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

Cockburn

groundwater allocation plan

methods report

Water resource allocation and
planning report series
Report no. 26
May 2018

Cockburn groundwater allocation plan: Methods report

Background information and methods used to set allocation limits for the Cockburn groundwater resources

Department of Water and Environmental Regulation

Water Resource Allocation and Planning Report series

Report no. 26

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What is this report?

This companion document to the *Cockburn groundwater allocation plan* (DWER 2018) explains how the Department of Water and Environmental Regulation (DWER) revised the allocation limits for the Superficial aquifer. It also provides further detail on the hydrogeological, environmental, and cultural and community information collected to inform the decision-making process used to revise the allocation limits and how the local licensing rules were developed.

The allocation plan details how the department will manage, license and monitor groundwater in the plan area.

What does this report include?

This report contains three main chapters, which follow the department's water allocation planning process for plan development set out in *Water allocation planning in Western Australia: a guide to our process* (DoW 2011):

- Chapter 2 – Stage A: describes the information used to improve the precision of the allocation limits
- Chapter 3 – Stage B: outlines how we set the management and resource objectives and the methodology for making the allocation limit decisions
- Chapter 4 – Stage C: describes how we considered the local licensing issues and developed specific policies to support the approach to managing groundwater.

The *Jandakot Mound allocation limits method report* (DoW 2016a) and *Western Trade Coast heavy industry local water supply strategy* (DoW 2016b) provide key reference material for groundwater management in and adjacent to the plan area.

Contact the Kwinana Peel regional office for further information on the plan area or read the technical documents listed in the references section of this report.

1 Introduction

The allocation limits for the Superficial aquifer set in the *Cockburn groundwater allocation plan 2007* (DoW 2007) were reviewed in 2015-16. The *Cockburn groundwater allocation plan* (DWER 2018) contains the new limits. This report details the method we used to update the allocation limits and explains why they were changed. The report also provides the context for the objectives and local licensing policies set in the 2018 plan.

1.1 Groundwater area and location

The Cockburn groundwater area is located 30 km south of Perth in the metropolitan area. It covers 157 km^2 of land adjacent to the coast and is evenly split between the local governments of City of Cockburn and City of Kwinana, with a small portion to the south in the City of Rockingham. Aquifers in the Cockburn groundwater area provide water for public open space, heavy and light industry, horticulture and rural land uses.

The hydrogeology of the Cockburn groundwater area is generally well understood and documented in the *Cockburn groundwater management plan* (DoW 2007). Aquifers present in the groundwater area (in order of increasing depth) are the Superficial (including a minor area of Rockingham Sand), Leederville and Yarragadee aquifers (Figure 1).

The Superficial aquifer in the plan area supports high value groundwater-dependent ecosystems (see section 3.1). This includes the Ramsar-listed Thomsons Lake and other conservation category wetlands that are significant to the community, several of which are managed collectively in the Beeliar Regional Park.

Five of these important wetlands[1], including Thomsons Lake, have water level criteria set by the Minister for Environment in the *Jandakot Mound groundwater resources [including Jandakot groundwater scheme, stage 2] Ministerial statement no. 688* (EPA 2005) which is used to manage groundwater abstraction.

The Leederville and Yarragadee aquifers are managed under two subareas that cover the whole plan area. They are the Cockburn confined Leederville aquifer and the Cockburn confined Yarragadee aquifer. We did not review the allocation limits for these confined aquifers through this process. The original allocation limits set in 2007 for these aquifers still apply.

The Cockburn groundwater area is divided into four subareas to manage how water is allocated and licensed from the Superficial aquifer[2] (Figure 1). The Superficial aquifer subareas are Kogalup, Thompsons, Valley and Wellard.

[1] Bibra Lake, Yangebup Lake, Kogalup Lake, Lake Thomsons and Lake Banganup

[2] Note: Water from the Rockingham Sand is managed and allocated together as part of the Superficial aquifer.

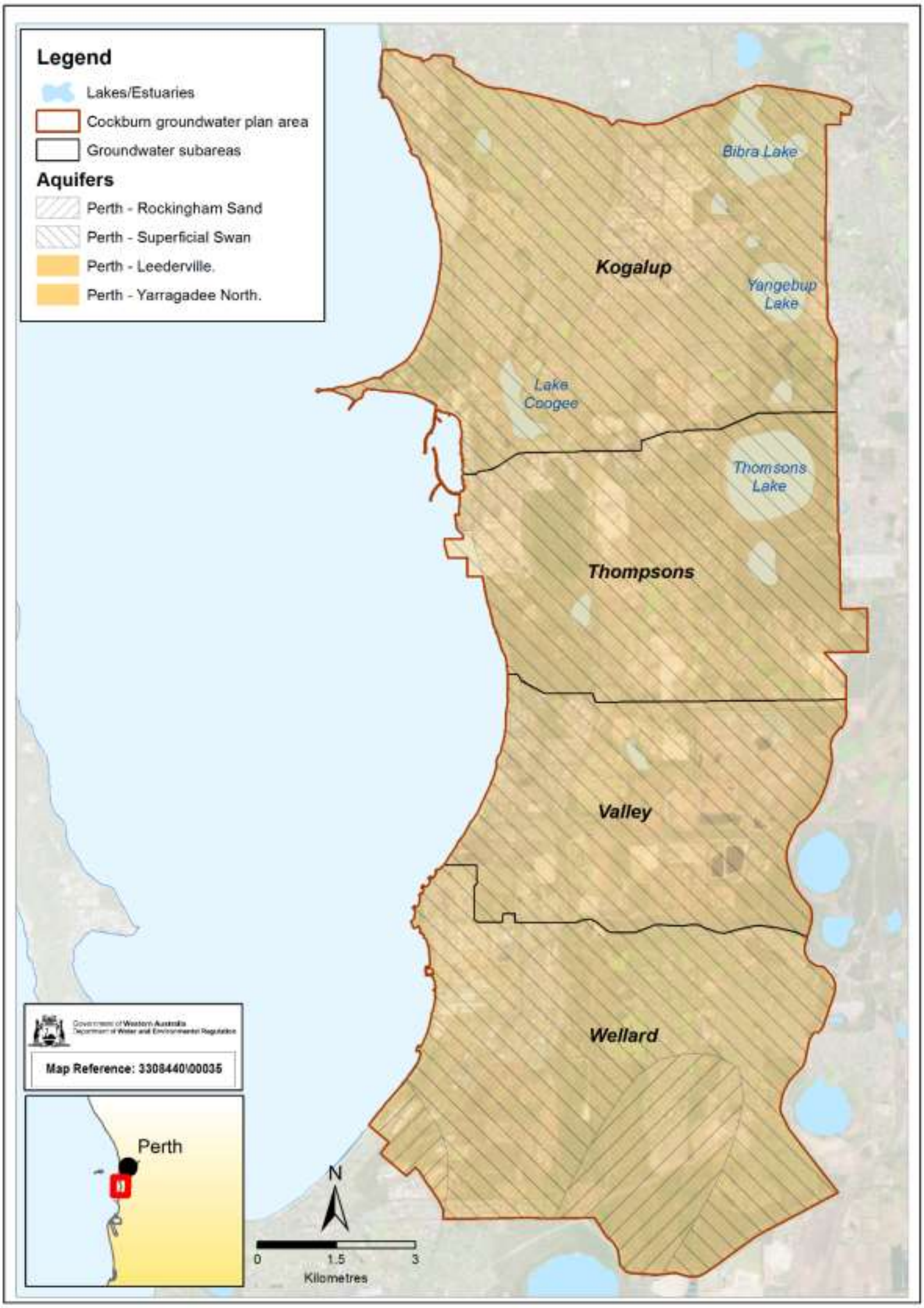

Figure 1 Subareas and groundwater resources in the Cockburn groundwater allocation plan area

1.2 Water allocation planning in the Cockburn groundwater area

The Department of Water and Environmental Regulation regulates and manages how groundwater is abstracted by issuing licences under the *Rights in Water and Irrigation Act 1914*. The allocation limits described here set the volume of groundwater that can be taken annually in the Cockburn groundwater area (the plan area).

The *Cockburn groundwater allocation plan 2018* replaces the *Cockburn groundwater area water management plan 2007.* The plan sets out how much water can be taken from the three aquifers present in the plan area and how groundwater abstraction will be managed. This supporting methods document describes how the department developed key elements of the plan and decided on the allocation limits for each resource in the plan area.

1.3 Allocation limits

The allocation limit is the annual volume of water set aside for consumptive use from a water resource. As shown in Figure 2, the allocation limit does not include water for environmental, cultural or community needs. This water is not for consumptive use and remains in the aquifer.

Allocation limits are used to manage groundwater resources within an acceptable level of risk to the environment and to maintain security of supply to water users. Water is allocated up to the limit through the department's licensing process. This is supported by ongoing water resource and licence compliance monitoring. Monitoring data collected by the department and licensees are used to evaluate the resource each year.

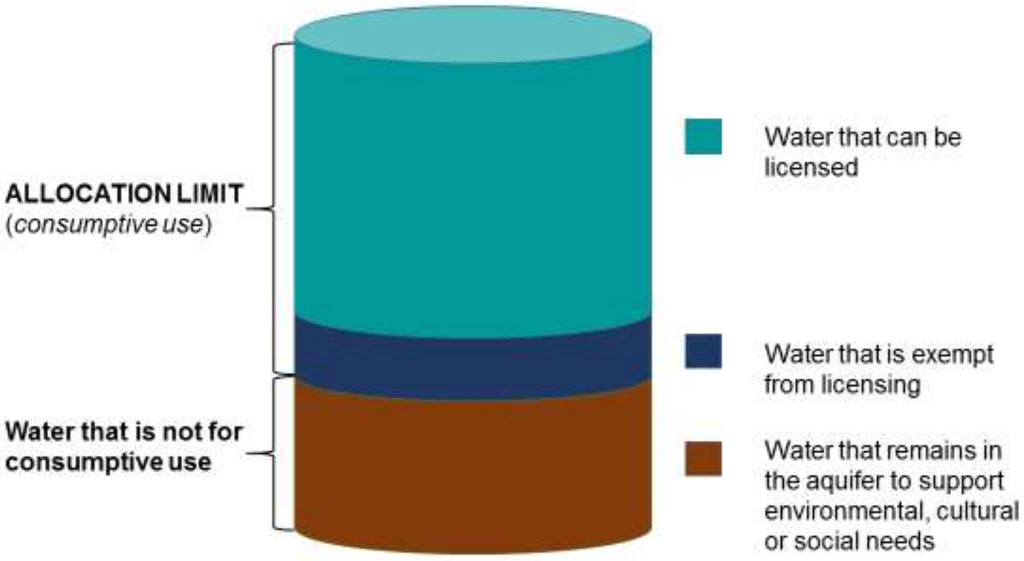

Figure 2 Conceptual diagram of how water availability is divided up into consumptive and non-consumptive use

For administrative and water accounting purposes, the allocation limit is divided into water that is available for licensing and water that is exempt from licensing (unlicensed).

Managed aquifer recharge schemes are accounted for as extra water to that naturally occurring in the aquifer. Any approved managed aquifer recharge activities are assigned a volume in a separate component, which sits outside of the allocation limit. Access to this water is managed through the water licensing process.

Previous allocation limits and approach

Allocation limits for all aquifers accessed in the Plan area were first set in the *Cockburn groundwater area management plan* (Water Authority of Western Australia 1993). In the original 1993 plan, allocation limits for the Superficial aquifer were set using a basic water balance calculation. Rainfall recharge was divided up, with 75 per cent set as the allocation limit of 32.8 GL/year and the remaining 25 per cent left in the aquifer to maintain wetlands and the seawater interface.

The allocation limits were revised through the *Cockburn groundwater area water management plan 2007* (DoW 2007). The 2007 plan increased the Superficial aquifer allocation limits to 38.2 GL/year to account for throughflow from adjacent subareas. The limits from the 2007 plan and current entitlements are shown in Table 1.

Rainfall has been declining in the Cockburn area since the 1980s (see section 2.1). The long-term average annual rainfall (1946–2015) at Jandakot rainfall station no. 9172 is 841 mm. The last ten years' average annual rainfall is 719 mm (2006–2015), with a 30-year average of 812 mm (1985–2015).

An increase in licensed entitlements (Table 1), coupled with less rain and demand for more water to support local industry, triggered the review of allocation limits. Industry groups also wanted certainty on groundwater availability. This will allow them to identify how much water may need to be sourced from alternative supplies, such as managed aquifer recharge, to support the future growth of the industrial area (see Section 1.5 below).

Table 1 2007 allocation limits for the Superficial aquifer and entitlements, 30 November 2016 (GL/yr)

Subarea	2007 allocation limit	2016 licensed entitlements
Kogalup	11.46	10.05
Thompsons	8.70	5.70
Valley	7.70	7.30
Wellard	10.32	6.85
Total	**38.18**	**29.9**

Allocation limits were reviewed for the Superficial aquifer only. This review is critical to maintaining water quality and quantity for existing licensees and high value wetlands for future generations.

The allocation limits for the Leederville and Yarragadee aquifers were not reviewed and will remain the same as those set in the *Cockburn groundwater area water management plan 2007.* As these aquifers extend beyond the plan area and are affected by regional scale use, the limits will remain the same until further hydrogeological investigations are completed outside of the plan area.

This future work will help to better understand groundwater recharge and regional-scale impacts of use in the adjacent Jandakot and Serpentine groundwater areas.

We will also use the results of the recently completed Perth Region Confined Aquifer Capacity (PRCAC) study to inform how we manage seawater intrusion, throughflow and managed aquifer recharge in the deeper aquifers.

1.4 Allocation limit review process

The review of allocation limits was undertaken using our standard allocation-planning model (Figure 3). This report describes:

- The information we collected to understand current use and the water resources (Part A).
- The objectives and method used to set the allocation limits using standardised future climate projections (Part B).
- Our approach to licensing and water allocation under the new allocation limits (Part C).

For more information about allocation planning see *Water allocation planning in Western Australia: a guide to our process* (DoW 2011), which is available online at <www.dwer.wa.gov.au>.

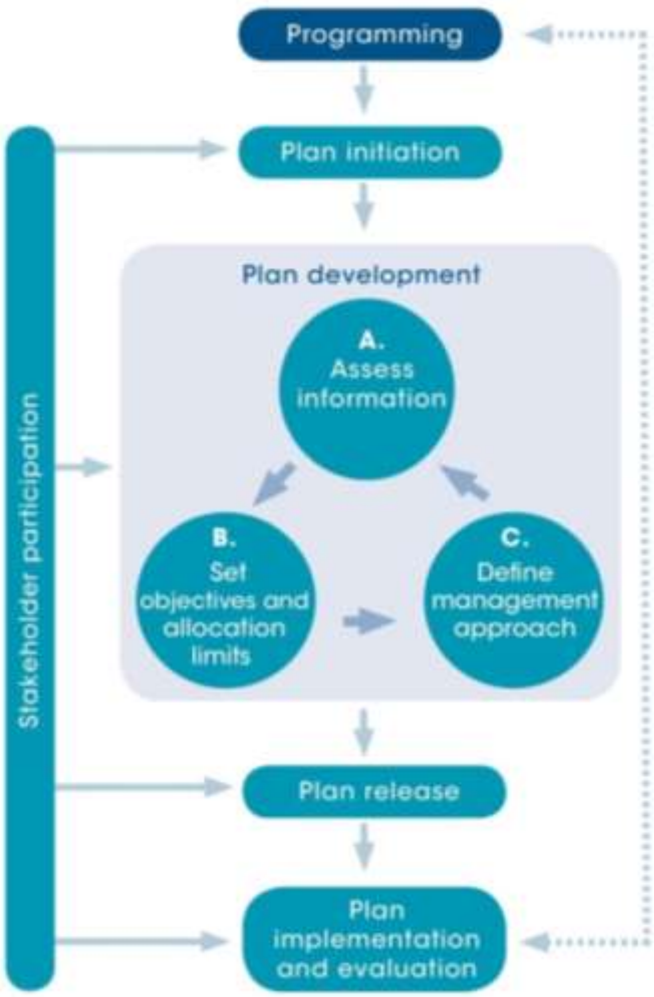

Figure 3 Our water allocation planning model for WA

1.5 Working with water users and other stakeholders

The department continues to work with licensees and local stakeholders to better manage the water resources in the plan area. This ongoing relationship will improve how we share water and maintain supply for future generations.

Industry

A key driver to review the allocation limits was a preliminary review and assessment of water supply and demand for the Western Trade Coast industrial precinct[3]. This work identified that existing groundwater supplies were unlikely to meet future demand for heavy industry. Water users wanted certainty on the volume of groundwater available for use and how much water would need to be sourced from alternative supplies to meet projected demand for industry.

The *Western Trade Coast heavy industry water supply strategy* (DoW 2016b) outlines alternative water supply options available to meet the future industrial water demands for this area. The main alternative is treated (recycled) wastewater. Currently more than 50 GL/year of treated wastewater is discharged to the ocean through the *Sepia Depression Ocean Outfall Line* (SDOOL). This pipeline, managed by Water Corporation, runs straight through the centre of the Western Trade Coast making this option highly accessible.

A study led by CSIRO looked at the feasibility and cost of managed aquifer recharge schemes in the Western Trade Coast area (see GHD 2015a).[4] The study found that use of recycled wastewater, as part of a managed aquifer recharge (MAR) scheme, was the most cost-effective future water supply option.

The study also found alternatives such as using scheme water, desalinated seawater and stormwater harvesting are unlikely to be feasible based on costs and infrastructure (see GHD 2015b). Overall, the focus for the plan area will be on developing fit-for-purpose water supplies, increasing water recycling and improving water efficiencies.

The department regularly meets with Kwinana Industries Council on water matters. In April 2016, we met to discuss the process and method for reviewing the allocation limits. In February 2017, we presented the objectives and new allocation limits. This included discussion on how the new limits will be implemented and options for alternative water supplies.

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[3] The Western Trade Coast industrial precinct includes the Kwinana Industrial Area, Australian Marine Complex, Rockingham Industry Zone and the Latitude 32 industry zone (area covered by the *Hope Valley Wattleup Redevelopment Act 2000).*

[4] This study was one portion of the overarching *Recycled water for heavy industry and preventing seawater intrusion project* funded by the Australian Water Recycling Centre for Excellence let by CSIRO and partnered with Kwinana Industries Council, Western Trade Coast, Department of Water and Department of Health.

The outcome of the allocation limits review, which clearly states that groundwater is fully allocated in Cockburn, was presented in the *Western Trade Coast heavy industry water supply strategy* (DoW 2016b).

Environment

The department meets annually with the Jandakot Community Consultative Committee (JCCC). These meetings generally focus on how we are managing the Jandakot groundwater resources in relation to the objectives set in Ministerial statement no. 688. We presented the outcomes of the allocation limit review to the JCCC in September 2016.

In May 2016, we presented the results of the allocation limits review to the Beeliar Regional Park Community Advisory Committee[5]. This Committee helped us identify that water quality in the Valley subarea needed a higher risk than that originally assigned to it in the allocation limit review. This informed our decisions made on the new limits for this subarea. We met with this group again in November 2016 to present the final allocation limits.

Public open space and land use change

The department regularly works with local governments in the plan area to meet the challenges presented by climate change and respond to the constraints on water availability under a drying climate. Although steps are already underway to improve irrigation practices and technology, and design of public open spaces, these climate trends will need to continue. This message was communicated in February 2017 to the cities of Kwinana, Rockingham and Cockburn who are in support of these principles.

In 2014, the *North-West corridor water supply strategy* was developed by the department in collaboration with local government agencies, to improve water use practices for the irrigation of parks and gardens using new guidelines and standards. We are working with local governments, Water Corporation and the Cooperative Research Centre (CRC) for Water Sensitive Cities to apply these guidelines and standards.

The department expects further changes in land use, in some parts of the plan area, from rural to light industry in line with current state planning. This will reduce the amount of groundwater needed in these areas over time. To support these changes, we will continue to communicate with rural landholders, land developers and other state government agencies on their changing needs for water.

[5] Several high value wetlands are managed collectively as part of the Beeliar Regional Park.

Part A — Assessing information

In Part A of the limits review process, we assessed:

- past rainfall trends and future rainfall projections
- hydrogeology
- ecological, community and cultural values of groundwater
- current water use and future demand for groundwater.

The information from Part A is used to set the water resource objectives, allocation limits and define the licensing approach for the groundwater area.

Key points from this section:

- Only the allocation limits for the Superficial aquifer were reviewed and not the underlying deeper aquifers of the Leederville and Yarragadee.
- The Superficial aquifer supports groundwater use, high-value groundwater-dependent ecosystems, and both community and cultural values.
- Current rainfall is tracking in line with the projected driest (worst-case) climate scenario. Allocation limits need refining to reflect the effects of less rainfall recharge. This will protect use and the environment into the future.
- Departmental and licensee monitoring data showed that seawater intrusion is occurring in the Kwinana Industrial Area due to abstraction. This trend may extend up the coast if too much groundwater is abstracted, reducing the usability of groundwater for supply and affecting coastal wetlands.
- The volume of water currently licensed is below the original limits set in the 2007 plan. Metering data show long-term under use across the plan area. If use increases to match the 2007 limits there is a high risk of increasing seawater intrusion and water level drawdown at high-value groundwater-dependent ecosystems.
- Water demand from industrial expansion is significant and cannot be fully met by groundwater. Alternative water source options are presented in *Western Trade Coast heavy industry local water supply strategy* (DoW 2016b).

2 Understanding the water resource

2.1 Climate

Past climate

Rainfall, streamflow and recharge to groundwater has declined across south-west WA since the 1980s. In the plan area, the 30-year long-term average was 847 mm in 1980. In 2015, the 30-year average was 812 mm. The last 10 to 15 years were much drier (Figure 4), particularly the two very dry years of 2006 (510 mm) and 2010(496 mm).

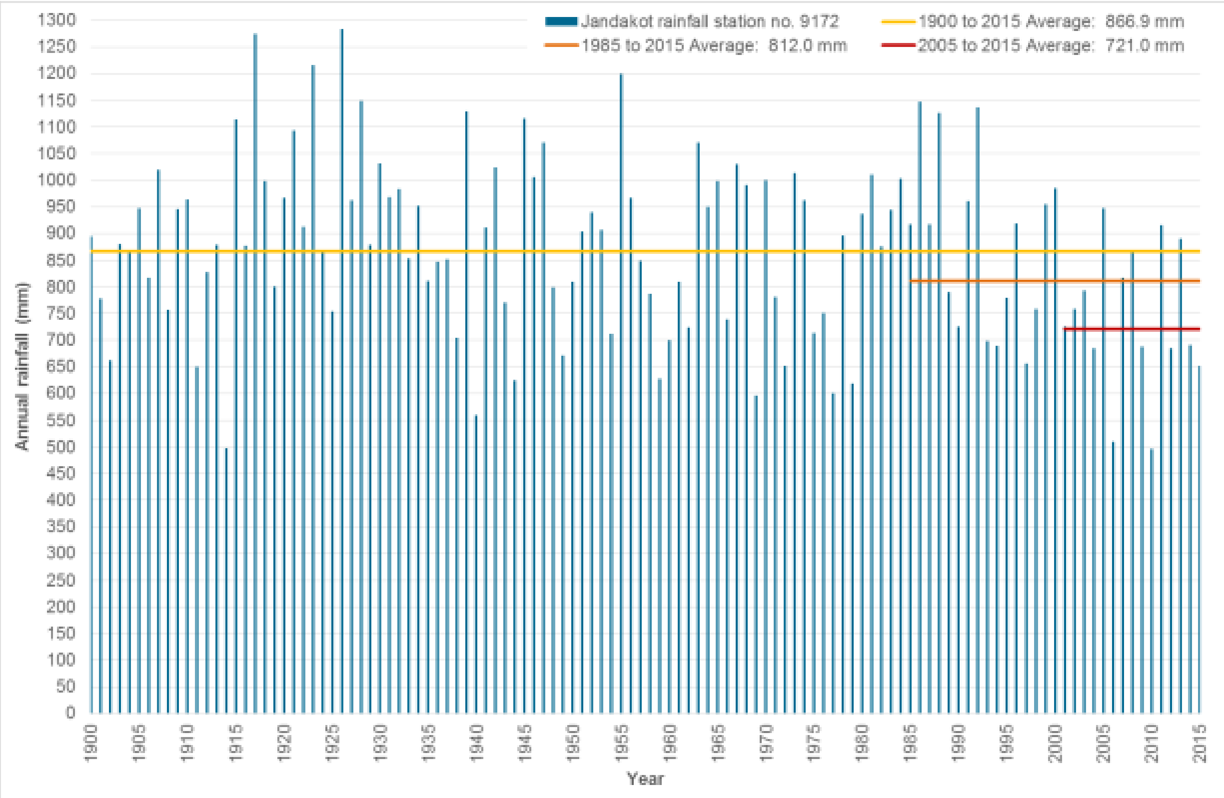


Figure 4 Annual rainfall at the Jandakot rainfall station 9172 from 1946–2015

Future climate

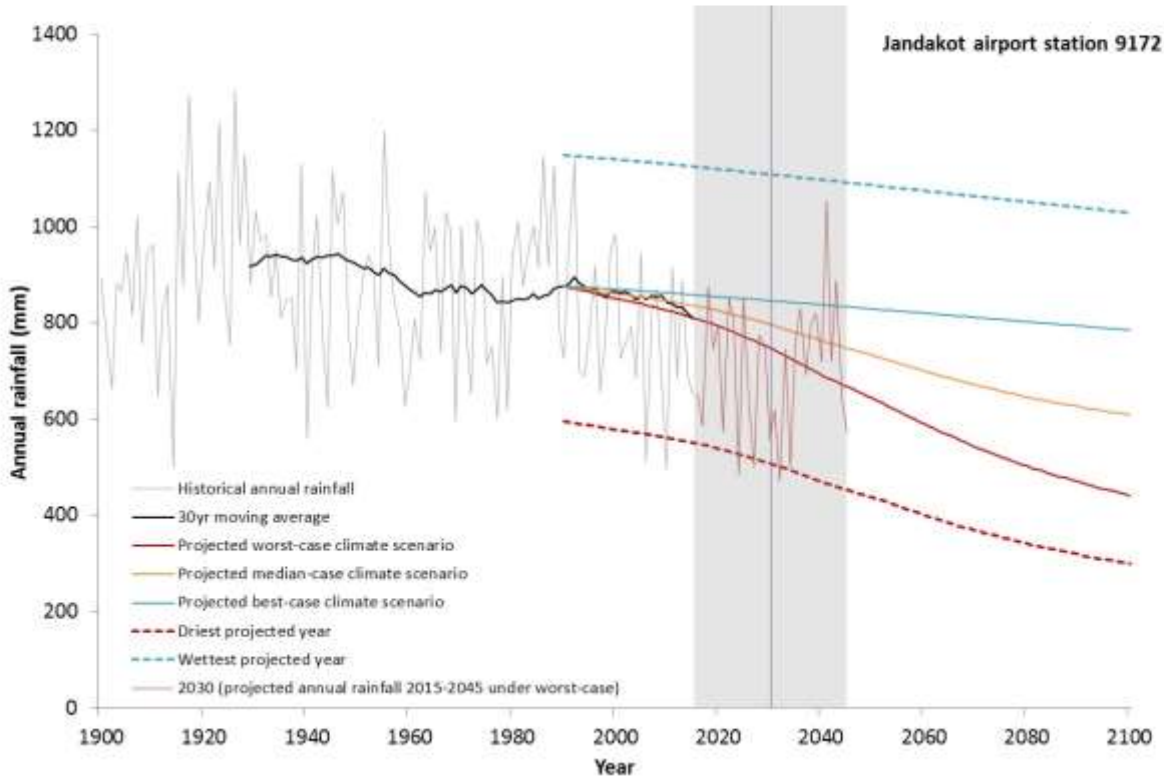
The department uses global climate model results generated by CSIRO and the Bureau of Meteorology to project rainfall, recharge and runoff. Our standard approach to projecting climate is detailed in *Selection of future climate projections for Western Australia* (DoW, 2015). Figure 5 shows the historical annual rainfall at the Bureau of Meteorology site in Jandakot (rainfall station no. 9172) and the projected patterns from 2015–2045, under a modelled best, median or worst-case climate scenario.[6] In all projected climate scenarios, annual rainfall will decline over time.

[6] The 'worst-case' scenario refers to a drier-hotter scenario, which is close to the 10th percentile change in rainfall and has a relatively large increase in temperature. The 'median' is a mid-range scenario, which is close to the

Rainfall is expected to decrease by 15 per cent by 2030 under the projected worst-case climate scenario when compared to the 1961–1990 baseline period (Figure 5; Table 2).

Table 2 30-year average projections at Jandakot rainfall station no. 9172 for each climate scenario

Climate scenario	2015–2045 projected average annual rainfall (mm)
Future best-case projection	846
Future median-case projection	794
Future worst-case projection	742



Note: The future scenarios are calculated relative to a 1961-1990 baseline, so the climate trends are plotted using 1990 as the starting year.

Figure 5 Historical and projected rainfall for best, median or worst-case climate scenarios

50th percentile change in rainfall and has a moderate increase in temperature. The 'best-case' scenario refers to a wetter-cooler scenario, which is close to the 90th percentile change in rainfall with a relatively smaller increase in temperature (DoW 2015).

The 'worst' and 'best' case scenario therefore do not represent the driest or wettest projection of annual rainfall for an area. They are the terms we use to describe the relative dryness of a projection compared to other projections.

2.2 Hydrogeology

This section briefly describes the hydrogeology of the superficial formations in the Cockburn plan area (Figure 6). For hydrogeological information on the deeper formations of the Leederville and Yarragadee aquifers, see the 2007 plan.

The superficial formations are an unconfined aquifer system consisting of Quaternary-tertiary sediments with a thickness of between 30 m and 65 m. These sediments consist of moderately to highly transmissive calcareous marine sands and eolianites or coastal limestone formations near the coast (Safety Bay Sand and Tamala Limestone). Inland, east of the linear chain of lakes, the superficial formations transition to variable sequences of fine and medium-grained sand with minor silt and limestone (mainly Bassendean Sand and Ascot Formation). In the transition zone, there are large vertical and horizontal hydraulic gradients that are relatively steep (Davidson & Yu 2008).

The Superficial aquifer has an average saturated thickness of approximately 30 m. Recharge occurs mainly by direct infiltration of rainfall. The amount of recharge depends on the rainfall pattern (intensity, frequency, and duration), land use, depth to water table and local geological conditions. Davidson & Yu (2008), and CyMod (2009), estimated between 10 and 25 per cent of rainfall becomes recharge across the area.

Groundwater flows from east (associated with the Jandakot Mound flow system) to west and then discharges to the ocean. Locally, flow directions may change in areas associated with wetlands.

Regionally, the Rockingham Sand aquifer is hydraulically connected to the Superficial aquifer. However, in a small part of the Wellard Subarea, discontinuous clay lenses at the base of the Superficial formations locally confine the Rockingham Sands creating a localised semi-unconfined aquifer. For the purposes of allocating groundwater, these aquifers are managed together.

The Kardinya Shale, except where the Rockingham Sand is present, separates most of the Superficial aquifer from the Leederville aquifer (Wellard Subarea). Where the Leederville aquifer directly underlies the superficial formation, it receives recharge by downward leakage. This occurs where there are downward hydraulic gradients along the eastern edge of the groundwater area (Davison and Yu, 2008).

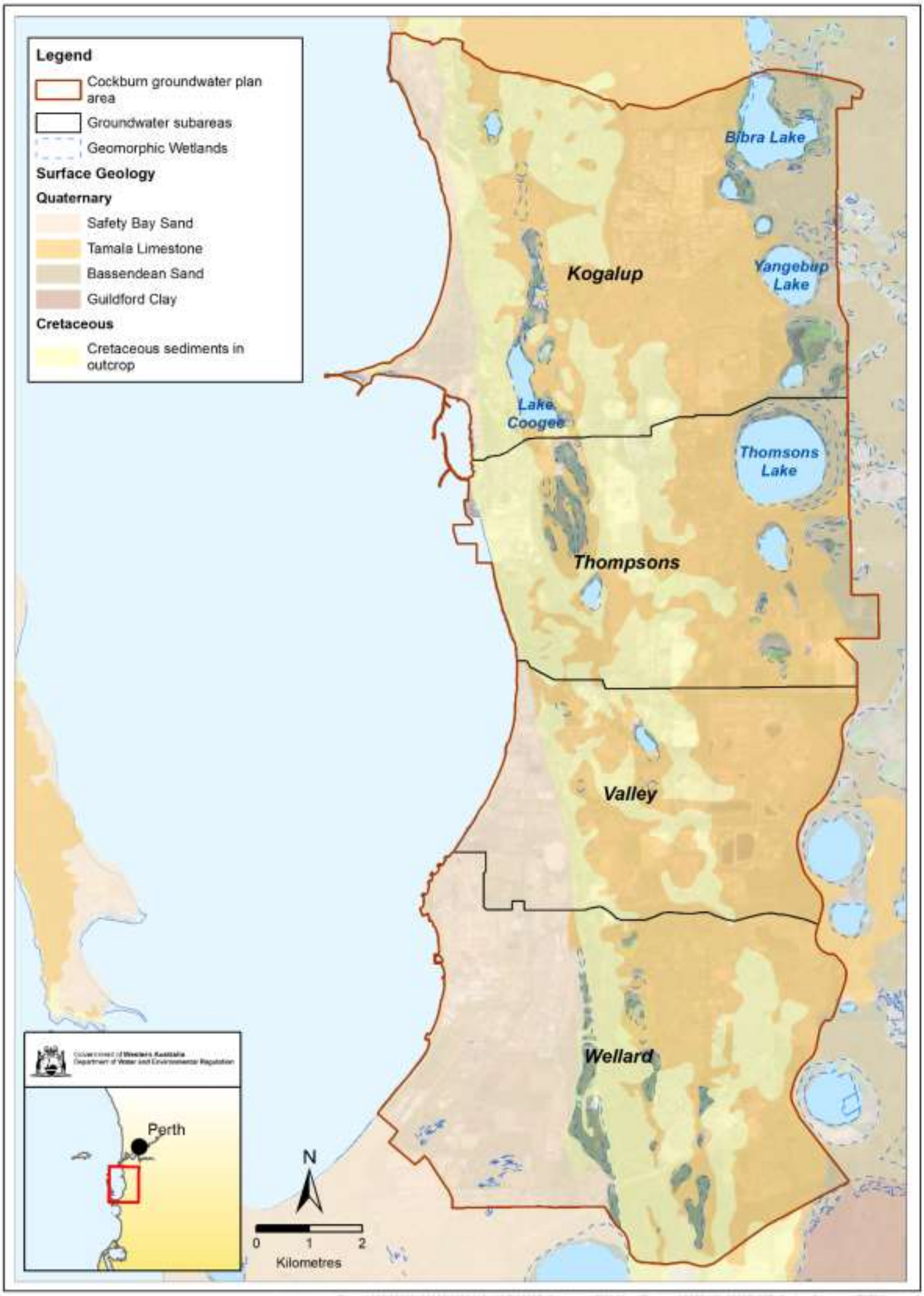


Figure 6 Surface geology of the Cockburn groundwater area

2.3 Aquifer trends

Superficial groundwater levels show a general declining trend of between 0.5–1 m at the coast and in some central locations over the last 30 years. Over the last decade declines have slowed relative to 1980–2000, and water levels have stabilised, with some seasonal variation, showing that groundwater abstraction is likely at its limit.

Examples of these trends are shown in Figure 7, with bores CSG6 (on the coast) and T230 (near wetlands) in Wellard subarea and bore T130 (I) in Valley subarea (south of the Kwinana Industrial Area).

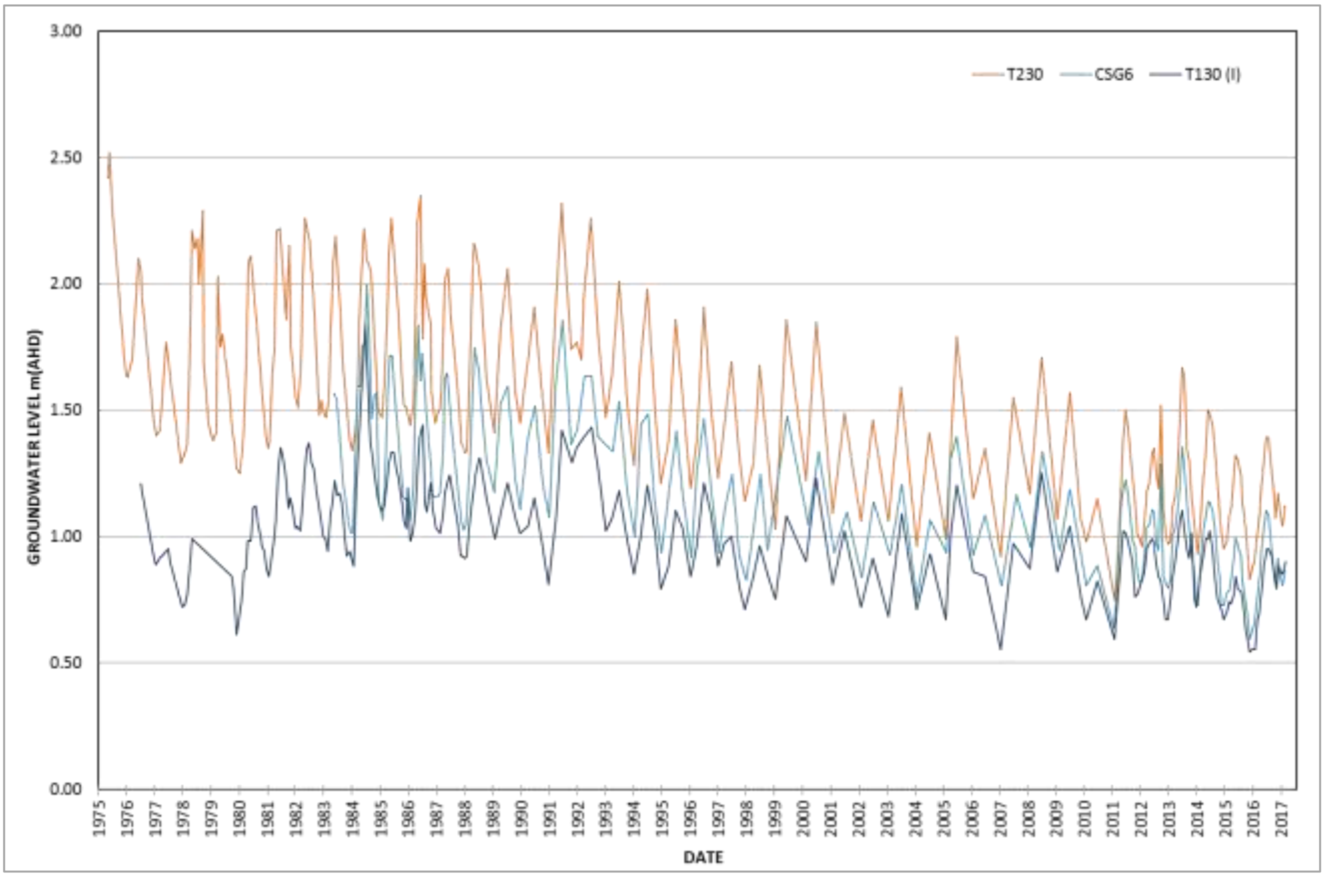


Figure 7 Groundwater levels at a sample of long-term Superficial aquifer monitoring bores

Groundwater levels have recovered since the dry year of 2010, when most sites recorded their lowest levels on record. This is likely due to a combination of good rainfall since 2010 and urban development, which locally increases recharge.

Groundwater level monitoring data is reviewed regularly for both short and long-term trends through the resource evaluation process. Long-term groundwater monitoring data is available from 32 (out of 43) operational monitoring bores.[7]

[7] See our Water Information Reporting database for examples <http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx>

Bores are primarily screened in the Superficial aquifer with two bores in the Leederville aquifer.

There are some localised sites in urbanised areas, which show a stable trend, while a few of the south-eastern bores show rising trends. These localised trends are buffering the effects of reduced rainfall recharge due to climate change. However it is not enough to alleviate long-term decline in groundwater levels on a subarea scale.

Groundwater level trends were used to inform our environmental risk assessment, understand the dynamics of the seawater interface, and define the new groundwater allocation limits.

2.4 Groundwater modelling

The Perth Regional Aquifer Modelling System (PRAMS), a groundwater flow and unsaturated zone model was used as part of refining the groundwater allocation limits in the plan area. The model was developed to assess the impact of land use, climate and abstraction on groundwater levels and water balances for all fresh-water aquifers in the Perth Region (including the Gnangara groundwater systems).

The department's current focus for modelling is to examine how different abstraction and land use scenarios will affect water levels, water users and environmental values under a predicted drying climate. Further information on PRAMS can be found in CyMod Systems (2014) and De Silva et al (2013).

2.5 Seawater intrusion

A naturally occurring seawater interface exists in the plan area. Saline ocean water intrudes as a slow moving, wedge-shaped body of water along the base of the aquifer beneath fresh water. Flow of water creates a zone of mixing in the aquifer between the fresh and saline water, which is thicker toward the top of the aquifer (Figure 8).

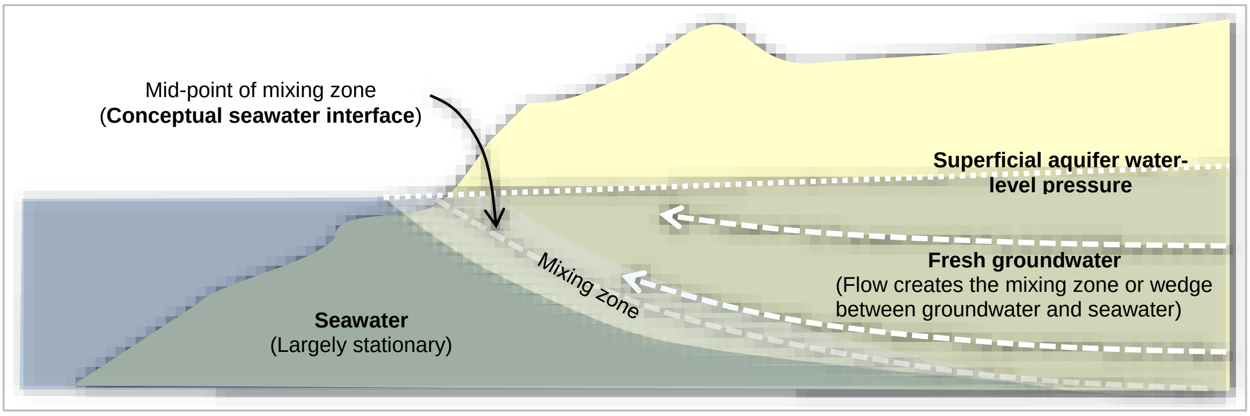


Figure 8 Conceptual representation of fresh groundwater interacting and mixing with seawater in a coastal aquifer

The position of the seawater interface is influenced by climatic and seasonal variability in groundwater recharge, through-flow, sea levels and rainfall. This results in the natural ebb and flow of the interface along the coastline.

Seawater intruding into the Superficial aquifer, not water level decline, poses the greatest risk to water users along the coast. Where seawater is intruding into the Superficial aquifer it replaces the freshwater, maintaining water levels, but reducing water quality. The changes in water quality increase the costs of use and can adversely affect groundwater-dependent ecosystems.

Departmental and licensee monitoring data show that the seawater interface now extends onshore about 300 metres in Munster and up to one kilometre in the Kwinana Industrial Area. At Kwinana, intrusion has resulted from localised abstraction.

Geology of the seawater interface in Cockburn

In the plan area, the landward location of the seawater interface in the Superficial aquifer is influenced by geology. In the Kogalup and Thompsons subareas the coastal Superficial aquifer consists of Tamala Limestone. However, in the Valley and Wellard subareas the moderately permeable Safety Bay Sand overlies the Tamala Limestone.

The Tamala Limestone has a higher hydraulic conductivity than the Safety Bay Sand. Coastal discharge is higher when only the Tamala Limestone is present in the Superficial aquifer and lower when the aquifer contains both formations. This results in the interface being closer to the coast where the Safety Bay Sand occurs.

In addition, a silty layer is generally present at the base of the Safety Bay Sand, which reduces vertical hydraulic connectivity between it and the underlying Tamala Limestone. A seawater interface exists at the base of the Tamala Limestone and, where the Safety Bay Sand is present, a small wedge on the basal silty layer. Outcrops of Tamala Limestone offshore also influences the location of the interface (CSBP Limited, 2015).

Understanding the location of the seawater interface

At present, there are only three seawater interface bores monitored by the department in the plan area. They are located at Mount Brown in the Thompsons subarea. Several large licensees from the Kwinana Industrial Area monitor salinity profiling in the Valley and Wellard subareas.

Results of private seawater interface monitoring data collected from January 2013 to December 2014 were used to identify seawater intrusion in the Valley subarea. Taking high volumes of groundwater in some localised areas has moved the interface 250 m inland over a period of 15 years, with the wedge thickening.

Data collected from departmental and licensee monitoring was compared to the calculated results of the Strack (1976) analytical solution to estimate the extent of the seawater interface[8]. These results were refined using water balance outputs from the version 3.5.2 of PRAMS (see Table 3 and Appendix A).

Table 3 Location of the seawater interface (2013)

Subarea	Location based on recent monitoring data*
Kogalup	• Calculated distance of the interface from the coast is 300 m • Interface unlikely to be stationary • >750 km in southern part of subarea at Woodman Point
Thompsons	• Calculated distance of the interface from the coast is 710 m • Interface unlikely to be stationary • >750 km in northern part of subarea at Woodman Point • <400 m in south (CSI-1 bores)
Valley	• Active intrusion known • >800 m in central area • Close to coast in southern part
Wellard	• Calculated distance of the interface from the coast is 270 m • Interface unlikely to be stationary

**See Appendix A for more detail on the calculated distances.*

[8] The seawater interface toe is the furthest inland point of the mixing zone (Figure 8). It is at the bottom of the aquifer furthest from the coast where the seawater wedge intrudes from the ocean.

3 Ecological, community and cultural values

The Superficial aquifer in the plan area supports groundwater-dependent ecosystems, including wetlands, and supports community and cultural values related to water.

3.1 Groundwater-dependent ecosystems

There are numerous groundwater-dependent ecosystems in the plan area including wetlands of high conservation value (Figure 9). Most wetlands are in the Beeliar Regional Park and are managed collectively through the *Beeliar Regional Park Management Plan 2006* (CALM, 2006).

Sites with water level criteria set in *Ministerial statement no. 688*

The Department of Water and Environmental Regulation manages abstraction of groundwater from the Jandakot groundwater system in line with *Ministerial statement no. 688* (EPA 2005). This statement sets the environmental water provisions in the form of water level criteria at 23 sites across the system. The criteria are specific water regimes required to sustain ecosystems dependent on groundwater.

Five of the sites are found along the eastern boundary of the Kogalup and Thompsons subareas. They are Bibra Lake, Yangebup Lake, Kogalup Lake, Lake Thomsons (Ramsar-listed) and Lake Banganup. Water level criteria include preferred and absolute minimum water levels, rate of decline and timing of drying.

The water level criteria were critical in setting resource objectives and risk assessment through the allocation limit setting process (see section 5.2 and 5.3).

Though groundwater use in the Kogalup and Thompson subareas was within the 2007 allocation limits, we are still seeing non-compliance with water level criteria at Bibra and Thomsons lakes (shown in red in Table 4; DoW 2016).

Other representative groundwater-dependent ecosystems

Other high value groundwater-dependent ecosystems in the plan area are protected under state, federal or international legislation. They are mostly high conservation value wetland sites and are found along the coast in the Kogalup and Thompsons subareas and in the southern part of Wellard subarea.

Six representative wetlands were selected in areas where there were no Ministerial criteria sites. These sites were used to inform the resource objectives and risk assessment for each allocation limit option. The representative selected wetlands are shown in Table 5.

Table 4 Wetlands in the plan area with water level criteria set in Ministerial statement no. 688 (from DoW 2016a)

Subarea	Wetland	Reference number	Water level criteria (mAHD)		Comments
			Preferred	Absolute	
Kogalup	Bibra Lake	Staff 6142520	13.6–14.2	13.6	Non-compliant with absolute minimum water level criterion. The lake has been non-compliant since 2006–07.
		Bore BM7C 61410177	<15.0 peak		
	Yangebup Lake	Staff 605 6142523	13.9–15.5	13.8	Compliant with absolute minimum and other criteria.
		Bore JE21C 61419707	<16.5 peak		
	Kogalup Lake (South)	Staff 6142522	13.1–14.0	13.1	Compliant with absolute minimum criterion.
		Bore 6015 61410727	<14.8 peak		
Thompsons	Thomsons Lake	Staff 609 6142517	11.3–11.8	10.8	Compliant with absolute minimum criterion. Non-compliant with other criteria.
		Bore TM14A 61410367			
	Banganup Lake	Staff 5719 6142516	N/A	11.5	Compliant with absolute minimum criterion. 2015 was the first year that groundwater levels were compliant with criteria since 2009–10.
		Bore LB14 61419614			

Table 5 Representative wetlands in the Cockburn groundwater area

Subarea	Wetland	Conservation value	Reference number
Kogalup	Manning Lake	Conservation category wetland	Staff 595 6142515
	Lake Coogee	Conservation category wetland	Staff 613 6142514
Thompsons	Lake Mount Brown	Conservation category wetland	Staff 611 6142505
Valley	Long Swamp	Conservation category wetland	Staff 610 6142509
			Bore T130 (I) 61410068
Wellard	Group of wetlands associated with the Sedgelands in Holocene dune swales TEC	Conservation category wetlands and TEC	Bore T230 (O) 61410033
	Group of wetlands located in Leda Nature Reserve	Conservation category wetlands	Bore T240 (I) 61410076

TEC = Threatened ecological community

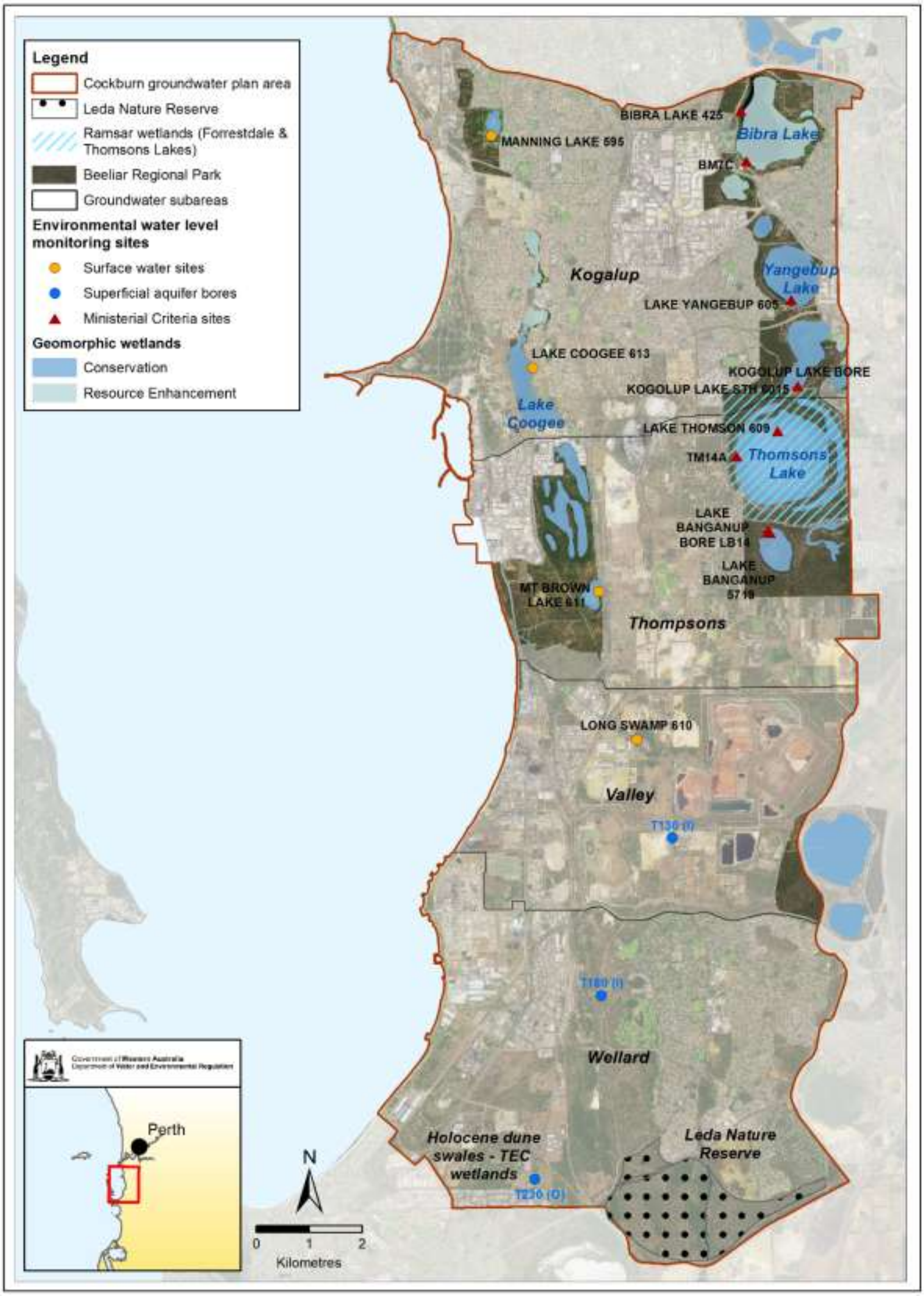


Figure 9 Groundwater-dependent ecosystems and important environmental assets in the plan area

3.2 Community and cultural values of groundwater

Groundwater has a community and cultural value where it is integral to maintaining areas of high social significance. To protect these values associated with groundwater in the Cockburn plan area, we maintain groundwater-dependent ecosystems and the environmental values they support. This is because most sites in Cockburn that have cultural significance for both local and indigenous people are linked to the wetlands.

Cockburn's traditional owners are the Whadjuk People, part of the Beeliar Nyungar group. Wetlands of the Beeliar Regional Park hold significance for the indigenous people, as they were important camping and ceremonial areas. The salty western chain was largely avoided in preference for the fresh eastern chain, which provided food and was part of a major trade route with the north (Polglaze 1986).

North and Bibra lakes are areas of spirituality for the Nyungar people. Sixteen indigenous campsites are known from the Cockburn area, most of them located on the fringes of Bibra Lake (*Walliabup*). Other important cultural sites linked to groundwater include Lake Coogee, Woodman Point, Yangebup Lake and Thomsons Lake (CALM 2006, Cockburn heritage list, 2014).

Groundwater-dependent sites throughout Cockburn have significant community based values. Although close to urban areas many areas provide recreational opportunities in a relatively undisturbed natural environment. These areas include Bibra Lake, Lake Mount Brown, Leda Nature Reserve and Woodman Point (Figure 9).

University research stations at Banganup Swamp and Thomsons Lake provide valuable information on marsupial breeding, wetland habitats (including vegetation and macroinvertebrates) and water quality. The research value is particularly significant given the large areas of intact vegetation that, although disturbed, represent ecological communities that were once more widespread on the Swan Coastal Plain. These areas support threatened ecological communities (Woodman Point) and rare and priority flora and fauna.

4 Understanding water demand

Providing long-term certainty for existing groundwater users was a key driver for this allocation limits review. To do this we assessed current and future demand for water in the plan area. Groundwater is used for industry, agriculture and irrigation of public open space. Future demand is mostly from planned expansion of heavy and light industry throughout the groundwater area.

4.1 Current water demand

Licensed abstraction

There are approximately 300 users licensed to abstract just under 30 GL/year from the Superficial aquifer in the plan area (Table 6). Metering data shows that there is long-term under-use against some licence entitlements, with only an estimated 23 GL/year abstracted.

Table 6 Comparison of licensed and committed entitlements in December 2007 and January 2016 (GL/yr) for the Superficial aquifer

Subarea	Aquifer	2007 Allocation limits	2007 Licensed	2016 Licensed	2016 estimated use*
Kogalup	Superficial	11.40	8.40	10.05	8.0
Thompsons		8.57	6.85	5.70	5.5
Valley		7.68	6.72	7.30	5.5
Wellard		10.30	6.14	6.85	4.0
TOTAL		**37.95**	**28.11**	**29.90**	**23.0**

**Based on metered use data over the last three years and rounded to the nearest 0.5 GL/yr.*

The dominant use of groundwater (17.5 GL/year) across all aquifers in the plan area is industry and related purposes. This is concentrated in the Valley and Wellard subareas. The second biggest use for groundwater (4.9 GL/year) is horticulture, which is currently concentrated in the Thompson subarea. Water used for public open space in Kogalup and Wellard is the third largest use of groundwater (3.2 GL/year). The volume of licensed water per use category is outlined in Table 7.

Table 7 Water uses in the plan area as a percentage of total licensed water entitlements from the Superficial aquifer, January 2016

Use category	Percentage of total entitlements	Volume of water allocated (GL/yr)
Agriculture	17	4.9
Commercial and Institutional	5	1.4
Environment and Conservation	10	3.0
Stock and domestic	3	0.9
Industry and power generation	54	16.1
Parks, gardens and recreation	11	3.2
Committed (to be licensed)	-	0.5
TOTAL	**100**	**30**

Exempt use

We also account for water that is abstracted by the community for stock, domestic and garden use. This use is exempt from licensing when taken from the water table aquifer (Superficial aquifer).

Exempt use includes domestic garden bores on urban blocks and bores for stock and domestic use on larger 'lifestyle lots' and rural properties. The method used to calculate exempt use is presented in Appendix B, and the results are presented in Table 8.

Table 8 Exempt use figures for the Superficial aquifer, 2015

Subarea	Number of bores	Volume GL/year
Kogalup	1971	1.06
Thompsons	152	0.22
Valley	0	0
Wellard	1132	0.62
TOTAL	**3255**	**1.90**

4.2 Future demand

Understanding future land use and the likely demand for water is an important part of the allocation limits review process. Groundwater is typically the most accessible and cheapest source of water for consumptive use. It is important to manage use so that the quality and accessibility of the water resource and its dependent environmental values are maintained. Where there are risks to the sustainability of the resource, it is essential that we signal where water is not available so that potential and planned future land uses can be identified and appropriate alternative water sources activated.

Industry

The Western Trade Coast industrial precinct is identified in *Perth and Peel Green growth plan for 3.5 million to 2050* (DoP & WAPC 2015) as a significant industrial centre (Figure 10). Expansion of industry, and water to support this, was a key driver to review the allocation limits in the plan area. The *Western Trade Coast heavy industry local water supply strategy* (DoW 2016) projects demand from heavy industry and details current and future water supply options to meet demand.

The supply strategy projects demand for heavy industry to increase by up to 25 GL to a maximum of 52 GL/year by 2031 (under a high growth scenario). Demand for light industry (proposed for Latitude 32 industry zone) in development areas is projected to be low, around 3 GL/year and likely to be met by scheme water from the Perth Integrated Water Supply Scheme.

Current demand in the Western Trade Coast is 28.5 GL/year of which 58 per cent is met by groundwater – largely from the Superficial aquifer. The remainder is provided from several other water sources:

- the Kwinana wastewater recycling plant
- stormwater captured on site
- scheme water
- recovery water from industrial processing for internal or third-party reuse.

To meet the expected increase in demand, CSIRO led a study of the feasibility and cost of managed aquifer recharge (MAR) schemes for the Western Trade Coast (GHD 2015). The study was in collaboration with the Australian Water Recycling Centre of Excellence, the Kwinana Industries Council, Water Corporation, Western Trade Coast Office and departments of Water and Health. The department has built on this work and has identified feasible, cost-effective and affordable non-potable supply options to meet additional demand (DoW 2016).

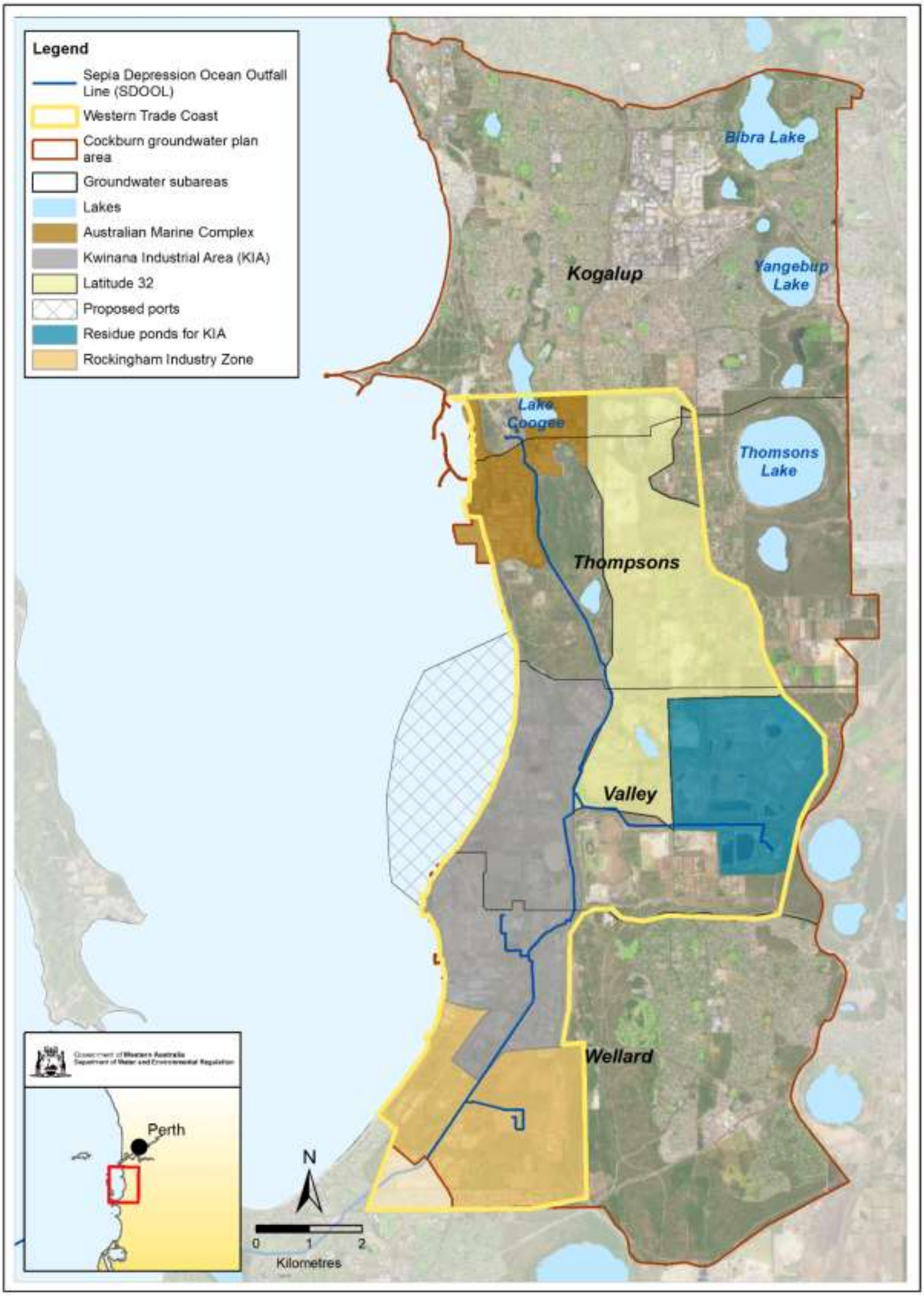


Figure 10 Western Trade Coast industrial precinct

Urban and rural land use

To estimate demand for urban and agricultural development, we used the *Outer metropolitan Perth and Peel sub-regional strategy* (draft) (WAPC & DoP 2010). No new urban areas are planned for Cockburn – only the completion of existing urban areas in Kogalup, Thompsons and Wellard subareas. Based on 0.0073 GL/year/km^2 (6750 kL/ha) we estimate that 3.35 GL/year is required for the long-term maintenance of public open space.[9] Currently 2.82 GL/year is licensed for this purpose.

We will be working with the cities of Cockburn, Kwinana and Rockingham to identify ways to improve how water is used, meet any shortfalls in expected demand, and map out how we can manage water needs for public open space as land use changes.

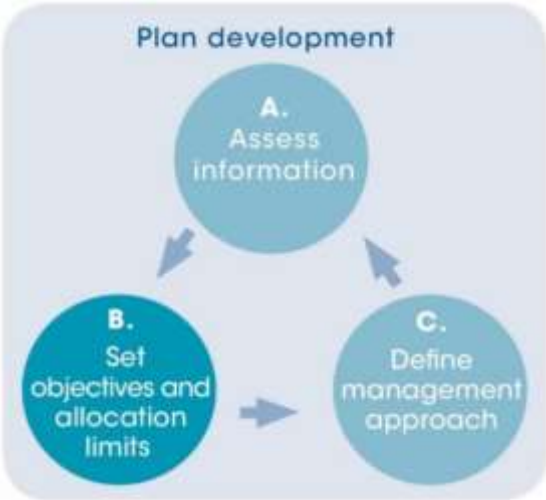
Irrigated agriculture (4.9 GL/yr) in Cockburn is likely to reduce over time with land use changing from rural to light industry and urban in the Latitude 32 industry zone (see WAPC & DoP 2010, and DoP & WAPC 2015). As this demand for water lessens, it can be reallocated for other purposes or returned to the system to reduce over-allocation of the resource.

[9] The 0.0073 GL/year/km^2 is used by the department for estimating water needs of public open space in regional-scale water planning. This volume was developed during detailed planning for public open space in Perth's North-West Corridor. In that instance approximately 2.8 GL/year was required to service about 38.5 km^2 of urban development. Best practise public open space design and average irrigation rates were used, together with other (non-water related) land planning rules (e.g. 10 per cent of urban area for total area of public open space). It is assumed that new areas of urban development in the Perth area are generally comparable to one another as far as the number and type of public open spaces, their design standards, and their average water requirements. For further information about the North-West Corridor, refer to the *North-West Corridor water supply strategy* (DoW 2014) on our website.

Part B — Setting objectives and allocation limits

In Part B of the allocation planning process we define the:

- outcomes for the allocation limit review
- resource objectives for the area
- allocation options to be assessed
- method and results of assessing risk
- the revised allocation limits.



Key points from this section:

- The outcomes set the context for what we considered during the allocation limit review. They informed the decisions made on the final allocation limits.
- The resource objectives were designed to minimise the risks of taking water on groundwater-dependent ecosystems and moving the seawater interface further inland, while still achieving the outcomes.
- We tested four allocation options to set limits. These options represent a range between current use (21.5 GL) and current licensed entitlements (30 GL). These options were designed to identify the maximum volume of groundwater that could be allocated for consumptive use without adversely affecting water quality or the environment.
- A risk-based approach was applied to assess each allocation option based on the modelled results of version 3.5.2 of PRAMS for water levels under a projected worst-case climate scenario.
- The final allocation limits allowed for some growth in use over the next decade but all resources are now fully or over-allocated.
- Improving water use efficiency, changes in land use over time and localised recouping of unused water entitlements will help balance the system.

5 Setting outcomes and resource objectives

In administering the *Rights in Water and Irrigation Act 1914* the Department of Water and Environmental Regulation provides for the sustainable use of water resources and the protection of ecosystems associated with water resources. Part of achieving this goal is setting clear outcomes and objectives for how we allocate and manage water.

5.1 Outcomes

In reviewing and refining the allocation limits in the plan area, we aim to achieve these outcomes:

- Provide water security for users and the environment as the climate changes.
- Protect important lakes and wetlands from any adverse effects of taking or reinjecting groundwater.
- Minimise the impacts of abstracting groundwater on water quality and the long-term productivity of the resource.
- Encourage improved water use efficiency and investment in alternative water sources.

These outcomes are designed to improve how water is allocated.

5.2 Resource objectives

Resource objectives were developed to manage the impacts associated with taking and reusing groundwater in the Superficial aquifer. Each water resource objective relates to how we want the resource to perform when water use is managed within the allocation limit. In defining these objectives, we also considered the effects of climate change and the predicted drying climate trend over the next decade to 2030.

The factors considered in setting each objective are summarised in Table 9. To set the allocation limits we designed risk parameters to assess how much water could be allocated for each objective under worst-case climate scenario (see section 6.3).

Objective 4 relates to managing individual licensees and the impacts of taking groundwater. It did not inform how allocation limits are set. This objective informed how the local licensing policies were developed.

Table 9 Developing the resource objectives for setting the allocation limits

	Objective	Factors considered in developing the objective
1	Water levels are sufficient to meet water level criteria set under Ministerial statement no. 688 each year.	The department is responsible for meeting water level criteria at Ministerial criteria sites in the Kogalup and Thompsons subareas.
2	Water levels in the Superficial aquifer are sufficient to protect the current values of groundwater-dependent ecosystems each year.	For the allocation limit setting process we split this objective into two parts. At most representative sites we need to maintain groundwater levels. In the Wellard subarea we needed to recover water levels.
	a) Maintain Superficial aquifer levels at representative wetlands.	The Cockburn plan area contains many highly valued ecosystems that depend on groundwater. The department is responsible for minimising the risk to these ecosystems in areas where groundwater is abstracted. The minimum groundwater levels set to achieve acceptable risk to each site is the lowest on record over the last ten years.
	b) Recover Superficial aquifer water levels at 'Sedgelands in Holocene dune swales' threatened ecological community.	Groundwater level decline observed since the 1990s was identified as threat to this threatened ecological community (Department of Environment and Conservation 2011). Our resource objective is to recover water levels by reducing the impacts of taking groundwater at this localised site.
3	Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness.	Abstraction can artificially change the natural seawater interface by moving it further inland or increasing its thickness. If the freshwater portion of the aquifers becomes saline it restricts what the resource can be used for in the future and may affect groundwater-dependent ecosystems. A continued supply of fresh groundwater for existing users and the environment should be achieved by maintaining groundwater through-flow and minimising the impacts of abstraction.
4	Abstracting or reinjecting groundwater does not cause adverse changes in water quality.	The plan area contains several contaminated sites that may impact on local water quality. Maintaining or improving groundwater quality will contribute to the continued supply of freshwater for existing users and the environment. If groundwater quality is adversely affected it restricts what the resource can be used for in the future and may affect groundwater-dependent ecosystems.

6 Setting allocation limits

Setting allocation limits represents a balance between current and future groundwater use, and the amount of water that needs to be retained in the aquifer for environmental and resource-protection purposes. To revise allocation limits the department:

- assessed future water availability using results from climate projections
- developed each of the allocation options to maximise water availability
- developed a risk-based process to assess and categorise each allocation option against the objectives for groundwater-dependent ecosystems and the seawater interface
- assessed the results of modelling and the calculated seawater interface to identify the level of risk under each allocation option
- selected a preferred allocation option

6.1 Climate projections for allocation scenarios

The department assessed allocation options against the projected best, median and worst-case climate scenarios to predict future rainfall at Jandakot airport (2015–2045; refer to Figure 4).

The projected worst-case climate scenario was used to set allocation limits. This decision secures a reliable and good quality supply of water for users and maintains sufficient water in the Superficial aquifer to support important wetlands as the climate changes. While we chose to apply this climate scenario, some years may be drier than projected (as seen in 2006 and 2010).

6.2 Allocation options

Four allocation options were developed and applied to each Superficial subarea in the plan area (Table 10). These options were designed to test the maximum volume of groundwater that could be allocated for consumptive use without adversely affecting water quality or the environment (Table 11).

Options ranged from full use of 2015 licensed entitlements and exempt use (Base case at 30 GL) to average metered use and exempt use (Option 1 at 21.5 GL). This range of options was chosen because our assessment of groundwater trends (Section 2.3) and preliminary modelling showed:

- current use was a low risk to the resource (meets objectives)
- full use of current licensed entitlements was likely to cause unacceptable impacts to water quality and the environment (doesn’t meet objectives).

To test this range beyond the Base case we used different allocation volumes in the Thompsons subarea as it contained the most Ministerial criteria sites (see notes in Table 10).

The allocation limit options assessed were:

Base case (30 GL/yr): abstracting the full licence entitlements for November 2015 plus exempt use.

Option 1 (21.5 GL/yr): abstracting average metered use for 2013–2015 plus exempt use.

Option 2 (25.5 GL): mid-point between the Base case and Option 1.

Option 3 (28.5 GL/yr): mid-point between Base case and Option 2.

Table 10 Allocation limit options (GL/year)

Subarea	Option 1	Option 2	Option 3	Base case
Kogalup	8	9	10	11
Thompsons	4	4.5	6.5	5
Valley	5.5	6	6.5	7.5
Wellard	4	6	5.5	6.5
Total	**21.5**	**25.5**	**28.5**	**30**
Notes	The modelled amount abstracted for Thompsons subarea was reduced to test if we could meet Ministerial criteria water levels.		More water was modelled in Thompsons subarea to test if we could abstract more than the Base case.	The amount modelled was set at 30 GL as more than this was showing unacceptable impacts across the whole plan area.

6.3 Risk framework to assess against the objectives

A risk-based process was applied to assess each allocation option against the objectives under the projected worst-case climate scenario. Risk categories were developed to assess the results of the modelled water level drawdowns and calculated the location of the seawater interface to define the level of risk for each allocation option.

The following information was used to define the risks and criteria set in each category:

- our understanding of groundwater-dependent ecosystems, significant environmental assets, and community and cultural values
- trends in groundwater levels
- current licensed and exempt-from-licensing water use
- future demand for water based on land use planning.

The levels of risk for each objective are described in Table 11. The risk categories were used to define the performance indicators for assessing how the resource is performing against the objectives of the plan.

Groundwater-dependent ecosystem risk criteria

The risk categories were defined using existing water level criteria for the Ministerial criteria sites (Table 4) and 2015 minimum water levels at representative wetland sites (Table 5). We also assessed past water level declines at the Sedgelands in Holocene dune swales threatened ecological community to set the baseline for this site.

Seawater interface risk criteria

Groundwater throughflow and discharge to the ocean needs to be maintained to minimise moving the seawater interface further onshore and retaining good water quality for use. We assumed that groundwater users and groundwater-dependent ecosystems within 3 km of the coast (coastal zone) are most at risk if the seawater interface moves further inland.

The level of risk to groundwater-dependent ecosystems from seawater intrusion is based on the calculated location of the interface using modelled water balance results (see Appendix A and Table 12 below). Groundwater-dependent ecosystems are assessed at high risk where there is no ocean outflow, medium risk where ocean outflow is below 1 GL/year/subarea, and low risk where ocean outflow is above 1 GL/year/subarea at the coast.

To understand how supply of groundwater for use would be affected we identified the percentage of ‘total volume licensed in a subarea’ at varying distances where the interface was calculated to stabilise (for results see Table 13).

Table 11 Risk categories for each objective

	Objective	Low risk	Medium risk	High risk
1	Water levels are sufficient to meet water level criteria set under Ministerial statement no. 688 each year.	Superficial aquifer levels at 2030 above absolute minimum water level criteria by >0.1 m.	Superficial aquifer levels at 2030 within 0.1 m of the absolute minimum water level criteria.	Superficial aquifer levels at 2030 below absolute minimum by >0.1 m.
2	Water levels in the Superficial aquifer are sufficient to protect the current values of groundwater-dependent ecosystems each year: a) Maintain Superficial aquifer levels at representative wetlands.	No change or rise in Superficial aquifer levels at 2030.	Fall in Superficial aquifer levels at 2030 by 0.1–0.2 m.	Fall in Superficial aquifer levels at 2030 by 0.2–0.5 m.
	b) Recover Superficial aquifer levels at Sedgelands in Holocene dune swales threatened ecological community.	Rise in Superficial aquifer levels at 2030 by 0.3–0.5 m.	No change to rise by <0.3 m in Superficial aquifer levels to 2030.	Fall in Superficial aquifer levels at 2030.
3	Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness: • Supply of groundwater for use.	<25% of licensed volume is within inland extent of interface.	25-50% of licensed volume is within inland extent of interface.	>50% of licensed volume is within inland extent of interface.
	• Groundwater-dependent ecosystems.	Ocean outflow is above 1 GL. Feature is east of the seawater interface.	Ocean outflow is below 1 GL. Feature is on border of the seawater interface.	No ocean outflow. Feature is inside the seawater interface.

6.4 Assess results

Model outputs

We used version 3.5.2 of PRAMS to produce the following modelling outputs under the projected worst-case climate scenario for each allocation option:

- **Spatial drawdown maps:** these maps show the simulated changes in groundwater levels from abstracting the volumes in each option (Figure 11 to Figure 14). The scale of the drawdown (blue to red) is how much we expect the groundwater levels to rise (blue) or fall (red).

  These maps show where groundwater level changes are acceptable at 2030. Areas shaded in red show where water level drawdown is largest and classified as high risk (unacceptable). The areas shaded in white and blue are where water level drawdown is considered acceptable.
- **Predicted water levels at key monitoring bores (time series):** spatial and time-series modelling were used to show the change in water level predicted at 2030 at the groundwater-dependent ecosystem sites (Table 12) because of abstracting the volumes in each option. These drawdowns at each key monitoring site are categorised using the groundwater-dependent ecosystem risk categories from Table 11.
- **Calculated distance of the seawater interface (using water balance outputs):** The water balance outputs (throughflow, recharge, abstraction, ocean outflow, storage change and vertical and horizontal flow) for each modelled scenario were used to calculate the distance of the seawater interface from the coast (see Table 13 and Appendix A for more detail).

We used these results to assess the risk (risk criteria set in Table 11) for each allocation option and subarea (Table 14 to Table 17).

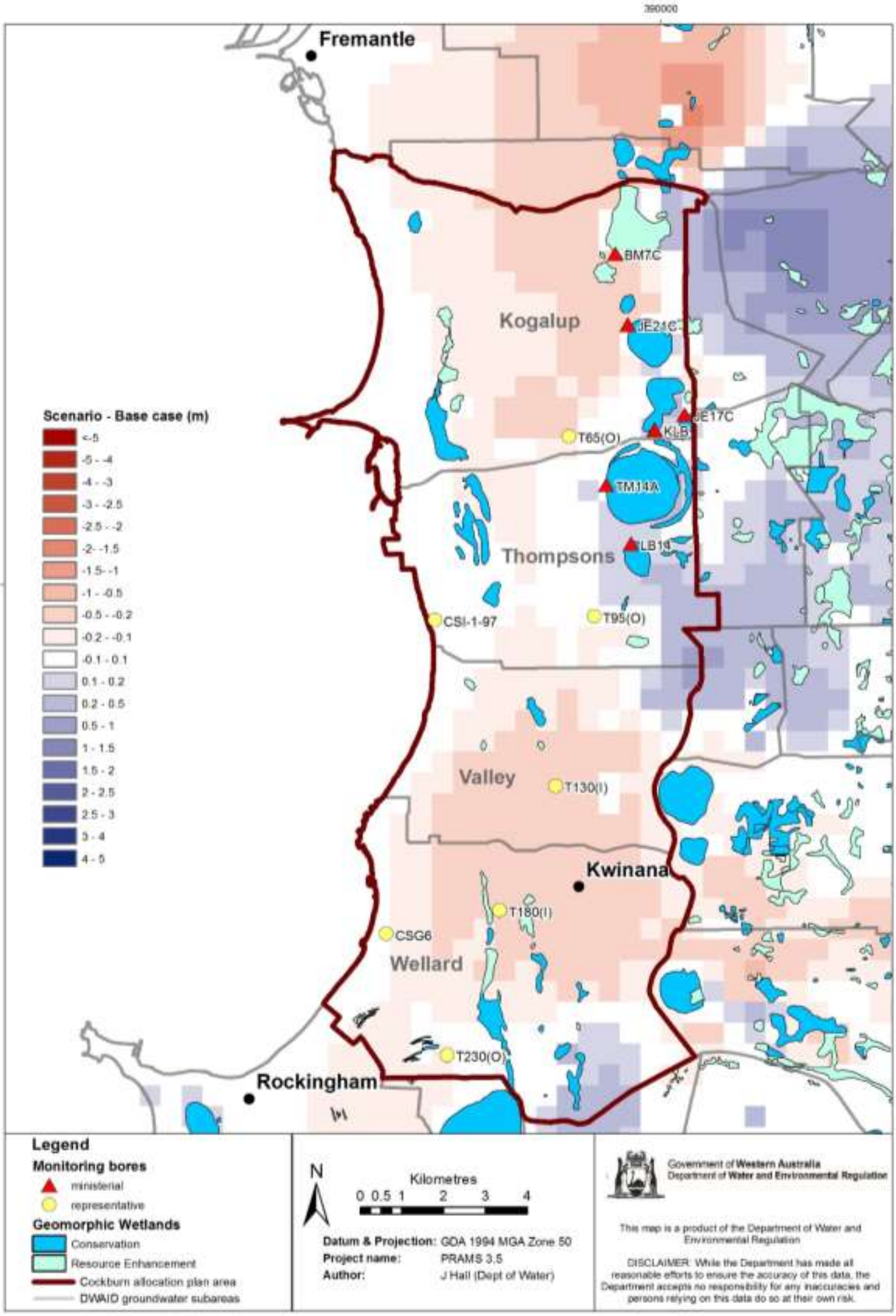


Figure 11 Spatial map of simulated water levels changes for the Base case (30 GL) under the projected worst-case climate scenario

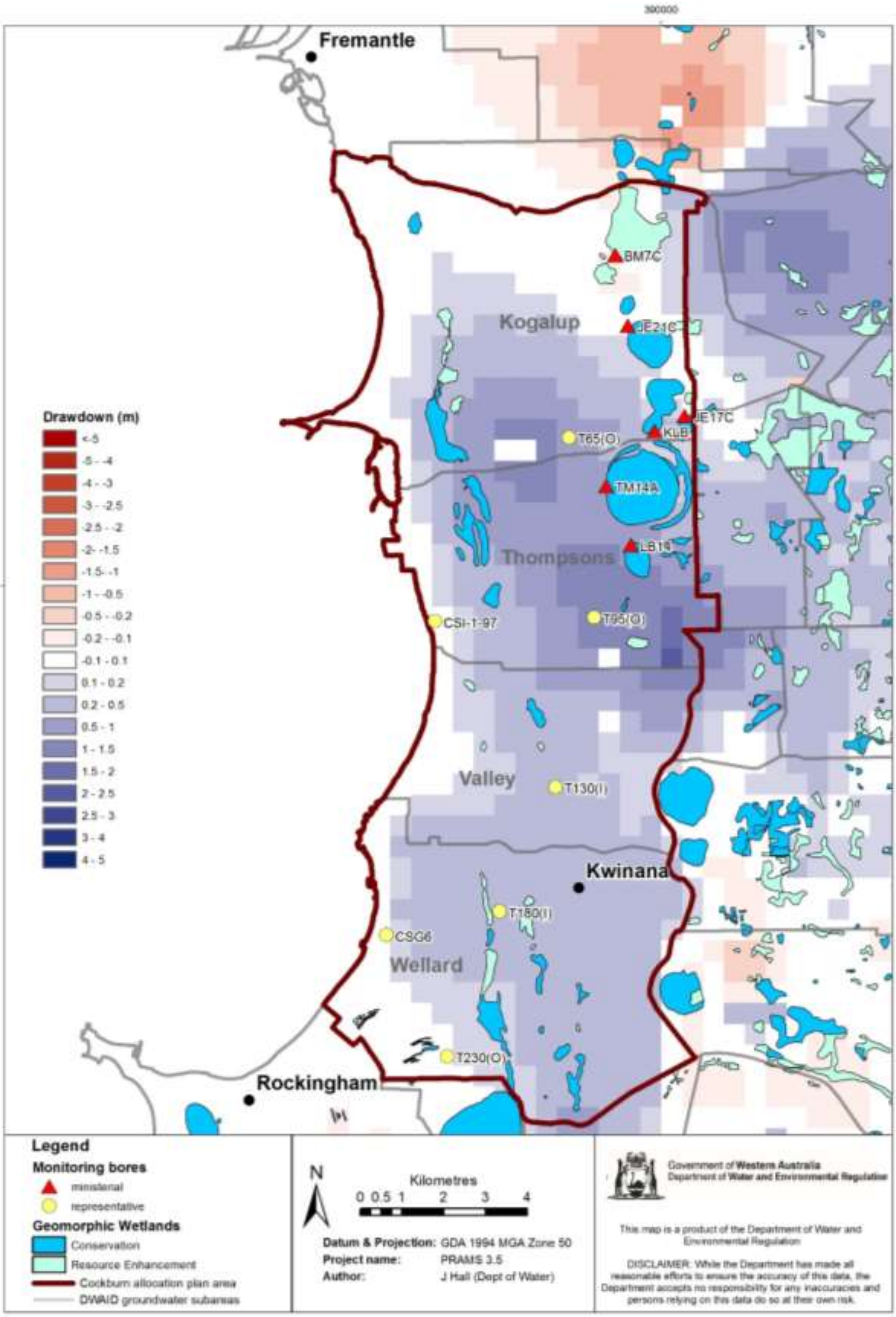


Figure 12 Spatial map of simulated water level changes for Option 1 (21.5 GL) under a projected worst-case climate scenario

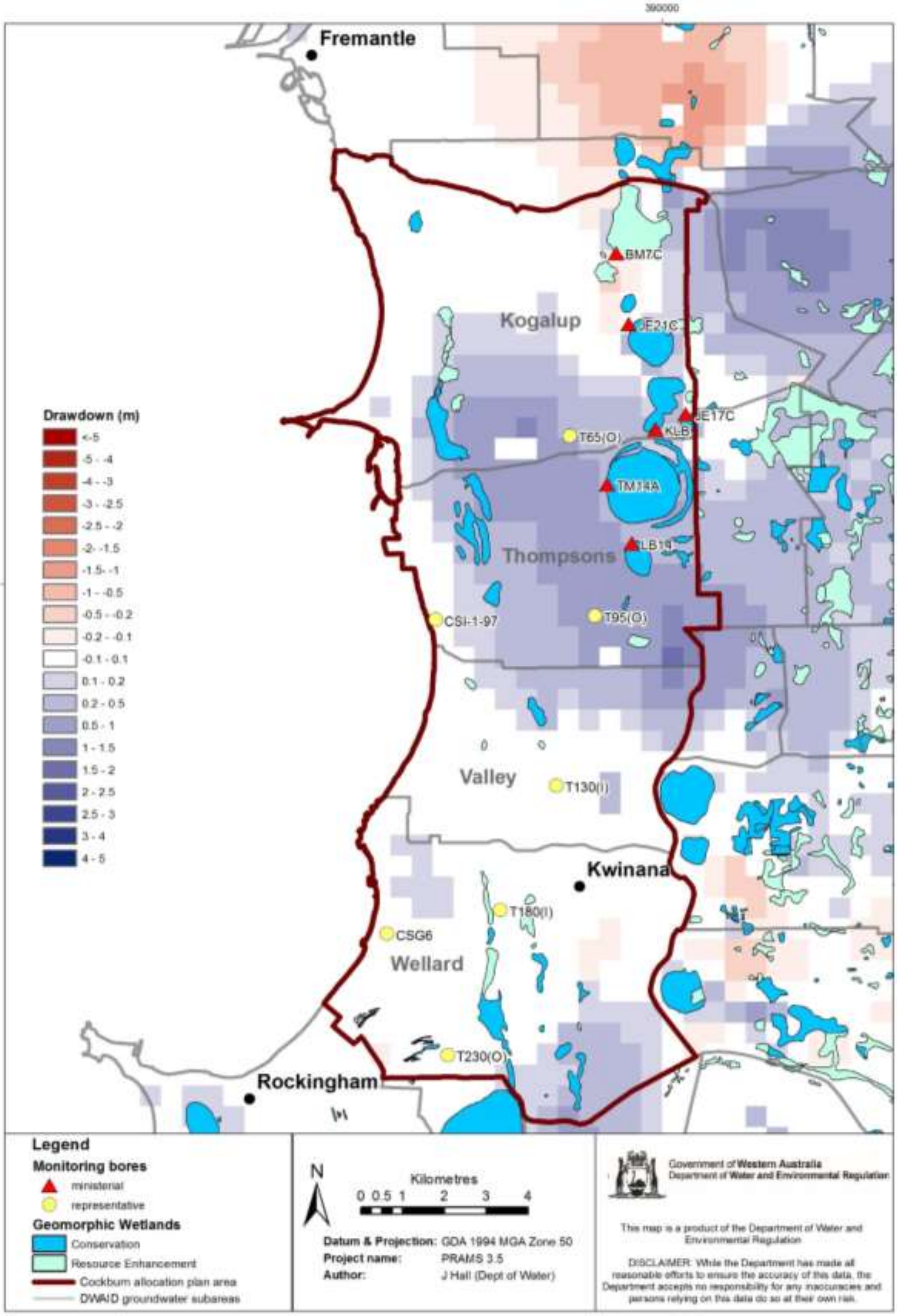


Figure 13 Spatial map of simulated water level changes for Option 2 (25.5 GL) under a projected worst-case climate scenario

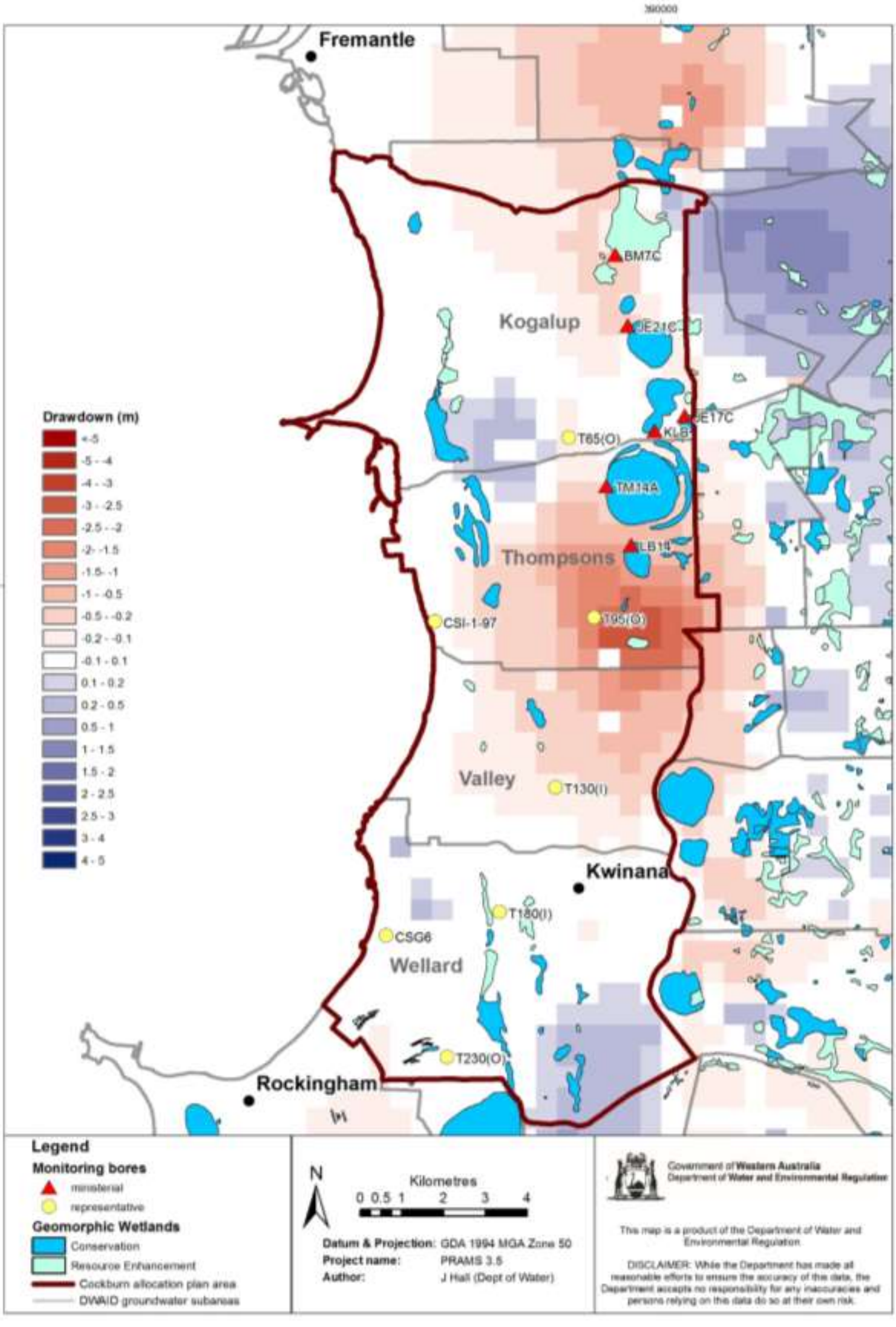


Figure 14 Spatial map of simulated water level changes under Option 3 (28.5 GL) under a projected worst-case climate scenario

Assessing the risks to wetlands

Each scenario was run through version 3.5.2 of PRAMS to investigate if Ministerial and other water level criteria would be met under each option. The model produced spatial drawdown maps (Figure 11 to Figure 14) that compared water level change against the criteria to show if a site was compliant under an allocation option.

The Base case spatial map, in which current licensed entitlements and exempt use is maintained, showed that the objectives would not be met as there would be greater drawdown than the criteria levels set in Table 11.

The water level drawdown mapped for Options 1 and 2 showed most water level criteria would be met. However, in Option 2 groundwater levels are not recovered to meet Objective 2a in Wellard subarea.

Option 3 shows similar water levels to the Base case, except for a large area of drawdown in Thompsons subarea. This drawdown was the results of testing if more water could be taken from this subarea without affecting Ministerial water level criteria (see Table 10).

The spatial information was coupled with the time series results to see if the water level targets set for each objective were met under each allocation option at 2030. This is shown in Table 13 with each output colour coded to correspond with the level of risk for each site (Table 11).

Assessing the risks of moving the seawater interface onshore

The risks of moving the seawater interface further onshore were calculated using the water balance outputs from the model and the Strack (1976) analytical solution (see Appendix A). This method calculated the change in the average maximum distance inland that the interface could intrude past the coastline under each allocation option.

Estimates of net recharge were determined for a 3 km coastal zone of each subarea to understand recharge and through-flow under each allocation scenario. The average change in location of the interface was considered and used to determine the level of risk (Table 13; colour coded using Table 11). The calculations did not include groundwater recharge at the Kwinana wastewater treatment plant. See Appendix A for more detail on these calculations.

The calculated average distance of the seawater interface was highest in Thompsons subarea under Option 3. This is because we were testing to see if more water could be allocated to meet licensed entitlements, exempt use and additional requested water as of November 2015. This clearly showed that allocating more water than the Base case option was not acceptable in this subarea.

Table 12 Modelled drawdown (water level) and risks to wetlands under each allocation option

Subarea	Wetland	Ministerial or representative wetland	Bore time series or spatial assessment	Allowable drawdown for Ministerial wetlands (m)*	Drawdown under projected worst-case climate scenario (m)**			
					Base case 30 GL	Option 1 21.5 GL	Option 2 25.5 GL	Option 3 28.5 GL
Kogalup	Bibra Lake	Ministerial	Bore BM7C	-0.6	0	-0.2	-0.2	-0.1
	Yangebup Lake	Ministerial	Bore JE21C	0.8	0.2	-0.1	0	0.1
	Kogalup Lake (South)	Ministerial	Kogalup Lake Bore	0.5	-0.3	-0.6	-0.5	-0.3
	Manning Lake	Representative	Spatial		0.2 to 0.1	0.1 to -0.1	0.1 to -0.1	0.1 to -0.1
	Lake Coogee	Representative	Spatial		0.2 to 0.1	-0.2 to -0.5	-0.2 to -0.5	-0.1 to -0.2
Thompsons	Thomsons Lake	Ministerial	Bore TM14A	0.33	-0.2	-0.7	-0.5	0.1
	Banganup Lake	Ministerial	Bore LB14	-0.13	-0.2	-0.8	-0.5	0.8
	Lake Mount Brown	Representative	Spatial		0.2 to 0.1	-0.2 to -0.5	-0.1 to -0.5	0.5 to 0.2
Valley	Long Swamp	Representative	Bore T130 (I)		0.3	-0.2	0	0.2
Wellard	Group of Conservation Category Wetlands associated with the Sedgelands in Holocene dune swales TEC.	Representative	Bore T230 (O)		-0.1	-0.3	-0.2	-0.2
	Group of Conservation Category Wetlands located to the north of the Leda Nature Reserve.	Representative	Bore T180 (I)		0.2	-0.4	-0.1	-0.1

**Note that a negative allowable drawdown means a rise in levels is required to meet the water level criteria.*

** *Red = high risk*

Orange = moderate risk

Blue = low risk

Table 13 Calculated average distance the seawater interface moved inland between 2013 to 2040 (m) for each allocation scenario (GL)

Subarea	2013 (baseline)		Base case 30 GL		Option 1 21.5 GL		Option 2 25.5 GL		Option 3 28.5 GL	
	m	GL*	m	GL*	m	GL*	m	GL*	m	GL*
Kogalup	300[a]	9.0	*288*[b]	8.8	*235*[b]	6.0	*260*[b]	6.7	*270*[b]	7.7
	a. Calculation achieved by forcing net recharge to 0.000001 otherwise not able to be calculated.									
	b. Italicised figures show the calculated distance with corrected net recharge factoring in a 6 GL licence with most of this being recharged on south east corner of the subarea.									
Thompsons	706	0.7	830	0.7	340	0.5	380	0.6	>1600[c]	0.9
	c. Estimated by iteratively reducing abstraction in the water-balance calculation to achieve net positive recharge in the coastal zone.									
Valley	NA	6.9	NA	7.0	NA	5.1	NA	5.5	NA	6.1
	NA – does not calculate because of negative net recharge in the 3 km coastal strip (abstraction is greater than recharge for all scenarios)									
Wellard	270	4.9	400	4.9	276	2.8	351	4.4	330	4.0

**The volume of groundwater abstracted (GL) in the coastal zone (0 – 3km inland) as modelled in version 3.5.2 of PRAMS*

6.5 Allocation limits selected for each subarea

The results of the water level drawdown modelling (Figure 11 to Figure 14, and Table 12) and the calculated seawater interface (Table 13) were used to categorise the level of risk associated with each allocation limit option under the projected worst-case climate scenario at 2030. The risk category showed whether each allocation option was acceptable and could meet the objectives. These results, including the chosen allocation limit are presented below for each allocation option by subarea.

Kogalup subarea

The allocation limit for the Kogalup subarea was set at 9 GL/year (Option 2). This decision means we have an allocation limit with an acceptable level of risk to the water resource that maximises water availability. The new allocation limit is less than what is currently licensed (10 GL/year) and more than current use (estimated at 8 GL/yr).

If the current licensed volume was abstracted in full, there would be an unacceptable risk to meeting water level criteria at Ministerial criteria sites (ecological) in Bibra Lake, a key site for community and cultural activities in Cockburn (see Table 12).

Table 14 Risk assessment for Kogalup subarea (GL/yr)

Objective	Risk	Base case	Option 1	Option 2	Option 3
		11	*8*	*9*	*10*
Water levels are sufficient to meet water level criteria set under Ministerial statement no. 688 each year Maintain Superficial aquifer levels at representative wetlands.	Water level decline				
	Location relative to seawater interface toe				
Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness.	Percentage of licensed use affected by the extent of toe				

Thompsons subarea

The allocation limit for the Thompsons subarea was set at 4.5 GL/year (Option 2). This means we have an allocation limit with an acceptable level of risk to the water resource that maximises water availability. The new allocation limit is less than what is currently used (estimated at 5.5 GL/yr) and what is licensed (5.7 GL/year).

The volume currently used is likely to reduce by 2030 as land use changes from rural to industrial and urban in the central parts of the subarea. If current use remains high in the long-term then it represents an unacceptable risk to meeting water level criteria at Ministerial criteria sites (Ramsar wetlands), potentially causing water level declines.

When water is no longer needed, such as through land use changes, it will be recouped to reduce the level of over-allocation and the risks to the resource.

Table 15 Risk assessment for Thompsons subarea (GL/yr)

Objective	Risk	Base case	Option 1	Option 2	Option 3
		5	*4*	*4.5*	*6.5*
Water levels are sufficient to meet water level criteria set under Ministerial statement no. 688 each year Maintain Superficial aquifer levels at representative wetlands.	Water level decline				
	Location relative to seawater interface toe				
Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness.	Percentage of licensed use affected by the extent of toe				

Valley subarea

The allocation limit for the Valley subarea was set at 5.5 GL/year (Option 1). This means we have an allocation limit with an acceptable level of risk to the water resource that minimises further movement of the seawater interface.

This volume is less than what is currently licensed in Valley (7.3 GL/year) which is already causing localised impacts on the seawater interface. This is managed through individual licences.

Allocating more than 5.5 GL/year represents an unacceptable risk of water level declines at sites that are environmentally significant and further drawing the seawater interface inland.

Limiting the amount of groundwater available in this subarea will assist with managing existing contaminated sites. Taking more groundwater could move these contaminated plumes, which will impact on other groundwater users and potentially Cockburn Sound.

Table 16 Risk assessment for Valley subarea (GL/yr)

Objective	Risk	Base case	Option 1	Option 2	Option 3
		7.5	*5.5*	*6*	*6.5*
Maintain Superficial aquifer levels at representative wetlands	Water level decline				
	Location relative to seawater interface toe				
Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness.	Percentage of licensed use affected by the extent of toe				

Wellard subarea

The allocation limit for the Wellard subarea was set at 6 GL/year (Option 2). This means we have an allocation limit with an acceptable level of risk to the water resource. It should allow for recovery of water levels at target ecological sites. It also minimises moving the seawater interface further inland and maximises water availability.

This volume is less than what is currently licensed in Wellard (6.85 GL/year). If the licensed volume is abstracted in full it will be taking more water than modelled in the Base case option. Abstracting more than the Base case would affect the continued supply of freshwater on the coast and impact water levels at environmental sites.

Table 17 Risk assessment for Wellard subarea (GL/yr)

Objective	Risk	Base case	Option 1	Option 2	Option 3
		6.5	*4*	*6*	*5.5*
Maintain Superficial aquifer levels at representative wetlands Recover Superficial aquifer levels at Sedgelands in Holocene dune swales threatened ecological community	Water level decline				
	Location relative to seawater interface toe				
Abstracting groundwater does not cause the seawater interface to move further inland nor increase in thickness.	Percentage of licensed use affected by the extent of toe				

6.6 Allocation limits set in December 2016

All groundwater resources are now either fully or over-allocated. Improving water use efficiency, changes in land use over time, and localised recouping of long-term unused water entitlements will allow for some growth in use over the next decade.

Table 18 2016 Allocation limits for the Superficial aquifer (GL/yr)

Subarea	2007 allocation limit	2016 allocation limit	2016 Allocation limit component	
			General	Exempt
Kogalup	11.46	9.0	7.940	1.060
Thompsons	8.70	4.5	4.275	0.225
Valley	7.70	5.5	5.50	0
Wellard	10.32	6.0	5.375	0.625
Total	**38.18**	**25.0**	**22.990**	**1.910**

Part C — Defining the management approach

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

The approach is to licence the take of groundwater in accordance with the:

- new allocation limits
- department's state-wide and operational licensing policies
- any local licensing policies specific to the plan area.

To identify if this approach is appropriate, we monitor the resource and evaluate how it is performing.

Our approach is adaptive and work will be ongoing in the plan area to refine how we monitor, report and licence groundwater over time.

Key points from this section:

- The department uses a suite of tools that complement our allocation limit decisions to manage how groundwater is abstracted.
- The water licensing approach and local licensing rules set out in Chapter 4 of the plan aim to achieve the outcomes and objectives through licensing.
- We developed the monitoring program, detailed in Chapter 5 of the plan, to evaluate how the resource is performing against the objectives.
- We will assess and report on how well we are achieving the outcomes by evaluating how we implemented the plan.

7 Water licensing and monitoring

A water licence issued under the provisions of the *Rights in Water and Irrigation Act 1914* provides legal and secure access to water for the life of the licence. The department allocates through a licence water up to the limits set. To ensure that groundwater is abstracted in line with the licence and the objectives of the plan we monitor water levels and water quality. We evaluate this monitoring data and adapt how we licence, allocate and manage the resource.

7.1 Water licensing approach

Chapter 4 of the allocation plan outlines our water licensing approach and sets the local licensing policies applied in the plan area. It also details what is required under the *Rights in Water and Irrigation Act 1914*, Regulations under this Act, and other laws that the department must apply in the plan area. This includes how we align regulatory approvals under other laws or government policy.

Under the 2016 allocation limits, there is no additional groundwater available for licensing. The water licensing approach focuses primarily on how proponents can meet their water demands in fully allocated resources. We have provided our policy and position on the following issues in the plan:

- Managing water in over-allocated and fully allocated resources, including recouping unused water entitlements.
- Impacts of land use change on licensed entitlements.
- Water use efficiency – improving how water is used is one way that proponents may be able to access additional water. It may also make water available for trading.
- Water trading and transfers – we will apply *Operational policy 5.13: Water entitlement transactions for Western Australia* (DoW 2010).
- Alternative water source options – we are committed to working with proponents to identify potential sources as part of implementing the plan and meeting future demand projections. The department recommends the use of our *Guideline for the approval of non-drinking water systems in Western Australia: Urban Developments* (DoW 2013) to provide information about considerations and approvals for possible alternative sources.
- For potential managed aquifer recharge projects, we have developed *Operational policy 1.01: Managed aquifer recharge in Western Australia,* to provide information on the considerations and licensing requirements of these schemes.

The department's state-wide operational policies and guidelines apply in the plan area. They are available on our website <www.dwer.wa.gov.au> or alternatively you can contact the Kwinana Peel regional office.

7.2 Local licensing policies

Local licensing policies outlined in the plan were set up to manage local resource issues that are not addressed in the department's strategic, state-wide or operational policies. Each local policy is designed to help us achieve the outcomes and objectives of the plan through licensing. They apply to all subareas and aquifers.

As there is no additional water available in the plan area, local licensing policies will only be applied if water becomes available at licence renewal, or if monitoring shows there is a need to amend a licence. Table 19 describes the intent of each local licensing policy presented in the plan.

Table 19 The intent of the local licensing policies in the allocation plan

Local licensing policy group in the plan	Intent of local licensing policy in the plan
1. General licence assessment	
1.1 Bore construction and groundwater licensing	
• Bore construction and groundwater licensing • Bore screening • Spacing between production bores.	To maintain continuity, we included several local licensing policies from the 2007 plan on bore construction, location and screening. These local licensing policies remain relevant to how we manage groundwater and were carried over into the 2018 plan.
1.2 Licences requiring operating strategies	
• Licences requiring operating strategies.	The 2007 plan's local licensing policy that defines when an operating strategy is needed, was revised for the 2018 plan. The revised policy (1.2.1) was adapted to respond to emerging water use issues. The department's state-wide policy on operating strategies still applies here. Operating strategies contain vital information on how monitoring is undertaken by the licensee and what steps will be taken if there are impacts from their take. An operating strategy is a binding condition of the licence. In the plan area, an operating strategy is requested for new, renewed or amended licences, depending on the criteria set up in the local licensing policy.
2. Managed aquifer recharge	
2.1 Locating and developing a managed aquifer recharge and recovery scheme	
• Managed aquifer recharge in highly transmissive aquifers • Minimising interactions between contaminated sites and managed aquifer recharge.	In the 2018 plan this policy group covers where the department is likely to support (licence) an appropriately managed aquifer recharge and recovery scheme. Although these schemes are a good source of alternative water it may not be practical to set them up in some areas. This includes where a proposed scheme is injecting water into highly transmissive parts of the Superficial aquifer or where there are known (or potential) contaminated sites. In these cases access to groundwater may be restricted.

Local licensing policy group in the plan	Intent of local licensing policy in the plan
3. Managing the impacts of groundwater abstraction and/or managed aquifer recharge on groundwater-dependent ecosystems and water quality	
3.1 Assessing the impacts of a proposal to take water (including a managed aquifer recharge scheme) on groundwater-dependent ecosystems and water quality	
• Managing and preventing impacts on groundwater-dependent environmental values • Managing impacts on water quality, particularly contaminated sites.	The department applies a consistent approach to assessing the potential impacts of a licence application on groundwater-dependent ecosystems across the state. The intent of these policies is to minimise and prevent impacts for existing and new licences. This policy group aims to prevent or manage any potential impacts to the environment or the resource (water levels and water quality) from abstracting or injecting groundwater. This policy group details what an applicant or licensee may be asked to undertake as part of the process to assess a licence. Identifying the potential impacts of a proposal early ensures that they can be prevented or managed appropriately under licence conditions (where water is available). Before we can assess the impacts of a proposal, the applicant needs to clearly demonstrate how they will prevent or manage the effect of their proposal on significant wetlands, acid-sulfate soils or contaminated sites, or the seawater interface. The department will direct each proponent on what needs to be provided to support their licence application.
3.2 Construction of bores in areas at risk of groundwater impacts	
• Monitoring water quality in high risk areas • Minimum distance of production bores from wetlands.	There are several sites in the plan area where drilling new bores may impact on existing users, the environment or the groundwater resource. In these cases, the department may request the applicant move the proposed location of their bore or alter how much water can be taken from the bore to minimise impacts on water quality or water levels.
3.3 Amending licences if impacts on groundwater-dependent ecosystems or water quality are observed and reported	
• Amending licences when significant impacts are observed and reported.	Where it is identified that taking groundwater is significantly impacting on groundwater-dependent ecosystems and/or water quality the department will act to address the impacts. This may lead to amending the conditions of a groundwater licence or compliance actions. Amendments may include: • Reducing the entitlement (less water allocated) or request the licensee to change the pump rate (volume drawn over time) • Directing the licensee to relocate the production bore/s, including new or replacement bores • Directing the licensee to measure groundwater levels (in a new or existing monitoring bore)

Local licensing policy group in the plan	Intent of local licensing policy in the plan
	• Directing the licensee to sample and measure water quality (in a new or existing monitoring bore) Any extra drilling, sampling or pumping changes are at the licensee's expense. Any proposal to amend a licence will be discussed with the licensee and follow the standard process applied by the department across the state. How the department defines a significant impact in the plan area is detailed in local licensing policy group 3.1.
Seawater interface coastal management zone (Figure 15*)*	
• Licensing, monitoring and reporting in the coastal zone.	The allocation limits are designed to maintain through-flow to the ocean, keeping the natural seawater interface stable. Taking too much water from the coastal area will interfere with the natural seawater interface. Our seawater interface coastal management zone extends from the coastline to 2 km inland (Figure 15). In this zone the department will closely manage how groundwater is abstracted or injected to achieve the objectives of the plan. Several local licensing policies in the plan refer to this zone.

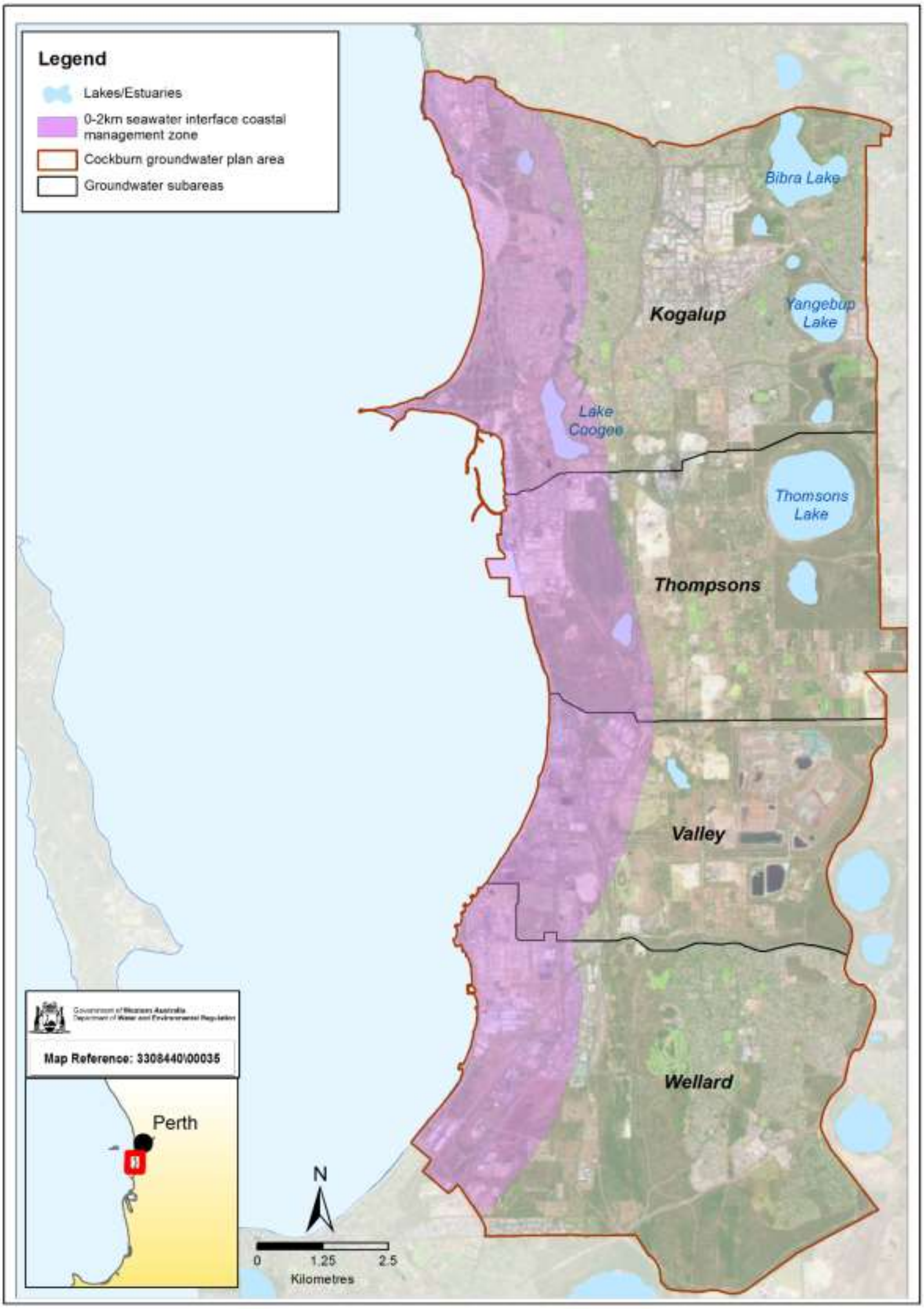


Figure 15 Seawater interface coastal management zone

7.3 Monitoring program

To adaptively manage groundwater, we need to evaluate how the resource is performing against the objectives. This is achieved through monitoring and assessing the response of the groundwater resources to changes in recharge and use over time.

Chapter 5 of the plan details the monitoring we will carry out to manage and allocate groundwater. The monitoring program is also important for understanding how declining rainfall is affecting groundwater resources, and how ecological values are responding.

Over time, we will adapt the monitoring program to include appropriate water quality monitoring, particularly in the coastal zone. We will be actioning this as part of implementing the plan.

Appendices

Appendix A — Method for calculating the seawater interface

Deciding the best analytical approach to use

Several analytical approaches were evaluated to determine whether these could be adapted to estimate seawater intrusion using outputs of scenarios modelled using version 3.5.2 of PRAMS. The approaches investigated were Ghyben-Herzberg equation and Strack analytical solution.

Ghyben-Herzberg equation

The location of the seawater interface can be estimated from water table measurements in the near coastal zone using the Ghyben-Herzberg equation (Cheng and Ouazar, 1999). The equation calculates the depth of the interface below the water table as being 40 times the depth of the water table above sea level, where this is measured above the interface. The estimated interface is the inland extent of the mid-part of the mixing zone between intruding seawater and coastal flowing fresh water. Imperfect transfer of pressure through the aquifer often results in the interface being closer to the coast. This affects the pressure exerted by seawater more than freshwater.

A regional estimation of the interface can be obtained using this approach if data is available for transects of bores extending from the coast or contoured groundwater levels. However, water levels in the bores must reflect the water table, which requires bore construction with screen intervals at, or near, the water table. This was not possible with any certainty in the plan area.

Strack

The Strack (1976) analytical solution to calculate the extent of the seawater interface for an unconfined aquifer was adapted using water-balance outputs from version 3.5.2 of PRAMS. This calculation was developed for an unconfined aquifer and is widely accepted as a solution suitable for regional estimation of seawater interface (Cheng and Ouazar, 1999; Werner et al. 2012).

Applying the Strack solution

The distance of the interface from the coast (x_T) is calculated as:

$$x_T = \frac{Q_o}{W_{net}} - \sqrt{\left(\frac{Q_0}{W_{net}}\right)^2 - \frac{K\delta(1+\delta)z_0^2}{W_{net}}}$$

where:

- Q_o is ocean discharge (m^2/day)
- W_{net} is net recharge (recharge – abstraction) for the coastal zone (m/day)
- K is average hydraulic conductivity (m/day) in the coastal zone
- Z_o is the base of the aquifer below sea level at the coast (m)
- δ is an expression for seawater density (ps) relative to fresh water density (pf) as $(p_s - p_f)/p_f$. In this assessment δ was set as 0.025 for all calculations.

Ocean discharge (Q_o) was calculated as the net flow to the ocean for coastal cells in version 3.5.2 of PRAMS for each subarea. In some subareas, this included adding where there is seawater inflow in some parts and offsetting outflow in others. The length of the coastline for each subarea was used to convert water-balance estimates in GL/annum to m^2/day.

Net recharge was the sum of recharge minus abstraction from licenced and exempt bores in the 3 km coastal zone. The input value for the equation as m^2/day was calculated using the area of the coastal zone from which the net recharge was modelled.

Estimates of net recharge were determined for a 3 km coastal zone for each groundwater subarea. This zone covered the area of mostly Tamala limestone and avoided the need to factor in land-use and pumping effects on net recharge from areas further inland that have far less direct influence on coastal water levels.

The aquifer parameters K and Z_o for this equation were extracted from calibrated values for the coastal zone of the Superficial aquifer in version 3.5.2 of PRAMS.

Correcting ocean discharge to a 2013 baseline

Ocean discharge (Q_o) for each subarea was calculated by correcting modelled outputs to an ocean discharge baseline for 2013. This was applied to minimise the effects of potentially over-estimating Q_o on the interface location.

Ocean discharge was calculated, treating each subarea as a ‘flow cell’, using the equation:

$$Q_{2013} = KZ_0 iL$$

Where:

- Q_{2013} is daily average discharge to the ocean in 2013 (m^3/day),
- i is the coastal hydraulic gradient,
- L is the coastline length of the sub-area (m) and
- K and Z_o as are as defined previously.

Total discharge for 2013 (GL) was calculated as q_{2013} x 365/10^6.

The average coastal gradient in each ‘flow cell’ was calculated from the average water levels for selected monitoring bores, assuming an average sea level of 0.2 m AHD. For most flow cells the gradient was an average of water levels in two or three bores.

Priority was given to bores:

- closest to the coast with no licenced pumping within 1 km or between the bore and the coast
- surrounded by uniform land use at bore and towards coast
- judged to be not influenced by seawater intruding below the bores.

These ocean discharge estimates were used as the baseline against which the discharge at 2040 (Q_{2040}) was calculated for the various allocation options.

In this case $Q_{2040} = Q_{2013} + (Q_{PRAMS2013} - Q_{PRAMS2040})$, where $Q_{PRAMS2013}$ and $Q_{PRAMS2040}$ are the ocean discharge outputs from the model for 2013 and 2040. The calculated analytical estimates of ocean discharge (Q_{2013}) were 0.6-1.8 GL/yr/subarea less than modelled estimates ($Q_{PRAMS2013}$).

Limitations with the Strack method

The results presented provide the response of the interface location to changes in pumping or recharge and are not a reliable indicator of the absolute location.

The average location of the interface is based on assuming uniform thickness of the aquifer, uniform hydraulic conductivity and evenly distributed abstraction and recharge in the 3 km coastal zone. This assumption may over-state the effects of net recharge, if most abstraction is distant from the coast, or concentrated in one part of the subarea near the coast. However, abstraction near to, or exceeding, net recharge is clearly a risk to water levels declining in the 3 km coastal zone. This results in seawater intruding beyond 3 km inland. At this point, aquifer discharge to the coast still occurs but mostly as brackish overlying saline water through the whole thickness of the aquifer.

The true interface (mid-part of the mixing zone) is likely to be closer to the coast than predicted if low permeability layers occur in the aquifer. These limit the transfer of water pressures in and around the saline water wedge (where flow and pressure transfer is slowest). This applies most to the Valley and Wellard subareas, where a known low-permeability layer occurs in the Superficial formation where the position of the saltwater wedge is different between the lower and upper parts of the Superficial aquifer. Local water levels vary because of changes in pumping and recharge which results in the interface being different from the average.

Results

Calculated vs indications from observations

Calculated interface distances are broadly comparable with available information on the measured interface in the Kogalup subarea, but less so for Thompsons subarea (see Table 3).

The interface was calculated for Kogalup by forcing a negative net recharge value (abstraction > recharge) to a value just above zero. Abstraction exceeds recharge by 0.6 GL in the coastal zone of the subarea. This falls within the water-balance error margin for the subarea and was set at 0.000001 so that a value could be calculated. The location of the interface was unable to be calculated in Valley as groundwater abstraction is greater than recharge by more than 2 GL (see Table 13).

The calculated interface distance inland is generally expected to be conservative (closer to the coast). The calculated interface is an average for the subarea, assuming the near-coastal groundwater gradient is uniform along the coast. Local variations in pumping and land uses affect water levels, which influences the location of the interface.

The calculations also contain uncertainties arising from the estimate of ocean discharge (Q_{2013}) from the few bores with water level data near the coast, as well as assumptions about the uniformity of the hydraulic conductivity (K) of the aquifer. In the Valley and Wellard subareas K was assumed to be 85 m/day throughout the aquifer except there is a low permeability zone mid-aquifer.

Differences between the on-ground data and calculated estimate are due to the conservative nature of the calculations and variations in the aquifer along the coastline. An example of this is in Kogalup where the interface near Woodman point was further inland than a recently constructed bore (approximately 750 m from the nearest coastline). However, the interface is likely closer to the coast in the north and south of the peninsular because aquifer discharge per length of coastline is not dissipated along the longer coastline of the peninsular.

Water level monitoring for the bores closest to the coast in Kogalup also show a declining trend resulting in a slow pattern of intrusion occurring. A decline at the coast near sea level at monitoring bore CSG2 occurred for a period of six years from 2005 until the bore was destroyed. Data from this site correlates with a continued declining trend from 2012 onwards at monitoring bore SCC 18/08 in the south.

The calculated interface in Thompsons was further inland than monitoring data showed in the south of the subarea. However, the monitoring bores were in an area covered by native vegetation, with little groundwater use. This bore poorly reflects local variation in the aquifer to the north of the subarea. The calculated interface in the northern part of the subarea is closer to the estimated interface distance of 750 m at Woodman Point.

Factoring the effects of abstracting groundwater in the coastal zone

Large abstraction on the inland boundary of the 3 km coastal zone can affect net recharge and the estimated location of the seawater interface.

In Kogalup subarea this is because 6 GL (of the 9.49 GL licensed) is abstracted in the 3 km coastal zone and was for a single licence located near the border of Thompsons subarea. The licence is to manage a leachate plume from a waste storage facility, with some pumping occurring at more than 3 km land and approximately 3 GL recharged annually.

Abstraction was modelled as falling in the 3-kilometre coastal zone of the subarea and the effect of this is carried through to future abstraction scenarios. Net recharge in the coastal zone of Kogalup was reduced by 6 GL to overcome the potentially exaggerated impact of the large inland abstraction. Correcting for the 6 GL licence enabled the location of the interface to be calculated for the allocation options in Kogalup subarea. This showed that varying abstraction between allocation options resulted in moving the interface 40–50 m relative to a 60 m movement with climate (projected best vs worst-case climate scenarios).

The overall location of the interface for the Option 1 scenario was similar to the estimated location without correcting for abstraction. This indicated that the location of the interface is more dependent on ocean discharge than net recharge as shown in the Strack equation.

Understanding the effect of the climate scenarios

The location of the seawater interface was most sensitive to climate in the Thompsons subarea and least in Wellard and Kogalup subareas. Movement of 400 m onshore was likely between the projected worst-case climate scenario compared with the best-case climate scenario in Thompsons for the Base case allocation option. However, there was less sensitivity to climate in Wellard subarea (150 m movement) or Kogalup subarea (65 m when correcting for effect of 6 GL inland). This is largely a function of the interface being sensitive to the greater change in recharge in the less urbanised Thompsons coastal zone compared with the more urbanised Wellard and Kogalup coastal zones.

Sensitivity to climate increases with increased abstraction. This was clearest in the Wellard subarea where the interface calculated as 90 m further onshore between climate scenarios for allocation Option 1, but was calculated at almost double this with the greater abstraction in the Base case. A similar effect occurred in Kogalup subarea.

Negative net recharge in the coastal strip in Valley prevented calculation of the interface for the Base case allocation scenario. Abstraction exceeded recharge in this subarea, ranging from 1.92 GL in Option 1, up to 2.85 GL in the Option 3, under the worst-case climate scenario.

Factoring in the artificial recharge from Kwinana Waste Water Treatment Plant

The additional recharge from the Kwinana Waste Water Treatment Plant resulted in a net effect of 0.1 GL discharge to the ocean for the subarea. This has minimal effect on the interface because abstraction is still greater than recharge.

Results of the allocation options

Varying abstraction had a significant effect on the location of the interface in the Kogalup and Thompsons subareas. Little effect was seen in the Wellard subarea under the various allocation options and climate scenarios. The most useful data for the decision-making on allocation limits is presented in Table 13.

The location of the interface in Kogalup was at least 300 m inland in 2013 and sensitive to abstraction in the coastal strip. Reducing what can be abstracted in this subarea will better maintain the interface by 40–50 m closer to the coast, assuming the existing 6 GL licence has no net effect. This can potentially offset impacts of reducing net recharge with climate change.

In Thompsons subarea, the calculations suggest the interface is sensitive to abstraction in this area because of the fine margin between recharge and abstraction. The sensitivity to abstraction is close to reality as it is focused in the northern coastal part of the subarea where it is unlikely to be locally balanced by recharge. In the southern portion of the subarea abstraction is likely to have lower impacts on the interface location (pumping is inland of the coastal zone). Impacts on water levels towards the coast may be locally balanced by recharge from areas of native vegetation.

There was no abstraction scenario where the seawater interface was likely to stabilise in the Valley subarea. Each allocation option only reduced the deficit between recharge and abstraction. Abstraction needs to be reduced by approximately 2 GL in the coastal zone to achieve a stable interface.

The location of the seawater interface was moderately sensitive to abstraction in the Wellard subarea. The relative increase in abstraction between each allocation option had little effect on the movement of the interface (<130 m). The difference in interface location between 2013 and future scenarios is attributed to greater recharge modelled in PRAMS for 2013. Groundwater is still likely to discharge to the ocean, but this is because of a mix of brackish to saline water in a wedge near the coast.

Key outcomes

The key outcomes of assessing the risks of moving the seawater interface were:

- The seawater interface is more sensitive to abstraction than climate in the near coastal zone. However, increased abstraction leads to an increasing sensitivity to climate.
- The seawater interface is calculated to move inland between 90 and 400 m depending on the future climate. Abstraction in these areas results in moving the interface greater than 400 m onshore.
- Allocation option 1 under a worst-case climate scenario showed minimal movement of the interface. The interface stabilised within 300 m of the coast, in Kogalup, Thompsons and Wellard. The seawater interface would continue to intrude under all modelled abstraction options in Valley and could not be calculated.

Appendix B — Method for setting the volume of water for exempt stock and domestic use

To set the volume of water available for licensing we need to account for groundwater that is exempt from licensing, particularly water that is abstracted by the community for stock, domestic and garden uses.

Groundwater use is exempt from licensing if the bore and its use complies with the current by-laws and exemption orders under the *Rights in Water and Irrigation Act 1914* and the *Water Agencies (Powers) Act 1984.* This includes water used for:

- stock[10], domestic and "backyard" garden use[11]
- fire-fighting
- short-term dewatering[12]
- monitoring purposes.

The department's standard for estimating how much water is used for stock, domestic and garden uses is to apply the process described in the *Strategic policy 2.03 – managing unlicensed groundwater use* (DoW 2010). To account for growth in domestic bore use since 2012 we incrementally increased this estimate by 1 per cent annually up to 2015 for each subarea (Table B21).

Abstracting groundwater for stock, domestic and garden purposes is accounted for in setting the total allocation limit because it is used on a continual basis. Other exempt purposes are not regularly abstracted and are not accounted for in setting the allocation limits.

This review of exempt-from-licensing groundwater use covers the Superficial aquifer in each of the subareas in the plan area. We identified free hold properties that are likely to be using groundwater and do not have, or require, a groundwater licence. This information was then used to estimate the volume of water likely being used.

The final estimates shown in Table B21 were rounded down to the nearest 1 ML. These estimates replace the domestic estimates in our water accounting system and the 2007 plan. Table B22 below shows how the estimates calculated using this process correspond with the modelled estimates.

Our review of exempt use showed that the likelihood of water being abstracted in the Valley subarea for this purpose is extremely low. Therefore, the volume for exempt use was at zero.

[10] To water cattle or other stock, other than those being raised under intensive conditions (see Section 21 (4) of the *Rights in Water and Irrigation Act 1914* for the definition of intensive)

[11] lawn or garden that does not exceed 0.2 ha (2000 m^2)

[12] refer to definitions of exempt dewatering within the Rights in Water and Irrigation Exemption (Section 26C) (Dewatering) Order 2010

Table B20 Volume of exempt use in the plan area, 2015

Subarea	Esitmated number of bores	Bore use ML/yr
Kogalup	1971	1060
Thompsons	152	220
Valley	0	0
Wellard	1132	620
Total	**3255**	**1900**

Table B21 Other estimates of exempt-from-licensing groundwater use in the plan area (ML/year)

Exempt use estimates	Volume	Source of estimate
2015 estimate	1900	Estimate of domestic, garden bore use for the plan area 2015
2012 domestic	1886	2012 Perth garden bore metering project 2009-2012
PRAMS version 3.5.2	1922	2012 domestic bore use plus 1% annually
Licensing database	233	From cancelled stock and domestic licences
2007 plan	6430	Method not documented

Information used to estimate exempt use

- *Strategic policy 2.03 – managing unlicensed groundwater use* (DoW 2010) provides generic water use values that are applied to estimate the volume of water taken from domestic garden bores. Because the policy is generic some estimates were refined to suit local conditions (Table A1).
- 2013 North West Corridor calculations (see DoW 2014). A domestic bore use survey in the Quinns subarea (which is already fully urbanised) indicated domestic garden bores are installed at a rate of only four percent per year and annually use 405 kL/yr.
- Cadastral information, block size, zoning, land use, proprietor, locality and tenure obtained from the departments' GIS database.
- Water resource licensing and drawpoint data. Properties with a current (inforce or draft) groundwater licence were excluded from the exempt use data set.
- The Department of Planning's *Building Footprints* GIS layer. We filtered out freehold residentially zoned properties with no building on the lot.
- Scheme water supply locations.

Assumptions

To estimate volumes abstracted for stock, domestic and garden use several assumptions:

- all exempt use is abstracted from the Superficial aquifer
- domestic water supply that is abstracted from resources other than the Superficial aquifer is licensed e.g. confined aquifers
- eligible exempt users are found only on freehold, privately held residential land
- exempt users comply with the three day a week domestic garden bore sprinkler roster
- new urban developments have less back yard bores
- exempt users in predominantly residential subareas will use their bore in a similar way to Perth metropolitan backyard bore users
- the estimates of exempt use are a snapshot in time (2015) and do not account for increases or decreases in exempt use in the future
- any future allocation limit reviews will need to undertake additional investigations into exempt use to identify and account for any changes
- there is no exempt-from-licensing groundwater use in the Valley subarea.

Method

The following steps were taken to estimate exempt use:

1 Collate GIS data and calculate the number of blocks likely accessing groundwater for exempt purposes by filtering the data based on the following points:

- include only freehold, privately-held land with residential land use
- exclude properties smaller than 350 m^2 and greater than 1000 m^2 with no building on the lot
- exclude properties in the industrial localities of Kwinana Beach, East Rockingham, Naval Base, Henderson and part of Bibra Lake.

2 Apply the water use values from *Strategic policy 2.03* to the data collected in step 1. To address local conditions, we made the following adjustments to the values calculated using the policy:

- 430 kL/yr was applied to both small and large urban blocks. This volume comes from the department’s Perth garden bore metering project 2009–2012 and reduces the estimated volume for large urban blocks down from 800 kL/yr.
- Bore incidence for large urban blocks has reduced from 30 per cent to 25 per cent.
- The incidence of bores on large urban blocks was reduced further in Kogalup and Wellard. These subareas are highly urbanised with a high incidence of

large urban blocks. However, this does not mean the incidence of domestic bores also increased. To address this a five per cent installation rate of back yard bores was applied to half of the large urban blocks and 25 per cent was applied to the other half in Kogalup and Wellard subareas.

Table B22 Indicative water use by property category and block size in the plan area

Category	Land size m^2	Estimated water use kL/yr	Estimated percentage of properties with a bore
Small urban blocks	350-500	430	5
Large urban blocks	500-999	430	5* 25*
Semi-rural properties	1000-5000	1000	50
Rural holdings	Over 5000	1500	80

**In new urban areas half of large urban blocks are estimated to have 5%, the other half 25% incidence of bore use.*

The project area is covered by the three day a week domestic garden bore sprinkler roster. This initiative has reduced the volume of water abstracted from backyard bores.

Scheme water is available for most small and large urban blocks in the area. Piped scheme water infrastructure is established as new housing developments progress, which reduces the instance, and reliance on, backyard bores.

The indicative volume of 1000 kL/yr in *Strategic policy 2.03* was retained for semi rural properties in the area. Sprinkler restrictions apply to these properties which has likely reduced use however, scheme water supply is restricted for some of these larger blocks so they may rely fully on self supply groundwater to meet their water needs.

Table B23 Calculations for exempt-from-licensing groundwater use in the plan area

Subarea	Block type	No. of blocks	% of blocks with exempt bores	No. of bores	Indicative use kL/yr	Estimated bore use kL/yr	Rounded down to nearest 1 ML
Kogalup	small urban	733	5	37	430	15 760	15
	large urban	10 667	5	266	430	114 670	114
			25	1333	430	573 351	573
	semi-rural	565	50	283	1000	282 500	280
	rural	65	80	52	1500	78 000	78
Subtotal		*12 030*		*1971*		*1 064 281*	*1060*
Thompsons	small urban	0	5	0	430	0	0
	large urban	2	25	1	430	215	0
	semi-rural	9	50	5	1000	4500	4
	rural	183	80	146	1500	219 600	219
Subtotal		*194*		*152*		*224 315*	*220*
Valley	small urban	0	5	0	430	0	0
	large urban	3	25	1	430	430	0
	semi-rural	2	50	1	1000	1000	1
	rural	4	80	3	1500	4800	4
Subtotal		*9*		*5 (0)*		*6123*	*5 (0)*
Wellard	small urban	285	5	14	430	6128	6
	large urban	5762	5	144	430	61941	61
			25	720	430	309 707	309
	semi-rural	503	50	252	1000	251 500	250
	rural	2	80	2	1500	2400	2
Subtotal		*6552*		*1132*		*631 676*	*620*
Total		18 785		3259		1 926 395	1900

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

Project information

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File path: gisprojects\Project\330\80000_89999\3308440_WAP\00035_Cockburn_GW_Alloc_Plan\

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Disclaimer

These maps are a product of the Department of Water and Environmental Regulation, Water Assessment and Allocation Division. These maps were produced with the intent that they be used for information purposes at the scale as shown when printed.

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Sources

The Department of Water and Environmental Regulation acknowledges the following datasets and their custodians in the production of this map:

- Allocation plan areas – DWER 2016
- WA Coastline – DWER 2000
- Perth Basin, Superficial aquifer, groundwater salinity – DWER 2009
- Towns – Western Australia – DWER 2013
- Imagery – Landgate 2015
- Cadastre – DLI 2017
- Groundwater subareas – DWER 2013
- Aquifers – DWER 2017
- WIN Sites - Ministerial Criteria – DWER 2017

- Road Centrelines – DWER 2016
- Lakes (Linear hydrography water poly) – AUSLIG 2013
- Geomorphic Wetlands, Swan Coastal Plain – DPaW 2013
- WRL Draw points – DWER 2017
- WIN Sites – DWER 2017
- Nature reserves/regional parks – DPaW managed Lands & Water – DPAW 2013
- Regional Parks (Beeliar) – CALM 2002
- Local Government Authority and Locality Boundaries – Landgate 2013
- Geology – Geological Survey of WA 1986
- Ramsar Wetlands – DPaW 2013

Shortened forms

AHD	Australian height datum
CALM	Conservation and Land Management
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Department of Environmental Regulation (now DWER)
DPaW	Department of Parks and Wildlife
DoP	Department of Planning
DWER	Department of Water and Environmental Regulation
DoW	Department of Water (now DWER)
DWAID	Divertible water allocation information database
IWSS	Integrated Water Supply Scheme
MAR	Managed aquifer recharge
PRAMS	Perth Regional Aquifer Modelling System
WAPC	Western Australian Planning Commission
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.
Allocation limit	Annual volume of water set aside for use from a water resource.
Conservation category wetland	Wetlands identified in geomorphic wetlands mapping (Hill *et. al* 1996) which are considered to be of high conservation significance.
Consumptive use	Water used for consumptive purposes considered as a private benefit including irrigation, industry, urban and stock and domestic uses.
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 current ecological values (including assets, functions and processes) of water-dependent ecosystems consistent with the objectives of an ecological water requirements study.
Fit-for-purpose water	Water that is of suitable quality for the intended end purpose. It implies that the quality is not higher than needed.
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.
Groundwater-dependent community value	An in situ quality, attribute or use associated with a groundwater resource (or dependent on a groundwater resource) that is important for public benefit, welfare, state or health.
Licence (or licensed entitlement)	A formal permit which entitles the licence holder to take water from a watercourse, wetland or underground source under the Rights in Water and Irrigation Act 1914.

Non-artesian well or bore	A well, including all associated works, from which water does not flow, or has not flowed, naturally to the surface but has to be raised, or was raised, by pumping or other artificial means.
Over-allocation	A situation where licensed water entitlements, together with exempt uses and public water supply reserves, exceed the allocation limit set for a water resource.
Over-abstraction	A situation where the total volume of water actually abstracted by licensed and exempt water users exceeds the allocation limit set for a water resource.
Ramsar-listed wetland	Wetlands recognised as internationally significant and listed under the Convention on Wetlands of International Importance (Ramsar 1971).
Reference groundwater level	A groundwater level that triggers management actions or responses to be implemented that will reduce the impacts associated with abstraction on the water resource and dependent values.
Reliability	The number of years over time that a water licence holder can obtain their full licensed volume.
Seawater interface	The interface is a zone where dense salty water from the ocean meets the fresh groundwater flowing out to sea below the surface of the land along our coastlines.
Seawater interface 'toe'	The point at the bottom of the aquifer furthest from the coast where the seawater wedge intrudes from the ocean.
State Agreement	A State Agreement is a legal contract between the Western Australian Government and an applicant of a major project within the boundaries of Western Australia. State Agreements detail the rights, obligations, terms and conditions for the development of the specific project. In some circumstances the agreement contains clauses regarding water supply and this can affect what is required under the Rights in Water and Irrigation Act 1914.
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.

Sustainable groundwater use	Abstracting groundwater in a way that does not result in unacceptable depletion of aquifer storage. Abstraction that causes significant long-term declines in groundwater levels is not acceptable and could ultimately have effects that cannot be reversed.
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.

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