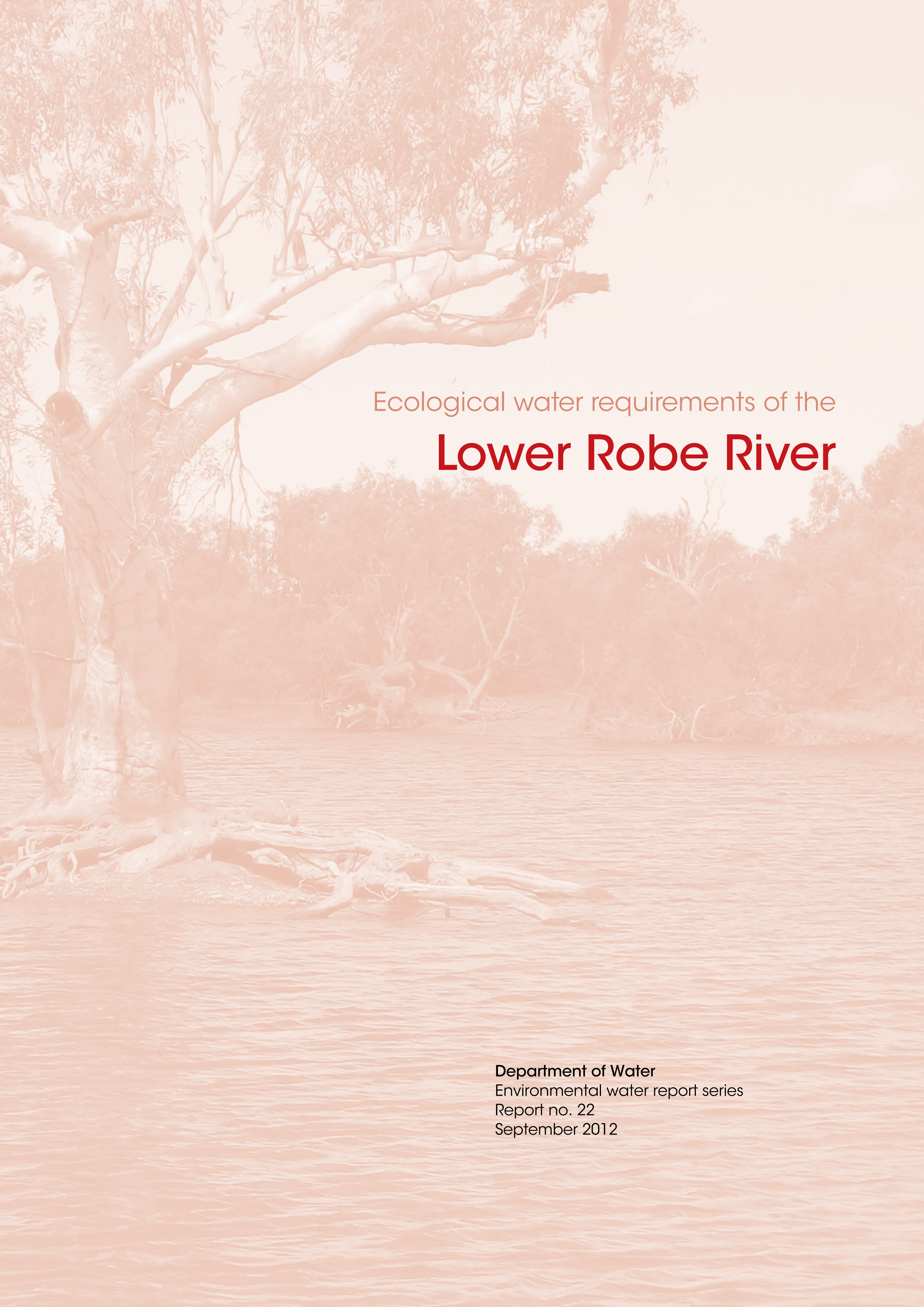
Government of **Western Australia**
Department of **Water**

Ecological water requirements of the

Lower Robe River

Looking after all our water needs

Environmental water report series
Report no. 22
September 2012



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This report describes the ecological water requirements (EWRs) for the groundwater-dependent ecosystems of the lower Robe River alluvial aquifer.

EWRs are the water regimes required to maintain dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). They are a key part of the water allocation planning process and are used during licensing decisions to manage the impacts of water abstraction on the environment.

Groundwater ecosystems that depend on the lower Robe River alluvial aquifer include river pools, riparian vegetation and aquifer ecosystems (stygofauna). These ecosystems depend on groundwater at least part of the time. EWRs have been developed for four sites that represent river pools and riparian vegetation across the study area.

The lower Robe River alluvial aquifer is recharged by direct infiltration through the riverbed when the Robe River flows. As with most Pilbara rivers, these flow events are highly variable – being reliant on summer cyclones and autumn thunderstorms. As a result, water levels in the aquifer and water available to ecosystems are also variable. To account for the natural variability in water availability, we determined EWRs for a range of climate conditions rather than only setting minimum groundwater level criteria.

To set EWRs reflective of variable conditions, we considered different water availabilities. These are presented as percentile thresholds and are defined as drought, dry and above-average water conditions.

Given the aquifer is recharged by river flow, recharge classes based on river flow were developed. These are used to determine which EWR (drought, dry or above-average) should be applied in any given year.

The following EWRs were recommended for the lower Robe River alluvial aquifer:

EWR site	Recharge class	Threshold applicable	EWR		
			EWR mAHD	**Duration of exceedence**	**Max magnitude**
Little Jimuttda Pool and riparian vegetation	Average	50%	42.94		
	Dry	20%	41.89	6 months	0.39 m
	Drought	5%	41.26	4 months	0.31 m
Unnamed Pool and riparian vegetation	Average	50%	31.71		
	Dry	20%	30.67	6 months	0.15 m
	Drought	5%	30.39	4 months	0.34 m
Maraminji Pool and riparian vegetation	Average	50%	24.18		
	Dry	20%	23.59	6 months	0.15 m
	Drought	5%	23.17	4 months	0.14 m
Warali Pool and riparian vegetation	Average	50%	12.136		
	Dry	20%	11.505	6 months	0.26 m
	Drought	5%	11.223	4 months	0.22 m

1.1 Purpose of this document

The Department of Water is developing a water allocation plan for the Pilbara groundwater area, which includes the lower Robe River alluvial aquifer. Under the *Rights in Water and Irrigation Act 1914* (WA), the department is required to include protection of groundwater-dependent ecosystems (GDEs) in this process. This is done by developing ecological water requirements (EWRs), which estimate how much water is required to maintain GDEs at a low level of risk from abstraction activities (Water and Rivers Commission 2000).

This report presents the EWRs for the lower Robe River alluvial aquifer's GDEs. It is stage two of a project to inform the *Pilbara groundwater allocation plan*. The stages are:

Stage 1 Ecological values and issues report (Antao and Braimbridge 2010)

– identifies and describes GDEs of the Robe River

Stage 2 EWRs – this report

Stage 3 Allocation limits method report (DoW 2012)

– describes how EWRs and other factors are considered in setting the annual volume of water set aside for consumptive use

Stage 4 *Pilbara groundwater allocation plan*

The ecological values and issues report identified the following GDEs (which are considered in this report):

- river pool ecosystems
- riparian vegetation ecosystems
- stygofauna.

1.2 Approach

The EWRs for the Robe River were developed using an approach that allows for the highly variable water conditions experienced in the Pilbara to be accounted for. This process is outlined in the flow diagram below (Figure 1).

In step one, key hydro-ecological linkages important in sustaining ecosystems were identified based on the conceptual model of the GDE. The linkages define the ecological objective and the components of the groundwater regime required to meet them (Section 2.3).

Step two involved the development of thresholds that defined the groundwater regime required to maintain the linkages. These are the generic groundwater conditions required to meet the ecological objectives and maintain the GDE. For this process percentiles were used because they represent the local water regime the dependent ecology has adapted to. This approach is similar to that recommended by ARMCANZ & ANZECC (2000) to derive biological, chemical and physical water quality stressors. Percentiles also allow us to translate the thresholds from one site to another.

Step three involved the development of a decision-making tool to allow water managers to apply the dry, drought or above-average groundwater EWR. Recharge classes were developed to provide an early indication of which EWR should be applied for the year, based on the preceding year's river flow.

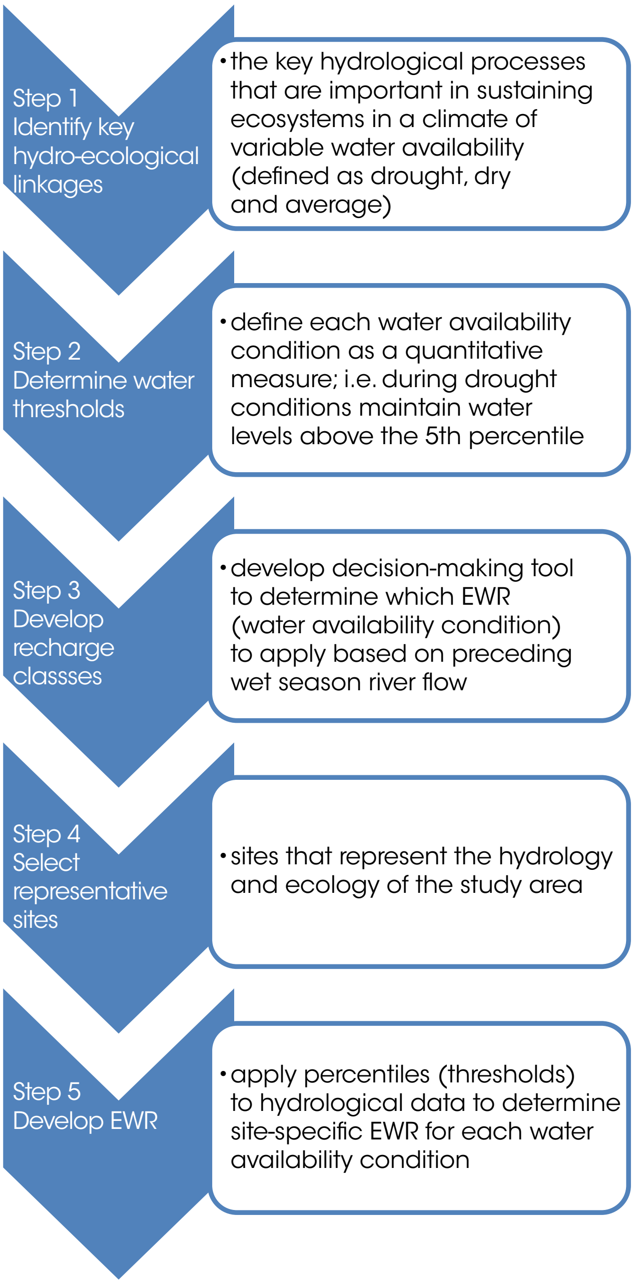

Figure 1
Approach to setting EWRs for Robe River GDEs

The next step was to select sites considered to represent the hydrology and ecology of the study area and the hydro-ecological linkages.

In step five, local groundwater data were applied to thresholds to develop site-specific EWRs. This process resulted in EWRs (groundwater levels) that can only be exceeded in applicable dry, drought or above-average conditions.

1.3 Study area

Location

The lower Robe River alluvial aquifer underlies the lower reaches of the Robe River as it crosses the coastal plain, 80 km east of Onslow. The EWR study area extends approximately 40 km along the Robe River, running downstream of the North West Coastal Highway (Figure 2).

Climate

The Pilbara region's climate is classified as semi-arid to arid with hot, dry conditions most of the year. Annual rainfall at nearby Pannawonica is highly variable, with totals ranging from 113 to 700 mm and an average of 410 mm. This variability is due to the episodic nature of tropical cyclones and thunderstorms that occur between December and March and account for 70 per cent of total annual rainfall.

Temperatures are high – mean maximums range from 41.1°C in January to 26.7°C in July. High temperatures and solar radiation result in high annual evaporation above 3000 mm.

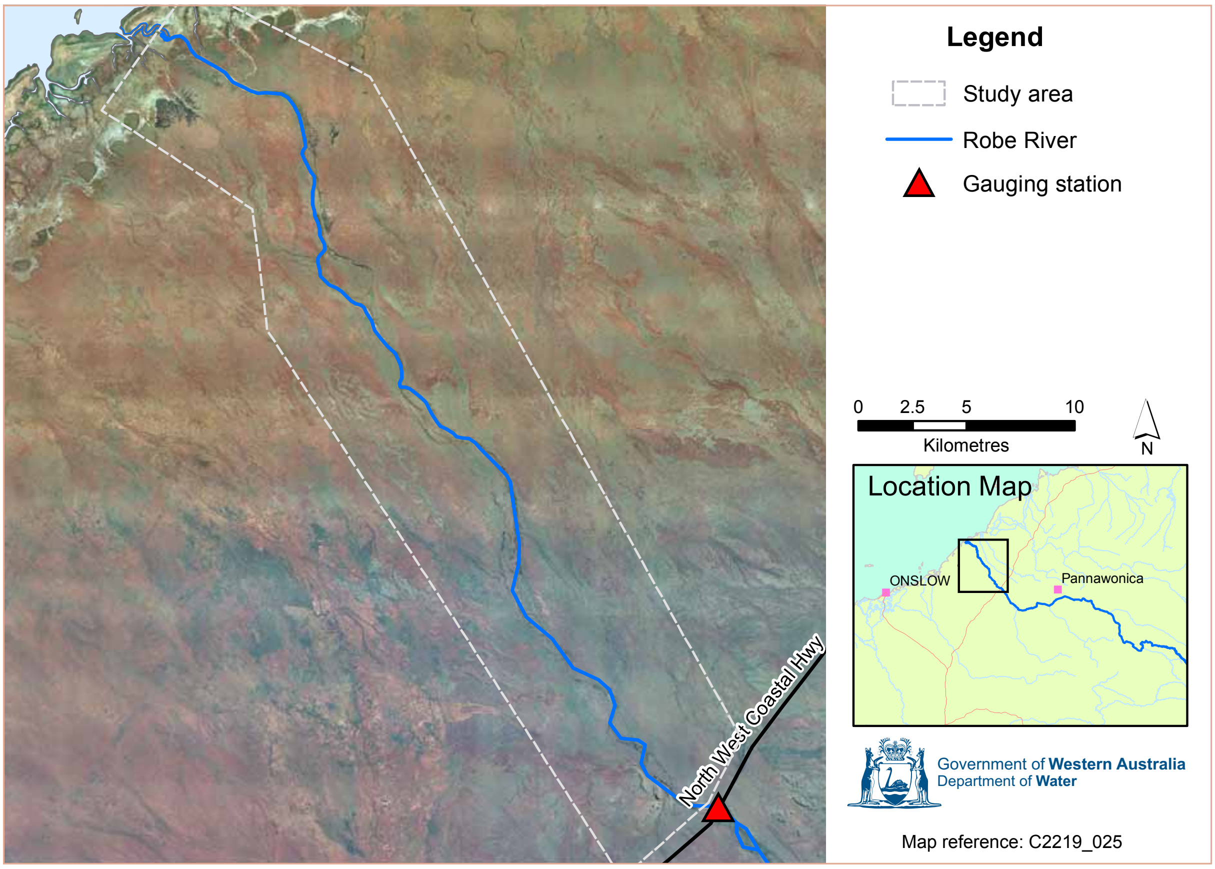

Figure 2
Robe River EWR study area

Hydrology

The Robe River lies on the Ashburton Plain, crossing the plain in a north-westerly direction. The river channel is narrow and incised as much as 5 m below the general level of the plain.

The mean annual flow at Yarraloola gauging station (707002) since 1972 is 108 GL (± standard error 30). Patterns in river flow are strongly correlated to rainfall in the catchment, with flows most likely to occur between December and April with peaks in March. The period from July to November is often very dry with minimal or no river flow (Figure 3).

Total annual flow is highly variable and unpredictable. Despite years of above-average flow occurring in about a quarter of years, years of low or even zero flow have been recorded in a third of years.

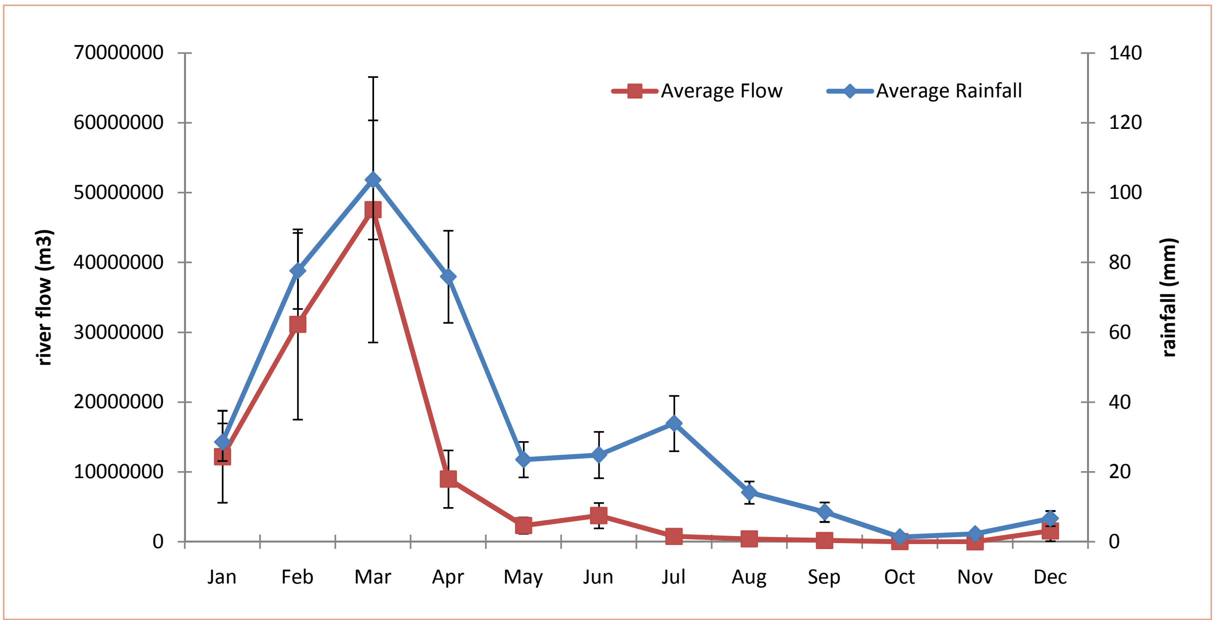

Figure 3

Average monthly flow at Yarraloola gauging station and rainfall at Pannawonica meteorological station (error bars represent standard error for monthly means)

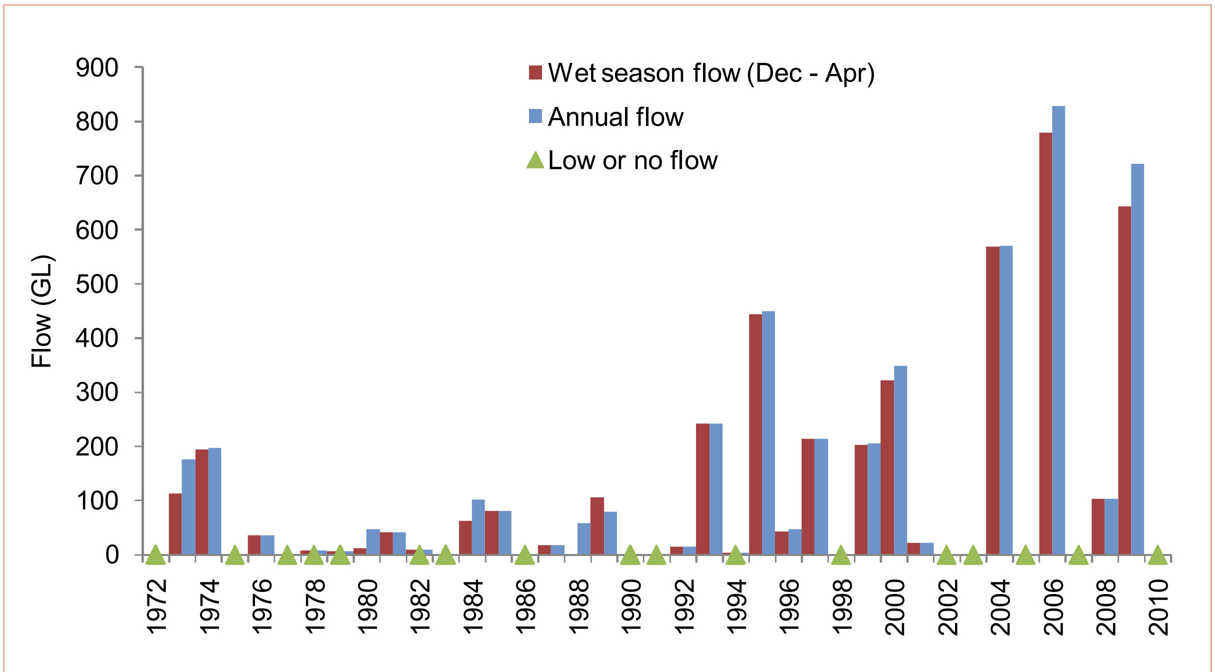

Figure 4

Total annual flow and total wet season flow (December–April) measured at Yarraloola gauging station

Hydrogeology

The Robe River is underlain by an alluvial aquifer consisting of gravel beds to a maximum depth of 17 m, interspersed with clay lenses. The aquifer thins away from the river to a distance of 5 km and towards the downstream end of the study area. Calcrete has formed in the alluvial sediments and, where present, is found at or up to 5 m below the watertable.

The aquifer is highly transmissive and is quickly recharged during river flow events (which are the predominant form of recharge). The aquifer has the potential to absorb a significant percentage of river flow, with the amount of recharge controlled by the frequency, size and duration of flows and current groundwater levels.

Along the river, the watertable sits close to the surface. Depth to groundwater stays within 10 m to a distance of about 1 km away from the main channel. In this area the watertable can fluctuate by up to 3 m a year due to high rates of evapotranspiration and river recharge. Where the river channel intersects the aquifer, permanent to semi-permanent pools occur as surface expressions of the alluvial aquifer.

Data availability

Within the study area seven groundwater bores have been monitored for groundwater level and water quality (electrical conductivity) at varying frequencies since 1983 (Figure 6). At present these bores are being monitored bi-annually in June and December. Intermittent monitoring has also occurred at other bores across the study area.

For the EWR project, monitoring data has been supplemented by outputs from the lower Robe River numerical groundwater model. This model was developed as part of the department's 'Water for the Future' *Pilbara groundwater allocation plan* project funded by the Federal Government between 2001 and 2010. The project's aim was to help assess groundwater response to a number of future groundwater extraction regimes. The model was used to produce a 50-year dataset of predicted groundwater levels at key GDE sites that had limited data.

Yarraloola gauging station is located on the Robe River at the North West Coastal Highway immediately upstream of the study area. The flow record at this station covers 40 years from 1972 to the present.

Several permanent and semi-permanent pools occur within the study area. While these pools have not been actively monitored, indirect observations have occurred through aerial photography, site visits and Pilbara pool mapping conducted by the department (Department of Water 2009) (see Appendix C).

Broad vegetation mapping along the course of the river has been completed through interpretation of aerial photography. Finer-scale community mapping was undertaken at representative sites through vegetation surveys along transects bisecting the riparian zone.

An accurate digital elevation model (DEM) of the study area was produced using LiDAR. The DEM and groundwater data were combined to produce a depth-to-groundwater map for the study area.

2 Groundwater-dependent ecosystems

In this assessment GDEs are defined as ecosystems that rely on groundwater directly (e.g. stygofauna or phreatophytic vegetation using water from shallow watertables) or indirectly (e.g. wetland vegetation or aquatic ecosystems sustained by groundwater discharge).

The following three types of GDE were identified on the lower Robe River during the first stage of this project (Antao and Braimbridge 2010):

- river pools
- riparian vegetation
- aquifer ecosystems.

The river pools and riparian vegetation provide valuable habitat for several priority fauna species, two federally protected migratory birds and potential new fish species. The aquifer ecosystems have distinct stygofauna species and are expected to be of high conservation value. These ecosystems were considered to have conservation significance at the regional scale.

A full description of the GDEs and their links to hydrogeology is presented in *Lower Robe River – ecological values and issues* (Antao and Braimbridge 2010). A brief description of each, how they were defined and the groundwater/ecology linkages have been provided here to give context.

2.1 Identification and dependence

Riparian vegetation

Riparian vegetation communities fringe the river and provide critical habitat corridors between upland and aquatic ecosystems. They are often biologically diverse (Scott, Shafroth et al. 1999) and provide important habitat for terrestrial fauna in arid environments (van Dam, Storey et al. 2005). Healthy riparian ecosystems also support river pool health by providing carbon inputs into aquatic foodwebs and habitat for flying aquatic insects during adult life stages (Douglas et al. 2005).

Results of the Pilbara Biological Survey (conducted by the Department of Environment and Conservation) identified riparian ecosystems as providing important habitat for several fauna groups. These include bats and birds, with the highest species richness being recorded in riparian environments (McKenzie and Bullen 2009; Burbidge, Johnston et al. 2010).

The riparian communities were mapped along the course of the lower Robe River for stage 1 of this project. It was determined they were very similar to others found along large rivers throughout the Pilbara, with *Eucalyptus camaldulensis* the dominant tree species and occasional occurrences of *Melaleuca argentea.*

Throughout the Pilbara *E. camaldulensis* is known to be associated with areas where depth to groundwater is less than 10 m (Loomes 2010). In the study area, depth-to-groundwater mapping demonstrates that *E. camaldulensis* is restricted to areas of shallow groundwater (<9 m) and the area inundated during flooding.

Regionally *M. argentea* is known to be restricted to areas where the watertable is very shallow or at the surface (Graham 2001; Loomes 2010). In the study area this species appears to be restricted to areas where the watertable is less than 5 m.

Given their close proximity to reliable water sources, these species are considered to be more sensitive to drought and hydrological change than other species (Rood, Braatne et al. 2003).

River pools

Permanent, near-permanent and intermittent pools are found along the lower Robe River. These pools are very important to the health and maintenance of aquatic ecosystems including freshwater and marine fish species, macroinvertebrates, waterbirds, frogs, reptiles and aquatic flora.

Surveys along the lower reaches of the Robe River have identified 12 species of fish, more than 100 macroinvertebrate taxa and 11 bird species that depend on river pools and associated habitats (Morgan, Gill et al. 2003; Biota Environmental Services 2006; Dobbs and Davies 2009).

The pools occur where the river channel intersects the aquifer. During river flow events the pools are topped up and the groundwater is recharged along the course of the river and through the inundated floodplain.

During the dry season (May–November), high evaporation rates result in pool levels dropping quicker than the local watertable. This causes groundwater to discharge into and maintain the permanent and semi-permanent pools. For the purposes of this study, semi-permanent pools are defined as those pools with a surface expression of water greater than 50 per cent of the time.

During dry periods declining watertables cause intermittent and semi-permanent pools to disconnect from the groundwater and dry out, reducing the river to a series of shallow permanent pools. These seasonal variations in water level are the major driver in habitat availability and consequently the abundance and composition of some aquatic communities (Douglas, Bunn et al. 2005).

Permanent pools maintain connectivity with the groundwater throughout the dry season. Pool mapping conducted on the lower Robe River identified only five permanent pools representing less than 1 km^2 of surface water at the end of the 2002–03 dry period. These pools provide critical habitat and are an important refuge for aquatic flora and fauna during drought periods.

Aquifer ecosystems

Aquifers with calcrete formations, such as the lower Robe River alluvial aquifer, have been found to support distinct stygofaunal assemblages (Humphreys 2001; Reeves, De Deckker et al. 2007). This is thought to be due to the physical structure of calcrete aquifers which have solution voids that provide habitat.

Sampling across the lower Robe River alluvial aquifer has recorded a relatively diverse and abundant stygofaunal assemblage (Biota Environmental Sciences 2006).

Groundwater abstraction activities that affect the quantity and quality of groundwater have the potential to impact on these communities. However, very little is known about the conservation status and habitat requirements of the stygofauna and their resilience to changes in water availability.

We have not attempted to determine a specific EWR for stygofauna in this project because of the lack of knowledge about their ecology. We are relying on the assumption that maintaining the groundwater to protect pool and riparian ecosystems will also protect stygofauna by maintaining the provision of habitat.

2.2 Hydro-ecological linkages

The interactions between ecosystems and their water sources can be complex and variable. To develop EWRs it is necessary to simplify these relationships and identify the key hydrological processes for sustaining the ecosystems. Conceptual models were developed as part of this project to illustrate how the hydrology interacts with and supports GDEs, and identify those parts of the water regime that are critical for each ecological component of the ecosystem. These are the components of the hydrology which, if they were to be significantly altered, would result in a significant change in the GDEs. These links between the hydrology and the GDEs are termed the hydro-ecological linkages.

For the purposes of this EWR only hydro-ecological linkages that may be affected by groundwater abstraction have been considered.

Pilbara rivers experience an underlying seasonality, with little or no flow during winter and spring. Substantial variability also occurs between years, including some periods of longer-term drought (Pinder & Leung 2009).

Depth to groundwater is considered to be the key groundwater attribute to be managed to maintain the health of terrestrial GDEs (Howe et al. 2005; SKM 2006). Because of the highly variable groundwater regime, we have taken the approach of grouping the six linkages defined for the lower Robe in terms of above-average, dry and drought groundwater levels (Table 1).

Table 1

Key hydro-ecological linkages for Robe River GDEs

Ecological feature	Linkage	Hydro-ecological linkage		Water condition
		Hydrological process	**Ecological objective**	
Riparian vegetation	1a	Periods of 'above-average' groundwater levels	Maintain periods of high water availability to allow for mature riparian trees to maintain new growth, periodically flower and set seed and maintain ecosystem resilience	Above-average
	1b	Minimum magnitude, duration and frequency of 'dry' period groundwater levels	Maintain sufficient water availability for phreatophytic vegetation by maintenance of accessible watertable levels during dry periods	Dry
	1c	Minimum magnitude, duration and frequency of 'drought period' groundwater levels	Maintain sufficient water availability for phreatophytic vegetation by maintenance of accessible watertable levels during extended periods with no or low river flow	Drought
River pool	2a	Periods of 'above-average' groundwater level aligning pools	Maintain areas of high water availability to provide increased habitat and resources for periods of high productivity	Above-average
	2b	Minimum frequency and duration of periods of 'dry' groundwater level aligning pools	Maintain areas of pools consistent with regional seasonality for fish and other fauna	Dry
	2c	Minimum frequency and duration of periods of 'drought' groundwater level aligning pools	Maintain areas of pools during drought periods consistent with regional seasonality to provide critical refuges for fish and other fauna	Drought

Figure 5 shows conceptually how these water conditions support riparian vegetation and permanent river pools along the Robe River.

Linkage 1a and 2a: Above-average groundwater levels

Periods of above-average water level provide conditions for mature riparian trees to maintain new growth, periodically flower and set seed (Pettit and Froend 2001). In addition, higher water levels meet a range of linkages for overall ecosystem health and resilience.

For semi-permanent pools, average groundwater levels maintain patterns of seasonal inundation consistent with the historic water regime. This is important for many macroinvertebrate species that base their lifecycles and dormancy on the timing of intermittently-available surface water flows and residual pools (WRM 2009).

Above-average groundwater level conditions also represent a period when large areas remain inundated, providing increased habitat and resources for periods of high in-pool productivity. Higher groundwater levels also support deeper pool habitat – which is an important driver of Pilbara fish community structure (Beesley 2006).

Linkage 1b and 2b: Dry groundwater levels

Dry groundwater levels maintain the watertable within the accessible range for riparian vegetation. This is important after periods of low rainfall and river recharge, when soil and surface water are likely to be restricted and some of the riparian vegetation will be using groundwater.

Dry groundwater levels also represent a period of reduced surface water expression, with many semi-permanent pools becoming dry and permanent pools being maintained entirely by groundwater inputs.

Those components of the biota that require permanent water will either migrate to permanent pools or perish. Certain vegetation and fauna are adapted to cope with drying. Some aquatic vegetation will produce seeds with desiccation-resistant stages (Brock et al. 2003; Jenkins & Boulton 2003) or vegetative stages that persist with limited moisture (Smith & Brock 2007). Some small aquatic invertebrates will produce eggs or respond to pools drying out by burrowing beneath the riverbed to follow the watertable.

Linkage 1c and 2c: Drought groundwater levels

During drought, soil and surface water become unavailable and riparian vegetation relies on declining groundwater levels to meet its water requirements. To sustain riparian vegetation, drought groundwater levels need to remain within the range accessible to its root systems.

In addition, drought groundwater levels need to be maintained to ensure that permanent pools along the river continue to provide critical habitat for aquatic ecosystems of freshwater and marine fish species, macroinvertebrates, waterbirds, frogs, reptiles and aquatic flora.

During drought conditions the extent of drying below semi-permanent pools may also be important. It has been suggested that watertable declines of more than 0.5 to 1 m below the bed of semi-permanent river pools represent the depth beyond which small aquatic invertebrates may not be able to burrow, while also exceeding the shallow rooting depth of many aquatic plants (SKM 2008).

Drought conditions are not a common occurrence within the historical water regime and are only likely to occur after repeated failed wet seasons (two or more years of low or no river flow). As such, drought water conditions may represent a period of stress to GDEs that can only be tolerated for short periods of time. Riparian vegetation communities are unlikely to maintain health and condition if these conditions persist for extended periods.

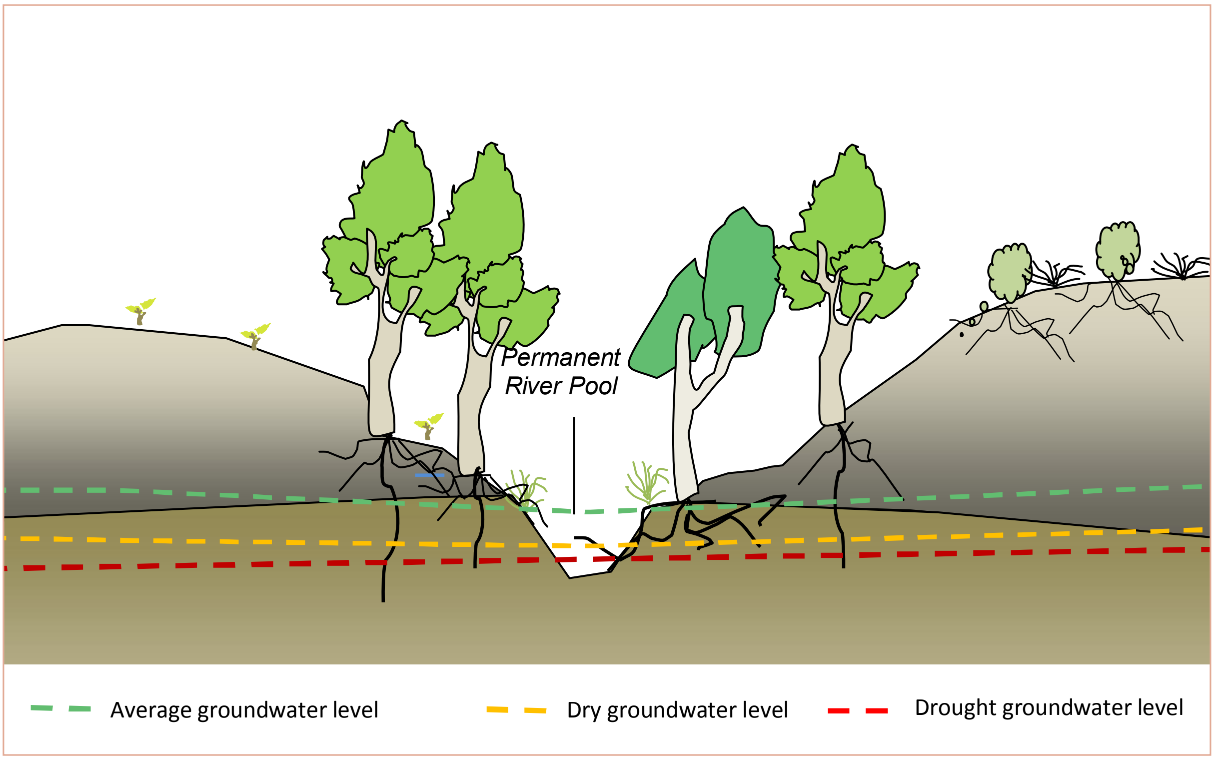

Figure 5

Conceptual diagram of hydro-ecological linkages between groundwater, riparian vegetation and a permanent pool

3 Approach to determining ecological thresholds

3.1 Overview

The hydro-ecological linkages presented in Table 1 describe how groundwater maintains important ecological processes and values. The next step in this study was to determine the groundwater level thresholds that would meet these linkages.

Groundwater level thresholds were determined using analysis of observed and modelled groundwater level data at the GDE and consideration of the results of eco-hydrology studies on similar systems.

3.2 How we determined thresholds

Riparian vegetation

Thresholds for riparian vegetation have been developed based on results from a drawdown trial at the Yule River, 40 km west of Port Hedland.

The Yule and Robe river study areas are similar in terms of type and compositions of ecosystems, the hydrological setting and climate variability (see Appendix A).

The Yule River trial measured the eco-physiological responses of riparian tree species during a period of low water availability and sustained abstraction. Based on the vegetation response, stress thresholds were identified in terms of depths to groundwater at local monitoring bores (Braimbridge 2011). To make these thresholds transferable to other sites, the water level thresholds were expressed as percentiles of the water level distribution as follows:

- 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 per cent of the time (20th percentile)
- 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 per cent of the time (5th percentile)
- significant recovery in water status in most phreatophytic vegetation when water levels returned to >50th percentile after being below the 5th percentile for four months and the 20th percentile for six months.

The use of percentiles allowed us to translate the thresholds from one site to another and to account for the natural variability in available water that the riparian ecosystems have adapted to.

Thresholds have been related to the water conditions identified in Table 1 and can therefore be applied to the linkages grouped under drought, dry or above-average conditions. They provide the basis for the EWR as follows:

- drought water conditions relates to <5th percentile groundwater level threshold
  - maintaining groundwater level above the 5th percentile except during drought periods will satisfy linkage 1c and 2c
- dry water conditions relate to <20th percentile groundwater level threshold
  - maintaining groundwater level above the 20th percentile except during dry periods will satisfy linkage 1b and 2b
- groundwater levels >50th percentile
  - maintaining groundwater level at the 50th percentile during periods of above-average water conditions will satisfy linkage 1a and 2a.

River pools

There is limited data available on the occurrence and depth of river pools along the lower Robe River. However, given the permanence of pools is dictated by local groundwater levels, it is expected that levels recorded in nearby bores are representative of seasonal variations in the pools. For this reason and in the absence of specific information on river pool bathymetry, water levels and ecological thresholds developed for riparian vegetation have also been applied to river pools.

Where possible, observations of pool permanency were used to cross-check the results derived from water levels projected from nearby bores. Available data on pool permanency are detailed in Appendix C. Recommendations on work required to validate this assumption are given in Section 4.2.

This approach of using thresholds based on statistical analysis of hydrological data is similar to that recommended by ARMCANZ & ANZECC (2000) to derive biological, chemical and physical water quality stressors. It has the advantage of representing the water regimes the ecology has adapted to, as well as the system's natural variability.

Literature suggests the sediments or river bed below a dry river pool may still provide habitat for some river pool fauna, as long as the watertable decline below the pool is no more that 1m (SKM 2008). This measure has been used as a way to determine when the thresholds apply for dry and drought water conditions, even once the river pool is dry.

3.3 How we apply a hydrological threshold (recharge classes)

Recharge classes have been developed to determine which EWR threshold (drought, dry or average) should be applied in any given year. Given the critical link between river flow and aquifer recharge, the recharge classes are based on river flow (see Appendix B for details on the correlations between river flow and groundwater levels and the criteria used to determine classes).

The relationship between river flow and groundwater levels enables flow conditions of the previous wet season (November–April) to predict the likely water availability conditions for the following year and thus determination of which EWR thresholds to apply.

This approach has the advantage of providing water managers with a tool to predict water availability conditions for the next 12 months. They can then apply specific EWRs that relate the target water levels to the recent climate.

The following recharge classes have been developed:

- recharge class 1 – drought: two years of combined flow <4000 ML
    - drought EWR applies
- recharge class 2 – dry: one year total flow <20 000 ML
    - dry EWR applies
- recharge class 3 – average: one year total flow 20 000–100 000 ML
    - not to exceed dry EWR
- recharge class 4 – above-average: one year total flow >100 000 ML
    - should remain above-average EWR.

3.4 Site selection

EWRs were determined at a subset of four sites representative of the GDEs across the lower Robe River alluvial aquifer study area (Table 2, Figure 6). The sites were selected based on the following.

- presence of representative GDE types; riparian vegetation and river pools
- degree of groundwater dependence
- availability of baseline data
- existing monitoring infrastructure.

The four sites selected are all located at a semi-permanent pool (inundated >50 per cent of the time) with riparian vegetation situated on shallow groundwater.

Table 2 provides information on the selected sites including available data. Observed data from nearby bores have been used for Little Jimuttda Pool and Unnamed Pool. At Maraminji Pool and Warali Pool observed data is limited so a combination of observed and modelled data has been used.

While we have made best use of the available data, we recognise there are certain limitations in using this data to develop EWRs. We address this further in the recommendations (Section 4.2).

Table 2

Selected EWR sites representative of GDEs across the aquifer

GDE description	Monitoring bores	Distance from pool	Data availability Observed	Data availability Modelled
Little Jimuttda Pool and riparian vegetation – semi-permanent pool on main channel, estimated permanence – dense woodland of *E. camaldulensis* situated on depths to groundwater ranging from 0–7 m	1A	420 m	*1983 – present: 1 or 2 points a year	50 yrs of monthly data
Unnamed Pool and riparian vegetation – semi-permanent pool on main channel – dense woodland of *E. camaldulensis* situated on depths to groundwater ranging from 0–5 m	9A	950 m	*1983 – present: 1 or 2 points a year	
Maraminji Pool and riparian vegetation – semi-permanent pool on main river channel – narrow strip of riparian vegetation situated on depths to groundwater ranging from 0–9 m	13A 20A	1.7 km 1.1 km	1983–91: only a few data points	*50 yrs of monthly data
Warali Pool and riparian vegetation – semi-permanent pool – dense woodland of *E. camaldulensis* situated on depths to groundwater ranging from 0–7 m	-	-	-	*50 yrs of monthly data

*denotes data used in EWR development

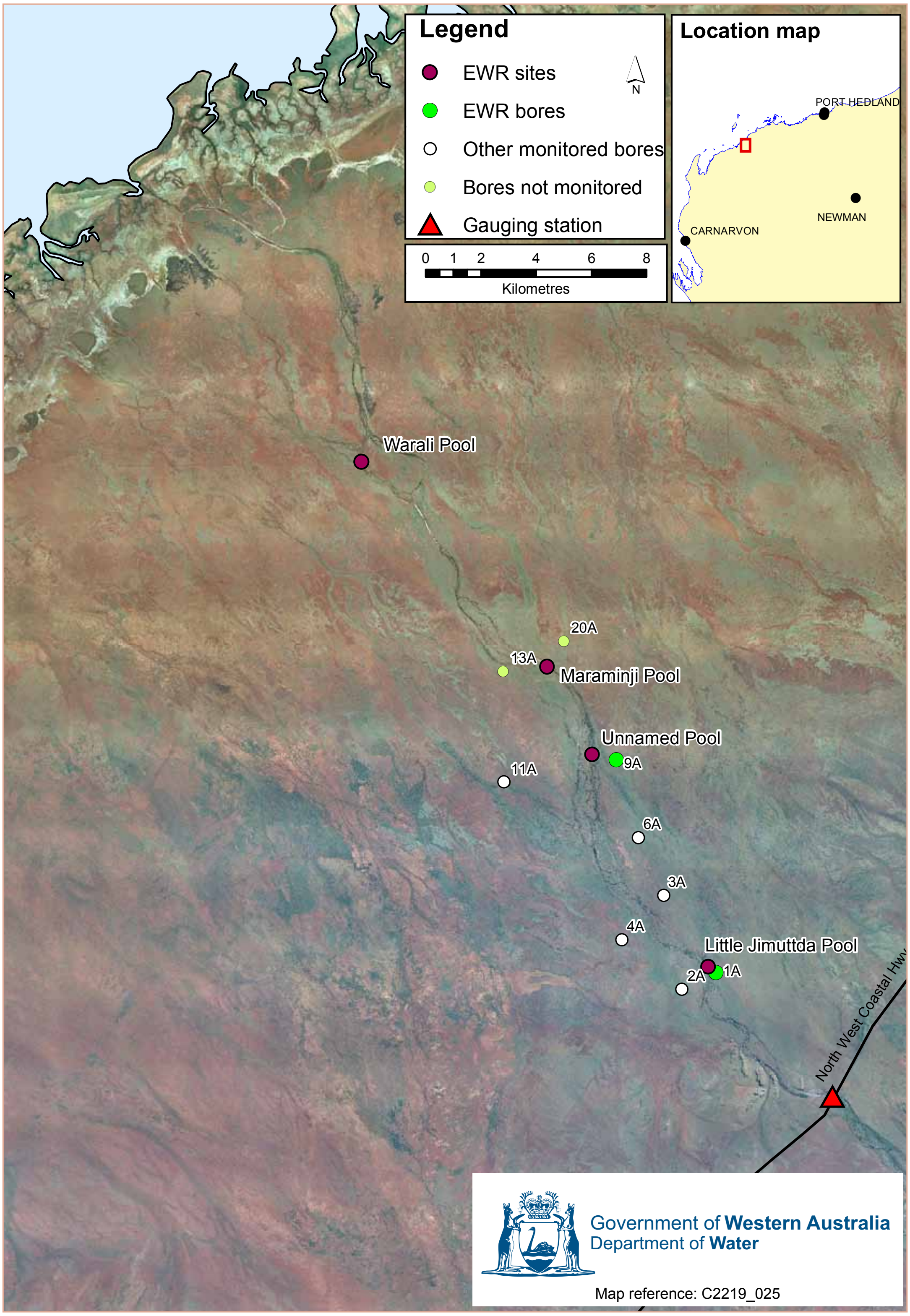

Figure 6
Robe River EWR sites

4.1 Approach

Thresholds represent groundwater levels that should only be exceeded when the previous year's recharge class permits:

- drought water conditions (5th percentile) can only be exceeded when a recharge class 1 year predicts that drought water conditions are likely
- dry water conditions (20th percentile) can only be exceeded when a recharge class 2 year predicts that dry water conditions are likely
- above-average water conditions (50th percentile) should be met when a recharge class 4 year predicts higher water availability is likely.

Thresholds have been calculated for each site using the available data and the approach described in Section 3. Thresholds were plotted on hydrographs from nearby bores (Little Jimuttda and Unnamed Pool) or from modelled outputs generated at the site (Maraminji Pool and Warali Pool).

The thresholds have then been extrapolated across river cross-sections (produced from the elevation model) to project how they relate to the actual water regime experienced at the GDE. This also allowed us to estimate maximum depths to groundwater, the percentage of time pools have a surface water expression, and the extent of drying below the pool bed.

During dry and drought conditions, the 5th and 20th percentile thresholds can be exceeded for four and six months respectively. This is based on results from the Yule trial. The magnitude of exceedence for threshold groundwater levels has been determined by averaging historical occurrences of exceedence.

Little Jimuttda Pool and riparian vegetation

The thresholds for this site have been calculated from water level data from bore 1A which is situated about 420 m from the pool (Table 3). At bore 1A the depth to groundwater for the 5th and 20th percentiles is 9.63 m (41.27 mAHD) and 9.02 m (41.89 mAHD) respectively. Historically the 5th percentile has been exceeded twice by an average of 0.31 m, while the 20th percentile has been exceeded three times by an average of 0.39 m.

Groundwater levels projected across the riparian zone at Little Jimuttda Pool suggest that depth to groundwater usually sits within 7 m of the surface (Figure 7). As this is well within the 10 m considered accessible to riparian tree species, riparian ecosystems at this site are likely to be groundwater dependent. Riparian vegetation linkages 1a, 1b and 1c are applicable at this site.

The 50th percentile groundwater level crosses the base of the pool – suggesting the pool has surface water around 50 per cent of the time. At the 20th and 5th percentile, the watertable is more than 1 m below the base of the pool. During these periods the depth to groundwater is likely to preclude this area being used as refugia for burrowing invertebrates and is beyond the rooting depth of most aquatic plants. Linkages 2b and 2c are therefore not considered applicable at this site and EWRs to meet them have not been calculated.

Table 3

Recommended EWR to meet ecological objectives at Little Jimuttda Pool

GDE	Hydro-ecological linkage	Threshold	EWR measured at bore 1A	Magnitude of allowable exceedence	Duration below this level
Riparian vegetation	1a	50%	42.94 mAHD		
	1b	20%	41.89 mAHD	0.39 m	6 months
	1c	5%	41.27 mAHD	0.31 m	4 months
River pool	2a	50%	42.94 mAHD		

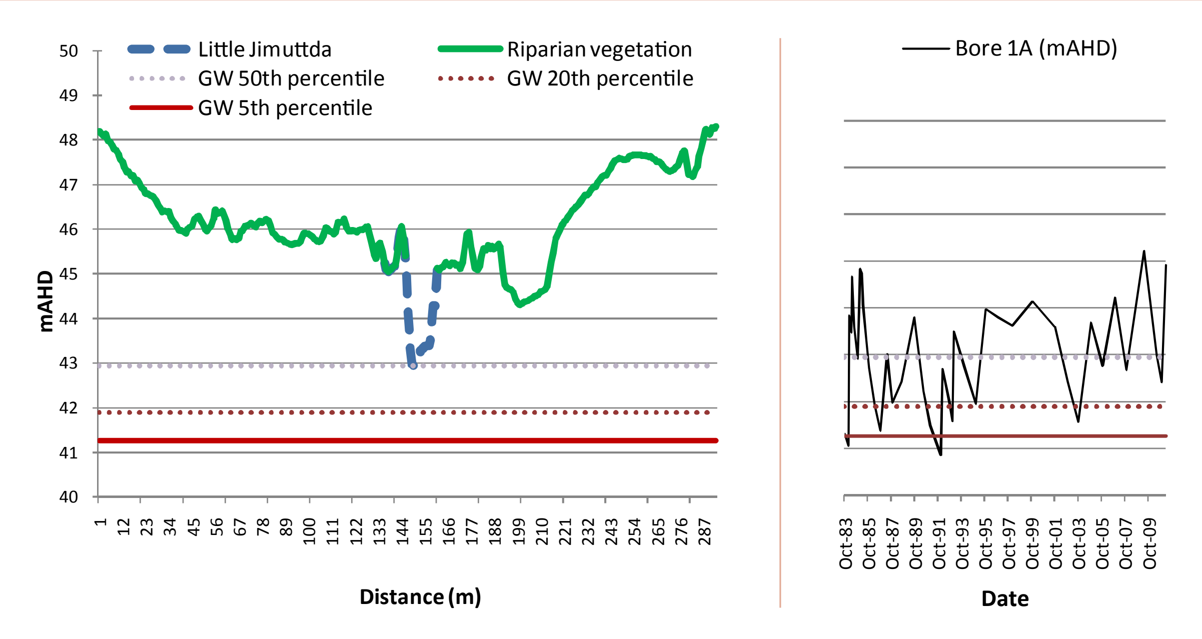

Figure 7

Cross-section of Little Jimuttda Pool and hydrograph showing hydrological percentiles and regime experienced at this site

Unnamed Pool and riparian vegetation

The thresholds for this site have been calculated from water level data from bore 9A which is situated about 950 m from the pool. At bore 9A the depth to groundwater for the 5th and 20th percentiles is 7.53 m (30.39 mAHD) and 7.25 m (30.67 mAHD) respectively. Historically the 5th percentile has been exceeded twice by an average of 0.34m, while the 20th percentile has been exceeded twice by an average of 0.15 m.

Groundwater levels projected across the riparian zone at Unnamed Pool suggest that depth to groundwater for the period of the dataset was within 5 m of the surface (Figure 8). As this is well within the 10 m considered accessible to riparian tree species, riparian ecosystems at this site are likely to be highly groundwater dependent. Riparian vegetation linkages 1a, 1b and 1c are applicable at this site.

The river pool is estimated to have had surface water about 80 per cent of the time and water levels have declined no more than 0.4 m beyond the base of the pool. This suggests that surface water or the hyporheic zone has been available for aquatic ecosystems during the period of this dataset. As such, linkages 2a, 2b and 2c for river pools are applicable for this site.

Table 4

Recommended EWR measured at bore 9A to meet ecological objectives at Unnamed Pool

GDE	Hydro-ecological linkage	Threshold	EWR measured at bore 9A	Duration below this level	Magnitude of allowable exceedence
Riparian vegetation	1a	50%	31.71 mAHD		
	1b	20%	30.67 mAHD	6 months	0.15 m
	1c	5%	30.39 mAHD	4 months	0.34 m
River pool	2a	50%	31.71 mAHD		
	2b	20%	30.67 mAHD	6 months	0.15 m
	2c	5%	30.39 mAHD	4 months	0.34 m

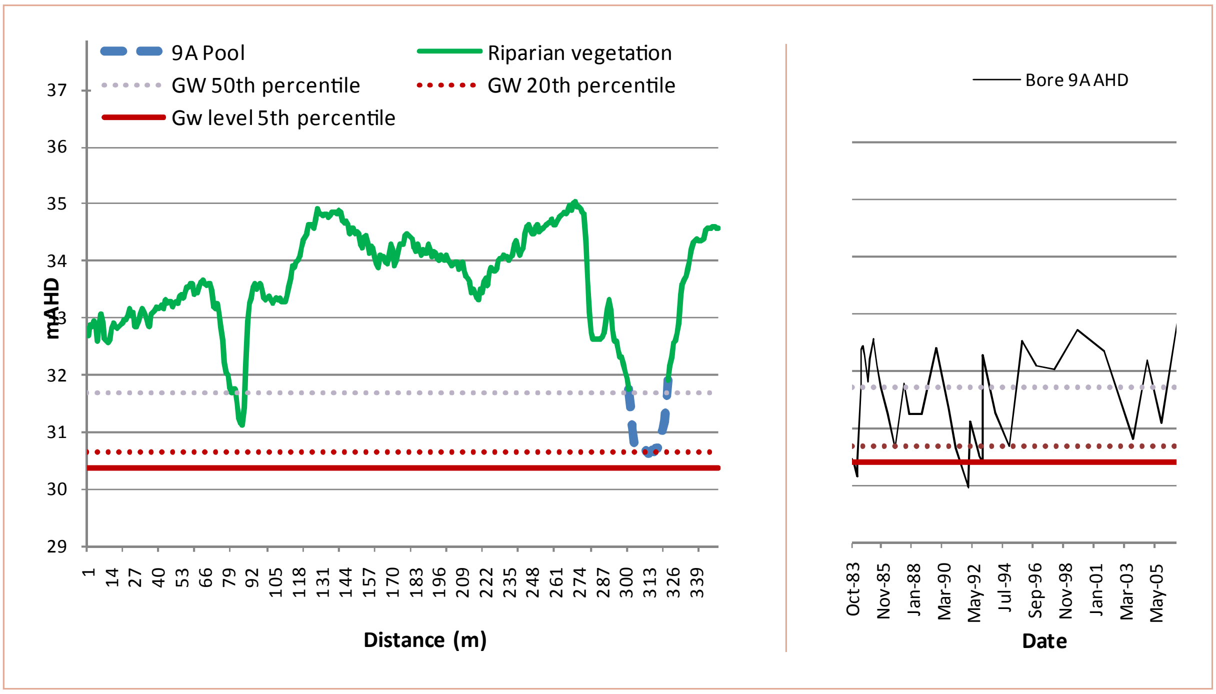

Figure 8

Cross-section of Unnamed Pool and hydrograph showing hydrological percentiles and regime experienced at this site

Maraminji Pool and riparian vegetation

The thresholds for this site have been calculated from modelled data (Table 5). Depth to groundwater for the 5th and 20th percentiles is 5.26 m (23.17 mAHD) and 4.84 m (30.59 mAHD) respectively. In the 50-year synthetic dataset the 5th percentile has been exceeded six times by an average of 0.14 m, while the 20th percentile has been exceeded 14 times by an average of 0.15 m.

The riparian vegetation cross-section indicates that maximum modelled depth to groundwater was 9 m (Figure 9). As such, riparian vegetation linkages 1a, 1b and 1c are applicable.

Modelled data suggests the river pool has surface water about 75 per cent of the time, with the water level declining no more than 1 m beyond the base of the pool. This indicates that surface water or the hyporheic zone remains available for aquatic ecosystems. As such linkages 2a, 2b and 2c for river pools are applicable for this site.

Table 5

Recommended EWR to meet ecological objectives at Maraminji Pool

GDE	Hydro-ecological linkage	Threshold	EWR measured at bore 1A	Duration below this level	Magnitude of allowable exceedence
Riparian vegetation	1a	50%	24.18 mAHD		
	1b	20%	23.59 mAHD	6 months	0.15 m
	1c	5%	23.17 mAHD	4 months	0.14 m
River pool	2a	50%	24.18 mAHD		
	2b	20%	23.59 mAHD	6 months	0.15 m
	2c	5%	23.17 mAHD	4 months	0.14 m

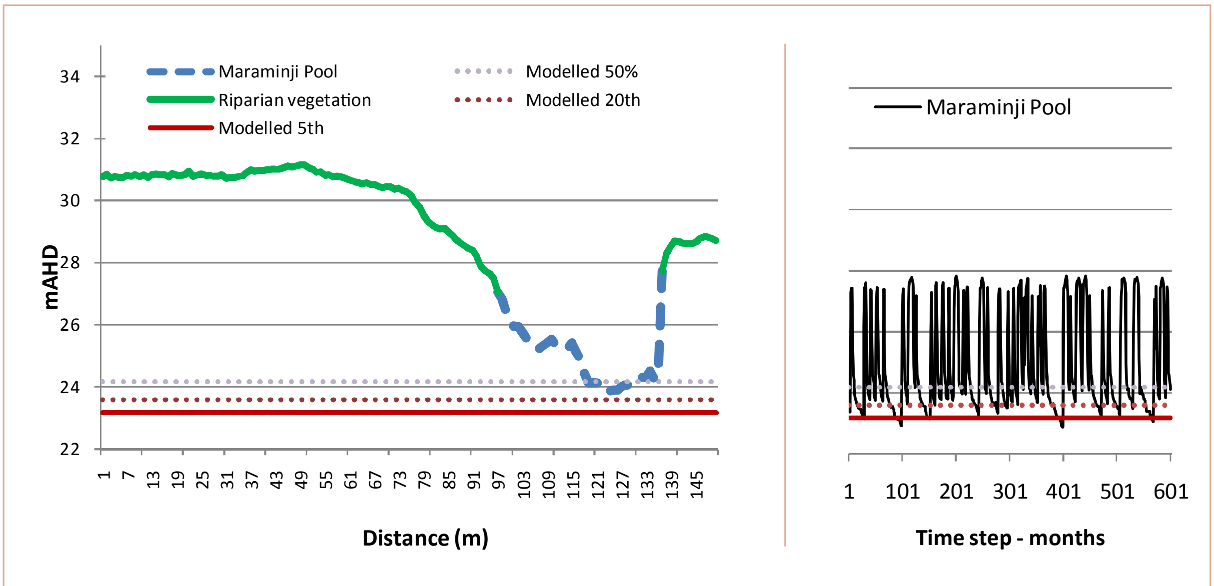

Figure 9

Cross-section of Maraminji Pool and hydrograph showing modelled percentiles and water availability experienced at this site

Warali Pool and riparian vegetation

The thresholds for this site have been calculated from modelled data (Table 6). Depth to groundwater for the 5th and 20th percentiles is 5.26 m (23.17 mAHD) and 4.84 m (30.59 mAHD) respectively. In the 50-year synthetic dataset the 5th percentile has been exceeded six times by an average of 0.14 m, while the 20th percentile has been exceeded 14 times by an average of 0.15 m.

The riparian vegetation cross-section indicates that maximum modelled depth to groundwater was 7 m (Figure 10). As such, riparian vegetation linkages 1a, 1b and 1c are applicable.

Modelled data suggests the river pool has surface water about 65 per cent of the time, with water level declining no more than 1 m beyond the base of the pool. This indicates that surface water or the hyporheic zone remains available for aquatic ecosystems. As such, linkages 2a, 2b and 2c for river pools are applicable for this site.

Table 6

Recommended EWR to meet ecological objectives at Warali Pool

GDE	Hydro-ecological linkage	Threshold	EWR measured at bore 1A	Duration below this level	Magnitude of allowable exceedence
Riparian vegetation	1a	50%	12.14 mAHD		
	1b	20%	11.51 mAHD	6 months	0.26 m
	1c	5%	11.22 mAHD	4 months	0.22 m
River pool	2a	50%	12.14 mAHD		
	2b	20%	11.51 mAHD	6 months	0.26 m
	2c	5%	11.22 mAHD	4 months	0.22 m

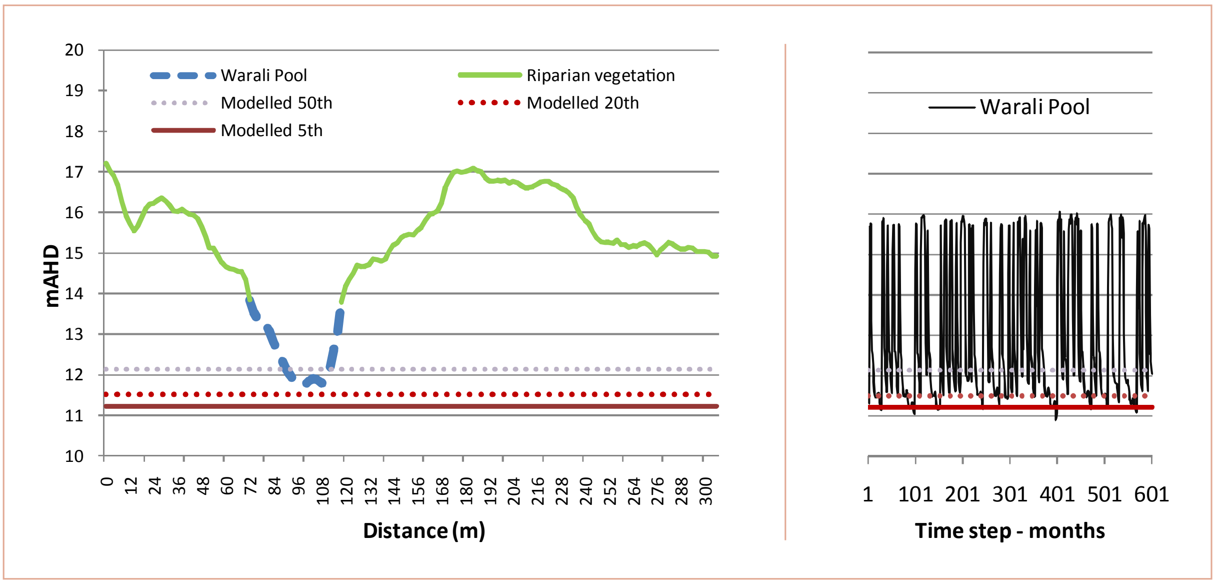

Figure 10
Cross-section of Warali Pool and hydrograph showing modelled percentiles and water availability experienced at this site

4.2 Proposed EWRs and recommendations

Proposed EWRs

To account for the natural variability in water conditions we grouped linkages into three water availability conditions and determined water level thresholds for each. The resulting EWRs present a variable set of thresholds rather than static water level criteria. These are characterised by threshold groundwater or pool surface water levels as follows:

- drought conditions: pool or groundwater levels <5th percentile
- dry conditions: pool or groundwater levels <20th percentile
- average/above-average conditions: pool or groundwater levels >50th percentile.

Recharge classes were developed to determine which EWR threshold should be applied for the year – based on the previous year's river flow.

The recommended EWRs for the lower Robe River alluvial aquifer are detailed in Table 7.

Table 7
Recommended EWRs for lower Robe River alluvial aquifer

EWR site	Recharge class	Threshold applicable	EWR		
			EWR mAHD	Duration of exceedence	Max magnitude
Little Jimuttda Pool and riparian vegetation measured at bore 1A	Average	50%	42.94		
	Dry	20%	41.89	6 months	0.39 m
	Drought	5%	41.26	4 months	0.31 m
Unnamed Pool and riparian vegetation measured at bore 9A	Average	50%	31.71		
	Dry	20%	30.67	6 months	0.15 m
	Drought	5%	30.39	4 months	0.34 m
Maraminji Pool and riparian vegetation based on modelled outputs	Average	50%	24.18		
	Dry	20%	23.59	6 months	0.15 m
	Drought	5%	23.17	4 months	0.14 m
Warali Pool and riparian vegetation based on modelled outputs	Average	50%	12.136		
	Dry	20%	11.505	6 months	0.26 m
	Drought	5%	11.223	4 months	0.22 m

We have made best use of the available data to work out the thresholds and set the EWRs. However, we recognise there are limitations (given the data that were available), the major ones of which are discussed below.

For riparian vegetation at Little Jimuttda Pool and Unnamed Pool, thresholds have been calculated based on historical groundwater levels measured at bores 420 m and 950 m away. These groundwater levels are assumed to accurately depict levels at the riparian vegetation. In addition, groundwater level data were only recorded once or twice a year and thus may not have captured the extremes in groundwater level at these sites.

For Maraminji Pool and Warali Pool, data were unavailable so thresholds have been calculated using outputs from the lower Robe River numerical groundwater model based on a 50-year synthetic climate. Due to the limitation of the model, we consider there is a significant level of uncertainty around the data, so cautious interpretation and validation of them is required.

For river pools, water level and bathymetry data were unavailable so water level thresholds are assumed to be the same as those calculated for the nearby riparian ecosystems.

Recommendations

To improve the EWRs the following actions are recommended:

- increase to monthly the bi-annual monitoring of groundwater levels representative of riparian vegetation at Little Jimuttda Pool (bore 1A) and Unnamed Pool (bore 9A)
- drill new monitoring bores in areas representative of riparian vegetation at Maraminji Pool and Warali Pool and instigate monthly monitoring
- conduct bathymetry surveys of all EWR pool sites and instigate monthly pool level monitoring
- consider installing loggers at all monitoring points
- continue monitoring at the Yarraloola gauging station required to determine annual recharge classes
- collect and assess at least one year's baseline data (as detailed above) against proposed EWRs before abstraction activities begin
- subject to Environmental Protection Authority guidance statement 54 and 54a, a site-specific survey to determine the conservation status of stygofauna inhabiting the aquifer may be required.

Appendicies

Appendix A — Yule River trial

The Yule River study area is located approximately 40 km west of Port Hedland downstream of the North West Coastal Highway. The GDEs described for the Yule River are comparable (in terms of types and composition) with ecosystems occurring at the Robe River. GDEs at both sites are supported by alluvial aquifers that are subject to similar trends in water availability.

Results of a groundwater drawdown trial on the lower Yule River (from December 2008 to April 2011) found water stress responses in riparian trees when groundwater levels fell after a sustained period of no recharge and continued pumping. The water stress responses were:

- increased pre-dawn leaf water potential and a lack of recovery between midday and pre-dawn readings
- decline in canopy density and canopy condition
- decline in rates of tree water use as indicated by sap flow velocity.

Based on the vegetation responses, thresholds for water stress responses were identified in terms of depths to groundwater at local monitoring bores (Braimbridge 2011). These thresholds were compared with historic groundwater records for the monitoring sites and were found to coincide consistently with the 20th percentile of water level for a low level of stress response and the 5th percentile for an increased level of stress response.

Base on the outcomes of this trial, the 5th and 20th percentiles have been used to provide the basis for EWRs for several GDE sites across the Pilbara where the ecosystems, groundwater variability and the key hydro-ecological linkages are representative of those experienced at Yule River.

Recharge classes have been developed to determine which thresholds (drought, dry or average) should be applied in any given year. Given the critical link between river flow and aquifer recharge, the recharge classes are based on river flow. This enables flow conditions of the previous wet season (November–April) to predict the water availability conditions for the following year and determination of which threshold should be used.

Approach

The degree of river pool and groundwater recharge is determined by the magnitude, duration and frequency of river flows. These parameters were examined to see which single parameter, or combination of parameters, is the greatest driver of recharge along the lower Robe River based on recorded and modelled response in groundwater levels.

To establish recharge classes, each year was categorised into a water availability condition (drought, dry or average) based on the minimum groundwater level in the preceding year (Table B1).

The relationships between groundwater level and a range of flow characteristics including total annual flow, total wet season flow, period since flow and period of flow were examined. Total wet season flow was found to be the strongest predictor of the subsequent year's water conditions, with the following general relationships found (Figure B1):

1. Minimum groundwater level only fell below the 5th percentile level when combined flow for the previous **two** years was <4000 ML.
2. Minimum groundwater level may fall below the 20th percentile but not below the 5th percentile when flow in the previous year was <20 000 ML (excluding 1).
3. Minimum groundwater level may fall below the 50th percentile but not below the 20th percentile when flow in the previous year was >20 000 ML.
4. Minimum groundwater level generally did not fall below the 50th percentile when flow in the previous year was >100 000 ML.

Based on these observations the following recharge classes have been developed:

- recharge class 1 – drought: two years of combined flow <4000 ML
  - drought EWR applies
- recharge class 2 – dry: one year total flow <20 000 ML
  - dry EWR applies
- recharge class 3 – average: one year total flow 20 000–100 000 ML
  - not to exceed dry EWR
- recharge class 4 – above-average: one year total flow >100 000 ML
  - should remain above-average EWR.

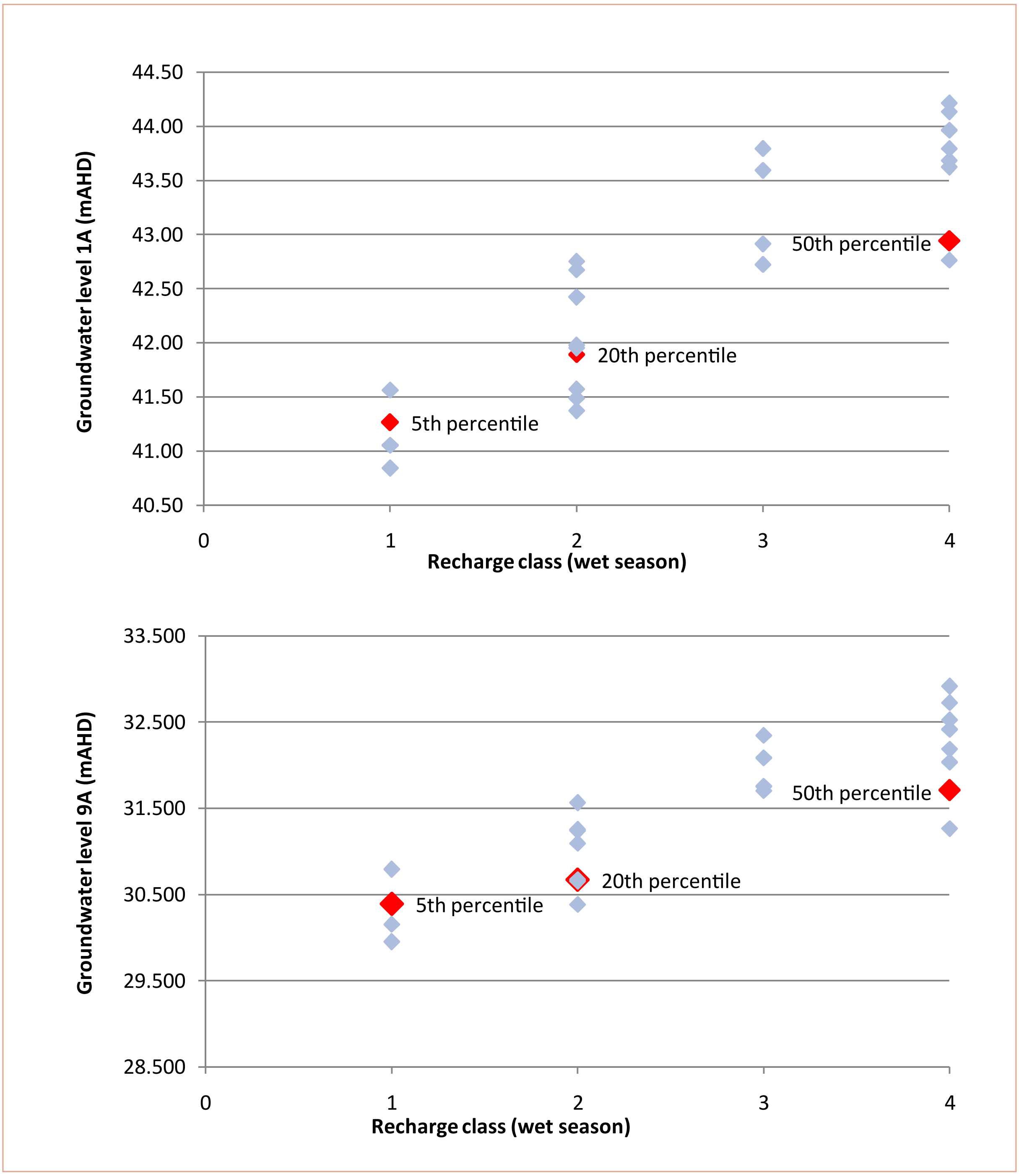

Figure B1

Observed minimum yearly groundwater level measures at bore 1A (top) and 9A (bottom) classified into recharge classes based on recharge class rules

Table B1

Total annual wet season flow and recharge class classification for historical streamflow data at Yarraloola gauging station

Date	Min obs next 12 months	Mod average next 12 months	Total wet season flow	Recharge class
May-83	41.06	40.00	0.00	1
May-84	42.92	41.49	63.16	3
May-85	42.73	41.73	80.85	4
May-86	41.38	40.54	0.00	2
May-87	41.98	40.98	18.04	3
May-88	42.43	41.52	0.00	2
May-89	43.80	42.51	105.67	4
May-90	41.49	40.53	0.00	2
May-91	40.85	39.97	0.00	1
May-92	41.58	41.07	14.85	3
May-93	42.77	41.82	242.85	4
May-94	41.96	41.11	3.79	2
May-95	43.97	42.01	443.82	4
May-96	43.80	41.48	43.24	3
May-97	43.63	41.85	213.37	4
May-98		40.56	0.00	2
May-99	44.14	42.74	202.93	4
May-00		42.98	322.45	4
May-01	43.60	41.11	22.24	3
May-02	42.43	40.29	0.00	2
May-03	41.57	39.79	0.00	1
May-04	43.69	41.47	569.72	4
May-05	42.76	40.24	0.00	2
May-06	44.22	42.89	779.23	4
May-07	42.68	40.83	0.00	2
May-08		41.90	103.83	4
May-09			688.00	4

C Appendix C — Pool permanency data

Date	Status (size if known m²)	Groundwater level (mAHD)	Source
Little Jimuttda Pool		**1A, 2A**	
23/11/1999	Present (3160)	44.136 (Nov 11)	Pool mapping
01/08/2001	Present	43.596 (Oct 01)	Yarraloola imagery
16/02/2002	Present (635)	43.596 (Oct 01)	Pool mapping
21/06/2004	Present (20119)	43.686 (Nov 04)	Pool mapping
16/02/2005	Present (635)	43.686 (Nov 04)	Pool mapping
01/09/2009	Present	45.2116 (Jun 09)	Field trip
01/01/2010	Dry (damp)	42.971 (Jul 10)	Field trip (SKM)
Unnamed Pool		**9A**	
23/11/1999	Present (1270)	32.725	Pool mapping
10/09/2001	Present	32.345	Mardie imagery
21/06/2004	Present (14490)	Flow	Pool mapping
31/08/2007	Dry	31.565	Mardie imagery
Maraminji Pool		**Model and 13a**	
01/08/2001	Present	NA	Yarraloola imagery
10/09/2001	Present	NA	Mardie imagery
Dec 2000	Dry	NA	Pool mapping
Dec 2002	Dry	NA	Pool mapping
21/06/2004	Present (35189)	NA	Pool mapping
16/02/2005	Present (2525)	NA	Pool mapping
31/08/2007	Present	NA	Mardie imagery
01/09/2009	Present	NA	Field survey
Warali Pool		**Model**	
23/11/1999	Present (1895)	NA	Pool mapping
01/08/2001	Dry	NA	Yarraloola imagery
19/02/2003	Present (635)	NA	Pool mapping
21/06/2004	Present (12590)	NA	Pool mapping
31/08/2007	Dry	NA	Mardie imagery
01/09/2009	Present	NA	Field survey

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: J:\gisprojects\Project\C_series\C2219\025_Robe_River_Maps/mxd
Filename: Robe_Location_Map

Robe_EWR_Sites

Compilation date: August 2012

Disclaimer

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

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Sources

The Department of Water acknowledges the following datasets and their custodians in the production of these maps:

Main Roads – DLI – 2010
Towns – DLI – 08/04
Rivers – DoW - 2007
Robe Monitoring Bores – DoW project specific data – 2012
Robe Riparian Vegetation – DoW project specific data – 2012
WIN surface water sites – stream gauging – DoW – 2012
WIN groundwater sites – all – DoW – 2012

Shortened forms

ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
DEM	digital elevation model
DoW	Department of Water
EWR	ecological water requirements
GDE	groundwater-dependent ecosystem
LiDAR	Light Detection and Ranging
SKM	Sinclair Knight Merz
WRM	Wetland Research and Management

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resource of the locality.
Alluvium	Fragmented rock transported by a stream or river and deposited as the river floodplain.
Aquifer	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.
Bore	A narrow, normally vertical hole drilled in soil or rock to measure or withdraw groundwater from an aquifer.
Ecological water requirement	The water regime needed to maintain ecological values of water-dependent ecosystems at a low level of risk.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. a lake. Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological and social surroundings and the interactions between them.
Flow	Streamflow in terms of m^3/second, m^3/day or ML/year. May also be referred to as discharge.
Groundwater	Water that occupies the pores and crevices of rock or soil beneath the land surface.
Groundwater-dependent ecosystems	An ecosystem that depends on groundwater for its existence and health.
Habitat	The area or natural environment in which an organism or population normally lives. A habitat is made up of physical factors such as soil, moisture, range of temperature and availability of light, as well as biotic factors such as food availability and the presence of predators.
Hydrology	The study of water, its properties, movement, distribution and use above, on or below the Earth's surface.
Hydrogeology	The hydrological and geological sciences concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.

Invertebrate	An animal without a backbone.
Lifecycle	The series of changes in the growth and development of an organism from its beginning as an independent life form to its mature state in which offspring are produced.
Macrophyte	A plant, especially an aquatic or marine plant, large enough to be visible to the naked eye.
Phreatophyte	A plant (often relatively deep rooted) that obtains water from a permanent ground supply or from the watertable.
Riparian vegetation	Plant communities along the river margins and banks or at the interface between land and a river or stream.
Stygofauna	Fauna that live within groundwater systems, such as caves and aquifers; or more specifically small, aquatic groundwater invertebrates.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
Wetland	Areas that are permanently, seasonally or intermittently waterlogged or inundated with water that may be fresh, saline, flowing or static, including areas of marine water or where the depth at low tide does not exceed 6 m.

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