



## Lower Robe groundwater allocation limit report

Background information and method used to set an allocation limit for the Lower Robe alluvial aquifer

October 2012

*Looking after all our water needs*



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Department of Water

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Department of Water  
168 St Georges Terrace  
Perth Western Australia 6000  
Telephone +61 8 6364 7600  
Facsimile +61 8 6364 7601  
National Relay Service 13 36 77  
[www.water.wa.gov.au](http://www.water.wa.gov.au)

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For more information about this report, contact:

Allocation Planning Section  
Department of Water  
Telephone 08 6364 7600  
Email [allocation.planning@water.wa.gov.au](mailto:allocation.planning@water.wa.gov.au)

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## Summary

This report explains how the Department of Water developed the allocation limit for the lower Robe River alluvial aquifer. It supports the *Pilbara groundwater allocation plan* which will be released in 2013. The aquifer is in the Ashburton subarea of the Pilbara groundwater area.

This report summarises the available hydrogeological, environmental, cultural and social information for the aquifer and describes the method used to define the aquifer boundary and to set an allocation limit.

In setting the allocation limit we considered monitoring data and the results of hydrogeological investigations, groundwater modelling and reviews of groundwater-dependent ecosystems and cultural values and current and future water use.

The department has set an allocation limit of 5.09 GL/year for the lower Robe alluvial aquifer. This is a suitable allocation limit given the amount of monitoring data and hydrogeological information we have for the resource. It will enable us to continue to investigate the resource's potential as a water supply while being consistent with the level of information available.

Details of how the department will manage abstraction through the allocation limit will be included in the *Pilbara groundwater allocation plan*.





# 1 Introduction

## 1.1 Water allocation planning in the Pilbara region

The Department of Water manages water abstraction through individual water licences issued under the *Rights in Water and Irrigation Act 1914*. As demand and the volume of water use increases, a water allocation plan is needed to guide our licensing decisions for a specified area.

This report supports the *Pilbara groundwater allocation plan: for public comment* (Department of Water 2012). The final *Pilbara groundwater allocation plan* will be released in 2013.

The groundwater allocation plan sets out how much water can be abstracted from coastal alluvial and sedimentary aquifers and how that abstraction will be managed now and in the future. It will also inform water licensing across other areas of the Pilbara where water is abstracted mainly from fractured rock aquifers.

This report describes how we have used the best information available to set allocation limits for the lower Robe alluvial aquifer, one of the aquifers covered by the Pilbara groundwater plan. We prepared this report to make the process used in setting allocation limits transparent and publically available.

## 1.2 Resource area and location

The lower Robe alluvial aquifer is in the Ashburton subarea of the Pilbara groundwater area. The Pilbara groundwater area was proclaimed under the *Rights in Water and Irrigation Act 1914* on 12 February 1996. This means that a licence is required to legally take groundwater unless it is for stock and domestic use.

The Robe alluvial aquifer is located along the Robe River, north-east of Onslow, in the Pilbara region of Western Australia. The catchment of the river covers an area of about 7104 km<sup>2</sup>. The area of the Robe alluvial aquifer assessed in the Pilbara groundwater allocation plan extends about 40 km inland from the coast along the Robe River (Figure 1).

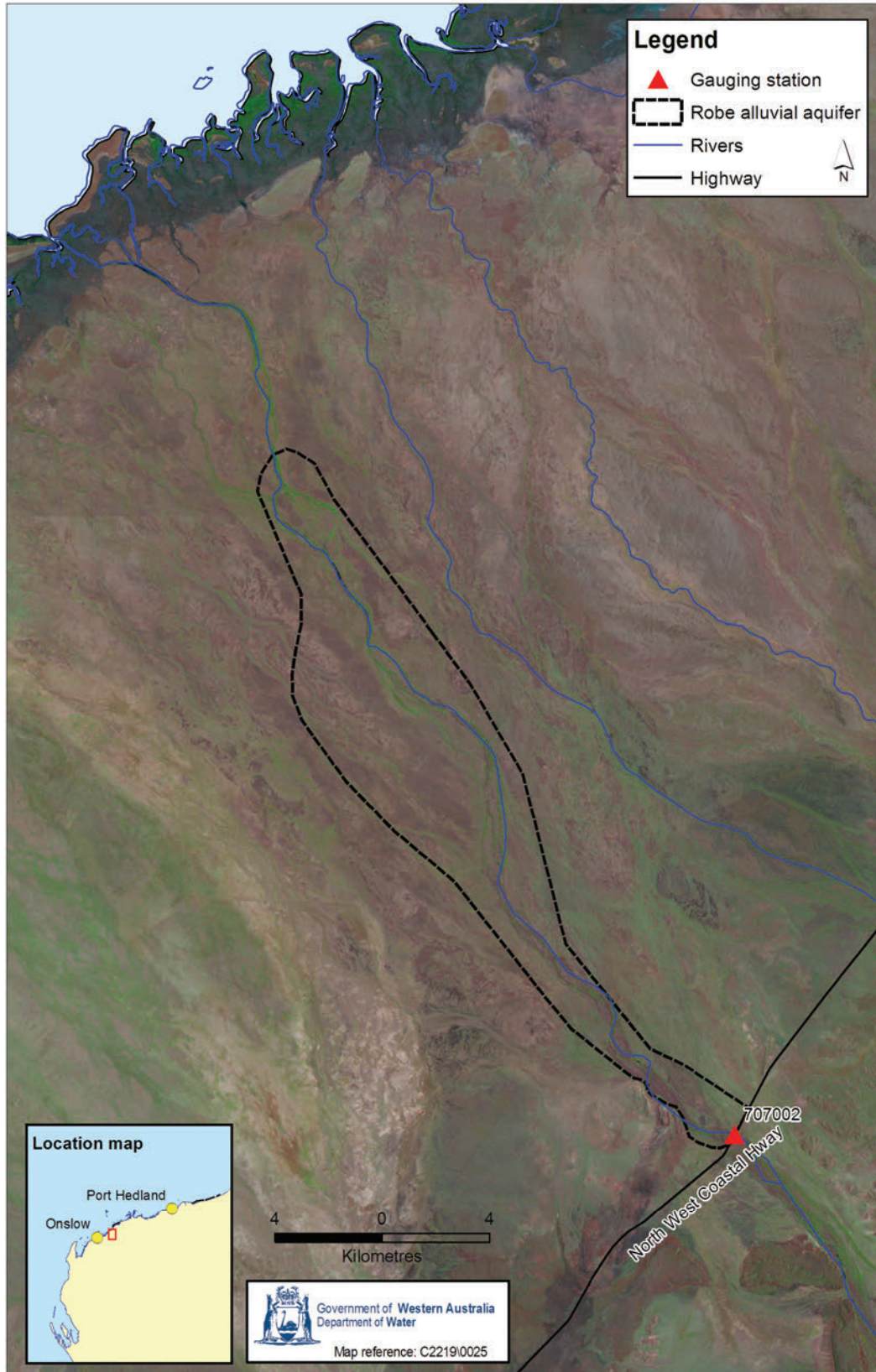


Figure 1 Location of Robe alluvial aquifer

## 1.3 Allocation limits

### Definition of an allocation limit

An allocation limit is an annual volume of water set aside for consumptive use from a water resource. For administrative purposes, the allocation limit can include components for:

- water that is available for licensing
  - general licensing
  - public water supply licensing
- water that is exempt from licensing
- water that is reserved for future public water supply.

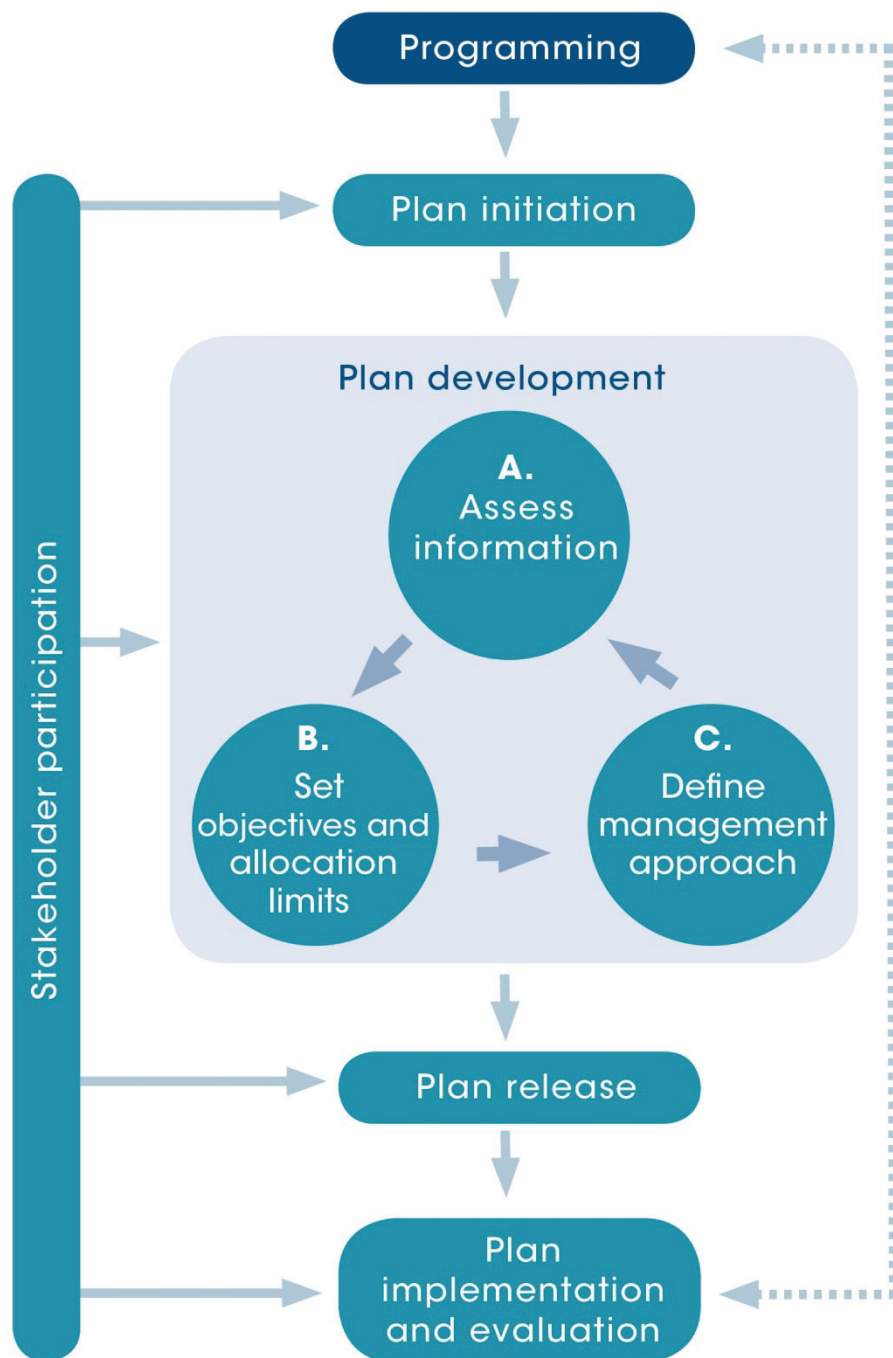
In the Robe alluvial aquifer the allocation limit includes water that is available for general licensing, water set aside for future public water supply and water used for stock and domestic purposes that is exempt from licensing.

### Previous allocation limits and approach

There is currently no licensed abstraction within the aquifer boundary, only some exempt (unlicensed) stock and domestic use. The aquifer boundary and allocation limit have been defined for the first time as part of this project.

## 1.4 Allocation planning

The Department of Water follows the process shown in Figure 2 to develop a water allocation plan and set allocation limits. This report describes how we assessed the information available on the Robe alluvial aquifer (Section 2) and how we set the objectives and allocation limit (Section 3). Our management approach is described in the *Pilbara groundwater allocation plan*.



*Figure 2 Water allocation planning process*

For more information about allocation planning see *Water allocation planning in Western Australia: a guide to our process* (Department of Water 2011), which is available online at <[www.water.wa.gov.au](http://www.water.wa.gov.au)>.

## 1.5 Working with water users and other stakeholders

The Department of Water consulted with traditional owners, pastoralists, industry and water service providers about the Robe alluvial aquifer to identify water related values and discuss water resource issues. The main concerns identified by stakeholders were:

- water availability
- water quality
- managing impacts between different users
- water related environmental values
- water related Indigenous cultural values.

We were able to use this understanding of how water is used and valued by the community when we were setting objectives and allocation limits and when developing the management approach for the Robe alluvial aquifer.

There will be further opportunities for stakeholders to contribute to the planning process while we finalise the *Pilbara groundwater allocation plan*.

## 2 Assessing information

In part A of the allocation planning process (Figure 2) we assessed information on:

- the resource hydrogeology
- how much water needs to be left in the system
- current use
- future demand.

Information from part A informs the groundwater allocation plan objectives and the Department of Water's allocation limit decisions.

### 2.1 Understanding the resource

#### Resource boundaries

The lower Robe River alluvial aquifer boundary has been created within the Ashburton subarea and has been separated from the broader Carnarvon – Superficial aquifer (Figure 3 and Figure 4).

The boundary is based on the extent of the aquifer defined as part of the hydrogeological assessments for the Robe River groundwater model (Sinclair Knight Merz 2010).

There is currently no licensed abstraction within the aquifer boundary. There is some stock and domestic use which is exempt from licensing.

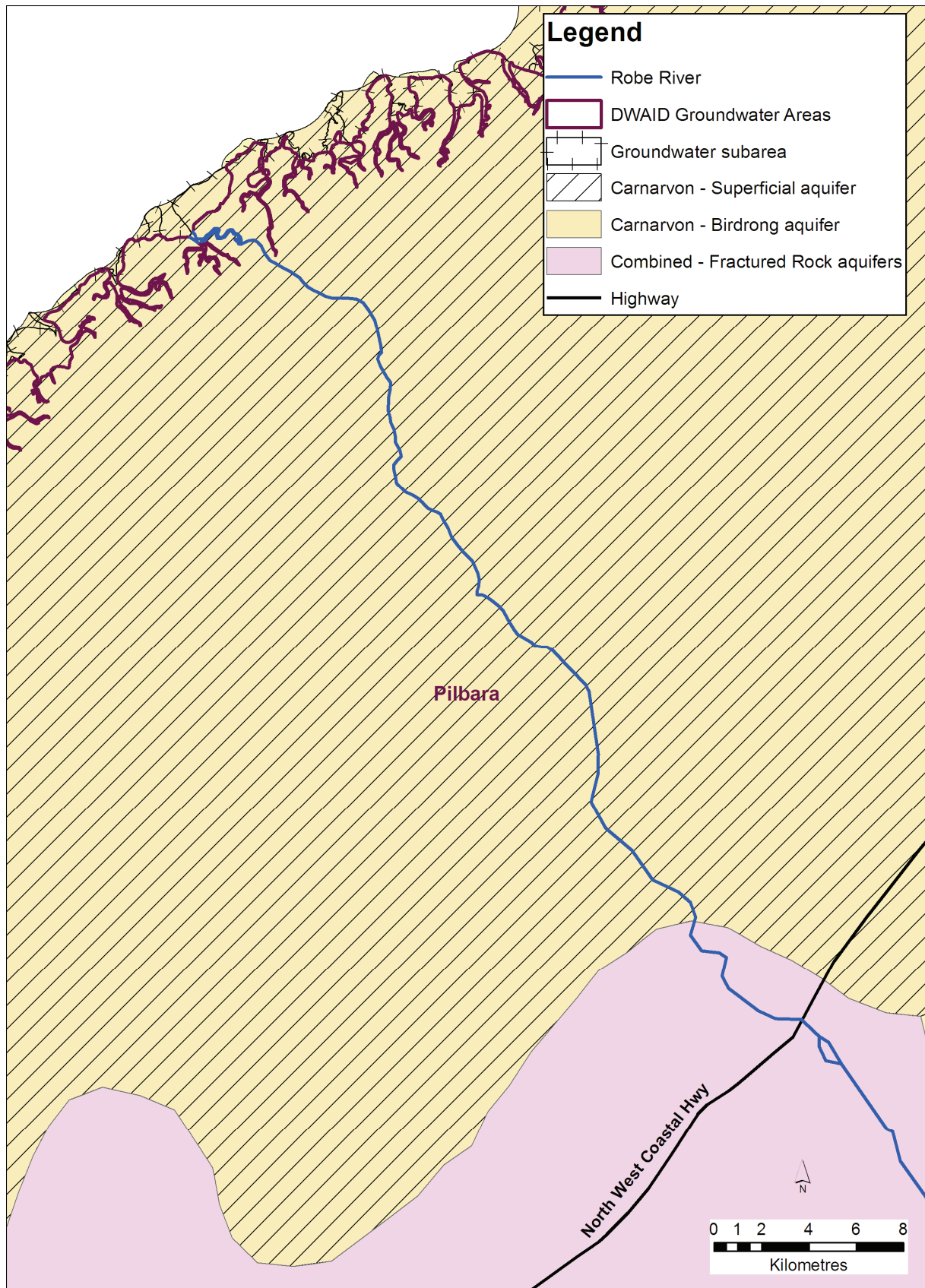


Figure 3 Previous subarea and aquifer boundaries with Robe alluvial aquifer included as part of the Carnarvon – Superficial aquifer



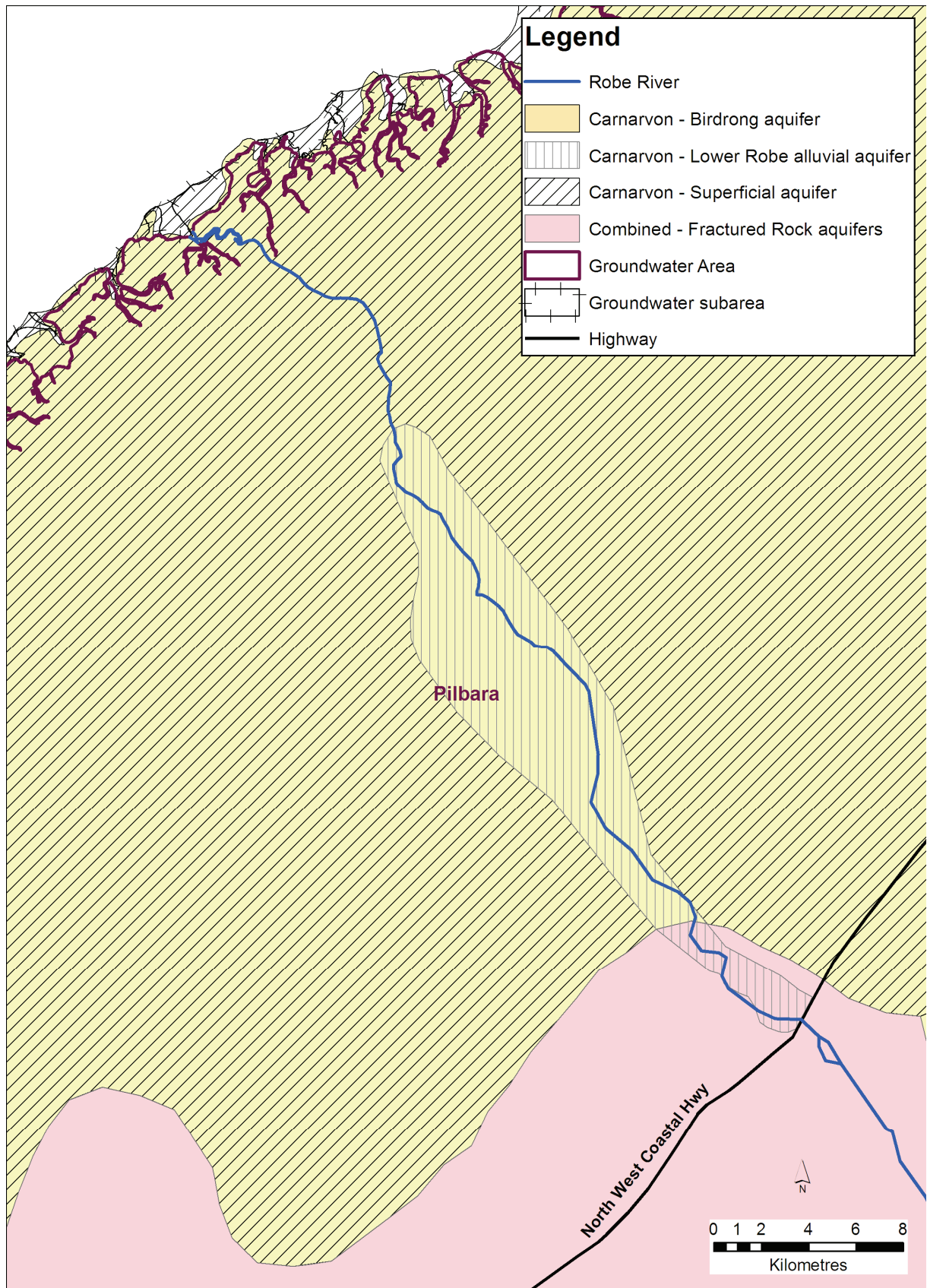


Figure 4 Robe revised subarea and aquifer boundaries



## Climate and rainfall

The Pilbara region has a semi-arid to arid climate with hot, dry conditions most of the year.

Rainfall is highly variable and largely results from cyclonic events and localised thunderstorms between December and March. The long-term mean annual rainfall at Pannawonica (Bureau of Meteorology (BoM) station 05069), near the Robe River, is 410 mm. Annual average evaporation is 3196 mm and greatly exceeds rainfall, causing an extreme moisture deficit (Table 1).

*Table 1 Robe climate data summary (1971 to 2012)*

<b>Pannawonica BoM station 05069 mm</b>	
Average annual rainfall	410
Average annual evaporation	3196
Maximum annual rainfall	700 (2006)
Minimum annual rainfall	113 (2002)

Future climate model predictions for the region are uncertain. However, our best indications suggest that future cyclonic events will occur with decreased frequency and increased magnitude (Hodgkinson et al. 2010). The CSIRO, in partnership with the department, other agencies and industry, is investigating future climate predictions for the Pilbara and the implications for water resources.

## Hydrology

The Robe River catchment covers approximately 7104 km<sup>2</sup>. Downstream of the North West Coastal Highway the river crosses the coastal plain in a north-westerly direction in a narrow channel incised as much as 5 m below the general level of the plain.

Streamflow has been recorded at Yarraloola gauging station (AWRC reference 707002) since 1972. Over this period total annual flow has ranged from 0 to 780 GL with a mean of 108 GL and a median of 21 GL. Records indicate that yearly flows are unreliable, with 17 of the past 37 years recording no or very low flow (<10% of mean annual flow).

Flooding of the Robe River and its floodplains is the greatest source of recharge to the Robe aquifer. The aquifer has the potential to absorb as recharge a significant percentage of river flow, and groundwater levels respond quickly to flow events.

## Hydrogeology

Exploratory drilling completed by the Geological Survey of Western Australia in 1994 investigated the extent and characteristics of the resource (Commander 1994). No additional investigative work appears to have been completed between 1994 and 2009 (Haig 2009).

An airborne electromagnetic survey was undertaken in 2009 to identify seawater intrusion (FURGO 2009).

The Robe alluvial aquifer has been defined as the Quaternary alluvium and the Tertiary formations - Trealla Limestone and Robe Pisolite. The groundwater supply from the Quaternary alluvium is reliable while the underlying Tertiary formations may provide additional groundwater where secondary porosity has been developed.

The aquifer is composed of gravels and calcrete grading laterally into floodplain silts and clays. The gravel layers, up to 13 m thick, form the most productive part of the aquifer. These layers decrease in thickness and productivity with increasing silt and clay content towards the coast and with distance from the river.

Hydraulic conductivity is estimated to be from 140 to 400 m/day where the gravel is not cemented. Recharge has previously been estimated to be between 8 and 10 GL/yr (Commander 1994).

The underlying Trealla Limestone consists of clay. However, due to fracturing it has a high permeability in places of up to 220 m/day.

Robe Pisolite (Pisolitic ironstone), which is found along the present course of the Robe River, unconformably underlies the Trealla Limestone. Underlying the Robe Pisolite is up to 45 m of Cretaceous sediments made up of either Windalia Radiolarite or Muderong Shale and then Toolonga Calcilutite overlying Yarraloola Conglomerate.

The basement rock of the lower Robe River alluvium consists of the Proterozoic Ashburton Formation which outcrops in low hills on either side of the river.

### **Groundwater quality**

Basic groundwater chemical analysis was undertaken by Commander (1994). Nitrate was measured at concentrations of up to 12 mg/L. The groundwater was found to be hard to very hard with CaCO<sub>3</sub> measured at 470 mg/L.

Commander also reported groundwater salinity levels ranging from less than 500 mg/L TDS (total dissolved solids) close to the river increasing to 1280 mg/L TDS away from the river (Figure 5). Salinity also decreases with depth below the watertable.

Airborne electromagnetic survey has detected hypersaline groundwater believed to be seawater intrusion at 6 km from the coast (at -10 m AHD). Chemical analysis has not been undertaken to confirm these results.

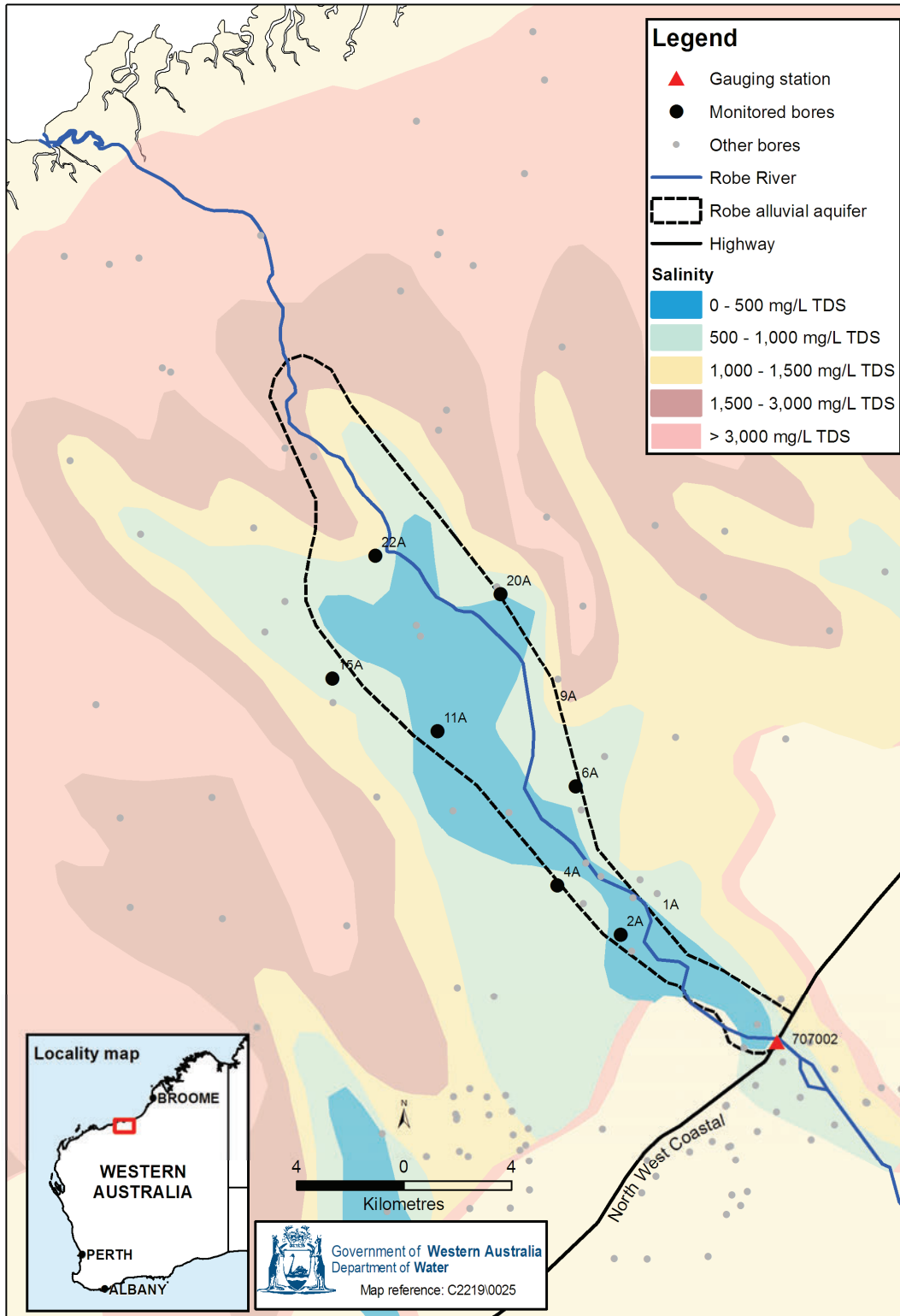


Figure 5 Robe alluvial aquifer salinity levels

**Surface water and groundwater interaction**

During river flow events, groundwater is recharged through the base of the river channel and the floodplain. During periods of no river flow, river pools of varying permanency remain along the river channel. While shallow pools quickly evaporate,

some deeper pools intersect the aquifer and are maintained by groundwater discharge.

During extended periods of no flow (drought conditions) groundwater levels decline and semi-permanent pools may become disconnected from the groundwater and dry out. During these times the river is reduced to a series of shallow permanent pools which are maintained by groundwater discharge.

These permanent pools are critical refuges for aquatic (and terrestrial) ecosystems during drought periods.

### **Groundwater modelling**

In 2010 a numerical groundwater model was completed for the Robe alluvial aquifer (Sinclair Knight Merz 2010) with funding from the Commonwealth Water for the Future program. The model covers the lower 30 km of the Robe River downstream from the North West Coastal Highway crossing (Figure 6).

The groundwater model was built using FEFLOW (a finite element numerical model) and follows guidelines for numerical groundwater models for the Murray-Darling Basin (Murray-Darling Basin Commission 2001). The RMS (normalised root mean square) error of the model was 8%, which is within the guideline's requirement for calibration to achieve an RMS error of less than 10%.

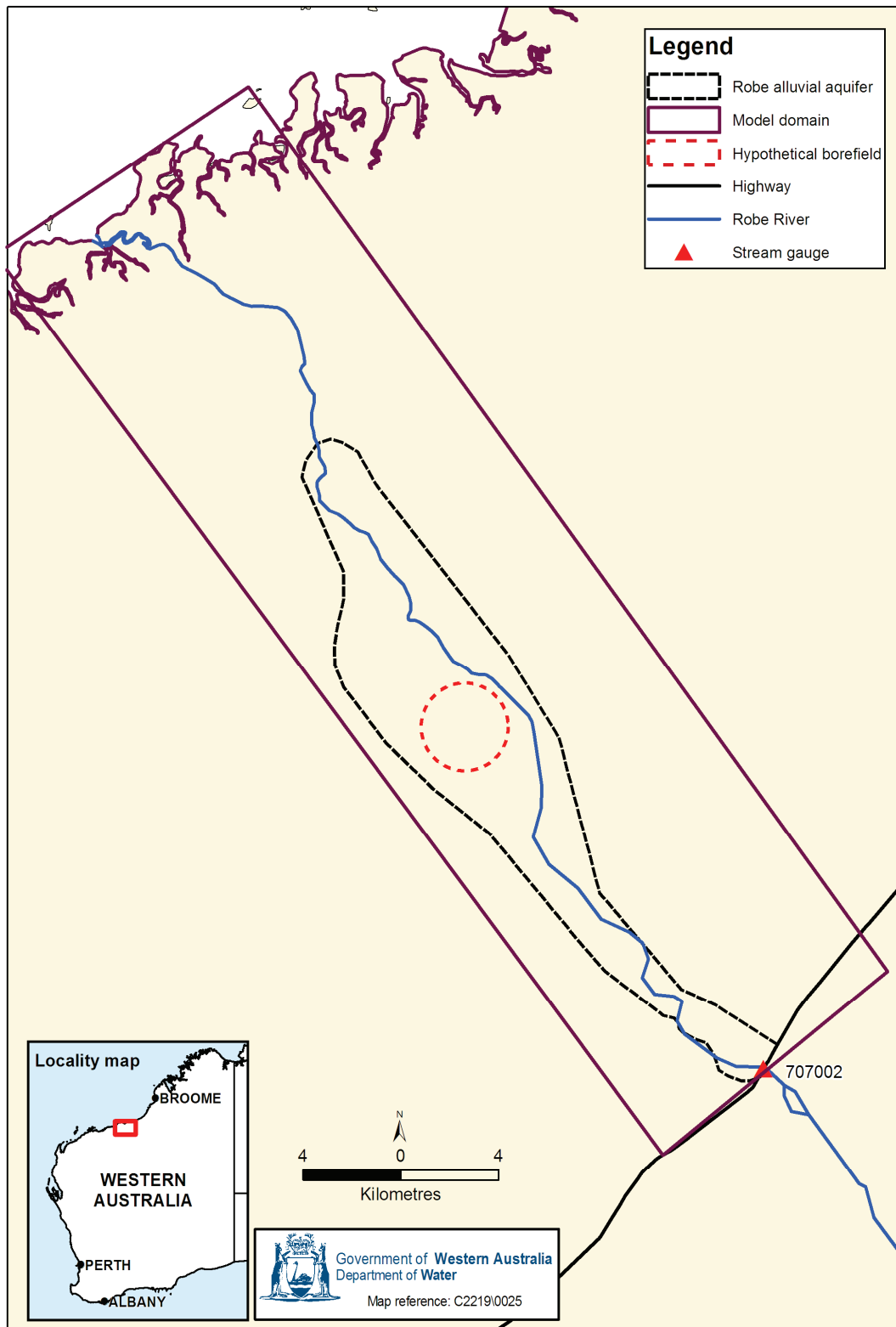


Figure 6 Lower Robe River Groundwater model area

To develop the model, SKM used information from earlier hydrogeological work and from geophysical investigations completed by the department in 2009 as part of the Water for the Future program. The model was developed using the following data:

- daily streamflow and stage height data measured at Yarraloola gauging station (707002) from January 1987 to October 2009
- groundwater data from 11 monitoring bores from the 1980s
- sporadic, one-off groundwater level readings from more than 50 bores in the vicinity of the model area
- bore logs for 87 bores
- surface water levels from one river pool and location and permanency of other pools along the river from remote sensing analysis
- results of aerial geophysics survey
- a digital elevation model developed from LiDAR (light detection and ranging) survey
- geological cross-sections developed from drilling and pump tests (Commander 1994)
- rainfall data (BoM)
- previous hydrogeological assessments including Commander (1994) and Haig (2009).

SKM (2010) noted a lack of groundwater data in the coastal half of the model and no longer term test pumping. This created significant uncertainty when modelling the potential for seawater intrusion and the effects of abstraction on groundwater levels.

The department has used the model to assess the potential effects of future allocation options on the alluvial aquifer. This included assessing effects on the groundwater-dependent ecosystems and risks of changes in water quality.

Modelled allocation options and results are presented in Section 3.2 – Assessing allocation options.

## 2.2 Water for the environment

To set an appropriate allocation limit we consider the amount of recharge entering the system and the amount of water that needs to remain in the system to support:

- the productivity and water quality of the resource
- water-dependent ecosystems and values
- social and cultural values.

### **Maintaining the productivity of the resource**

To support the long-term productivity of the Robe alluvial aquifer, it is essential to maintain the water quantity and quality of the aquifer. It is important to prevent landward movement of the seawater interface. Too much abstraction from the resource could pull the interface inland and reduce groundwater quality.

The seawater interface in the Robe area is currently about 6 km inland from the coast. Adequate freshwater throughflow downstream toward the coast is needed to maintain the position of the seawater interface and water quality in the aquifer.

Salinity in the aquifer increases laterally away from the river (Figure 5), which is the main source of freshwater recharge. To prevent saline intrusion, freshwater volumes need to be maintained to prevent salt water moving in from the aquifer flanks.

### Water-dependent ecosystems and values

The Robe alluvial aquifer supports river pools, fringing riparian vegetation communities and stygofauna, all of which depend on groundwater to some extent (Figure 7).

As part of the Water for the Future program we reviewed available information on ecosystems dependent on the Robe alluvial aquifer. We also:

- mapped depths to groundwater
- mapped groundwater-dependent ecosystems (vegetation and river pools)
- established monitoring transects and assessed the health of riparian vegetation
- calculated water level ranges of key riparian species and compared them to regional resources
- compared fish in the Robe River to regional datasets.

We used this work to describe the groundwater-dependent ecosystems and develop conceptual models of the links between ecosystems and hydrogeology (Antao and Braimbridge 2010). We then developed ecological water requirements (EWRs) to describe the water regimes required to maintain the groundwater-dependent ecosystems (Antao 2012).

The river pools support aquatic flora and fauna ecosystems and provide valuable habitat for two federally protected migratory birds, several priority fauna species, and a potentially new fish species. Deep pools that maintain connectivity with the groundwater throughout the dry season are critical refuges from which aquatic fauna will repopulate when floods return. Continued input of groundwater to permanent pools is critical for maintaining adequate habitat and water quality during the dry season and extended droughts.

Phreatophytic (groundwater-dependent) riparian vegetation communities fringe the river. Riparian vegetation provides habitat for native fauna, acts as wildlife corridors, helps control erosion and is generally more productive than the surrounding landscape. Riparian communities of the Robe River are dominated by the tree species *Eucalyptus camaldulensis* (River red gum) with the occasional occurrence of *Melaleuca argentea* (Cadjeput).

Mapping of vegetation and depth to groundwater shows that riparian communities are restricted to areas of shallow groundwater (<9 m). Within this area groundwater levels can fluctuate by up to 5 m depending on the period of time between recharge events.

The shallow depth to groundwater in the alluvium along the river provides areas where deep rooted vegetation can reach groundwater, which sustains these communities in the absence of rainfall and/or surface water flow.

Stygofauna are also known to occur in the alluvial aquifer (Biota Environmental Sciences 2006). Survey results to date indicate that the lower Robe River alluvial aquifer contains five distinct genetic groups and several species that are currently only known to occur within this study area (Biota Environmental Sciences 2006). As there is little specific information on their ecology and tolerances to water level changes we have assumed that the ecological water requirements we have established for river pools and riparian ecosystems will act as surrogate requirements for stygofauna by keeping the habitat available.

The environmental values of the Robe River are considered to be significant at the local scale due to the good condition of the riparian zone and river pools (despite grazing pressure) and the diversity of stygofauna species.



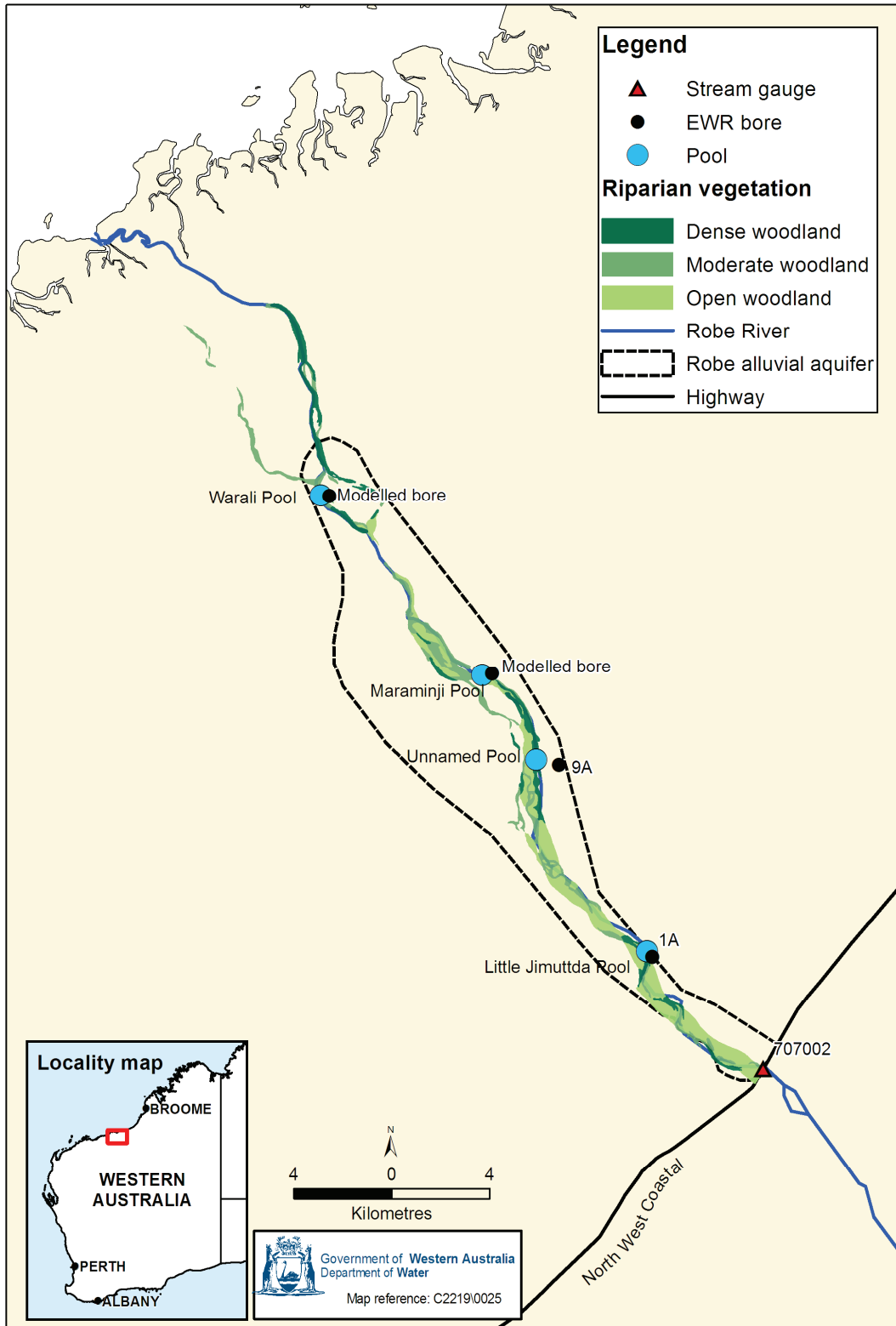


Figure 7 River pools and riparian vegetation of the lower Robe River

## Water related cultural and social values

Water requirements to maintain the social and cultural values associated with groundwater and river pools and riparian vegetation are considered when we set allocation limits and licensing rules and are usually closely related to ecological water requirements. See Section 3.2.

Our approach to Aboriginal engagement in the Pilbara has three stages:

- 1 Meeting with the traditional owner native title working groups to outline the role of the Department of Water and our approach to allocation planning.
- 2 On-Country visits with representatives from the native title working group to identify culturally important aspects related to water.
- 3 Ongoing engagement whereby we talk to the working groups about the allocation limits we set and the management rules that go into the allocation plan.

Consultation has been coordinated through the Yamatji Marlpa Aboriginal Corporation, the official representative body for the region.

### *Cultural values of the lower Robe River*

The lower Robe River is located within the boundaries of the Kuruma Marthudunera native title claim area (undetermined) (Pilbara Native Title Service 2009).

Initial consultation with the representatives of the Kuruma Marthudunera community occurred in September 2009. This was followed up with an on-Country visit by department staff and members of the Kuruma Marthudunera community on 23 September 2009.

The lower Robe River contains a series of Aboriginal sites and was determined to have a very high ethnographic heritage value to the traditional owners (Pilbara Native Title Service 2009). The river pools are of special significance because of the abundance of fish and proximity to sites which are significant for ceremonial reasons as well as to burial sites.

Water requirements to maintain the social and cultural values associated with groundwater and river pools and riparian vegetation are considered when we set allocation limits and licensing rules and are usually closely related to ecological water requirements. See Section 2.2.

## 2.3 Understanding water demand and trends

### How water is abstracted and used in the area

There is no licensed groundwater abstraction from the Robe alluvial aquifer.

Mardie and Yarraloola stations use groundwater from the alluvial aquifer for stock and domestic purposes. Based on the average cattle carrying capacity in the Pilbara groundwater area, stock water use was estimated at 90 000 kL. This use is exempt from licensing.

## Future demand

Due to its proximity to Onslow the Robe alluvial aquifer is being considered as an additional water source to meet growing demand at Onslow and could provide water to Karratha.

The resource is also being considered by industry for use in mineral processing.

## 2.4 Points to consider from assessing information

From the information we have on the Robe alluvial aquifer, there are a number of points that we need to consider when setting objectives and allocation limits:

- The flow in the Robe River is unreliable, with recharge to the Robe River alluvial aquifer being very low in about 40% of years.
- Our understanding of the seawater interface and aquifer response to abstraction is limited.
- We have a groundwater model to assess the possible effects of abstraction from the Robe aquifer.
- The aquifer supports river pools, riparian vegetation and aquifer ecosystems which are of conservation value at the local scale.

## 3 Setting objectives and allocation limits

In Part B of the allocation planning process (Figure 2) we:

- set objectives
- assess allocation options
- decide allocation limit.

### 3.1 Setting objectives

In administering the *Rights in Water and Irrigation Act 1914*, the Department of Water provides for both the sustainable use and development of water resources and the protection of ecosystems associated with water resources.

#### Outcomes

Our desired outcomes from managing the Robe alluvial aquifer are that:

- there is certainty about how much water is available to support regional development
- groundwater productivity is maintained into the future
- valuable environments and ecosystems dependent on groundwater are protected
- Indigenous values relying on groundwater are managed with input from local traditional owners
- planning and investing in water supplies can be done with certainty about the requirements for managing groundwater
- the understanding of groundwater resources is continually improved.

#### Resource objectives

Water resource objectives relate to maintaining, increasing, improving, restoring, reducing or decreasing groundwater levels or water quality.

The water resource objectives for the lower Robe alluvial aquifer are:

- prevent saltwater intrusion into the aquifer caused by abstraction
- maintain water quality for the most beneficial use (potable water supply)
- maintain groundwater and pool levels within a target range, to maintain aquatic habitat and riparian vegetation dependent on groundwater.

### 3.2 Assessing allocation options

In setting an allocation limit for the Robe alluvial aquifer we considered the information provided in Chapter 2 and the outcomes and objectives listed above. We then developed and modelled a number of allocation options, assessed the model results and monitoring data and made a decision about how much water will be made available for abstraction.

## Allocation options

The department used the Robe groundwater model (Section 2.1) to assess risks to the resource from a range of allocation options (Table 2). Previous model runs, estimates of recharge, and projected demand were used to focus on the likely range of options for deciding the allocation limit.

Predictive models were run for 50 years using a standard set of climate scenarios that were statistically similar to the recorded historical climate (Appendix A). This therefore assumes that climate in the Pilbara will remain approximately the same as in recent history. We took this approach because the climate change predictions for the Pilbara at the time of modelling were not consistent (Loo and Humphreys 2009).

Model runs were conducted for seven allocation options (Table 2) simulating abstraction for a hypothetical bore field (Figure 6). Option 1 represented a no abstraction case. Options 2 to 6 represented abstractions rates from 5 GL to 9 GL/yr. These options also included non-licensed stock and domestic use as an additional 200 000 kL/yr.

Option 3-1 also represented an abstraction rate of 6 GL/yr but with a worst case dry climate option achieved by reducing overall mean annual streamflow by 10% (see Appendix A for further detail).

*Table 2 Allocation options modelled for the Robe alluvial aquifer*

Option	Climate		Abstraction						
	Based on historical climate	Dry climate	None	200 000 kL/yr stock and domestic	5 GL/yr	6 GL/yr	7 GL/yr	8 GL/yr	9 GL/yr
1	*		*						
2	*			*	*				
3-1		*		*		*			
3-2	*			*		*			
4	*			*			*		
5	*			*				*	
6	*			*					*

## Assessing model results

The department used the model results to determine how much water we could take from the aquifer while still maintaining its integrity and its ability to provide for the needs of the environmental and cultural values described in Section 2.2.

### Hydrogeological assessment

In this assessment we considered changes to groundwater quality and aquifer storage using a combination of recorded groundwater and flow data and groundwater model outputs. We focused on potential effects on the seawater interface and water quality across the aquifers under each of the modelled options. The hydrogeological assessment was based on the following guidelines:

- Abstraction should not draw seawater or saline water (from the aquifer's sides) directly into the bore or bore field and cause permanent or significant decline in water quality.
- Some landward movement of the seawater interface is expected as a new equilibrium is established with increased abstraction. Movement will be slow and occur over decades, and can be managed through monitoring and adapting bore field operation.
- Groundwater levels should stabilise within a new range, where the drawdown in the bore field does not continue to expand over several cycles of drought and recharge.

The risks of seawater intrusion (Table 3) and potential salinity effects from the sides of the aquifer (Table 4) were qualitatively classified as high, medium or low for each option. This was done using the hydrographs and drawdown contours produced from the model.

*Table 3 Definitions of categories for seawater intrusion risks for the Robe alluvial aquifer*

<b>Risk</b>	<b>Definition</b>
High	Abstraction causes the watertable gradient to fall in the seawater interface zone, increasing the potential for seawater intrusion.
Medium	Abstraction generally maintains the watertable gradient at the seawater interface. However, there is still a risk of seawater intrusion.
Low	Abstraction maintains the watertable gradient in the seawater interface zone, preventing seawater intrusion.

*Table 4 Definitions of categories for risk of water quality effects from the sides of the Robe alluvial aquifer*

<b>Risk</b>	<b>Definition</b>
High	Drawdown extends into aquifer areas mapped as having salinity levels of 3000 mg/L TDS or greater.
Medium	Drawdown extends into aquifer areas mapped as having salinity levels of between 500 and 3000 mg/L TDS.
Low	Drawdown restricted to aquifer areas mapped as having salinity levels of 0 to 500 mg/L TDS.

Results from a 50 year modelled sequence for all allocation options were assessed, excluding the first two years of model output to allow it to adjust and stabilise.

Localised aquifer levels declined in response to all allocation options (Table 5). Levels reached equilibrium very quickly (within 10 years) and appeared to recharge

completely during river flow events. However, a permanent, localised drawdown of water levels near the hypothetical bore field (bores 11A and Maraminji Pool) were predicted.

Bores located away from the bore field did not experience any discernible change in aquifer level (Table 5) (Figure 8).

The seawater interface is at least 12 km from the modelled abstraction area. The model predicted no detectable changes in flux across a hypothetical boundary in the upper model layers. Nor were any changes detected in groundwater levels at selected nodes near the saltwater interface (Seawater bore 1 – Table 5). The risk of saltwater intrusion based on the modelled bore field is considered low under all options.

It should be noted that there is only a small amount of data (drilling and monitoring) in the northern part of the Robe alluvial aquifer and hence the model results in this area need to be assessed with caution. Ongoing monitoring of water quality will be required to manage any movement of the seawater interface.

With modelled annual abstraction of 6 GL/yr and greater (options 3 to 6) there is a medium risk of groundwater salinity in the aquifer increasing over time due to higher salinity groundwater being drawn in from the aquifer sides.

*Table 5 Robe alluvial aquifer – modelled maximum drawdowns at selected locations*

Allocation option	Volume abstracted GL/yr	Maximum drawdown (m) (distance from bore field)*			
		Seawater bore 1 (14 km)	Bore 1A (10 km)	Bore 11A (0.5 km)	Maraminji Pool (1 km)
1	0	0.65	10.90	6.40	5.55
2	5	0.65	11.00	9.20	7.25
3-1	6 dry climate	0.65	11.00	9.80	7.79
3-2	6	0.64	10.90	9.70	7.79
4	7	0.66	11.00	10.50	8.36
5	8	0.66	11.00	11.00	9.00
6	9	0.64	11.00	11.60	9.55

\* see Figure 8

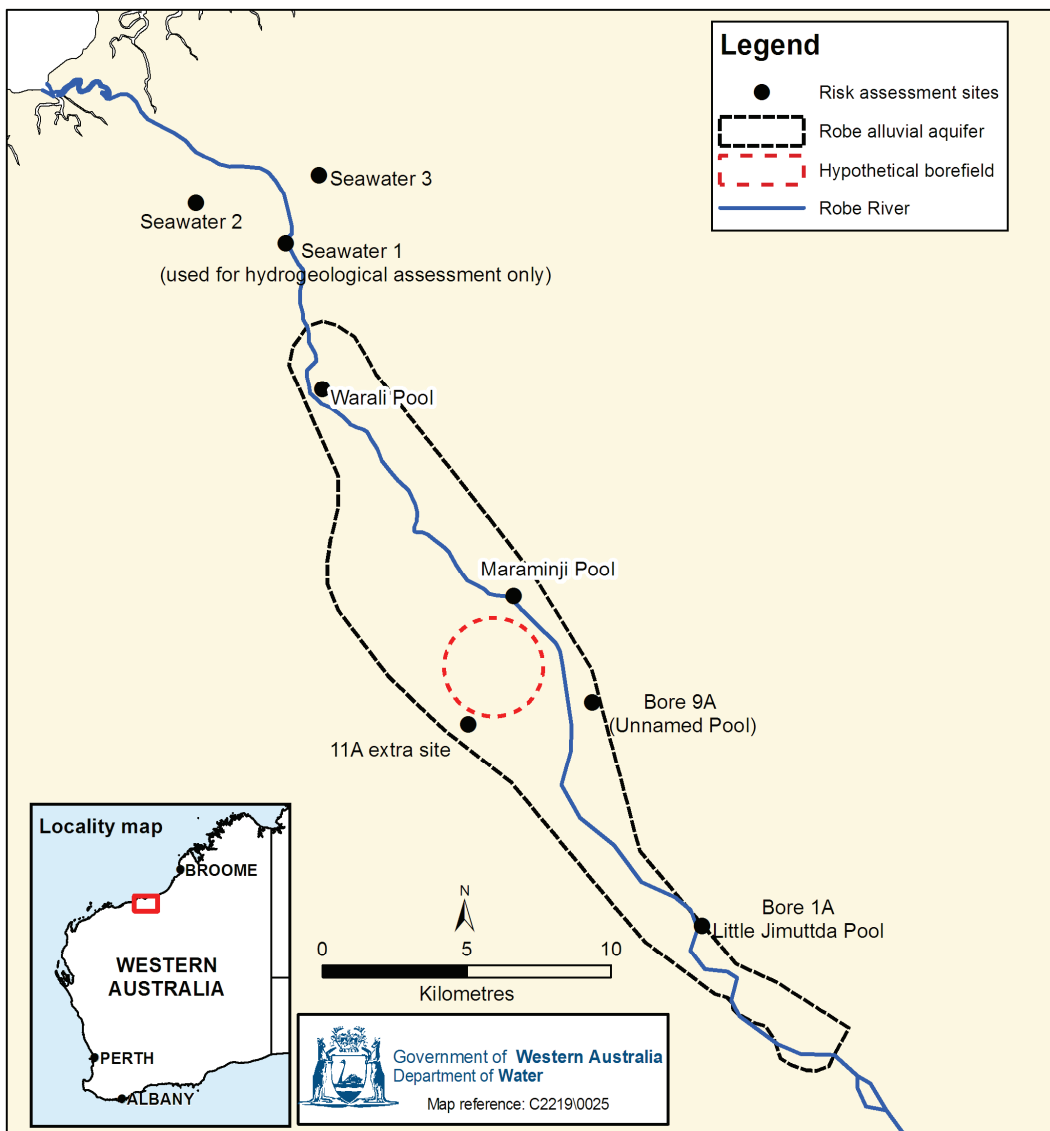


Figure 8 Sites used in Robe alluvial aquifer risk assessment

### Ecological assessment

#### Ecological water requirements - background

Ecological water requirements are the water regimes required to maintain water-dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). They are an important consideration in deciding the allocation limit.

We have described the ecological water requirements for the Robe alluvial aquifer as groundwater levels required to support river pool and riparian vegetation ecosystems, but not for stygofauna communities because of uncertainties about habitat requirements, tolerances and responses to water regime change (Antao 2012).



Four sites were selected for assessment as they were considered to be representative of river pools and riparian vegetation ecosystems (Figure 8). Site selection was based on the degree of groundwater dependence and the hydrological and ecological data available. The sites used were:

- Warali Pool
- Maraminji Pool
- Unnamed pool – bore 9A
- Little Jimuttda Pool – bore 1A.

We selected an additional site (11A) because it was close to the modelled bore field and hence likely to be at significant risk.

In describing the EWRs it was important to recognise the natural variability in water conditions that ecosystems experience along the Robe River. To do this we used results of the Yule alluvial aquifer bore field drawdown trial which identified two thresholds of vegetation responses to changes in groundwater level:

- Medium risk of adverse effects based on early signs of water stress in riparian trees when depth to groundwater fell to levels close to those which had been experienced less than 20% of the time (20th percentile of groundwater level distribution).
- High risk of adverse effects based on increased signs of water stress in riparian trees when depth to groundwater fell to levels close to those which had been experienced less than 5% of the time (5th percentile of groundwater level distribution).

These percentiles were calculated using Robe River recorded or modelled groundwater data to determine a set of threshold groundwater levels. Thresholds were calculated using recorded bore data if available (Little Jimuttda Pool – bore 1A and Unnamed pool – bore 9A) or modelled data where recorded data was not available (Maraminji and Warali pools).

We also identified a threshold for a ‘high’ water level equivalent to the 50th percentile to represent the higher groundwater levels needed for periods of recovery and regeneration.

The EWR thresholds relate to three water availability conditions – drought, dry and above average. This approach recognises that a range of water levels are needed to maintain productive ecosystems and means that we can manage the resources using a variable set of triggers (and responses based on recent climate conditions). Table 10 in Section 4.2 contains the trigger, criteria and target water levels used in the assessment. Antao (2012) has further details of ecological water requirements for the Robe River alluvial aquifer.

### Ecological risk assessment

Model outputs were used to assess the ecological risk of each allocation option. To do this we recalculated the ecological water requirements (5th and 20th percentile groundwater levels) with the model data for Option 1 (0 GL abstraction), and

compared it to the predicted 5th and 20th percentile groundwater levels calculated for the other allocation options.

We calculated EWR thresholds using modelled data rather than using recorded data to deal with errors in predicting absolute water levels typical of outputs from numerical groundwater models. By transferring thresholds across into modelled data we dealt with relative changes in groundwater levels that the model predicts, with greater accuracy.

The ecological risk assessment focused on the duration and magnitude of water levels beyond the drought threshold (5th percentile). This is because the drought threshold represents the maximum risk to ecosystems and the duration and magnitude of water levels beyond this threshold is a major factor affecting ecological response (Roberts, Young et al. 2000).

We used the following categories for duration and magnitude:

A. Total duration below drought EWR thresholds (as a percentage of the 50 year modelled period) exceeded:

- less than 10% of the time – low risk (L)
- between 10 to 25% of the time – medium risk (M)
- more than 25% of the time – high risk (H).

B. Magnitude of exceedence by:

- less than 50 cm – low risk (L)
- 50 to 100 cm – medium risk (M)
- more than 100 cm – high risk (H).

The assessment showed that predicted groundwater levels were sensitive to the overall rate of abstraction and proximity to the hypothetical bore field (Figure 8).

Ecological risk assessment results are shown in Figure 9 (duration below drought threshold) and Figure 10 (magnitude of exceedence of drought threshold).

At bore 11A, the site closest to the bore field, the lowest abstraction option of 5 GL/yr (Option 2) resulted in groundwater levels being below the drought EWR threshold about 26 % of the time (high risk) by up to 2.5 m (high risk). The duration and magnitude of exceedence increased to 50% of the time and 3.5 m under Option 3-2 (6 GL/yr).

At Maraminji Pool, the next closest site, groundwater levels under Option 2 were below the drought EWR threshold 24% of the time (medium risk) by up to 2 m (high risk), increasing to high risk for both categories at 6 GL/yr.

At 6 GL/yr bore 9A was also assessed as high risk with groundwater levels exceeding the drought EWR threshold by up to 1.4 m.

The magnitude and duration of exceedence increased with greater abstraction at all three sites.

The sites located away from the bore field (Warali and Little Jimuttda pools) did not respond to abstraction and were assessed to be at low risk under all the allocation options.

Allocation options were assigned a qualitative overall risk based on an 'average' of the risk categories for the three sites found to be affected by abstraction (Table 6). The overall risk categories in Figure 9 apply to risk from duration, and those in Figure 10 to risk from magnitude of exceedence of thresholds.

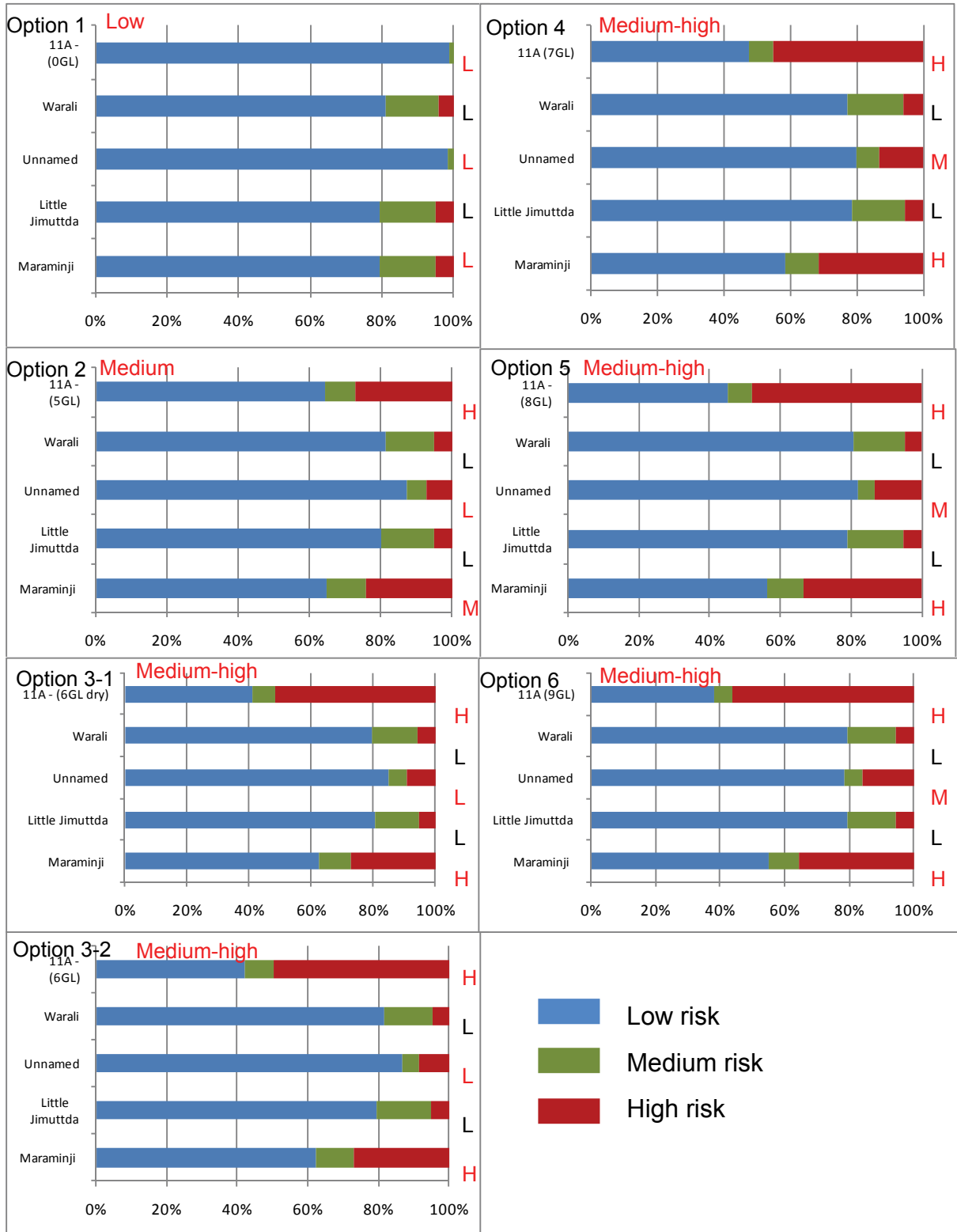


Figure 9 Duration of threshold classes at assessment sites as a percentage of the total model period (50 years) for all options

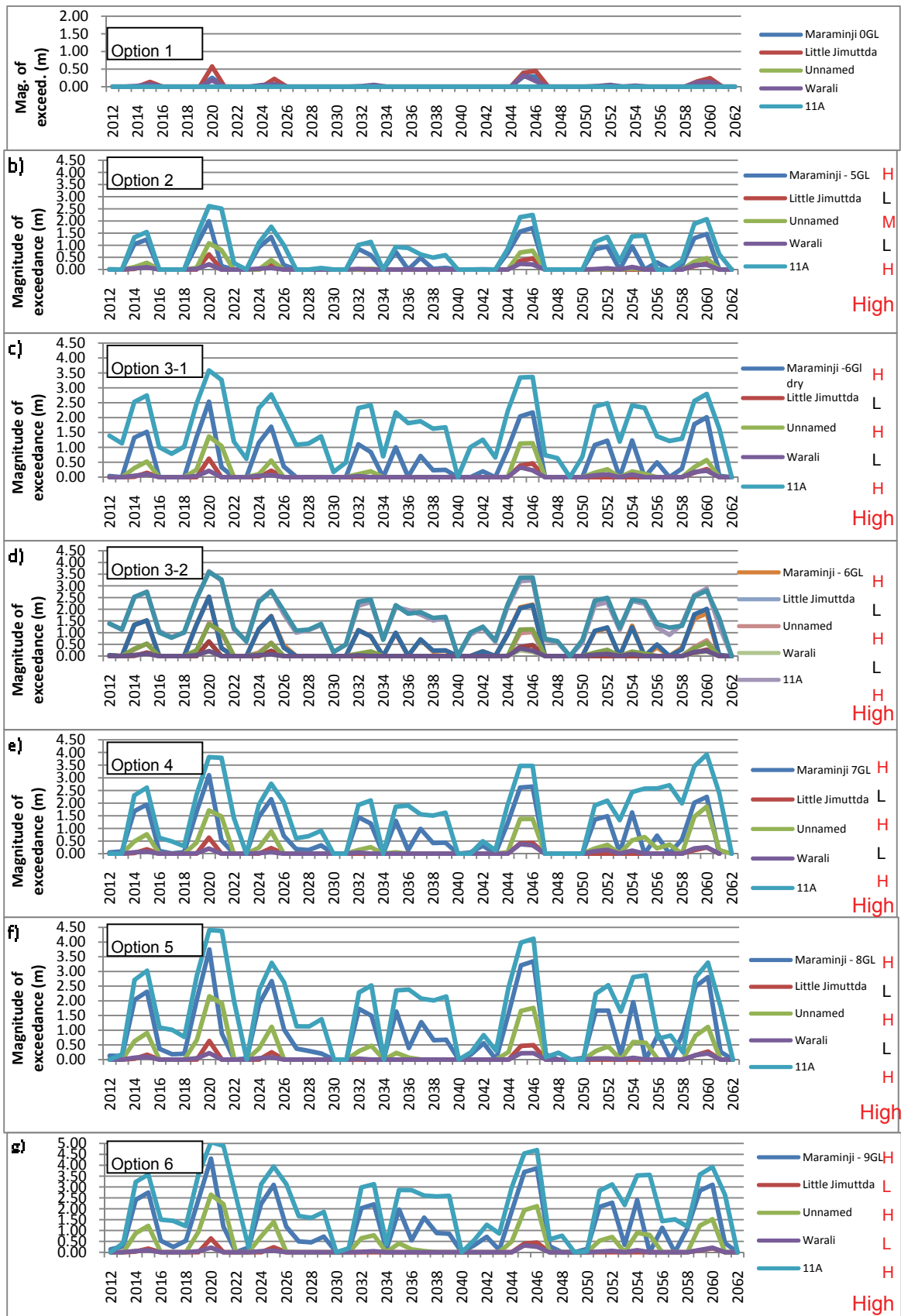


Figure 10 Magnitude of threshold exceedence for all options

### Hydrological and ecological assessment results

To determine an overall level of combined hydrogeological and ecological risk (low, medium or high) for each allocation option, we firstly ranked the assessments individually.

For the ecological assessment, we ranked allocation options by combining the duration and magnitude risk ratings. The ecological assessment concluded that abstraction rates of 5 GL/yr represented a medium to high risk to the ecosystems and 6 GL/yr and above represented a high level risk (Table 6).

*Table 6 Summary of ecological risk assessment*

Allocation option	Volume abstracted GL/yr	Ecological risk		
		Duration	Magnitude	Overall
1	0	Low	Low	Low
2	5	Medium	High	Medium–high
3-1	6 dry climate	Medium–high	High	High
3-2	6	Medium–high	High	High
4	7	Medium–high	High	High
5	8	Medium–high	High	High
6	9	Medium–high	High	High

For the hydrogeological assessment we ranked allocation options by combining the risk ratings for potential adverse effects on the seawater interface and water quality across the aquifer. The hydrogeological assessment concluded that abstraction rates of up to 5 GL/year represented a low risk to the Robe River aquifer. Risk increased to low–medium at abstraction rates of 6 GL/yr and above (Table 7).

*Table 7 Summary of hydrogeological risk assessment*

Allocation option	Volume abstracted GL/yr	Hydrogeological risk		
		Seawater intrusion	Water quality effects from the flank	Overall
1	0	Low	Low	Low
2	5	Low	Low	Low
3-1	6 dry climate	Low	Medium	Low–medium
3-2	6	Low	Medium	Low–medium
4	7	Low	Medium	Low–medium
5	8	Low	Medium	Low–medium
6	9	Low	Medium	Low–medium

For each option we then combined the hydrogeological and ecological risk assessments, giving equal weightings to both assessments, to determine an allocation option risk (Table 8).

**Table 8** Summary of overall risk assessment

Allocation option	Volume abstracted GL/yr	Hydrogeological risk	Ecological risk	Overall risk
1	0	Low	Low	Low
2	5	Low	Medium–high	Medium
3-1	6 dry climate	Low–medium	High	Medium–high
3-2	6	Low–medium	High	Medium–high
4	7	Low–medium	High	Medium–high
5	8	Low–medium	High	Medium–high
6	9	Low–medium	High	Medium–high

### 3.3 Deciding allocation limits

The department decided to set the allocation limit for the Robe alluvial aquifer at 5.09 GL/yr (including 0.09 GL/yr for stock and domestic use) (Table 9). The decision was based on:

- a predicted medium to high risk to groundwater-dependent ecosystems which could be managed by spreading the draw across the aquifer
- a predicted low risk to groundwater quality
- the predicted short to medium term demand
- groundwater dependent ecosystems considered to be of conservation value at the local scale
- no testing of, or real data on, the aquifer response to abstraction
- previous recharge estimates of 8 to 10 GL/yr.

The distribution of abstraction is important in managing the risk to ecosystems and the aquifer. Therefore, through our licensing arrangements, we will require the configuration and management of future bore fields be designed to ensure that risks to groundwater-dependent ecosystems are minimised. This will include spreading the draw across the aquifer and checking the water level changes against those predicted once abstraction has begun and monitoring results become available.

**Table 9** Allocation limits components for the Robe alluvial aquifer

Allocation limit GL/ yr	Licensable components GL/ yr		Un-licensable component GL/ yr
	General licensing	Public water supply	Unlicensed use (stock and domestic)
5.09	3.00	2.00	0.09

## 4 Defining the management approach

In part C of the allocation planning process (Figure 2) we define our ongoing management for the groundwater allocation plan area. The department will manage risk through the allocation limits, licensing policy and monitoring.

At the aquifer scale the allocation limit, as described in this report, will help us meet the resource objectives for preventing seawater intrusion, maintaining water quality and maintaining groundwater and pool levels within a target range.

At the local scale, the department will use licensing policy to help us assess groundwater licence applications and manage licences on a case-by-case basis. We will use monitoring to allow us to understand how the resource is performing over time and in particular how the aquifer and environment are responding to abstraction.

In this section we describe how we developed the licensing policy and monitoring requirements described in the *Pilbara groundwater allocation plan*.

### 4.1 Licensing policy

The ability to abstract the full allocation from the resource and not cause significant adverse effects on hydrogeological, environmental and cultural values is dependent on the spread of the abstraction. Licensees will be required to develop a bore field configuration to ensure that values are protected.

To maximise abstraction while maintaining environmental and cultural values the department has developed a licensing policy that links management to the recharge that the Robe alluvial aquifer receives.

As the allocation limit for the Robe aquifer poses risks to the dependent values, a high level of management effort is needed.

We will work with proponents to ensure that:

- the resource remains productive in the long term
- any adverse effects on groundwater-dependent ecosystems are minimised
- effects on groundwater-dependent ecosystems are anticipated.

Any operating strategies associated with licences will also include requirements for longer term hydrological and ecological monitoring, assessment and reviews.

### 4.2 Monitoring - trigger and response framework

Risks to the Robe alluvial aquifer will be managed through a trigger and response framework. Water level triggers will be used to manage any adverse effects on environmental and cultural values and on the resource. When reached, these water levels trigger a response so that management can be adapted and any adverse effects can be minimised. Trigger levels ensure that adequate water is left in the alluvial aquifer to meet the EWRs described in Section 3.2.

Trigger levels for water quality will be developed for operating strategies.



The framework has target, trigger and criteria water levels. Target levels are above average water levels that should be met under average and wet conditions, to reflect periods of greater recharge. Trigger water levels are an early warning which indicates that a water level is declining and approaching the more critical, criteria water level. Criteria water levels have been set to meet water resource objectives and should not be breached.

The management response to the triggers includes reporting, monitoring and adjustment of take from the bore fields. The level of response increases as groundwater levels decline.

### **How we set trigger, criteria and target water levels**

Because we need to balance demand for water with how much water is left in the aquifer to support the environment and aquifer productivity, the volume of water needed to meet the EWRs may not be available all the time. We have therefore determined environmental water provisions (EWP) that are a compromise between the EWR and the water levels predicted under the full allocation of 5.09 GL/yr. The EWP represents modelled water levels under abstraction rates of 5.09 GL/yr. We recognise that this poses a risk to the environment but think these risks are either manageable or consistent with the resource objectives.

Target water levels relate to above average water conditions (> 50th percentile) and are based on EWRs. Trigger levels are set as the EWR thresholds as described in Section 3.2.

The criteria water levels are the EWP which were set by calculating the difference between predicted groundwater level percentiles under Option 1 (0 GL/yr) and Option 2 (5 GL/yr) abstraction, and subtracting this difference from the EWR (trigger) groundwater levels. This process is shown in Table 10. For average conditions we have set the criteria as the 20th percentile EWR.

Because of the way the bore field was configured in the model, water levels at sites close to the hypothetical bore field were predicted to decrease by more than 0.50 m (moderate to high risk), while sites further away experienced little or no decrease. Consistent with our requirement for future bore fields to spread the take across the aquifer to minimise any adverse effects, we have averaged the difference across the EWR sites to develop EWP. Based on these calculations an average difference of 0.48 m and 0.25 m (5th and 20th percentile) was applied to the EWR to produce EWP (criteria water levels). This difference between the EWR and EWP represents the amount by which EWR thresholds will not be met under the allocation limit. It is the trade-off that we have made to provide water for abstraction in setting the allocation limit.

Table 10 Developing trigger, criteria and target water levels

Site	Water condition	EWR <sup>1</sup> = Trigger	Average difference between 0 & 5 GL <sup>2</sup>	EWP = Criteria
<b>1A Little Jimuttda</b>				
5th percentile	Drought	41.57	0.48	40.47
20th percentile	Dry	42.28	0.25	41.25
50th percentile	Above average	42.94		42.94 (target)
<b>9A (unnamed pool)</b>				
5th percentile	Drought	30.73	0.48	29.57
20th percentile	Dry	30.82	0.25	30.27
50th percentile	Above average	31.71		31.71 (target)
<b>Maraminji Pool</b>				
5th percentile	Drought	23.32	0.48	22.56
20th percentile	Dry	23.74	0.25	23.19
50th percentile	Above average	24.18		24.18 (target)
<b>Warali Pool</b>				
5th percentile	Drought	11.45	0.48	10.53
20th percentile	Dry	11.77	0.25	11.00
50th percentile	Above average	12.14		12.14 (target)

<sup>1</sup> Incorporates allowable magnitude of exceedence as defined in EWR (Antao 2012)

<sup>2</sup> Represents the average difference in percentiles between modelled data for 0 GL allocation and 5 GL (options 1 and 2) allocation (across the four sites)

### Applying trigger, criteria and target levels

The triggers, criteria and/or target levels will be applied based on groundwater availability conditions (drought, dry, average or wet). Because river flow is not affected by abstraction and is the major source of aquifer recharge (and therefore a good predictor of groundwater level), we have developed categories for recharge or 'recharge classes' based on river flow. These will allow us to apply the appropriate trigger, criteria or target in any given year based on the likely groundwater availability.

We assessed a number of hydrological parameters to determine which has the strongest relationship to groundwater recharge. The total wet season flow in the previous two years was found to be the most important.

The flow volumes and water availability conditions for each class are shown in Table 11. More detail on recharge classes is provided in Antao (2012).

Table 11 Robe river recharge classes

Recharge class	Water availability conditions	Total wet season flow (Nov-Apr)ML
1	Drought	Previous 2 years flow < 4 000
2	Dry	less than 20 000 (except where class 1 applies)
3	Average	20 001 to 100 000
4	Wet	More than 100 000

To apply the trigger, criteria and target levels we determine the recharge class and then decide which levels are applicable using Table 12.

For example, if total wet season flow is 18 000 ML, it is a recharge class 2 year, dry water availability (Table 11). The trigger and criteria levels for the following year are based on the 20th percentile water levels and there is no target level (Table 12). If the flow was greater than 100 000 ML, it would be recharge class 4 year and water levels should reach the target level based on the 50th percentile.

Table 12 Applying trigger, criteria and target water levels

Threshold	Recharge class			
	1 Drought	2 Dry	3 Average	4 Above average/wet
Trigger	5th percentile (EWR)	20th percentile (EWR)		
Criteria	5th percentile (EWP)	20th percentile (EWP)	20th percentile (EWR)	
Target			50th percentile (target)	50th percentile (target)

The trigger and response framework for the Robe alluvial aquifer will be linked to licence/s and implemented by future water users as part of operating strategies developed as a condition on the licence/s.

Details of the trigger and response framework are included in the groundwater allocation plan.



# Appendices

## Appendix A - Synthetic 100 year climate sequences for the Robe area

The Robe River groundwater model was run using 50 year subsets of a 100 year climate options generated by the Department using a 'bootstrapping' approach to historical climate data. The bootstrapping method uses repetitive random sampling of the historical time series on an annual basis and joining them end to end to build up the 100 years of synthetic time series.

The 100 year sequence was statistically similar to the recorded historical climate. This therefore assumes that climate in the Pilbara will remain approximately the same as recent history. We took this approach to modelling because the climate predictions for the Pilbara at the time of modelling did not indicate a consistent predicted change (Loo & Humphreys 2009). The 50 year subset was used instead of the full 100 years to reduce model run times.

The following sections describe the data sources and the methods used to generate the synthetic 100 year long daily rainfall, streamflow and stage height sequences for groundwater modelling in the Pilbara.

### Introduction

Synthetic 100 year sequences of daily river flow and rainfall data have been generated for the Robe, Fortescue, Millstream, Yule, De Grey and West Canning groundwater model areas in the western Pilbara region. Only the Robe is discussed in detail here.

The 100 year sequences were generated on a daily timestep using the bootstrapping method used by DHI (2009) for the Millstream groundwater model. Data in the 100 year sequence was sampled from a 22 year period of historical record for which streamflow data was available (from October 1987 to September 2009).

The original work described above was completed in November 2010. An additional water depth series was generated in June 2011 to complement the river flow data.

### Historical data

#### Rainfall

Daily rainfall data were obtained from the SILO Data Drill (Department of Environment and Resource Management 2009) using grid cells close to the centroids of each of the existing groundwater model areas. The coordinates of the SILO grid cells used are listed in Table A.1.

The licence agreement for using the SILO Data Drill includes the following statement which applies to historical rainfall, streamflow and water depth data:

Based on or contains data provided by the State of Queensland (Department of Environment and Resource Management) [2009]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.

## Streamflow

Streamflow data was obtained from the Department of Water HYDSYS database in October 2010. The streamflow gauge used for the model area is described in Table A.1.

*Table A.1 Rainfall and streamflow data sources.*

<b>Groundwater model area</b>	<b>SILO grid Easting</b>	<b>SILO grid Northing</b>	<b>Streamflow gauge location</b>	<b>Streamflow gauge AWRC reference</b>
Robe	115.80	21.45	Robe River – Yarraloola	707002

## Water depth

Water depth data was obtained from the Department of Water HYDSYS database in June 2011. The water depths reported in the synthetic data sequences are at the gauge shown in Table A.1.

Water level varies over each day and measurements are taken as often as at five minute intervals. The water level for each site was extracted as a mean (average) level over each day. As a result of averaging, on days when the river level is rising or falling, the water level used to generate the daily synthetic data sequence may not correspond directly to the volume of water that flowed that day.

The water depth reported in the synthetic data sequences uses the cease-to-flow level (the level at which a stream stops flowing) at the gauge as a datum. The water depth is calculated as the stage measured at the gauge minus the cease-to-flow level. Consequently, the depths reported are positive when the river is flowing and zero or negative when it is not.

Negative depths in the synthetic data sequence are a result of water levels below the cease-to-flow level at the gauge (and indicate there may be a pool of water at the gauge at a level lower than the cease to flow level). The negative depths may be set to zero to generate a usable data sequence. However, it must be noted that at the gauge, this excludes the contribution of water below the cease-to-flow level over the entire data sequence.

## Period of record

The choice of the period of years from which to sample streamflow and rainfall data was based on the shortest streamflow record across all the modelled areas. This was

at the Fortescue River Bilanoo gauge, from 1987 to 2009. Having the same period of years from which to sample data should give synthetic sequences that represent the same climate.

## Synthetic series generation

### Current climate synthetic series generation

The current climate synthetic series generation uses the bootstrapping method DHI (2009) used for Millstream. Sampled years were selected from the period 1987 to 2009, using water years defined as 1 October to 30 September rather than calendar years.

### Dry climate synthetic series generation

A dry climate synthetic series was generated by replacing randomly selected years in the current climate synthetic series (for rainfall and streamflow) with a year where total water year streamflow was in the lowest tenth percentile (1989–1990 water year).

Years were replaced until the average annual flow was approximately 10% lower than for the current climate series.

## Appendix B - 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: Michelle Antao

Map Author: Michelle Antao

Filepath:

a) J:\gisprojects\Project\C\_series\C2219\0025\_Robe\_Maps\mxd\methods report

Filename:

120802\_ GDE.mxd

120802\_Robe\_Assessment\_Sites.mxd

120802\_Robe\_Model\_Domain.mxd

120802\_Robe\_revised\_boundary.mxd

120802\_Robe\_salinity.mxd

120802\_Robe\_current\_boundaries.mxd

120802\_Robe\_Revise\_Boundaries

Compilation date: August 2012

### *Disclaimer*

These maps are a product of the Department of Water, Water Resource Use 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 these maps:

Hydrography, Linear (Hierarchy) – DoW – 05/11/2007

Pilbara Pool Mapping – DoW – 2009



Road Centrelines – DoW – Current

Towns –DLI – Current

WA Coastline, WRC (Poly) – DoW – 20/07/2006

Main Roads, DLI, 2010

Pilbara Monitoring Program, DoW project specific data, 2012

WIN surface water sites – stream gauging, DoW, 2012

WIN groundwater sites – all, DoW, 2012

DWAID Aquifers, DoW

DWAID Groundwater areas, DoW

DWAID Subareas, DoW

## Shortened forms

AHD	Australian height datum
AWRC	Australian Water Resources Council
BoM	Bureau of Meteorology
DERM	Department of Environment and Resource Management, Queensland
DoW	Department of Water
DWAID	Divertible water allocation information database
EWP	Environmental water provision
EWR	Ecological water requirement
LiDAR	Light detection and ranging
MDBC	Murray-Darling Basin Commission
RMS	Normalised root mean square
TDS	Total dissolved solids
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

<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.
<b>Aquiclude</b>	An impermeable layer within an aquifer formation that prevents transmission of water or pressure.
<b>Aquifer</b>	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined and artesian
<b>Aquifer integrity</b>	The ability of an aquifer to maintain a supply of usable water indefinitely.
<b>Australian Height Datum</b>	The datum used for the determination of elevations in Australia. The determination used a national network of bench marks and tide gauges, and set mean sea level as zero elevation.
<b>Bore</b>	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
<b>Bore field</b>	A group of bores to monitor or withdraw groundwater.
<b>Consumptive use</b>	The use of water for private benefit consumptive purposes including irrigation, industry, urban and stock and domestic use.
<b>Criteria level</b>	A groundwater or pool level that should not be breached. This is to meet water resource objectives, usually relating to maintaining water quality, aquifer productivity and/or water for ecology.
<b>Discharge</b>	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants or engineering.
<b>Drawdown</b>	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure.

<b>Environmental water provision</b>	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic effects. They may meet in part or in full the ecological water requirements.
<b>Ecological water requirement</b>	Water regime needed to maintain the ecological values of water-dependent ecosystems (including assets, functions and processes) at a low level of risk.
<b>FEFLOW</b>	A finite element numerical groundwater model.
<b>Groundwater</b>	Water which occupies the pores and crevices of rock or soil beneath the land surface.
<b>Groundwater area</b>	Boundaries that are proclaimed under the <i>Rights in Water and Irrigation Act 1914</i> and are used for water allocation planning and management
<b>Groundwater subarea</b>	Areas defined by the Department of Water within a groundwater area, used for water allocation planning and management.
<b>Hydrogeology</b>	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
<b>HYDSYS</b>	Database used by the Department of Water to hold hydrographic records.
<b>Licence</b>	A formal permit which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source.
<b>LiDAR</b>	Remote sensing technology that can be used to develop ground contours by measuring the distance to on-ground objects.
<b>Recharge</b>	Water that infiltrates into the soil to replenish an aquifer.
<b>Salinity</b>	The measure of total soluble salt or mineral constituents in water. Water resources are usually classified by salinity in terms of totals dissolved salts (TDS)
<b>Stock and domestic water use</b>	Water that is used for ordinary domestic purposes associated with a dwelling, such as: water for cattle or stock other than those being raised under intensive conditions; water for up to 0.2 hectares (if groundwater) or 2 hectares (if surface water) of garden from which no produce is sold. This take is generally considered a basic right.

<b>Subarea</b>	A sub-division within a surface or groundwater Area, defined for the purpose of managing the allocation of groundwater resources. Sub-areas are not proclaimed and can therefore be changed internally without being gazetted.
<b>Target level</b>	A groundwater or pool level that is a goal to meet in years of average or above average water availability to reflect recovery of the aquifer.
<b>Trigger levels</b>	A groundwater or pool level that triggers management actions or responses so that the risk of abstraction having an adverse effect on the water resource and dependent values is reduced.

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## Department of **Water**

168 St Georges Terrace, Perth, Western Australia  
PO Box K822 Perth Western Australia 6842

Phone: 08 6364 7600

Fax: 08 6364 7601

[www.water.wa.gov.au](http://www.water.wa.gov.au)

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