



Government of **Western Australia**  
Department of **Water**

# Murray

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groundwater allocation limits  
method report

Department of Water

April 2012



# Murray groundwater allocation limits method report

*Looking after all our water needs*

Department of Water

Water resource allocation and planning series

April 2012

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April 2012

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ISBN 978-1-921907-19-7 (online)

### **Acknowledgements**

The Department of Water would like to acknowledge the Murray project team and project board for developing this plan:

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# 1 Introduction

The Department of Water has prepared this report to explain how we developed the allocation limits for the *Murray groundwater allocation plan* (DoW 2012a) and to make the process we used transparent and publicly available.

## 1.1 What is an allocation limit?

An allocation limit is the annual volume of water set aside for consumptive use from a water resource. Water is allocated up to the allocation limit through the department's licensing process. Generally, the allocation limit set for a water resource cannot be abstracted from a single draw point.

In the Murray groundwater area the following two types of information were assessed to determine how much groundwater should remain in storage to protect in situ values and groundwater-dependent ecosystems and how much should be made available for consumptive use.

Water use information:

- current management of groundwater in the plan area
- current licensed and unlicensed use
- future demand.

Groundwater resource information:

- aquifer integrity
- changes in rainfall and groundwater recharge
- groundwater flow and water levels
- groundwater quality and the nature of the saltwater interface
- groundwater-dependent ecosystems
- surface drainage.

## 1.2 Groundwater resources

In the plan area there are four sedimentary aquifers and a fractured rock aquifer system along the Darling Scarp (Commander 1975; Davidson 1995). The four sedimentary aquifers, in order of increasing depth, are the superficial, Rockingham Sand, Leederville and Yarragadee aquifers.

The Murray groundwater area is divided into four allocation subareas: Nambeelup, Coolup, Pinjarra and Waroona (Figure 1). The department defines a 'groundwater resource' as being a particular aquifer in a particular subarea and sets an allocation limit for each resource.

For allocation purposes the superficial and Rockingham Sands aquifers are managed as a single resource and the Leederville aquifer is divided into the upper and lower Leederville resources.

See *Murray groundwater area: subarea reference sheets* (DoW 2012b) for further information about the hydrogeology in the plan area.

### 1.3 1998 allocation limits

The allocation limits for the Murray groundwater area were first set in 1998 and reported in *Groundwater allocation plan – Murray groundwater area* (Water and Rivers Commission 1998, unpublished). Although the plan was not published, the allocation limits were endorsed by the (then) Water and Rivers Commission and used to grant licence entitlements.

The method used to develop the allocation limits for the Murray groundwater area in 1998 is explained in Appendices A and B. The total volume of groundwater available from the plan area at that time was 69.9 GL/year.

The 1998 allocation limits were based on recharge calculations using geological drilling investigations carried out in from 1970s until the 1990s. Rainfall recharge was calculated using the average annual figure of 900 mm. The allocation limit was set at 75% of calculated recharge. The remaining 25% was set aside to remain in the system to maintain groundwater flow, protect groundwater-dependent ecosystems and to prevent the saltwater interface moving inland.

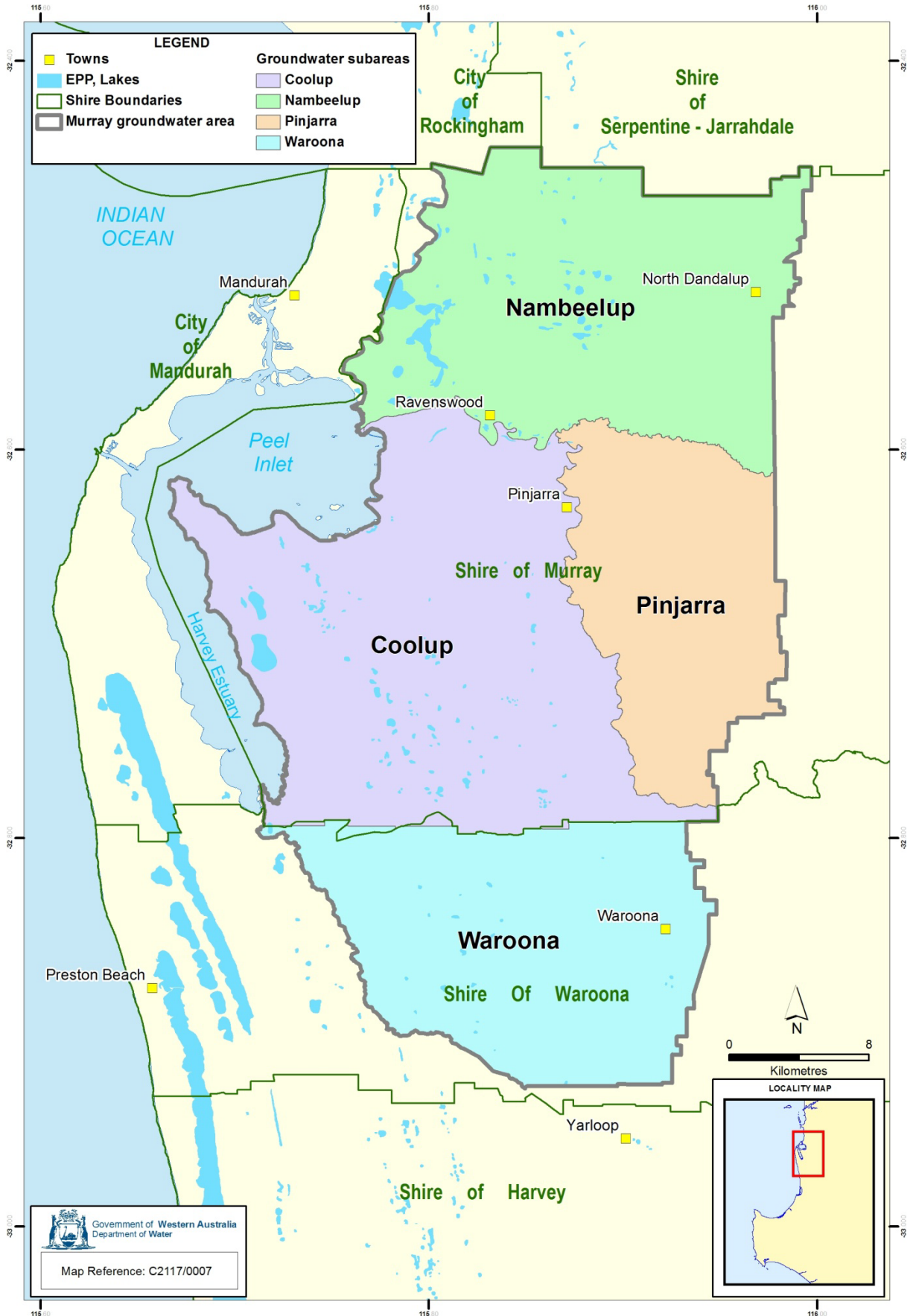


Figure 1 The Murray groundwater area and subarea boundaries

## 1.4 Why we are reviewing the allocation limits

The *Murray groundwater allocation plan* (DoW 2012a) is the first to be completed for these groundwater resources. Development of the allocation plan and replacement of the 1998 allocation limits was triggered by:

- the observed drying climate trend in the south-west of Western Australia
- the limited availability of water from some aquifers in the plan area
- the potential for increased risk to groundwater quality (salinity and acidity) and groundwater-dependent ecosystems from increased abstraction
- proposed development in the Peel region.

## 2 Setting the new allocation limits

The outcomes and objectives in Section 2 of the *Murray groundwater allocation plan* (DoW 2012a) guide the allocation limit decisions described in this report. The objectives encompass the Department of Water principles for setting allocation limits which are:

- maintain reliability of supply for existing water use
- consider the in situ social, cultural and ecological water requirements
- recognise climate variation when making decisions about water availability to make sure the allocation limits are renewable.

This section explains the three stages followed to review of the allocation limits for the Murray groundwater area:

- Stage one: Collect and assess existing information (Section 2.1)
- Stage two: Calculate resource yields (Section 2.2)
- Stage three: Apply allocation limit decisions (Section 2.3).

### 2.1 Stage one - collect and assess existing information

This section describes the water use and groundwater resource information we used to make the allocation limit decisions.

#### Current abstraction

As at April 2012 approximately 15 GL is licensed across the Murray groundwater area. The percentage of the total volume licensed is for:

- mining and industry – 48%
- agriculture – 26%
- parks and conservation – 10%
- commercial, including public water supply – 11%
- backyard bores (self-supply) – 5%.

At the time of release of the plan approximately 40 GL is available for licensing in 13 out of the 15 resources in the plan area.

We have estimated that approximately 4.9 GL is being abstracted for stock and domestic purposes which is exempt from licensing. An explanation of how we determined the volume of unlicensed use is provided in Appendix C.

#### Rainfall

Rainfall data was assessed for the Murray groundwater area from the long-term Pinjarra rainfall station (9596) (Bureau of Meteorology 2010). From 1877 to 2009 the average annual rainfall was 939 mm. The average annual rainfall from 1975 to 2009

was 850 mm which is 14% less than the 970 mm average between 1877 and 1975 (Hall et al 2010).

We have used the average annual rainfall figure of 850 mm (1975–2009) to calculate recharge for the groundwater resources in the plan area. By using this figure we have accounted for the drying climate trend being observed in the south-west of Western Australia (CSIRO 2009) in calculating groundwater yields and setting allocation limits for the Murray groundwater area.

### **Regional water levels and quality**

Aquifers in the plan area extend across management subareas and outside the plan boundary. We assessed monitoring data on groundwater levels and potentiometric heads from state reference network monitoring bores (Figure D2) to identify regional trends and account for groundwater flow outside the Murray groundwater area.

#### *Superficial aquifer*

The department's Harvey Shallow (HS) series superficial aquifer monitoring bores were installed during 1982 and 1983. Water levels have remained relatively steady over the period of record. Seasonal variation in water levels of between 1 metre and 2 metre (and individual fluctuations up to 4 metres) occur between the central and western parts of the Murray groundwater area. Monitoring bores in central and eastern parts have declining groundwater levels in summer and stable levels in winter.

The superficial aquifer tends to become saturated with water close to or at the surface in winter, and in summer the water levels decline. Superficial water levels are locally influenced by the surface drainage network in the plan area.

The clay content of the superficial aquifer generally increases from west to east, the higher the clay content the lower the bore yields are likely to be. Groundwater quality is generally fresh to brackish with salinity levels increasing near the Peel Inlet and Harvey Estuary.

#### *Leederville aquifer*

The Department of Water operates nine Leederville monitoring bores in the Murray groundwater area, all are screened in the lower Leederville aquifer. Seven are located in the Nambeelup and Pinjarra subarea and the northern extent of the Coolup subarea. Four are Artesian Monitoring series bores (AM65A, AM66A, AM68A and AM70A) and three are Mandurah series bores (MH4A, MH9 and MH10S). The remaining two are Harvey Line series bores (HL3A1 and HL4D) which are located in the Waroona subarea.

Potentiometric heads in bores AM65A, AM66A and AM68A have declined by approximately 2 metres since monitoring began in the 1980s, although this declining trend has stabilised in recent years. Only limited data is available from bores MH4A and MH10S, as these were commissioned in 2006 and 2009 respectively.



In the plan area, groundwater flow in the Leederville aquifer is generally in a south-westerly direction and throughflow occurs to the adjacent South West Coastal groundwater area, south of the Harvey Estuary.

The potentiometric head level in Leederville aquifer monitoring bore AM67A located in the Mandurah subarea of the South West Coastal groundwater area dropped below sea level in 1995 and has done so every year since 2001. Declining Leederville aquifer heads in this area increase the risk of the saltwater interface moving inland.

Water quality in the Leederville aquifer ranges from fresh to saline. It is generally fresh adjacent to the Darling Scarp and becomes marginal to brackish towards the west. Salinity also tends to increase with depth, as monitoring data suggests that groundwater in the upper Leederville aquifer is fresher than groundwater in the lower Leederville aquifer.

Salinity levels are higher in the vicinity of the Peel Inlet and Harvey Estuary, where hyper saline conditions exist in the underlying superficial aquifer; in this area it is likely that downward leakage of saline water occurs into the Leederville aquifer.

#### *Yarragadee aquifer (Cattamarra Coal Measures unit)*

There are nine operational bores to monitor potentiometric head in the Yarragadee aquifer. These include five Artesian Monitoring series bores (AM65B, AM66, AM68, AM69, and AM70) and three Mandurah series bores (MH10D, MH14A, MH16A), all of which are in the Nambeelup, Coolup and Pinjarra subareas. One Harvey Line series bore (HL4Y) is located in the Waroona subarea.

Hydrographs for AM66 and AM68 show declines in potentiometric head of 8 metres since monitoring began in 1981 to 2000. The rate of decline has accelerated since 2000 to greater than 8 metres. Declining potentiometric head in the Yarragadee aquifer has been recorded on a regional scale and is attributed to abstraction from both within and outside the Murray groundwater area.

Mandurah series bores MH10D, MH14A and MH16A were constructed in 2009 to replace damaged bores allowing for continued monitoring of the Yarragadee aquifer.

Water quality in the Yarragadee aquifer varies from fresh to saline, with the freshest water being in a zone adjacent to the Darling Scarp. Water quality is generally brackish to saline, with salinity increasing further to the west and with depth.

#### **Groundwater-dependent ecosystems**

Wetlands are generally groundwater-dependent ecosystems which in Western Australia are defined as areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline. Examples are waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries (Government of Western Australia 1997; Tiner 1999). Under the *Wetlands Conservation Policy*, further loss or degradation of valuable wetlands is to be prevented (Government of Western Australia 1997).

The Peel Inlet and Harvey Estuary forms the western boundary of the Murray groundwater area. The estuary system, rivers and wetlands in the area are of regional, state and international importance. They are managed and protected by state, federal and international legislation as well as by state environmental policy, including:

- Environmental Protection Authority System 6 report (EPA 1983)
- Peel–Harvey estuarine system environmental protection policy (EPA 1992a)
- Swan Coastal Plain lakes environmental protection policy (EPA 1992b)
- *Wetlands of the Swan Coastal Plain* (geomorphic database for wetlands of the Swan Coastal Plain) (Hill et al. 1996)
- Convention on wetlands of international importance especially as waterfowl habitat (Ramsar convention of wetlands) (UNESCO 1971).

The Peel Inlet and Harvey Estuary is the principal migration stopover and drought refuge area for waterbirds in the south-west of Western Australia. The estuary is part of the Peel–Yalgorup system which is the largest registered Ramsar site in the state's south-west. It has many interconnected wetlands, lakes, rivers, drainage features and groundwater aquifers. The Lake McLarty system is included in the Peel–Yalgorup system and is located in the Coolup subarea.

Along with the sites listed above, Barragup Swamp is also listed in the *Directory of important wetlands in Australia* (Environment Australia 2001). This state recreation reserve is a major breeding area for the largest known breeding colony of yellow-billed spoonbill in Western Australia.

There are also numerous conservation category wetlands throughout the plan area as identified in the geomorphic wetland database (Figure 2) (Hill et al 1996).

Most of the wetland vegetation and other terrestrial phreatophytic vegetation are groundwater dependent. Over-abstraction of groundwater resources and declining rainfall could adversely affect these groundwater-dependent ecosystems.

For this plan, 25% of calculated recharge was set aside to remain in the superficial and Leederville resources to protect aquifer integrity, in situ values and groundwater-dependent ecosystems. The allocation limits are based on the remaining 75% of calculated recharge.



Figure 2 Location and classification of wetlands in the Murray groundwater area

## Regional growth and future demand for water

The Murray groundwater area is mainly rural with pockets of urban and industrial land use.

The Department of Planning released two strategic land-use planning documents that cover most of the Murray groundwater area:

- *Directions 2031: spatial framework for Perth and Peel* (WAPC 2010).
- *Southern metropolitan and Peel sub-regional structure plan* (WAPC 2009).

These documents identify localities subject to immediate and future investigation for development. North Dandalup, Pinjarra, Yunderup, Ravenswood and Furnissdale in the north of the plan area are identified as locations to be developed for urban residential, light commercial, industrial, special rural and public open space.

The focus for development outside these locations is rural and related activities such as agriculture, strategic infrastructure, resource use and conservation.

The Waroona subarea is outside the planning boundary of these land-use planning documents.

Population in the Murray groundwater area is projected to increase from 13 000 in 2008 to 22 500 in 2030 (WAPC 2009). Population growth, land-use change and urban sprawl from Mandurah and Pinjarra will place additional pressure on scheme water and possibly local groundwater resources.

Additionally, residential and economic development in the Murray groundwater area faces the dual challenges of extensive areas of seasonally inundated land and limited availability of good quality groundwater in the future. The *Murray drainage and water management plan* (DoW 2011) is a guide to reduce the risk of flooding and inundation in urban development. It promotes fit-for-purpose use of drainage and stormwater by incorporating it into the urban water cycle via storage in winter for use in summer.

The Water Corporation's Integrated Water Supply Scheme provides public drinking water to most localities in the Murray groundwater area. Water for the scheme is obtained from outside the plan area. A one gigalitre public water supply licence is current in the plan area but is not utilised due to poor quality. There is no drinking water source protection in the Murray groundwater area because the groundwater quality is not suitable for public water supply. Water quality ranges from brackish to saline in all resources and the hydrogeology of the superficial aquifer is such that bores are low yielding.

## 2.2 Stage two - calculate resource yields

The groundwater yield of each resource was estimated using the same method as that used in the 1998 allocation planning process (Appendix B) with up-to-date information applied. The recharge rates and yield calculation method applied to both the superficial and Leederville aquifers are described in Appendix A.

The average annual rainfall figure of 850 mm (1975–2009) was used for this review as opposed to 900 mm (1907–1998) used in the 1998 plan (unpublished). By using the annual average rainfall figure from the recent period we have accounted for the drying climate trend being observed in the south-west of Western Australia (CSIRO 2009).

Consistent with Davidson (1995), groundwater yield was limited to 75% of total rainfall recharge in the superficial and Leederville resources, leaving 25% remaining to:

- prevent inland movement of the saltwater interface along the Peel Inlet, Harvey Estuary and lower reaches of the Serpentine River
- protect groundwater-dependent ecosystems
- maintain groundwater flow.

### *Superficial aquifer*

Recharge to the superficial aquifer has been calculated as a percentage of average annual rainfall, 850mm. The percentage used depends upon the nature of the aquifer. Recharge rates of 10% for sandy areas and 3% for clayey areas were adopted for the superficial aquifer (Davidson 1995) as recharge is higher in sandy zones and lower in clayey zones. For this plan we re-mapped the distribution of sand and clay in the superficial aquifer to determine a more accurate estimate of recharge based on average annual rainfall (Appendix E).

Estimated yields for the superficial aquifer are presented in Table 1.

### *Leederville aquifer*

The distribution of the upper and lower Leederville aquifer was re-mapped for this planning process (Appendix E). This exercise involved re-investigation and interpretation of geological logs from existing monitoring bores.

Recharge to the upper and lower Leederville aquifers is from downward leakage from the overlying superficial aquifer. The recharge rate was calculated using the distribution of overlying sandy and clayey zones of the superficial aquifer. Recharge rates of 3% where the overlying stratum is predominantly sandy and 1% where it is predominantly clayey were adopted for the Leederville aquifer (Davidson 1995).

Estimated yields for the upper and lower Leederville aquifer are presented in Table 2.

### *Cattamarra Coal Measures*

The annual recharge of the Cattamarra Coal Measures was not re-calculated for this review. Recharge was estimated to be 3.1 GL/year for the Murray groundwater area in 1998 (Appendix B).

Table 1 Estimated yield for the superficial aquifer

Subarea	Area of sand km <sup>2</sup>	Area of clay km <sup>2</sup>	Combined area km <sup>2</sup>	Total recharge GL/yr	75% of recharge GL/yr	Induced recharge to Lower Leederville GL/yr	Net yield GL/yr <sup>1,2</sup>
Coolup	228.07	133.51	361.58	22.79	17.09		17.00
Nambeelup	207.99	65.95	273.94	19.36	14.52	-1.00	13.50
Pinjarra	0.00	143.01	143.01	3.65	2.73	-1.00	1.70
Waroonna	102.81	131.28	234.09	12.09	9.06	-1.00	8.00
<b>Total</b>	<b>538.87</b>	<b>473.75</b>	<b>1012.62</b>	<b>57.89</b>	<b>43.40</b>	<b>-3.00</b>	<b>40.20</b>

<sup>1</sup>The net yield = total recharge minus 25% to remain in situ and minus 1 000 000 kL/yr (induced recharge to the Lower Leederville aquifer in the Nambeelup, Pinjarra and Waroonna subareas).

<sup>2</sup>All net yields are rounded down to the nearest 100 000 kL/yr.

Table 2 Estimated yield for the Leederville aquifer

Subarea	Aquifer	Area of sand km <sup>2</sup>	Area of clay km <sup>2</sup>	Combined area km <sup>2</sup>	Total recharge GL/yr	75% of recharge GL/yr	Induced recharge from superficial GL/yr	Net yield <sup>1, 2</sup> GL/yr
Coolup	Upper Leederville	220.86	53.79	274.65	6.09	4.57		4.50
	Lower Leederville	7.20	79.72	86.92	0.86	0.65		0.60
Nambeelup	Upper Leederville	152.96	2.68	155.64	3.92	2.94		3.00
	Lower Leederville	55.03	57.00	112.03	1.89	1.42	+ 1.00	2.40
Pinjarra <sup>3</sup>	Lower Leederville	0.00	127.44	127.44	1.08	0.81	+ 1.00	1.80
Waroon	Upper Leederville	102.81	43.09	145.90	2.99	2.24		2.20
	Lower Leederville	0.00	88.20	88.20	0.75	0.56	+ 1.00	1.50
<b>Total</b>		<b>538.86</b>	<b>451.92</b>	<b>990.78</b>	<b>17.58</b>	<b>13.19</b>	<b>+3.00</b>	<b>16.00</b>

<sup>1</sup>Induced recharge of 1 000 000 kL/yr from the superficial aquifer is assigned to the lower Leederville resource in the subareas of Nambeelup, Pinjarra and Waroon.

<sup>2</sup>All net yields are rounded down to the nearest 100 000 kL/yr.

<sup>3</sup>The Upper Leederville is absent in the Pinjarra subarea.

## 2.3 Stage three - apply allocation limit decisions

The objectives for the Murray groundwater area are to maintain groundwater flow, groundwater-dependent ecosystems and water quality. They guide development of the local licensing policies in Section 4.3 of the allocation plan and the allocation limits decisions described below.

In addition to the objectives and the information assessed in Section 2.1, other important local factors considered in setting the allocation limits were:

- to protect reliability of supply for existing water users
- any pending applications and the future demand for urban and industrial development north-east of the Peel Inlet and Harvey Estuary
- the results of hydrogeological investigations submitted in support of licence applications.

### **Superficial and Rockingham Sands aquifers**

In all subareas, the allocation limits set for the superficial resources are equal to the estimated yield. These allocation limits are sufficient to:

- maintain reliability of supply for existing use
- provide water for future development of small scale, distributed abstraction.

Bore yields and water quality are generally low from the superficial resource throughout most of the Murray groundwater area. The superficial and Rockingham Sand aquifers are managed as a single resource for allocation purposes because they are hydraulically connected in the Nambeelup and Coolup subareas.

### **Leederville aquifer**

The allocation limits set for five Leederville resources are equal to estimated yield. These allocation limits are sufficient to:

- maintain reliability of supply for existing use
- provide fit-for-purpose water for future development.

We have set allocation limits that are greater than estimated yield for two Leederville resources in the Coolup and Nambeelup subareas. This is because there is local hydrogeological evidence to indicate that these resources can maintain a higher level of abstraction without adversely affecting existing use or groundwater-dependent ecosystems. We will monitor and manage abstraction in these resources through our licensing process and regional monitoring network. Monitoring data will be reported in the evaluation statements (Section 6 in the plan).

### *Coolup subarea*

Licensed abstraction and abstraction volumes requested in pending applications from the Coolup upper Leederville resource are low (as at April 2012). To provide for



predicted future development in the area the allocation limit is set at 4.50 GL/year which is equal to estimated yield (Table 2).

The estimated yield of the lower Leederville in the Coolup subarea is 0.60 GL/year. This is lower than licensed entitlements which total 1.15 GL/year (as at September 2011). Evidence that this level of abstraction can be maintained above yield is provided by a hydrogeological investigation submitted by a licence applicant and ongoing groundwater monitoring by the department.

The department has used this evidence to cap abstraction at the total of entitlements as at September 2011. The allocation limit for the Coolup lower Leederville resource has been reduced from 1.50 GL/year in the plan for public comment to 1.15 GL/year.

There are no pending applications for this resource (as at April 2012) and, due to water availability and shallower depth, the upper Leederville is a suitable alternative option to support future development in this subarea.

#### *Nambeelup subarea*

Licensed abstraction from the Nambeelup upper Leederville resource is low, but volumes requested in pending applications suggest demand is high (as at April 2012). The allocation limit for the Nambeelup upper Leederville resource has been reduced from 4.00 GL/year in the plan for public comment to 3.00 GL/year which is now equal to estimated yield (Table 2). This allocation limit provides for existing use and future development, subject to hydrogeological investigations.

The estimated yield of the lower Leederville resource in the Nambeelup subarea is 2.40 GL/year. This is above licensed entitlements which total 1.16 GL/year (total as at April 2012). Local hydrogeological evidence submitted by a licence applicant indicates that the resource can sustain an annual abstraction of up to 3.00 GL/year (EPA 2009). We have used this evidence to set the allocation limit at 3.00 GL/year, allowing for some development.

#### *Pinjarra and Waroona subareas*

Licensed abstraction and demand from the upper and lower Leederville resources in the Pinjarra and Waroona subareas is low (as at April 2012). The allocation limits for the Leederville resources in these subareas are set equal to estimated yield. The allocation limits are sufficient to:

- maintain reliability of supply for existing use
- provide fit-for-purpose water for future development.

#### **Cattamarra Coal Measures**

Current licensed entitlements from the Cattamarra Coal Measures resource are in excess of the 1998 *recharge* estimate of 3.10 GL/year.

In the Nambeelup and Pinjarra subareas current, permanent entitlements from the Cattamarra Coal Measures total 3.19 GL/year (0.59 GL/year and 2.60 GL/year respectively). The sustainability of these entitlements is supported by modelling and

ongoing monitoring by a licence holder in the Pinjarra subarea. We have used this evidence to set the allocation limit above the 1998 *recharge* estimate at the total of the current entitlements.

The department has set nominal allocation limits of 0.10 GL/year from the Cattamarra Coal Measures in the Coolup and Waroona subareas for water accounting purposes. The availability of these allocations is not supported by yield estimates and there are currently no licensed entitlements from this resource in these subareas.

Applicants seeking water from the Cattamarra Coal Measures resource may be required to complete hydrogeological investigations. The department's licensing decisions will also be guided by state-wide and local licensing policies described in Section 4 of the *Murray groundwater allocation plan* (DoW 2012a).

### **Fractured rock aquifer**

Allocation limits for the fractured rock resource were set for accounting purposes only in the department's water licensing database. These limits do not represent expected yield and have not been included in the allocation limits table because the aquifer is highly variable and unpredictable in nature. Consequently, reliable allocation limits cannot be set.

Groundwater licence applications for the fractured rock aquifer along the Darling Scarp will continue to be allocated on a case by case basis. Impact management assessments are required for fractured rock licence applications and should be conducted in accordance with the licensing policies in the *Murray groundwater allocation plan* (DoW 2012a).

### 3 Allocation limits

The allocation limits form the basis of the *Murray groundwater allocation plan* (DoW 2012a) and are the main tool we use to manage abstraction in the plan area (Table 3).

In the Murray groundwater area the allocation limits are split into two components:

- licensable (general licensing, public water supply)
- unlicensable (exempt use including stock and domestic).

The volume of water set aside for licensing is the allocation limit minus the volume of water estimated and set aside for the unlicensed component.

The actual volume of water available for licensing is subject to change as licence entitlements are issued or amended. Proponents are encouraged to contact the department's Kwinana Peel regional office in Mandurah or check the online water register on our website at <[www.water.wa.gov.au](http://www.water.wa.gov.au)>.

Table 3 Allocation limits and components in the Murray groundwater area

Subarea	Resource	Allocation limit GL/yr	Allocation limit components GL/yr			Is water available for licensing <sup>2</sup> ? (at April 2012)
			Unlicensable exempt use	Licensable general licensing	Licensable public water supply <sup>1</sup>	
Coolup	Superficial Swan	17.00	1.90	15.10		Yes
	Upper Leederville	4.50	0.00	4.50		Yes
	Lower Leederville	1.15 <sup>3</sup>	0.00	1.15		No
	Cattamarra	0.10	0.00	0.10		Restricted
	<b>Total</b>	<b>22.75</b>	<b>1.90</b>	<b>20.85</b>	<b>0.00</b>	
Nambeelup	Superficial Swan	13.50	1.40	12.10		Yes
	Upper Leederville	3.00 <sup>3</sup>	0.00	3.00		Limited
	Lower Leederville	3.00	0.00	2.00	1.0	Limited
	Cattamarra	0.60	0.00	0.60		Restricted
	<b>Total</b>	<b>20.10</b>	<b>1.40</b>	<b>17.70</b>	<b>1.00</b>	
Pinjarra	Superficial Swan	1.70	0.45	1.25		Yes
	Lower Leederville	1.80	0.00	1.80		Yes
	Cattamarra	2.60	0.00	2.60		No
	<b>Total</b>	<b>6.10</b>	<b>0.45</b>	<b>5.65</b>	<b>0.00</b>	
Waroona	Superficial Swan	8.00	1.20	6.80		Yes
	Upper Leederville	2.20	0.00	2.20		Yes
	Lower Leederville	1.50	0.00	1.50		Yes
	Cattamarra	0.10	0.00	0.10		Restricted
	<b>Total</b>	<b>11.80</b>	<b>1.20</b>	<b>10.60</b>	<b>0.00</b>	
<b>Total for the plan area</b>		<b>60.75</b>	<b>4.95</b>	<b>54.80</b>	<b>1.00</b>	

<sup>1</sup> There are no drinking water source protection areas in the Murray groundwater area. The 1 GL is licensed for public water supply but is commissioned for emergency purposes only due to poor quality.

<sup>2</sup> Available water applies to the general licensing component only. 'Yes' means the component is less than 70% licensed, 'Limited' means more than 70% of the component is licensed, 'No' means 100% of the component is licensed and alternative sources such as trading or managed aquifer recharge should be investigated. Cattamarra is restricted by depth, availability and quality.

<sup>3</sup> These allocation limits have been reviewed and reduced since the plan for public comment Section 2.3 explains the allocation limit decision.

## Appendices

### Appendix A – Recharge rate and yield calculation method

The following method was used to calculate groundwater yields in the 1998 and 2009 allocation limit reviews for the superficial aquifer and the 2009 allocation limit review for the Leederville aquifer.

#### Recharge

$$\text{Total recharge (kL/yr)} = (a \times b \times c \times 1000) + (d \times e \times c \times 1000)$$

a = area of sand (km<sup>2</sup>) (see Figure E1)

b = rainfall recharge rate in sand (%)

c = mean rainfall (mm)

d = area of clay (km<sup>2</sup>) (see Figure E3)

e = rainfall recharge rate in clay (%)

Groundwater storage and yield on the coastal plains depends on the proportion of sand to clay, with high proportions of clay usually associated with poor quality groundwater and low yields. The rainfall recharge rates used in the total recharge calculations are:

Superficial	Mostly sand recharge rate	10% (0.1)
	Mostly clay recharge rate	3% (0.03)
Upper and lower Leederville	Mostly sand recharge rate	3% (0.03)
	Mostly clay recharge rate	1% (0.01)

#### Yield calculation

$$\text{Net yield (kL/yr)} = (75\% \times \text{total recharge}) - \text{induced recharge to lower Leederville}$$

The net yield was limited to 75% of total recharge in the superficial and Leederville resources meaning 25% remains in situ to:

- maintain groundwater flow
- meet environmental needs
- prevent the saltwater interface moving inland.

The lower Leederville aquifer is hydraulically connected with the overlying superficial aquifer in the Nambelup, Pinjarra and Waroona subareas. An assumed induced recharge volume of 1.00 GL/year was deducted from the superficial recharge volume and added to the lower Leederville recharge volume in these subareas.

## Appendix B – 1998 yield calculations and allocation limits

### Superficial aquifer

Although the superficial aquifer is relatively thin in most parts of the Murray groundwater area, it is a significant groundwater resource. Groundwater in this aquifer supports environmental features such as wetlands and phreatophytic vegetation. The potential ecological effects of lowering the groundwater level in this aquifer limits the quantity of groundwater that can be taken without causing a long-term decrease in the resource yield.

The physiography of the Murray groundwater area can be divided into areas where the sand content is high or clay content is high. Sandy areas comprise the Bassendean Dunes and the Spearwood Dunes to the west of the Darling Fault and the Ridge Hill Shelf that occurs both east and west of the Darling Fault. Clay areas comprise the geomorphic unit of the Pinjarra Plain (Deeney 1989a).

The groundwater storage capacity and its potential yield depend upon the proportion of sand to clay. High proportions of clay are usually associated with poor quality groundwater and low yields. Clay also forms a relatively impervious (confining) layer. Quantifying the yield from the superficial aquifer with a high degree of confidence is difficult because of the:

- lack of a strongly defined regional flow system
- presence of rivers, drains and wetlands
- variability of sediments ranging from clays to sand and limestone
- variable thickness of the aquifer
- varying contact with underlying aquifers, which range from clays of the upper and lower Leederville aquifer to sands and sandstone of the Cattamarra Coal Measures.

For allocation planning purposes, the yield of the superficial aquifer in the Murray groundwater area has been estimated in bulk terms as a proportion of rainfall recharge using a percentage of rainfall. An annual rainfall recharge rate of 10% was selected for areas consisting mainly of sand and 3% was selected for areas consisting mainly of clay.

Other factors affecting the recharge rate, and hence the calculation of groundwater yields, are:

- vegetation cover
- rainfall and infiltration rates
- depth to watertable
- variable sediments e.g. clay, sand
- surface soil types and land use

- variable thickness of formation
- effects from underlying formations
- presence of rivers, drains and wetlands
- water quality.

To allow for these factors, the net yield has been limited to 75% of the total annual groundwater recharge minus induced recharge to the lower Leederville aquifer, where it is in hydraulic connection with the superficial aquifer. This reserves groundwater to support regional throughflow, which is believed to be relatively inactive in the confined aquifers beneath the superficial aquifer. This is required to allow flow through to the Peel Inlet and Harvey Estuary to prevent the movement of saline water further inland and maintain groundwater-dependent ecosystems.

### **Rockingham Sand aquifer**

The Rockingham Sand aquifer is hydraulically connected to the superficial aquifer. Its known extent is limited to the north-western part of the Murray groundwater plan area (in the Nambeelup and Coolup subarea). It is found at shallow depth due to the thin nature of the superficial formation sediments overlying it. The aquifer reaches a maximum known thickness of approximately 60 metres in the plan area.

Groundwater salinity is highly variable, ranging from about 500 to >3000 milligrams per litre of total dissolved solids.

Groundwater in this aquifer flows over a saltwater interface to the ocean. Upward migration of the saltwater interface into this aquifer may occur as a result of excessive groundwater abstraction. Because of this, abstraction from this aquifer will be restricted.

For allocation purposes the Rockingham Sand aquifer has been included as part of the superficial aquifer enabling both to be managed as a single resource.

Table B1 1998 allocation limit calculations for the superficial aquifer

Subarea	Area of sand km <sup>2</sup>	Area of clay km <sup>2</sup>	Combined area km <sup>2</sup>	Recharge sand area kL/yr	Recharge clay area kL/yr	Total recharge kL/yr	75% of recharge kL/yr	Induced recharge to Leederville aquifer kL/yr	Net yield kL/yr	Allocation limit kL/yr
Coolup	273	87	360	24 570 000	2 349 000	26 900 000	20 175 000		20 175 000	20 200 000
Nambeelup	157	110	267	14 130 000	2 970 000	17 100 000	12 825 000	-1 000 000	11 825 000	11 800 000
Pinjarra	0	127	127	0	3 429 000	3 400 000	2 550 000	-1 000 000	1 550 000	1 500 000
Warooka	67	155	222	6 030 000	4 185 000	10 200 000	7 650 000	-1 000 000	6 650 000	6 600 000
<b>Total</b>	<b>497</b>	<b>479</b>	<b>976</b>	<b>44 730 000</b>	<b>12 933 000</b>	<b>57 600 000</b>	<b>43 200 000</b>	<b>-3 000 000</b>	<b>40 200 000</b>	<b>40 100 000</b>

Note: Allocation limits were based on net yields for each subarea rounded to the nearest 1000 kL/yr.

**Assumptions:**

Rainfall recharge rate in sand: 10%

Rainfall recharge rate in clay: 3%

Estimated mean rainfall over last 30 years = 900 mm/yr (1998)

The areas of sand and clay are based on the 1998 mapping of the geomorphology



## Leederville aquifer

The Leederville aquifer in the Murray groundwater area is divided into two main aquifers for management purposes. It comprises the Pinjar Member (if present) and Wanneroo Member in the upper Leederville aquifer, and the Mariginiup Member in the lower Leederville aquifer. All members are from the Leederville Formation.

The Leederville aquifer extends throughout most of the Murray groundwater area and is readily accessible and found at shallow depths because the overlying superficial sediments are thin, generally less than 35 metres thick. The Leederville aquifer is known to be absent from a small area within the Pinjarra subarea, where the Cattamarra Coal Measures underlies the superficial aquifer. Groundwater in the Leederville aquifer generally flows from east to west and discharges into the ocean. However, some groundwater from the Leederville aquifer also discharges into the Rockingham Sand aquifer.

Recharge to the Leederville aquifer occurs in areas where downward heads are prevalent. Davidson (1995) indicated that the recharge rate is approximately 2 to 3% of the total annual rainfall over the recharge areas. Recharge areas contributing to the upper and lower Leederville aquifers were selected where the watertable in the superficial aquifer was higher than the 5.0 metre Australian height datum contour. Using a method similar to that adopted for determining recharge to the superficial aquifer, recharge rates were calculated based primarily on surface geology.

Downward leakage from the superficial aquifer is the main mechanism of groundwater recharge to the Leederville aquifer (Commander 1982). Due to the thin layer of surficial sediments overlying the Leederville aquifer near the Darling Fault, abstraction from the lower Leederville aquifer induces leakage from the superficial aquifer. An assumed induced recharge volume of 1 000 000 kL/year has been deducted from the superficial aquifer and added to the Lower Leederville aquifer recharge volumes in the Nambelup, Pinjarra and Waroona subareas.

No groundwater volumes from the upper Leederville aquifer were assigned as throughflow to the Falcon and Mandurah subareas of the South West Coastal groundwater area. This is because groundwater flow from the upper Leederville aquifer, west of the green clay marker bed, is believed to discharge to the Peel Inlet and Rockingham Sand aquifer.

Table B2 shows the allocation limits set for the Leederville aquifer from the 1998 review. The calculations are not presented (as in Table B1) because they were not documented.

## Cattamarra Coal Measures unit

The Cattamarra Coal Measures unit extends throughout the Murray groundwater area. It is found at shallow depth along the Darling Scarp and progressively deepens to the west, where it underlies the Leederville aquifer and South Perth Shale aquitard. Groundwater in the Cattamarra Coal Measures generally flows from east to west and discharges into the ocean.

Recharge by infiltration from streamflow and rainfall occurs where the Cattamarra Coal Measures is directly overlain by the superficial formations, and by downward leakage from the Leederville Formation.

The Cattamarra Coal Measures is recharged in the low salinity zones at a rate of 1 to 2% of the total annual rainfall. This estimate is supported by Alcoa's preliminary numerical flow modelling of the superficial and Leederville aquifers and Cattamarra Coal Measures unit (Hydrosearch 2010).

Davidson (1995) contended that most of the groundwater flow takes place in the top part of the aquifer, at least in the top 500 m. Below this depth, the increasing groundwater salinity indicated a lack of flushing, implying limited groundwater flow.

Commander (1982) and Davidson (1995) estimated that the area contributing to recharge north of the South Dandalup River is approximately 120 km<sup>2</sup>. This is in addition to the area recharging the Cattamarra Coal Measures south of the South Dandalup River. Additional recharge to the Cattamarra Coal Measures may be induced near the Darling Scarp (east of Pinjarra) as a result of abstraction from the aquifer. The annual recharge to the Cattamarra Coal Measures has been estimated to be 3 100 000 kL/year, based on a recharge rate of 1.5% of the mean annual rainfall of 900 mm.

Data from the Harvey borehole line (Deeney 1989b) implies that the main recharge area for the Cattamarra Coal Measures is west of the Harvey River Main Drain (outside the Murray groundwater area), where the Leederville aquifer consists mostly of sand and the heads are downward. The extent of this recharge area is not known. Recharge east of the Harvey River Main Drain near Waroona is considered negligible due to the predominance of confining siltstone and shale layers in the Leederville aquifer.

In the 1998 review, the Cattamarra Coal Measures allocation limits were set using the following assumptions:

- The allocation limit in the Nambelup subarea was set to zero (as there were no licensed entitlements at the time) to ensure other aquifers were used as sources for any new allocations in the subarea.
- The allocation limits for Coolup and Pinjarra subareas were set equal to current licensed entitlements. Any further access to this aquifer required a detailed hydrogeological investigation before the allocation limits could be reviewed.
- The allocation limit in the Waroona subarea was set to zero as the aquifer has no known recharge.

Table B2 shows the allocation limits set for the Cattamarra Coal Measures from the 1998 review. The calculations are not presented because they were not documented.

**Table B2** 1998 allocation limits set for the upper and lower Leederville and Cattamarra Coal Measures

Subarea	Allocation limit GL/yr			Total
	Resource			
	upper Leederville	lower Leederville	Cattamarra Coal Measures	
Coolup	3 500 000	4 500 000	100 000	
Nambeelup	6 000 000	3 000 000 <sup>1</sup>	0	
Pinjarra	100 00	2 500 000 <sup>1</sup>	2 600 000	
Waroona	0	7 500 000 <sup>1</sup>	0	
<b>Total</b>	<b>9 600 000</b>	<b>17 500 000</b>	<b>2 700 000</b>	<b>29 800 000</b>

<sup>1</sup> The allocation limit for these subareas = estimated annual groundwater recharge plus 1 000 000 kL/yr which forms part of the recharge from the overlying superficial aquifer.

The updated allocation limits are generally lower than those set in 1998 for the confined aquifers and are higher for the superficial aquifer.

**Table B3** Comparison of the 1998 to 2011 allocation limits for the Murray groundwater area

Subarea	Aquifer	1998 allocation limit kL/yr	2011 allocation limit kL/yr
Coolup	Superficial Swan	20 200 000	17 000 000
	Upper Leederville	3 500 000	4 500 000
	Lower Leederville	4 500 000	1 158 400
	Cattamarra	100 000	100 000
Nambeelup	Superficial Swan	11 800 000	13 500 000
	Upper Leederville	6 000 000	3 000 000
	Lower Leederville	3 000 000	3 000 000
	Cattamarra	0	600 000
Pinjarra <sup>1</sup>	Superficial Swan	1 500 000	1 700 000
	Upper Leederville	100 000	0
	Lower Leederville	2 500 000	1 800 000
	Cattamarra	2 600 000	2 600 000
Waroona <sup>2</sup>	Superficial Swan	6 600 000	8 000 000
	Upper Leederville	0	2 200 000
	Lower Leederville	7 500 000	1 500 000
	Cattamarra	0	100 000
<b>Total</b>		<b>69 900 000</b>	<b>60 758 400</b>

<sup>1</sup> The 2010 review determined that the Upper Leederville aquifer is not present in the Pinjarra subarea.

<sup>2</sup> The 2010 review determined that the Upper Leederville aquifer is present in the Waroona subarea.

## Appendix C – Determining the volume of water to set aside for exempt unlicensed use, 2009

The allocation limit determines the volume of water that is to be set aside for use, including unlicensed use. When determining the amount of water available for licensing it is important to understand how much is being used for stock, domestic and garden purposes, all of which are exempt from licensing.

Bores are exempt from licensing if their construction and 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 means that any use of water from the superficial aquifer in the Murray groundwater area is exempt from licensing if it is for the following purposes:

- for firefighting
- to water 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)
- for watering an area of lawn or garden that does not exceed 0.2 hectares
- other ordinary domestic uses.

### Information used to estimate unlicensed use

Unlicensed use in the Murray groundwater area was estimated using the following information:

- local and regional knowledge of unlicensed water use in the area
- recent investigations funded by the Department of Water into the incidence of bores and their water use in the Perth metropolitan area
- water use factors for domestic bore use, based on Strategic policy no. 2.03 – *Managing unlicensed groundwater use* (DoW 2009).

Data on lot zoning, size and number were obtained from the department's GIS cadastral database, which is supplied by the Department for Planning.

Superficial aquifer licences in the Murray groundwater area were reviewed on a subarea basis to establish what volume on the licence is assigned for stock, domestic and/or garden purposes.

### Assumptions

Because the volumes are not formally captured through licensing, unlicensed use must be estimated using assumptions. In the Murray groundwater area the following assumptions were used for this allocation limits review:

- all unlicensed use is abstracted from the superficial aquifer
- all use for stock, domestic and garden purposes not taken from the superficial aquifer is licensed

- water use estimates for domestic bores in the Murray groundwater area for each land planning type were:
  - urban areas: 400 kL/year as it is mostly for garden use
  - semi-rural areas: 800 kL/year as it is mostly for garden, occasional domestic use and small numbers of stock
  - rural areas: 1500 kL/year as it is likely to be either for stock use only or for combined domestic, garden and small numbers of stock.
- no unlicensed take was assumed for areas of crown reserve or land zoned as shops, vacant, service station or foreshore in the cadastral GIS layer used.

No account was made for future increases or decreases in unlicensed use across the plan area.

### **Methodology**

To determine the estimated volume of unlicensed use the following steps were taken:

- Data was collected on the number of blocks, block size and land-use zoning and filtered using the assumptions for each subarea.
- Data was collected on the volume of licensed entitlements for each subarea in the superficial aquifer where a proportion of use was assigned as stock, domestic and/or garden purposes.
- Estimates of total (licensed and unlicensed) stock, domestic and garden use were calculated using the assumptions above (See Table C1).
- The licensed volumes for stock, domestic and garden purposes were subtracted from the estimated totals. (See Table C2).
- The calculated estimates of unlicensed use were rounded to the nearest 50 000 kL/year to get the final estimated volume of unlicensed use to be used in the allocation limit setting process.
- The estimates were crosschecked with estimates of unlicensed use by Hall et al. (2010).

The results of this process are given in tables C1 and C2 and are accurate as at December 2009.

## Calculations

Table C1 Calculation of total stock, domestic and garden use

Subarea	Block size m <sup>2</sup>	Number of blocks	Percentage of blocks with bore %	Indicative use kL/yr	Estimated volume of stock and domestic use <sup>1</sup> kL/yr
Coolup	Urban (< 1000)	2058	30	400	246 960
	Semi-rural (1000–5000)	915	50	800	366 000
	Rural (> 5000)	1141	80	1500	1 369 200
	<b>Subtotal</b>	<b>4114</b>			<b>1 982 160</b>
Nambeelup	Urban (< 1000)	693	30	400	83 160
	Semi-rural (1000–5000)	582	50	800	232 800
	Rural (> 5000)	1110	80	1500	1 332 000
	<b>Subtotal</b>	<b>2385</b>			<b>1 647 960</b>
Pinjarra	Urban (< 1000)	386	30	400	46 320
	Semi-rural (1000–5000)	134	50	800	53 600
	Rural (> 5000)	321	80	1500	385 200
	<b>Subtotal</b>	<b>841</b>			<b>485 120</b>
Waroona	Urban (< 1000)	449	30	400	53 880
	Semi-rural (1000–5000)	717	50	800	286 800
	Rural (> 5000)	736	80	1500	883 200
	<b>Subtotal</b>	<b>1902</b>			<b>1 223 880</b>
<b>Total</b>		<b>9242</b>			<b>5 339 120</b>

<sup>1</sup>Estimated volume of unlicensed use = number of blocks x percentage of blocks with bore x volume of likely use (kL/yr)

Table C2 Estimation of unlicensed use in the Murray groundwater area

Subarea	Calculated estimation of stock and domestic use <sup>a</sup> kL/yr	Licensed stock, domestic and garden use <sup>b</sup> kL/yr	Estimate of unlicensed use <sup>c</sup> kL/yr	Final estimated volume of unlicensed use <sup>d</sup> kL/yr
Coolup	1 982 160	76 750	1 905 410	1 900 000
Nambeelup	1 647 960	274 950	1 373 010	1 400 000
Pinjarra	485 120	38 350	446 770	450 000
Waroona	1 223 880	49 650	1 174 230	1 200 000
<b>Total</b>	<b>5 339 120</b>	<b>439 700</b>	<b>4 899 420</b>	<b>4 950 000</b>

Column c = a – b

Column d = c rounded to the nearest 50 000 kL/yr.

## Appendix D – Distribution of sand and clay in 2009 recharge calculations

For the 2009 allocation limit review, the Department of Water has revised and updated the distribution of sand and clay sediments used in the 1998 recharge calculations. The following information was reviewed:

- the distribution of sand and clay in the superficial formations located in the plan area (Table D1 and Figure D1)
- the distribution of sub-cropping (shallow) upper Leederville and lower Leederville aquifers beneath the superficial formations, the following (Table D2 and Figure D3)

### Distribution of sand and clay in the superficial formations

We used the following maps, hydrogeological information and cross-sections to construct the distribution of sand and clay in the superficial formations (Figure D1):

- Information from departmental and other monitoring and investigation bores (Figure D2)
  - new HS-series and T-series monitoring bore logs in the Nambeelup and Coolup subareas
  - Lake Thomson series bores (T-series) monitoring bore logs
  - Harvey Shallow series bores (HS-series) monitoring bore logs
  - Mandurah series bores (M-series) monitoring bore logs
  - artesian monitoring series bores (AM-series) monitoring bore logs
  - Harvey Line series bores (HL-series) monitoring bore logs
  - cross-sections generated for the T-series bores in the northern part of the Nambeelup subarea
  - GHD investigation bore logs from May to July 2009
- Western Australian geological survey maps
- Pinjarra, Western Australia 1:50 000 urban geology series
- Mandurah, Western Australia 1:50 000 urban geology series
- Lake Clifton-Hamel, Western Australia 1:50 000 environmental geology series
- *Geology and groundwater resources of the superficial formations between Pinjarra and Bunbury, Perth Basin* (Deeney 1989a)
- *Hydrogeology of the Harvey Borehole line, Perth Basin* (Deeney 1989b)
- *Murray hydrological studies: Surface water, groundwater and environmental water, Conceptual model report* (Hall et al. 2010)

- *Shallow groundwater drilling – Swan coastal plain bore completion report* (URS 2008).

Lithology logs were reviewed and the dominant superficial geology (i.e. clay or sand) was annotated on maps for each bore. Areas of clay and sand were interpreted around clusters of similar lithology. Information from Western Australian geological survey maps was used as an aid to interpretation where coverage of drilling data was poor. This was particularly the case around the eastern side of the Pinjarra subarea.

An area of variable lithology with negligible recharge and poor aquifer potential has been mapped along part of the Darling Scarp in the Pinjarra subarea (Figure D1).

*Table D1 Area of sand and clay in the superficial formations*

<b>Subarea</b>	<b>Sand km<sup>2</sup></b>	<b>Clay km<sup>2</sup></b>	<b>Total km<sup>2</sup></b>
Coolup	228	134	362
Nambeelup	208	66	274
Pinjarra	0	143	143
Waroona	103	131	234
<b>Total</b>	<b>539</b>	<b>474</b>	<b>1013</b>



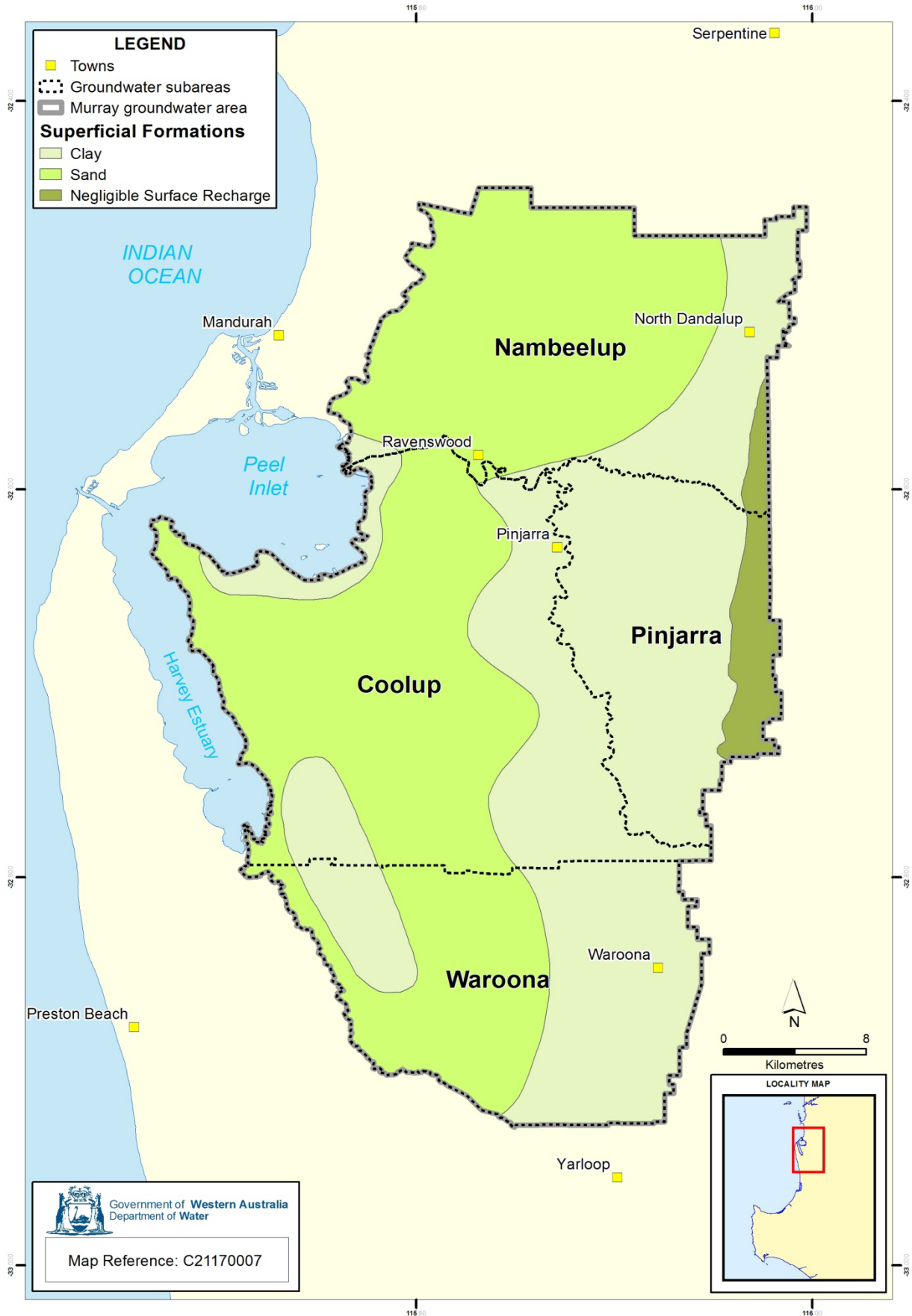


Figure D1 Area of sand and clay in the superficial formations



## Distribution of the upper Leederville and lower Leederville aquifers beneath the superficial formations

The distribution of the upper and lower Leederville aquifers (Figure D3) was constructed using hydrogeological reports (Commander 1975; Davidson 1995; Davidson and Yu 2006; Pennington Scott 2008). The information was in addition to that used to map the sand and clay formations.

The M-, AM- and HL-series monitoring bores were the primary sources of information used to define the boundary between the upper and lower Leederville aquifers in the Murray groundwater area. We assumed that:

- the upper Leederville and lower Leederville are distinguishable by a 'green clay' marker horizon which has been identified in numerous bores drilled in the plan area
- the green clay marker horizon divides the Pinjar Member (if present) and Wanneroo Member (upper Leederville) and Mariginiup Member (lower Leederville) of the Leederville Formation.

The depth to the green clay marker horizon was identified and the relevant sub-cropping members were mapped for each bore. Additional information from Figure 13 of the PRAMS report (Davidson and Yu 2006) was also used to aid the interpretation.

The interpolated boundary in Figure D3 shows that the sub-cropping upper Leederville (Wanneroo Member) is mostly found in the western half of the Murray groundwater area, and the sub-cropping lower Leederville (Mariginiup Member) is mostly in the eastern half. Some interpretation was required between the central and southern areas due to the scarcity of information about the Leederville Formation in the southern Coolup and northern Waroona subareas.

An area in the eastern extent of the Murray groundwater area was defined with no sub-cropping Leederville Formation, based on geological data from Mandurah series bore MH15. This relates to a localised area of sub-cropping Cattamarra Coal Measures (as shown in Figure 13 in Davidson and Yu 2006).

The amount of sand and clay that would affect throughflow into the Leederville Formation from the superficial formations was determined by overlaying Figure D1 onto Figure D3. Although this does not take into account recharge of the aquifer outside the plan area the volume of throughflow from the Serpentine groundwater area was considered to be small and unlikely to have a measurable effect on potential yields in the Murray groundwater area.

*Table D2 Area of sand and clay providing throughflow to the Leederville aquifer*

Subarea	Aquifer	Sand km <sup>2</sup>	Clay km <sup>2</sup>	Total km <sup>2</sup>
Coolup	Upper Leederville	221	54	275
	Lower Leederville	7	80	87
Nambeelup	Upper Leederville	153	3	156

	Lower Leederville	55	57	112
Pinjarra	Upper Leederville	0	0	0
	Lower Leederville	0	127	127
Waroona	Upper Leederville	103	43	146
	Lower Leederville	0	88	88
<b>Total</b>		<b>539</b>	<b>452</b>	<b>991</b>

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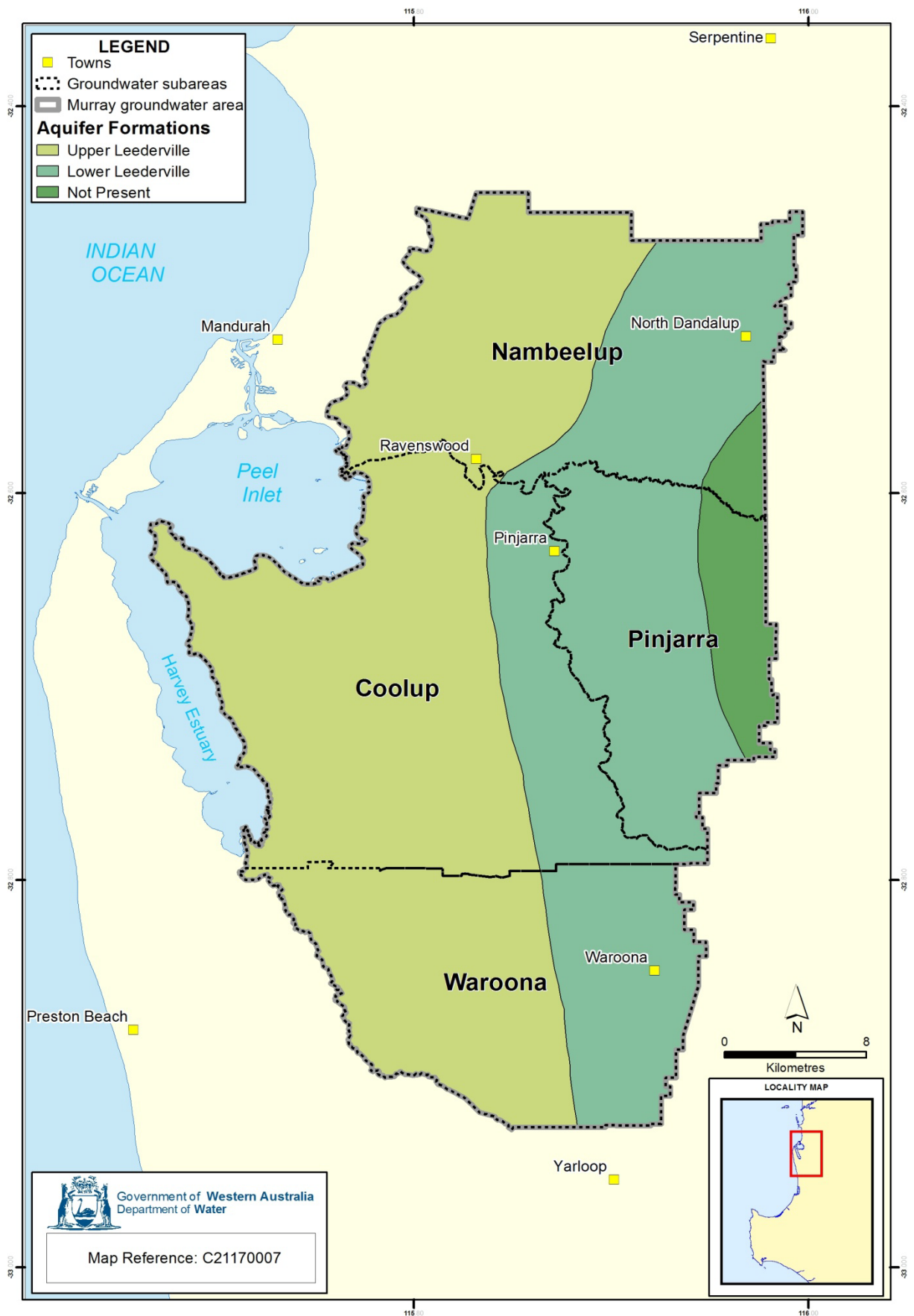


Figure D3 Distribution of the Upper and Lower Leederville aquifers

## Appendix E - Map information and disclaimer

### 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

Client: Christie Silva

Map author: Gary Floyd and Shona Shah

File path: J:\gisprojects\Project\C\_series\C2117...For all maps

File name: J:\gisprojects\Project\C\_series\C2117\0007\_Plan\_Maps... For all maps

Compilation date: 09 March 2012

### Disclaimer

These maps are a product of the Department of Water, Water Assessment and Allocation Division and were printed as shown.

These maps were produced with the intent that they be used for information purposes at the scale as shown when printing.

While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

### Sources

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

Hydrography, Linear (Hierarchy) – DoW – 2007

WA Coastline, WRC (Poly) – DoW –2006

RIWI Groundwater Areas – DoW – 2012

Groundwater Subareas – DoW – 2012

Groundwater Salinity, Confined Aquifers – DoW – 2001

DWAID Aquifers – DoW – 2012

WIN Sites – DoW – 2012

Western Australian Towns –Landgate – 2012

Local Government Authority and Locality Boundaries – Landgate – 2006

Geomorphic Wetlands, Swan Coastal Plain – DEC – 2012

EPP Lakes Policy Area – DEC – 1992

# Glossary

<b>Abstraction</b>	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
<b>Allocation limit</b>	Annual volume of water set aside for consumptive use from a water resource. This includes water available for licensing and water for uses exempt from licensing.
<b>Artesian bore</b>	A bore, including all associated works, from which water flows, or has flowed, naturally to the surface.
<b>Confined aquifer</b>	An aquifer lying between confining layers of low permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically.
<b>Consumptive use</b>	The use of water for private benefit (consumptive purposes) including irrigation, industry, urban and stock and domestic use.
<b>Dewatering</b>	Removing underground water to facilitate construction or other activity. It is often used as a safety measure in mining below the watertable or as a preliminary step to development in an area.
<b>Domestic bore</b>	A bore used for providing the household and household garden watering requirements.
<b>Exempt use</b>	Water use that is not required to be licensed under the <i>Rights in Water and Irrigation Act 1914</i> . This is sometimes referred to as stock and domestic use or a riparian right.
<b>Groundwater area</b>	An area proclaimed under Part III, Division 3, section 26B (1) of the <i>Rights in Water and Irrigation Act 1914</i> for the purposes of licensing and managing water use.
<b>Groundwater-dependent ecosystem</b>	An ecosystem that is dependent on groundwater for its existence and health.
<b>Groundwater resource</b>	A Department of Water management term to define the portion of an aquifer present in a groundwater subarea.
<b>In situ values</b>	The ecological, social, cultural and resource values supported by natural hydrological and hydrogeological processes

<b>Licence</b>	A formal authorisation which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source for a specified quantity and period of time.
<b>Phreatophytic</b>	A plant with a long root, adapted for survival in desert or arid environments, so that it can source water at deep levels underground
<b>Potentiometric head</b>	A surface representing the hydraulic head of ground water; represented by the water-table altitude in an unconfined aquifer or by the altitude to which water will rise in a properly constructed well in a confined aquifer.
<b>Subarea</b>	A smaller area determined by the Department of Water in a proclaimed area used for water allocation planning and management purposes, the boundaries of which are primarily defined by the location of the water resource.
<b>Unconfined aquifer</b>	Is the aquifer nearest to the surface, having no overlying confining layer. The upper surface of groundwater in the aquifer is called the watertable. An aquifer containing water with no upper non-porous material to limit its volume or to exert pressure.
<b>Water entitlement</b>	The quantity of water that a person is entitled to take on an annual basis in accordance with the <i>Rights in Water and Irrigation Act 1914</i> and a licence.
<b>Yield</b>	The calculated volume of water that can be taken out of the system renewably after the water requirements for in situ values have been accounted for.

### 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)



## List of shortened forms

CSIRO	Commonwealth scientific and industrial research organisation
DoW	Department of Water
EPA	Environmental Protection Authority
GHD	Gutteridge Haskins and Davey
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WAPC	Western Australian Planning Commission
PRAMS	Perth regional aquifer modelling system
GIS	Geographic information system
URS	United Research Services

## References

- Bureau of Meteorology 2010, *Climate data online*, Bureau of Meteorology, Canberra, viewed 23 January 2010, <[www.bom.gov.au/climate/data/](http://www.bom.gov.au/climate/data/)>.
- Commander DP 1975, *Hydrogeology of the Mandurah–Pinjarra area, Perth Basin, Western Australia*, Geological Survey of Western Australia, Record 1975/3, Perth.
- 1982, *An outline of the groundwater resources of the Mandurah–Bunbury Region*, report 2412, Water and Rivers Commission, Perth.
- CSIRO 2009, *Groundwater yields in south-west Western Australia. A report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project*, CSIRO Water for a Healthy Country Flagship, Canberra.
- Davidson WA 1995, *Hydrogeology and groundwater resources of the Perth region, Western Australia*, Geological Survey of Western Australia, Bulletin no. 142, Perth.
- Davidson WA and Yu X, 2006, *Perth regional aquifer modelling system (PRAMS) model development: Hydrogeology and groundwater modelling, Western Australia*, Hydrogeological record series HG20, Department of Water, Perth.
- Deeney AC 1989a, *Geology and groundwater resources of the superficial formations between Pinjarra and Bunbury Perth Basin*, Report 26, Geological Survey of Western Australia professional papers, Perth, pp. 38–68.
- 1989b, *Hydrogeology of the Harvey Borehole line Perth Basin*, Report 26, Geological Survey of Western Australia professional papers, Perth, pp. 59–68.
- Department of Water 2009, *Strategic policy no. 2.03 – Managing unlicensed groundwater use*, Department of Water, Perth.
- 2011, *Murray drainage and water management plan*, Department of Water, Perth.
- 2012a, *Murray groundwater allocation plan*, Department of Water, Perth
- 2012b, *Murray groundwater area: subarea reference sheets*, Department of Water, Perth.
- Environment Australia 2001, *A directory of important wetlands in Australia*, 3rd edn, Environment Australia, Canberra.
- Environmental Protection Authority 1983, *Conservation reserves for Western Australia – The Darling System, System 6*, report no. 13, Department of Conservation and Environment, Perth.
- 1992a, *Environmental protection (Peel Inlet–Harvey Estuary) policy*, Environmental Protection Act 1986, Perth.

- 1992b, *Environmental protection (Swan coastal plain lakes) policy*, Environmental Protection Act 1986, Perth.
- 2009, *Statement that a proposal may be implemented pursuant to the provisions of the Environmental protection Act 1986, Keysbrook mineral sands mine Shire of Serpentine-Jarrahdale and Shire of Murray statement no. 810*, Environmental Protection Authority, Perth.
- Government of Western Australia 1997, *Wetlands conservation policy for Western Australia*, Perth.
- Hall, J, Kretschmer, P, Quinton, B & Marillier, B, 2010, *Murray hydrological studies: Surface water, groundwater and environmental water, Conceptual model report*, Water science technical series WST 16, Department of Water, Perth.
- Hill A, Semeniuk C, Semeniuk V and Del Marco A 1996, *Wetlands of the Swan coastal plain, Volume 2b*, report to the Water and Rivers Commission, V and C Semeniuk Research Group, Perth Western Australia..
- Hydrosearch 2010, *Conceptual model for groundwater flow and recharge in the Cattamarra Coal Measures near Pinjarra*, unpublished report prepared for Alcoa of Australia.
- Pennington Scott 2008, *Southern Perth Basin groundwater bulletin: draft report*, prepared for Department of Water, Perth.
- Tiner RW 1999, *Wetland Indicators: A guide to wetland identification, delineation, classification, and mapping*, CRC Press LLC, Florida.
- United Nations Educational, Scientific and Cultural Organisation 1971, *Convention on wetlands of international importance especially as waterfowl habitat*, (Ramsar convention on wetlands), United Nations Educational, Scientific and Cultural Organization, Switzerland.
- URS 2008, *Shallow groundwater drilling – Swan coastal plain bore completion report*, final draft report, URS Australia, Perth.
- Water and Rivers Commission 1998, *Groundwater allocation plan – Murray groundwater area*, (unpublished), Water and Rivers Commission, Perth.
- Western Australian Planning Commission 2009, *Southern metropolitan and Peel sub-regional structure plan* (draft), Western Australian Planning Commission, Perth.
- 2010, *Directions 2031: spatial framework for Perth and Peel*, Western Australian Planning Commission, Perth.





RECYCLED CONTENT

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