used for water allocation planning and management.
Groundwater-dependent ecosystem	An ecosystem that is at least partially dependent on groundwater for its existence and health.
Licence (or licensed entitlement)	A formal permit which entitles the licensee to take water from a watercourse, wetland or underground source under the *Rights in Water and Irrigation Act 1914*.
Phreatophytic vegetation	Vegetation that uses groundwater to meet at least part of its water needs.
Reliability	The number of years over time that a water licensee can obtain their full licensed volume.
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Saline water intrusion	An increase in the area where dense salty water from the ocean, along our coastlines and saline parts of rivers, has reached into the bottom of the aquifer.

Subarea	A subdivision, within a surface or groundwater area, defined to better manage water allocation. Subarea boundaries are not proclaimed and can therefore be amended without being gazetted.
Terrestrialisation	The process whereby long-term drying of a wetland leads to colonisation of the site by species which are progressively less adapted to an aquatic habitat (e.g. terrestrial vegetation).
Water reserve	An area proclaimed under the *Metropolitan Water Supply, Sewerage and Drainage Act 1909* (WA) or *Country Areas Water Supply Act 1947* (WA) to protect and use water for public water supply.
Watertable	The groundwater surface in an unconfined aquifer.

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Department of Water and Environmental Regulation
Prime House, 8 Davidson Terrace
Joondalup Western Australia 6027
Phone: 08 6364 7000
Fax: 08 6364 7601
National Relay Service 13 36 77
dwer.wa.gov.au
12886 0518

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