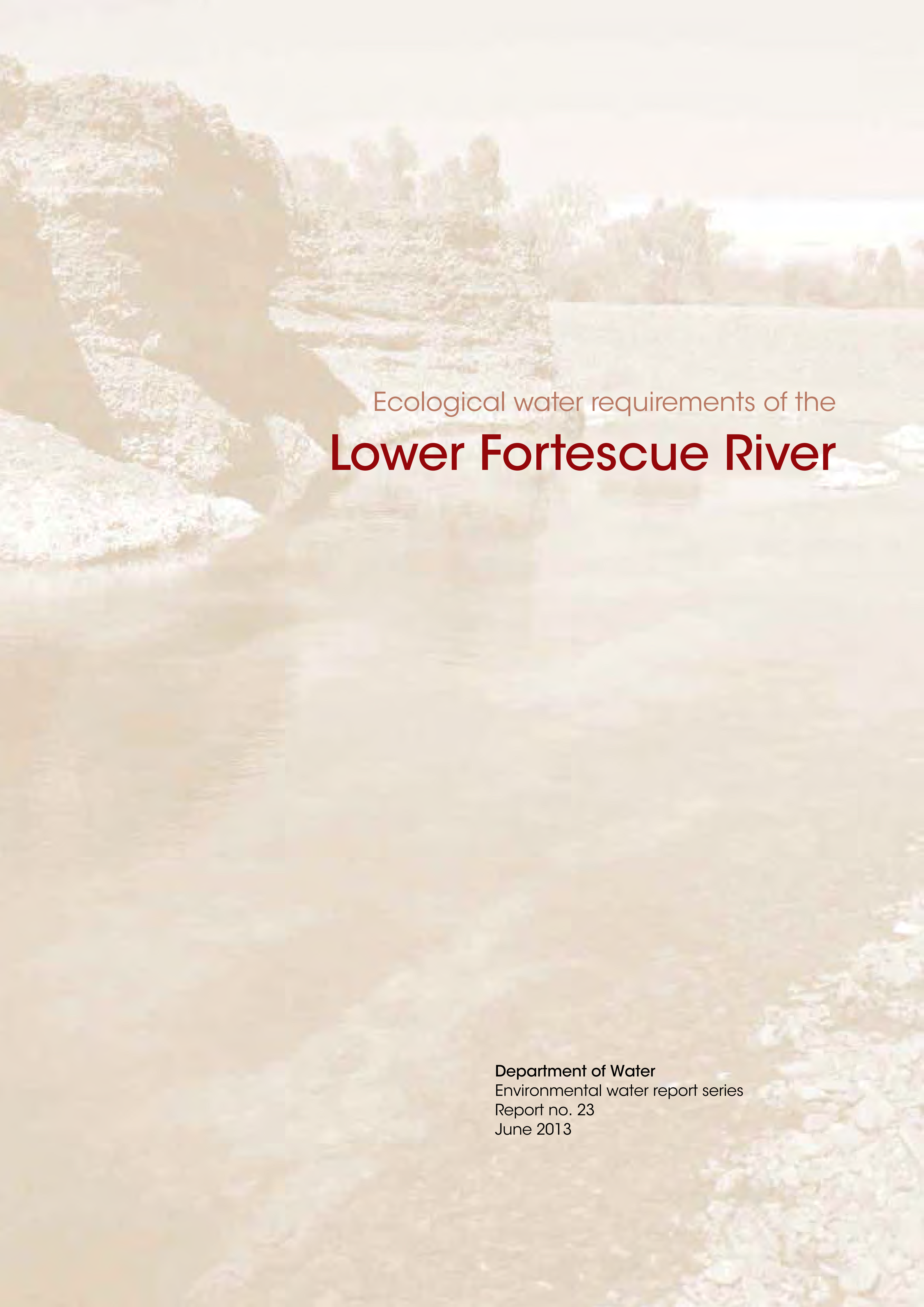
Government of **Western Australia**
Department of **Water**

Ecological water requirements of the

lower Fortescue River

Looking after all our water needs

Environmental water report series
Report no. 23
June 2013



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Contents

Appendices

Figures

Tables

Summary

The Department of Water has developed water licence conditions and policy to manage abstraction from the lower Fortescue alluvial aquifer for the *Pilbara groundwater allocation plan*. This document supports the allocation plan by describing the ecological water requirements for groundwater-dependent ecosystems of the lower Fortescue alluvial aquifer.

Ecological water requirements are the water regimes required to maintain water dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). An understanding of the ecological water requirements is a critical part of the water allocation process, which also considers the social and cultural values of the resource and the consumptive demand made on it.

We have expressed ecological water requirements as water levels that are linked to aquifer recharge, rather than set the same levels for every year, regardless of the conditions. This will better reflect the varying climate and water availability conditions of the Pilbara region.

The alluvial aquifer is recharged by infiltration of water through the bed of the Fortescue River. Ecosystems dependent on the aquifer include river pools, riparian vegetation and ecosystems within the aquifer itself (stygofauna). We have focused on the water requirements of river pools and riparian vegetation and have not described EWRs for stygofauna specifically.

We have used the concept of 'hydro-ecological linkages' to describe how groundwater maintains biodiversity and ecological processes. We have described the water requirements needed to maintain these linkages by using a combination of 'thresholds' (water levels below which ecosystems begin to suffer) established from previous relevant studies or from statistical analyses of hydrological data.

We described ecological water requirements for three conditions of water availability. These were:

- 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.

Ecological water requirements are linked to river flow as the source of aquifer recharge. We developed river flow or recharge classes to indicate which ecological water requirement (drought, dry or average-above average) should be applied in any given year. We allocated the possible flows into four 'recharge classes'. These are:

- class 1 – drought: total wet season flow <1000 ML
- class 2 – dry: total wet season flow 1000 to 50 000 ML
- class 3 – average: total wet season flow 50 000 to 600 000 ML
- class 4 – above average: total wet season flow > 600 000 ML.

To apply the appropriate ecological water requirements to a given water year, the volume of the previous wet season flow (January to April) is calculated and the water year is allocated to a recharge class. Note that classes 3 and 4 both lead to the same ecological water requirements being applied – those for average and above average conditions.

We were not able to study some pools due to lack of data or to bores being too far away – Stewart, Mungajee and North Jilan Jilan pools – so we recommend that the department or licensees set up pool level monitoring and carry out surveys of pool bathymetry. We were able to assess Bilanoo and Jilan Jilan pools using existing data, but we recommend that pool level monitoring and a survey of pool bathymetry be established for these as well.

The Department of Water has developed a groundwater allocation plan for the Pilbara groundwater area. The lower Fortescue alluvial aquifer is one of the target resources included in the *Pilbara groundwater allocation plan*: (Department of Water 2012).

Ecological water requirements (EWRs) are the water regimes required to maintain dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). An understanding of ecological water requirements is a critical part of the water allocation process, which aims to balance the consumptive demand for water with the needs of ecosystems and other in situ values.

1.1 Purpose of this document

This document presents the EWRs for groundwater-dependent ecosystems (GDEs) of the lower Fortescue alluvial aquifer. It represents the completion of Stage 2 of the EWR project for the lower Fortescue River area (Table 1). This report follows on from the ecological values and issues report, which summarised available information on GDEs (Loomes 2010).

The ecosystems identified in the EWR study were:

- river pools
- riparian vegetation
- aquifer ecosystems (stygofauna).

We have focused on the water requirements of river pools and riparian vegetation and have not determined EWRs for stygofauna specifically. It was assumed that if groundwater levels are kept at those needed to meet the ecological water requirements for river pools and riparian vegetation, then the needs of stygofauna would also be met.

1.2 General approach to ecological water requirements

The steps followed to establish and apply the EWRs are shown in Table 1. Steps one to four were completed in 2010 and were summarised in the values and issues report (Loomes 2010). In Stage 1 we identified GDEs, developed conceptual models of their interaction with groundwater and identified hydro-ecological linkages. The linkages describe the critical parts of the water regime that maintain important ecological features and processes. These were used as the ecological objectives to be addressed by the EWRs.

To establish the EWRs (Stage 2) we selected sites representative of river pool and riparian vegetation ecosystems. We assessed hydrological data to confirm the groundwater dependence of these ecosystems and developed 'ecological thresholds'. These are the minimum pool or groundwater levels needed to maintain a particular linkage. We then applied these thresholds to hydrological data to describe the EWRs.

The final EWRs took into account the highly variable water availability conditions of the Pilbara region.

The approach used is consistent with contemporary methods to describe EWRs for groundwater systems (see Eamus et al (2006) and Howe et al (2007)). The approach also includes elements found in surface water systems EWR methods (e.g. ELOHA – Poff et al. 2010).

Table 1
Steps followed to describe and apply EWRs

Steps	Reporting or applying phase
1. Identify known and potential GDEs 2. Assess conservation status of GDEs 3. Develop conceptual models of links between groundwater and GDEs 4. Identify groundwater regime components that support GDE – known as 'hydro-ecology linkages'	Stage 1: Values and issues paper (complete – Loomes 2010)
5. Select representative sites 6. Confirm groundwater dependence of GDEs 7. Develop 'ecological thresholds' needed to maintain hydro-ecology linkages 8. Describe EWRs for each site 9. Develop recharge related to water availability	Stage 2: EWR report (this report)
10. Set allocation limit and operating rules	Stage 3: Allocation plan (Department of Water 2012) and supporting document (Department of Water 2011)
11. Monitoring program	Stage 4: Operating strategy and allocation plan monitoring program (in preparation)

The ecological water requirements and how they are applied (as described in this report) represent Stage 2 of the EWR process shown in Table 1. In Stage 3, the supporting documents and allocation plan were developed.

The supporting document (Department of Water 2011) describes a risk-based method used to set an allocation limit for the lower Fortescue alluvial aquifer.

In the allocation plan (Department of Water 2012), the department has described how abstraction will be managed now and in the future. The plan provides licensing policy and monitoring to manage the risks associated with abstraction and to maintain the water resources in the long term.

In Stage 4, operating strategies for individual licensees and a monitoring program are developed. Operating strategies form part of the conditions of a water licence and set out in detail how the licensee intends to manage water over the life of the project.

Monitoring will allow us to understand how the aquifer is performing over time and in particular how it is responding to abstraction. By assessing information provided by the monitoring program against performance indicators (described in the plan), we can evaluate if the plan's objectives are being met and whether we need to adapt how we regulate and manage abstraction.

1.3 Study area

The lower Fortescue alluvial aquifer lies along the lower reaches of the Fortescue River on the Ashburton Plain, approximately 100 km south-west of Karratha. The EWR study area extends approximately 30 km along the Fortescue River, downstream of the North West Coastal Highway crossing (Figure 1).

Figure 1
Lower Fortescue River study area

Climate

The Pilbara region's climate is classified as semi-arid to arid with hot, dry conditions most of the year. Rainfall is highly variable and the largest rainfall events result from cyclones or tropical depressions. Average annual rainfall at Mardie Station (BoM site 005008), within the project study area is 272 mm. Approximately 90% of annual rainfall in the lower Fortescue area falls between January and June (Loomes 2010). The annual evaporation rate is greater than 3000 mm and greatly exceeds rainfall.

Hydrology

The Fortescue River catchment is one of the largest in the Pilbara region (~32 000 km2), behind the Ashburton (~71 000 km2) and De Grey (~56 000 km2) rivers. The Fortescue River has a north-west flowing drainage pattern. Through the majority of the study area the river has a well defined main channel, which is four to six metres deep and up to 100 m wide. Closer to the river mouth the channel becomes less well defined, allowing floods to extend over the adjacent floodplains (Aquaterra 2006).

The major tributaries within the study area are the Edwards and Du Boulay creeks. These creeks join the river at the delta, but are connected elsewhere in large floods. A number of minor tributaries and creeks join the river upstream of the study area.

The lower Fortescue River gauging station has been relocated twice following flood damage. The full flow record incorporating data from three stations extends back to 1968 (Bilanoo Pool: 1987– current, Jimbegnyinoo Pool: 1969–1998, Koolumba Pool: 1968–1974).

The mean annual flow at Bilanoo Pool for 1987 to 2011 is 334 GL/yr. The greatest total annual flow (1400 GL) occurred in 2004 (Figure 2). There have been two years with no recorded flow and seven years with flows less than 10% of the mean annual flow. The longest period of no flow was 32 months between June 2001 and February 2004.

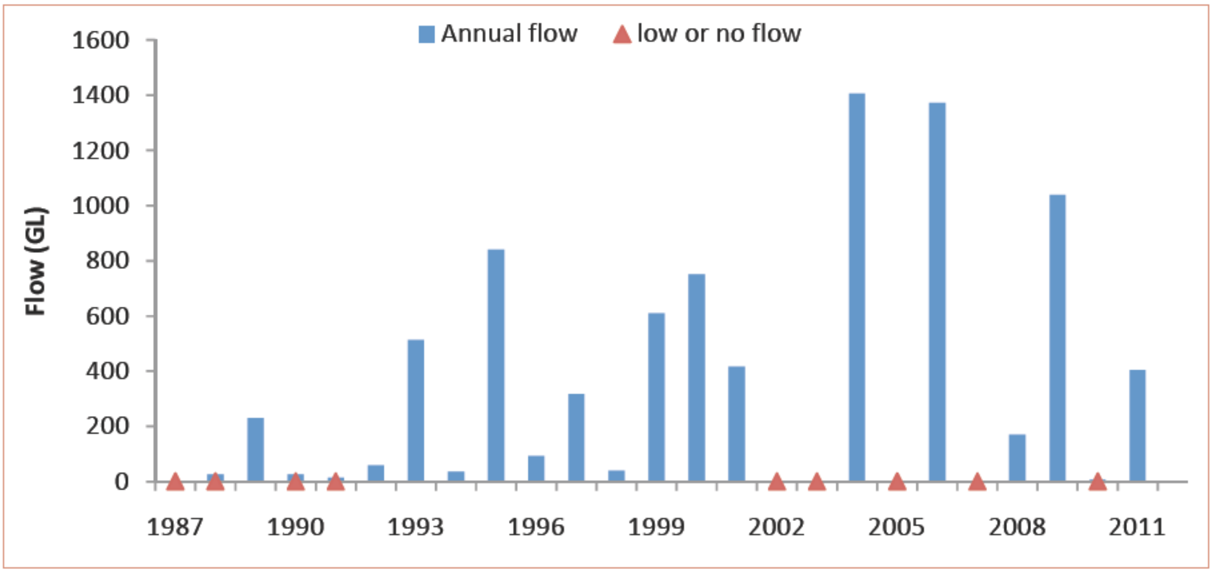

Figure 2
Lower Fortescue River total annual flow (Bilanoo Pool)

Hydrogeology

There are three aquifers present in the lower Fortescue River area:

- alluvial
- Yarraloola Conglomerate
- fractured basement aquifers.

The alluvial aquifer is the main productive aquifer. It extends over approximately 200 km2 of alluvial fan deposit to the west of the present day Fortescue River. Alluvial gravel deposits coincide with a freshwater lobe (< 1000 mg/L), which grades into saline groundwater near the saltwater interface and alluvial fan margin (Haig 2009).

The Yarraloola Conglomerate is less extensive than the alluvial aquifer. It underlies the current position of the river where it fills narrow channels in the underlying basement rock (Aquaterra 2006).

Groundwater also occurs in fractures and faults in the basement rock. Storage, however, is generally low due to the low portion of rocks containing voids and to the impermeability of rock itself (Skidmore 2008).

Flooding of the lower Fortescue River and its tributaries is the greatest source of recharge to the aquifers (MWH 2010). The volume of recharge depends on the duration, depth and frequency of flow and the storage available in the aquifer. The average annual recharge has been estimated as 11 GL/yr (Commander et al 1994).

Groundwater levels in the study area fluctuate with local topography and time since recharge. Extended periods of no or low flow result in falling groundwater levels. Where the river channel intersects the alluvial aquifer, permanent to semi-permanent pools occur as surface expressions of the watertable.

Current groundwater use

The current allocation limit for the alluvial aquifer is 6.6 GL/ yr (Department of Water 2011). This was determined as a proportion of average annual recharge.

The alluvial aquifer provides water for stock and domestic use on Mardie Station. Current groundwater use is well below the allocation limit but is expected to increase as mining companies operating in the area are licensed to take water from the alluvial aquifer in staged developments.

Mine pit dewatering from the adjacent bedrock is also occurring. Recent groundwater modelling shows that there is little connection between the bedrock and the alluvium (MWH 2010). It is therefore unlikely that dewatering will affect groundwater levels in the alluvial aquifer.

Data availability

Groundwater levels have been monitored discontinuously at up to 32 bores across the study area since 1983. As of 2012, 11 bores are monitored twice a year.

A detailed numerical groundwater model of the lower Fortescue was developed for the Department of Water in 2010 (MWH 2010). The model used all available information to quantify the available water resource, its sustainability and the effects of abstraction on groundwater-dependant ecosystems (MWH 2010). Historical data were generated for the period 1983 to 2007 and future abstraction scenarios were modelled over 50 years.

Figure 1 shows the location of the Bilanoo Pool gauging station, monitoring bores and alluvial aquifer.

Groundwater-dependent ecosystems are those that rely on groundwater directly (e.g. stygofauna or phreatophytic vegetation using groundwater from shallow watertables) or indirectly (e.g. wetland vegetation or aquatic ecosystems sustained by groundwater discharge).

A full description of the groundwater-dependent ecosystems and their links to hydrogeology is presented in *Lower Fortescue River: ecological values and issues* (Loomes 2010). A brief description of each, how they were defined, and the linkages between groundwater and ecology has been provided here to give context.

2.1 Identification and description

Three types of GDE have been identified on the lower Fortescue River:

- river pools
- riparian vegetation
- aquifer ecosystems.

River pools

The department characterised the degree of permanency of Pilbara river pools by analysing satellite imagery (Department of Water 2009). We found permanent, near permanent and intermittent pools occurring along the lower Fortescue River (Figure 3).

The pools support communities of freshwater and marine fish, macroinvertebrates, waterbirds, reptiles and aquatic flora. A biodiversity audit of the Pilbara region by the Department of Environment and Conservation (Kendrick & Stanley 2002) found that permanent pools on the lower Fortescue River are sub-regionally significant as they support vertebrate and invertebrate fauna.

In places the river and pools are connected to and interact with the underlying alluvial aquifer. When the river is in flood the pools, floodplains and riparian zone are connected, allowing biota and nutrients to move through the system (Beesley 2006). During river flow events groundwater is recharged and the watertable rises.

When there is no flow in the river, the groundwater movement reverses and discharges into the pools. As groundwater levels decline, connection between the river channel and aquifer is reduced, with only deep pools or low (elevation) sections of the river intersecting the watertable.

Aquatic habitat is reduced as surface water recedes and then groundwater levels decline. As groundwater continues to decline aquatic flora and fauna become isolated in a series of disconnected river pools. As pools become shallower, water quality can decline due to reduced buffering capacity and evapo-concentration (Pinder & Leung 2009).

Deep pools that maintain connectivity with the groundwater throughout the dry season become critical refuges from which aquatic fauna repopulate the river when floods return. The continued input of groundwater to permanent pools is important to maintain adequate habitat and water quality during the dry season and during extended droughts.

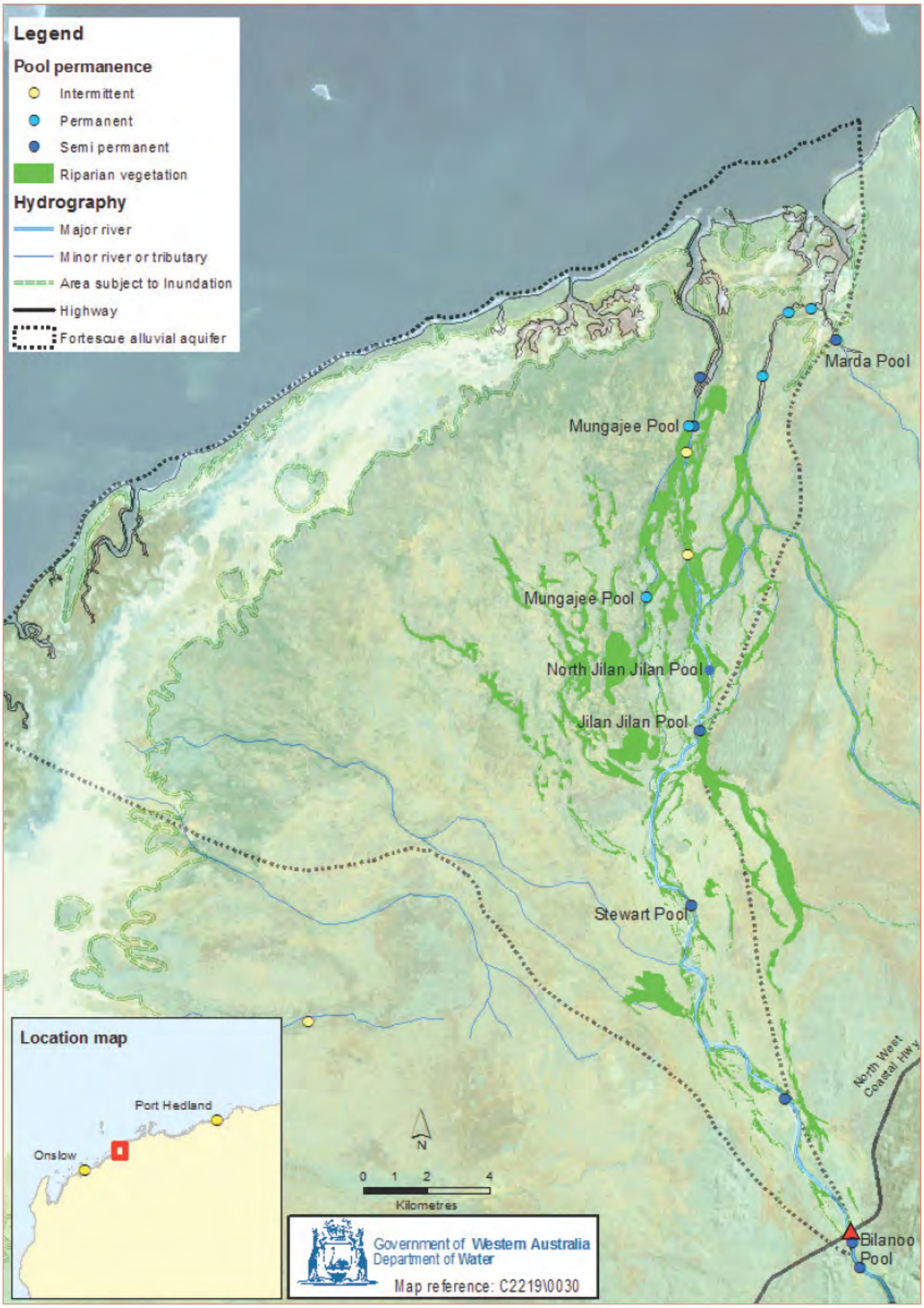

Figure 3
River pools and riparian vegetation of the lower Fortescue River study area

The Fortescue River has the highest diversity of fish species of all Pilbara rivers; with 15 species having been previously recorded (Morgan et al 2009). Bilanoo and Mungajee pools support all known species from the Fortescue River catchment, including those with restricted distribution and two that have not previously been described in the scientific literature (Morgan et al. 2009). These two pools therefore have high habitat value and are important to the maintenance of fish diversity in the Fortescue River system and wider Pilbara region (Morgan et al. 2009). Other permanent lower Fortescue pools may also support similar fish diversity.

Riparian vegetation

Healthy riparian ecosystems are important to river health as they provide relatively highly productive ecosystems in an arid environment (Douglas et al. 2005). Riparian ecosystems in arid environments also provide important habitat for terrestrial fauna (van Dam et al. 2005).

The riparian vegetation communities on the lower Fortescue River are dominated by perennial tree species: *Eucalyptus camaldulensis* (river red gum), *Melaleuca argentea* (cadjeput) and *E. victrix* (coolibah) (Figure 3). The distribution of riparian communities reflects the depth to groundwater and the area inundated during flooding (HGM 2000; Maunsell 2006; Loomes 2010).

Depth-to-groundwater contours (Figure 4) show that shallow groundwater (<10 m) occurs across the lower Fortescue study area (MWH 2010) and that the riparian communities are restricted to these areas (HGM 2000; HGM 2006). The shallow depth to groundwater in the alluvium, and especially along the river, provides areas where deep rooted vegetation can reach groundwater which sustains these communities in the absence of rainfall and/ or surface flow.

The dependence of riparian tree species on groundwater varies. For example, *M. argentea* is restricted to areas where the watertable is very shallow or at the surface (Graham 2001). *E. camaldulensis* can reach a deeper watertable, but its distribution is restricted by groundwater depth and reliance on flood waters for recruitment (Pettit & Froend 2001).

E. victrix tends to be found in drier conditions than *E. camaldulensis* and *M. argentea*. Although tolerant of long periods of drought *E. victrix* appears sensitive to prolonged inundation (Strategen 2006).

In addition to native riparian species, mesquite – a deep-rooted, perennial shrub (*Prosopis pallida*) (listed as a 'weed of national significance') – occurs in high densities across the lower Fortescue River delta (van Klinken et al. 2007). It is thought that at these densities, evapotranspiration from the mesquite is affecting the local watertable (Haig 2009; Miller 2010) and reducing the groundwater available for groundwater-dependent ecosystems.

Aquifer ecosystems

Diverse subterranean fauna have been found in aquifers across the Pilbara region, including the Fortescue alluvial aquifer. Research to date has focused on the distribution of stygofauna (and description of new species) rather than their habitat preferences and response to changes in water regime. We have therefore not determined EWRs for stygofauna specifically. However, they are indirectly taken into account in the EWRs through pool and riparian vegetation water requirements. We have assumed that if these are being met, then stygofauna requirements are also being met. Should more specific data become available these requirements can be reviewed.

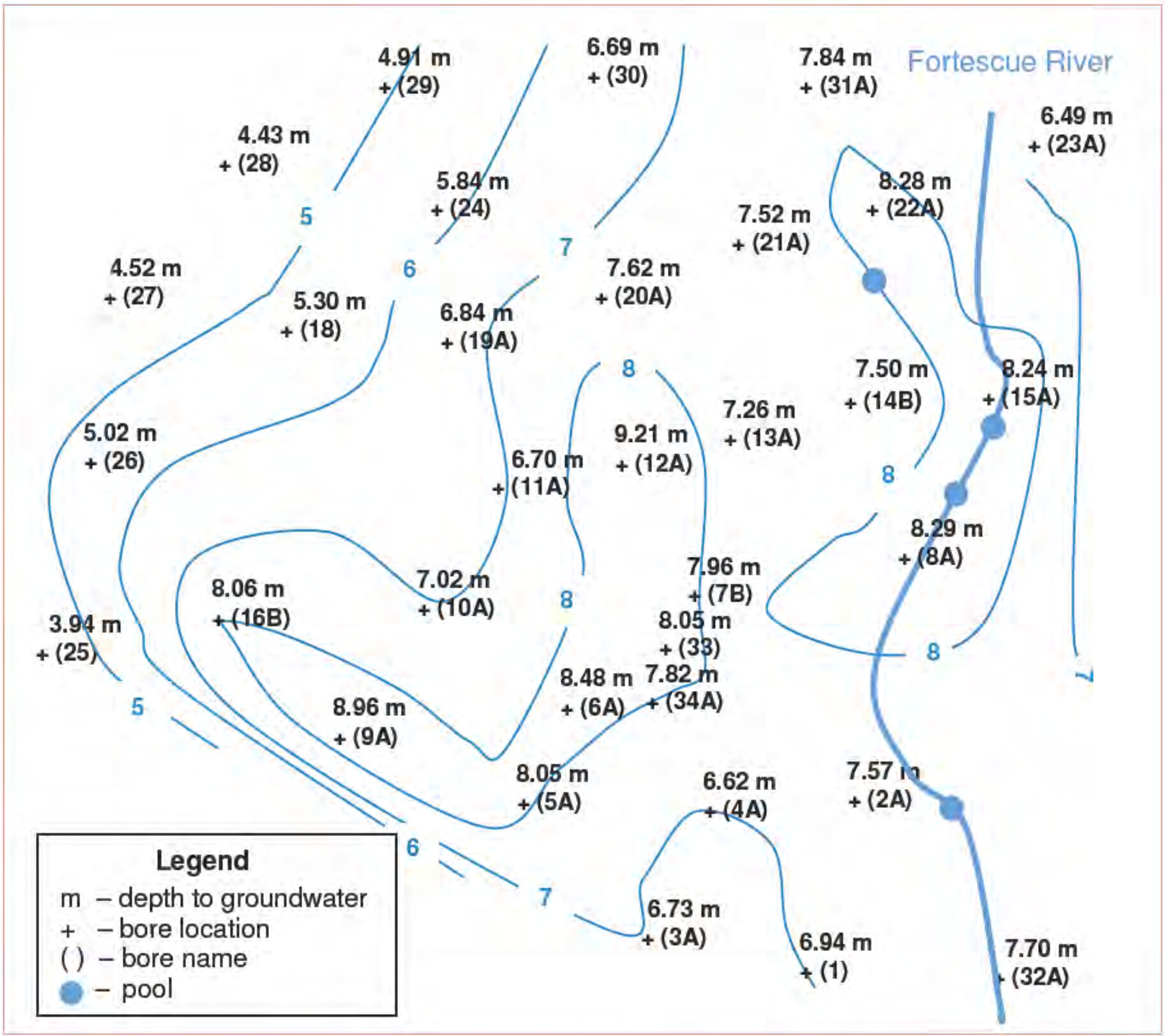

Figure 4
Depth-to-groundwater (average) contours across the lower Fortescue area (from MWH 2010)

2.2 Hydro-ecological linkages

Conceptual models were developed to describe the relationships between the water regime and groundwater-dependent ecosystems (Loomes 2010). We used these relationships to identify parts of the water regime that are critical for each ecological component of the ecosystem; fish, macroinvertebrates, riparian vegetation and water quality. These relationships are referred to as hydro-ecological linkages.

Hydro-ecological linkages were grouped by GDE type (Table 2). Some linkages relate to more than one ecological component.

The linkages formed the framework for describing the EWR.

A brief background on the most important linkages is provided in Table 2.

Table 2
Hydro-ecological linkages of river pool and riparian vegetation ecosystems

GDE	Ecological components
River pools	**Fauna** To maintain healthy fauna: 1. Permanent pool water levels need to be maintained consistent with regional seasonality, to maintain refuges for fish and other fauna. 2. Sufficient areas of shallow macrophyte habitat need to be inundated and hence available for macroinvertebrates, small-bodied fish and juveniles of large-bodied fish. 3. Sufficient deeper pools need to be permanently maintained as habitat for mature and large-bodied fish. **Water quality** To maintain the quality of water to keep fauna healthy: 4. Sufficient depth in need to be maintained in deeper pools.
Riparian ecosystems	**Riparian phreatophytic vegetation** To maintain healthy phreatophytic vegetation: 5. Groundwater levels need to be high enough to sustain vegetation during dry and drought periods when groundwater is the main source available to meet its water requirements. 6. Periods of high water availability are needed to maintain established vegetation and allow establishment of new vegetation.

Linkage 1: permanent pools maintained as refuges, consistent with regional seasonality

Flow in Pilbara rivers is intermittent and highly seasonal, with little or no flow during the winter and spring. Substantial variability also occurs between years, including some periods of longer term drought (Pinder & Leung 2009).

Many macroinvertebrate species complete life cycles and enter diapause (dormancy) based on the timing of intermittently available surface flows and persistence of residual pools (WRM 2009). While predictable seasonal drought is tolerated by Pilbara species, the unpredictable nature of long-term drought (inter-annual) may stress ecosystems and exceed the tolerance limits of species (Pinder & Leung 2009). For example, complete drying of previously permanent pools may result in local extinctions of fish. The loss of all drought refugia will mean loss of species from the river system.

Long periods of drought can reduce macroinvertebrate numbers. The effect on an individual pool depends on whether it dries completely and/ or reaches other critical ecological thresholds (e.g. water quality). At the river scale, the proportion of pools retaining water is important, as persistent pools provide refuge for fauna and act as sources of colonisers once the drought ends (Pinder & Leung 2009). Fish and other fauna (e.g. frogs and reptiles) have life cycle strategies for surviving variable conditions (WRM 2009).

The seasonality of pool water levels in the lower Fortescue River is important to ensure the normal availability and quality of fauna habitat. Seasonality will also ensure the normal variation in pool depth and volume, needed for life cycles to be completed and to maintain biodiversity across the river system. Seasonality and variation also ensures that non-permanent pools are at times available as aquatic habitat, allowing increased productivity of organic matter and exchange of biota between refuges.

Linkage 2: macrophytes inundated and available as habitat

Macrophytes provide important habitat for fauna in the lower Fortescue River pools that would otherwise be habitat poor (Pinder & Leung 2009). As other habitat types – such as woody debris and emergent macrophytes – are not widespread in coastal pools (Morgan et al 2009), submerged macrophytes shelter small-bodied fish species and juveniles of larger bodied species from predators (Storey 2003). They are also important to macroinvertebrates for egg laying and larval habitat (Pinder & Leung 2009).

The dominant species of macrophyte known from the lower Fortescue River – *Myriophyllum* sp., *Vallisneria* nana and *Potamogeton crispus* – have submerged roots and are typically only found in permanent pools (Beesley 2006).

Although V. nana is known to occur at a water depth range of 0.0 to 1.3 m (George et al. 2002) the minimum depth required to maintain other species and to form healthy beds as habitat in Pilbara rivers has not been determined (van Dam et al. 2005). Studies on the lower Ord River however, show that a minimum dry season depth of 0.45 m is required to maintain areas of macrophyte as habitat for small fish (Trayler et al. 2006).

We therefore used a depth of 0.45 m as the minimum depth needed to maintain macrophyte habitat in lower Fortescue River pools.

Linkage 3: deep pools available as habitat

Previous studies (van Dam et al. 2005; Beesley 2006; Dobbs & Davies 2009; Morgan et al. 2009) have shown that maximum pool depth and/or pool permanence influence fish diversity and community structure. Deeper pools in the Fortescue River contain more species, and in higher numbers, as they contain water for longer during dry periods. The deep pools are therefore a reliable drought refuge and a source of fish and other aquatic fauna to re-colonise dry reaches when flows do occur.

On the De Grey River a minimum depth of 1.50 m was identified as a threshold for change in fish species composition and richness. This is because large-bodied fish and marine species decline in abundances at shallower depths (van Dam et al. 2005). Permanent pool depths of greater than 1.50 m will also help maintain water quality.

We have therefore used a depth of 1.50 m as the minimum depth for maintaining deep pool habitat.

Linkage 4: sufficient depth in deeper pools to maintain water quality

Pool size and depth can reduce the risk of nutrient enrichment and anoxia through buffering extreme changes in temperature and evapoconcentration. We have used a depth of 1.50 m as the minimum depth for maintaining water quality.

Linkage 5: depth to groundwater within the range required by phreatophytic riparian vegetation

The distribution of dominant riparian species is restricted to areas where the depth to groundwater is relatively shallow. In these zones, relatively mature, deep rooted riparian vegetation has grown in the presence of the groundwater and tends to be at least partly reliant on it to meet its water requirements (Roberts et al. 2000). To maintain the health and vigour of riparian species the depth to groundwater needs to be maintained within the historical accessible range.

As discussed in Section 2.1, the shallow watertable along the lower Fortescue River (<10 m) shows that riparian vegetation is dependent on groundwater. This conclusion is supported by the fact that riparian woodland coincides with areas of shallow groundwater. This can be seen by comparing figures 3 and 4.

For the Fortescue, De Grey and Yule rivers, depths of <10 m are likely to be accessible to E. camaldulensis and M. argentea. However, while these minimum levels are acceptable for a short time, they are unlikely to maintain riparian communities in the longer term.

A minimum groundwater level that is within an accessible range will sustain riparian vegetation in drought years.

Linkage 6: periods of high water availability to maintain established vegetation and allow establishment of new vegetation

Greater water availability (i.e. higher groundwater levels) is required for mature riparian trees to initiate and maintain new growth, to flower and to set seed, and for seedlings to establish (Roberts et al. 2000). Hence, meeting only minimum water levels is not sufficient to maintain riparian community vigour in the long term, and periods of higher groundwater levels are also required.

The requirements for linkage 6 are provided by flood flows and since these are not affected by groundwater abstraction, they have not been considered further as part of this study.

2.3 Site selection

Representative sites

We described water requirements at five sites (river pools) selected to be representative of the groundwater-dependent ecosystems across the lower Fortescue area.

The sites selected are shown in Figure 5 and described in Table 3. The sites are:

- Bilanoo Pool
- Stewart Pool
- Jilan Jilan Pool
- Mungajee Pool
- an unnamed pool which we have called 'North Jilan Jilan' for this study.

Each pool is either semi-permanent or permanent. Surface water level data were only available for Bilanoo Pool – measured as stage height (m) at the gauging station. Only North Jilan Jilan Pool was close (<50 m) to a monitoring bore (see Loomes 2010 for further information on the ecology of the pools).

The sites were selected based on the:

- presence of representative GDE types (river pools and riparian vegetation)
- likely groundwater connectivity
- degree of river pool permanence
- availability of groundwater data or river stage heights
- inclusion in previous flora or fauna studies.

Because the data produced by the groundwater model for the historical period of 1983 to 2007 did not reflect the actual wide range between highest and lowest groundwater levels, and because these are the critical levels for ecosystems, we decided to use observed data to describe the EWRs, despite its patchy nature (Figure 6).

Groundwater level data for bores 15A and 22A were only recorded up to 1991, but bore 8A had data available up to 2011 (Table 3). There was a good correlation between levels in bores 15A and 8A which allowed us to extrapolate groundwater data for bore 15A forward to 2011 (Appendix A).

Table 3
Representative sites, associated bores and availability of data

Pool and description	Site or bore name	Distance from pool m	Data availability (observed)
Bilanoo – medium sized permanent pool at the crossing of the North West Coastal Highway	Bilanoo gauging station	0	1978–09/11 (daily readings)
Stewart – near permanent pool downstream of Bilanoo Pool	2B	2000	1983–04/11 (~2 readings/yr)
Jilan Jilan – near permanent pool on main river channel	8A	1580	1983–04/11 (~2 readings/yr)
Nth Jilan Jilan – near permanent pool on main river channel	15A	<50	1983–1991 (2011)*
Mungajee – narrow, possibly permanent pool on western anabranch of river	22A	300	1983–1991

*extrapolated using correlation with bore 8A

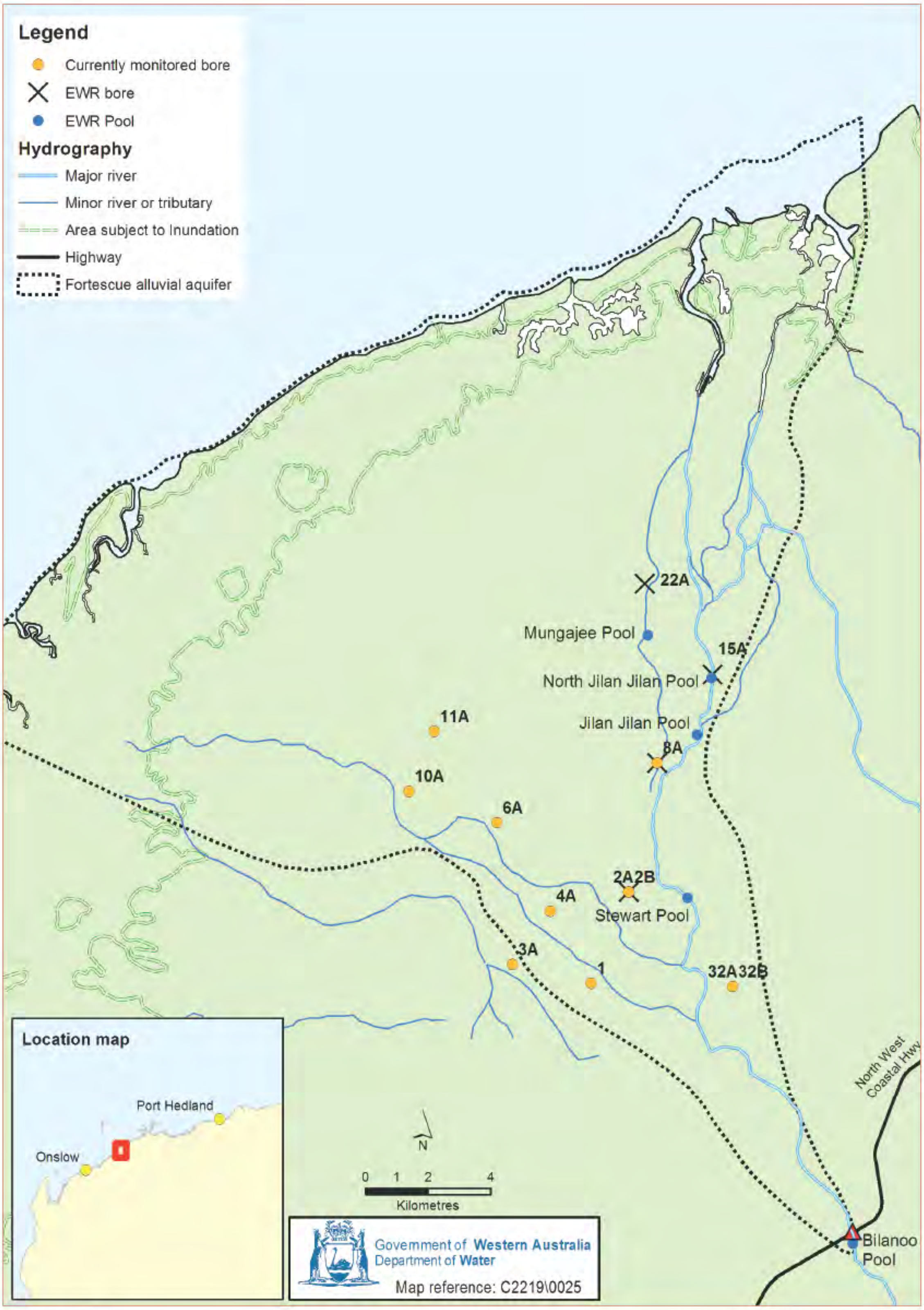

Figure 5
Location of representative EWR pools and bores and other monitoring bores

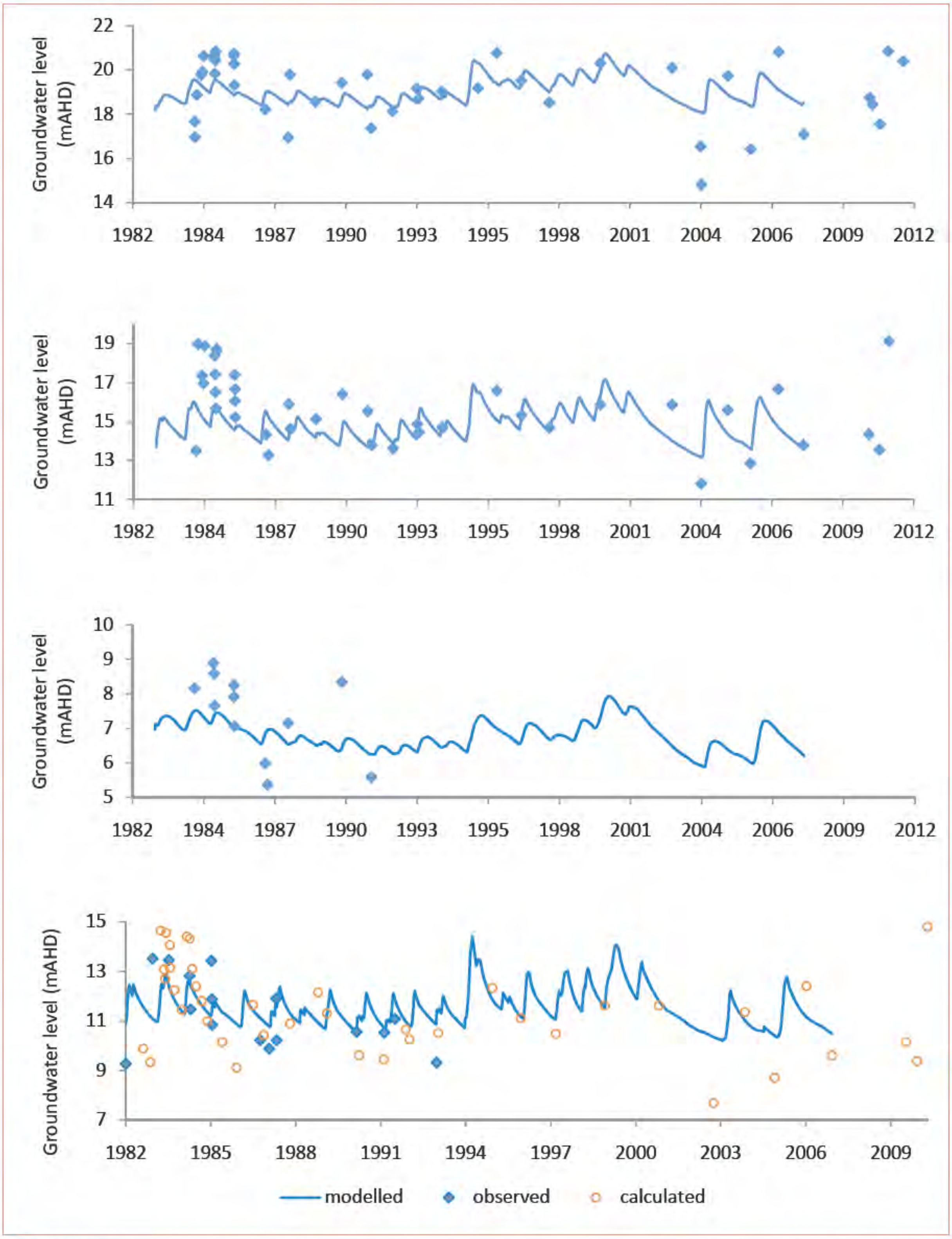

Figure 6

Observed and modelled groundwater levels (1982 –2012) a) bore 2B, b) bore 8A, c) bore 15A and d) bore 22A.

3.1 Overview of approach

The hydro-ecological linkages described in Section 2.2 formed the framework for describing the ecological water requirements. Linkages describe how the surface or groundwater levels maintain each ecological component or process. We calculated the minimum water levels, which we called 'thresholds', required to maintain each of these six linkages at each representative site (where applicable) and then combined them to describe define the overall ecological water requirement for each site.

The approach used to describe the EWRs for groundwater-dependent ecosystems on the lower Fortescue alluvial aquifer:

- recognises the variable nature of the system's climate and groundwater levels
- deals with the limited understanding of GDE response to changes in water availability.

We have used the best information available from previous studies on riparian systems to determine thresholds of ecological response. This was important as, although there have been previous surveys describing the ecology of the lower Fortescue, there was little specific information on the actual water requirements of its ecosystems.

Where thresholds (e.g. 1.50 m pool depth for large fish) have been established by previous work on the Yule and De Grey rivers (van Dam et al. 2005) and similar systems elsewhere in Australia (eg. Braimbridge & Malseed 2007), we have used them.

Where thresholds of pool depth or depth to groundwater were unknown we used statistical (percentile) thresholds of the existing water regime to describe the EWRs. This has the advantage of being representative of the local water regimes and of the natural variability in the system that the ecology has adapted to.

A groundwater drawdown trial on the lower Yule River found that riparian trees (*Eucalyptus camaldulensis* and *Melaleuca argentea*) began to suffer when water levels fell below the historical 20th percentile groundwater level (i.e. levels less than those experienced 80% of the time) (Braimbridge 2012). The degree of stress increased at levels below the 5th percentile. The use of percentiles allows us to translate the thresholds from one site to another and to identify site-specific or local conditions. Therefore, these thresholds – 5th and 20th percentiles – were used to describe the EWRs for riparian vegetation.

We also considered the 50th and 90th percentiles in the characterisation of pool level seasonality and higher water availability conditions.

We characterised three water availability conditions – drought, dry and average–above average – to account for the natural variability in water availability. These were based on river flow as the key determinant of aquifer recharge. Different thresholds apply to each water availability condition:

- 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.

We used frequency analyses to determine how often the 5th percentiles were not reached or the 20th and 50th percentiles were exceeded in the past. The results were used to define how often a minimum or the 5th percentile can be exceeded and how often the 20th and 50th percentiles should be met. We applied durations and frequencies of breaches over a five-year period to allow for inter-annual variation in recharge.

The specific approach, results and recommended pool or groundwater levels for maintaining each of the hydro-ecological linkages are presented below.

3.2 Linkage 1: permanent pools maintained as refuges, consistent with regional seasonality

Approach

Bilanoo Pool and bore 8A were used to describe baseline regional seasonality because suitable data were not available for other sites. Although bore 15A is within 50 m of North Jilan Jilan Pool, data have not been recorded since 1991 and historical data may not be representative of current water regimes. As bore 22A is more than 300 m from Mungajee Pool and bore 2B about 2000 m from Stewart Pool, and data have also not been recorded since 1991, these sites were also not included here.

Although surface water levels are not recorded for pools on the lower Fortescue River, stage height data (m) are available for Bilanoo Pool. As this pool is on the edge of the alluvial aquifer it may not reflect effects of aquifer development (Haig 2009).

We considered groundwater levels recorded in bore 8A (mAHD) as being representative of seasonal variations in Jilan Jilan Pool.

During a field visit in August 2010, Jilan Jilan Pool was approximately 1.50 m deep. This corresponded to a groundwater level of 14.347 mAHD at nearby bore 8A and allowed extrapolation of pools levels based on groundwater data.

Results

We calculated percentiles (5th, 50th and 90th) representing low, average and high water availabilities to describe the historical range in pool levels. We then compared these to pool hydrographs or groundwater for representative sites (Table 4, Figure 7)

Recommendations

Seasonality of pool levels should be maintained to meet the requirements of linkage 1. We recommend minimum dry season levels of 9.27 m at Bilanoo Pool and 13.28 mAHD in bore 8A at Jilan Jilan Pool. These levels should maintain the permanent nature of the pools characterised by the pool mapping.

Although the representative permanent pools act as drought refuges, seasonality in levels and depths – lower during dry seasons and higher during wet seasons – should be maintained. The changes in depth of these pools should also be indicative of the drying and re-filling of semi-permanent and intermittent pools on the lower Fortescue River, which we have not been able to assess because of lack of data. The pattern of these changes will meet the lifecycle requirements of aquatic fauna in those pools.

Maintaining water levels within the range of percentiles shown in Table 4 will provide inter-annual and seasonal variation at Bilanoo and Jilan Jilan pools. This will maintain pool habitats consistent with the historical water regimes.

We will apply thresholds based on recharge classes (Section 5) to link annual pool level requirements to regional climate.

Table 4
Pool level percentiles

Pool	Percentile pool water-level		
	5th	50th	90th
Bilanoo (m)	9.27	9.63	10.28
Jilan Jilan (bore 8A)(mAHD)	13.28	15.59	18.65

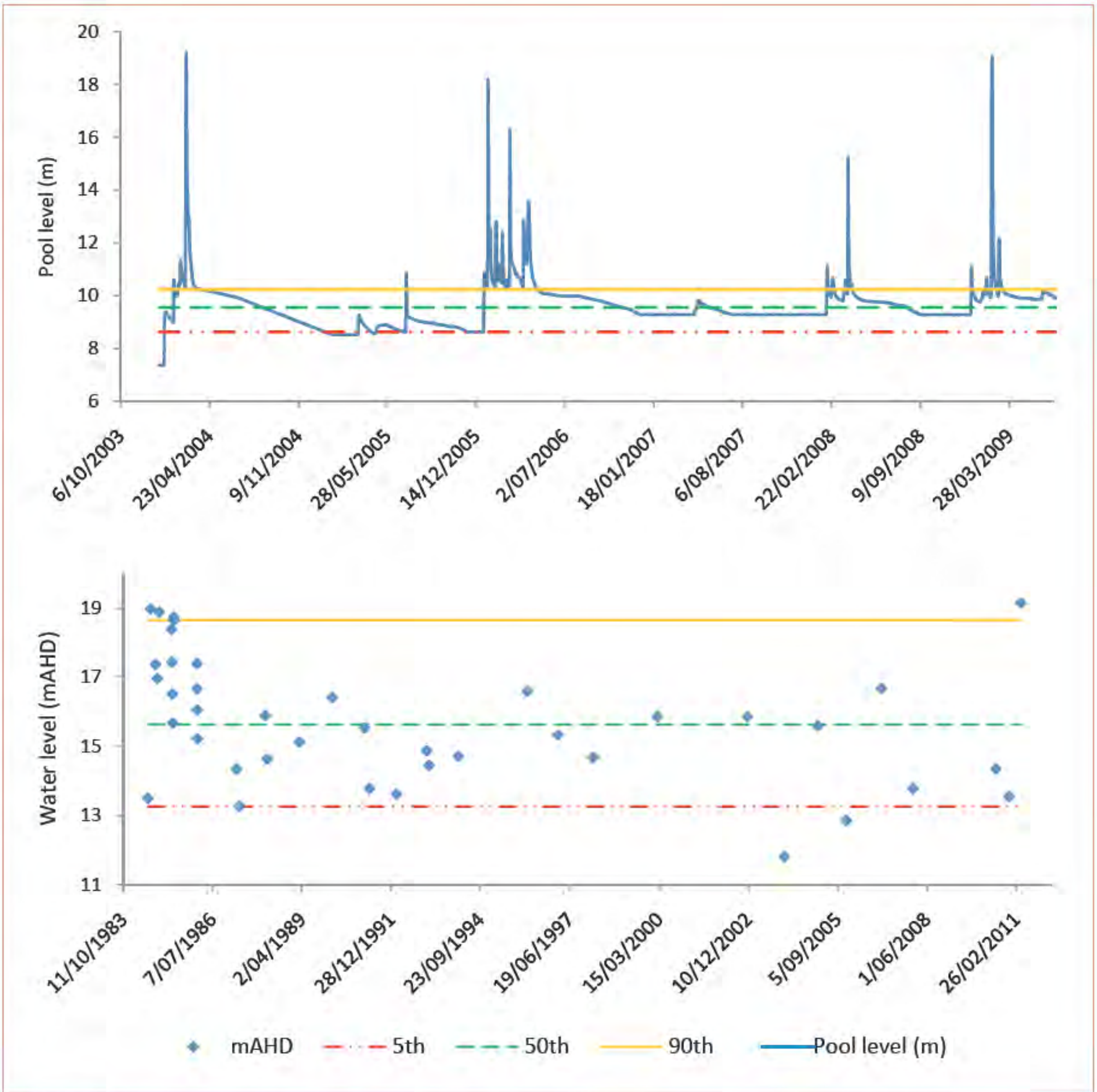

Figure 7
Pool level and percentiles a) Bilanoo, b) bore 8A as Jilan Jilan

3.3 Linkage 2: macrophytes inundated and available as habitat

Approach

We needed to determine if depths of 0.45 m are actually achieved in the lower Fortescue study sites, but although stage height data (m) were available for Bilanoo Pool, the pool bathymetry had not been surveyed and so levels could not be converted to depth.

We used levels in bore 8A as a surrogate for Jilan Jilan Pool and set the base of the pool as 12.856 mAHD (14.347 mAHD – 1.50 m observed pool depth). We then extrapolated pool depths across the available hydrological data set. This allowed us to determine if depths greater than 0.45 m were achieved under past water regimes, represented by the 5th, 20th and 50th percentiles.

Results

The minimum groundwater level at bore 8A required to maintain an extrapolated depth of 0.45 m in Jilan Jilan Pool is 13.28 mAHD.

Percentile pool depths representing the drought conditions (5th percentile) are 0.02 m deeper than the 0.45 m depth requirement, while the dry and average–above average condition depths are deeper (Table 5 and Figure 8).

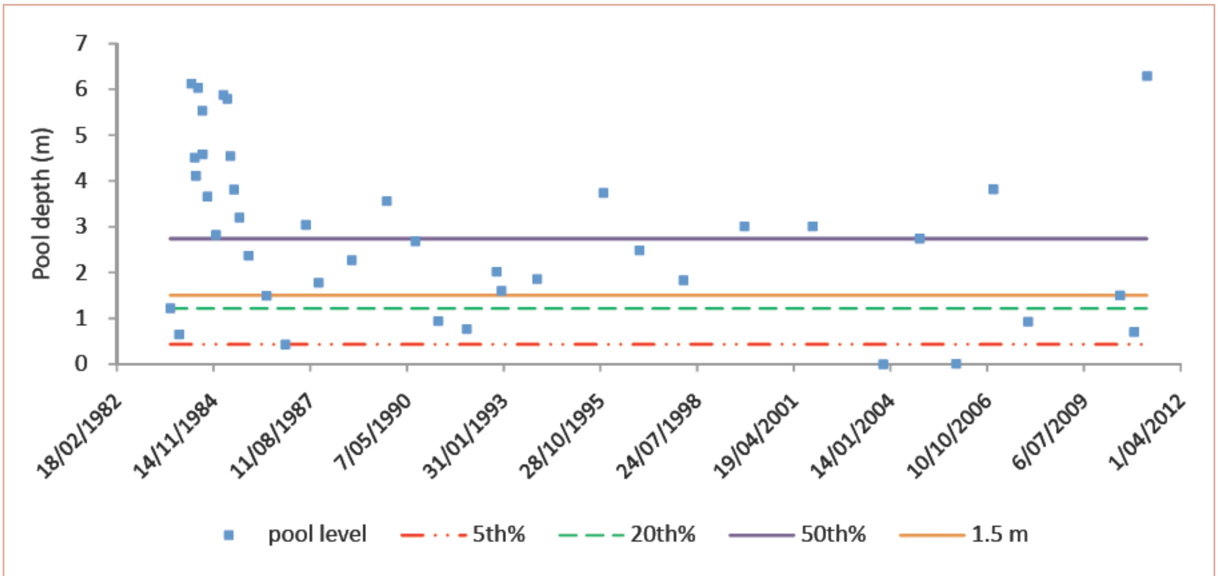

Figure 8
Extrapolated pool depth percentiles and 0.45 m depth at Jilan Jilan Pool

Maintaining the current water level regime, as represented by groundwater level percentiles in bore 8A, should therefore ensure sufficient water depths to support aquatic macrophyte habitat in Jilan Jilan Pool.

Recommendations

We recommend that a minimum dry season groundwater level of 13.28 mAHD be maintained at bore 8A to meet the requirements of linkage 2 (Table 5). However, this EWR is based on extrapolated data and should be reviewed when actual data become available. We cannot establish EWRs for other study pools as bores are too far away or data too incomplete to represent pool water regimes.

3.4 Linkage 3: deep pools available as habitat

Approach

We used groundwater levels in bore 8A as a surrogate for Jilan Jilan Pool surface water levels to determine if depths greater than 1.50 m were achieved under past water regimes. These were represented by the 5th, 20th and 50th percentiles.

Results

The minimum groundwater level at bore 8A required to maintain an extrapolated depth of 1.50 m in Jilan Jilan Pool is 14.34 mAHD (Table 5).

Table 5

Groundwater levels and extrapolated pool depths to meet linkages 2 and 3

Pool	Percentile or threshold	Groundwater level at bore mAHD	Extrapolated pool depth m	Frequency that level or depth was met*
Jilan Jilan (8A)	5th	13.28	0.46	3
	20th	14.07	1.23	7
	50th	15.59	2.75	7
	0.45	13.29	-	3
	1.5	14.34	-	6

*number of times water levels exceeded 20th and 50th percentiles or fell below 5th percentile

The 1.50 m depth requirement was met under average (50th percentile) water availability condition. The dry (20th percentile) condition depth was 1.22 m – only 0.28 m shallower than the 1.5 m threshold (Figure 9).

Jilan Jilan Pool appears to be the required 1.50 m deep in the majority of years and is likely to provide a dry season refuge.

Maintaining the current pool water level regimes, as represented by groundwater levels in bore 8A, should provide refuge habitat in the majority of years.

Recommendations

We recommend that a minimum dry season groundwater level of 14.34 mAHD be maintained at bore 8A in all but the driest of years (i.e. not in drought years) to meet linkage 3. However, this is based on extrapolated data and more comprehensive pool level data are required.

EWR cannot be established for other study pools as bores are too far away to represent pool water regimes.

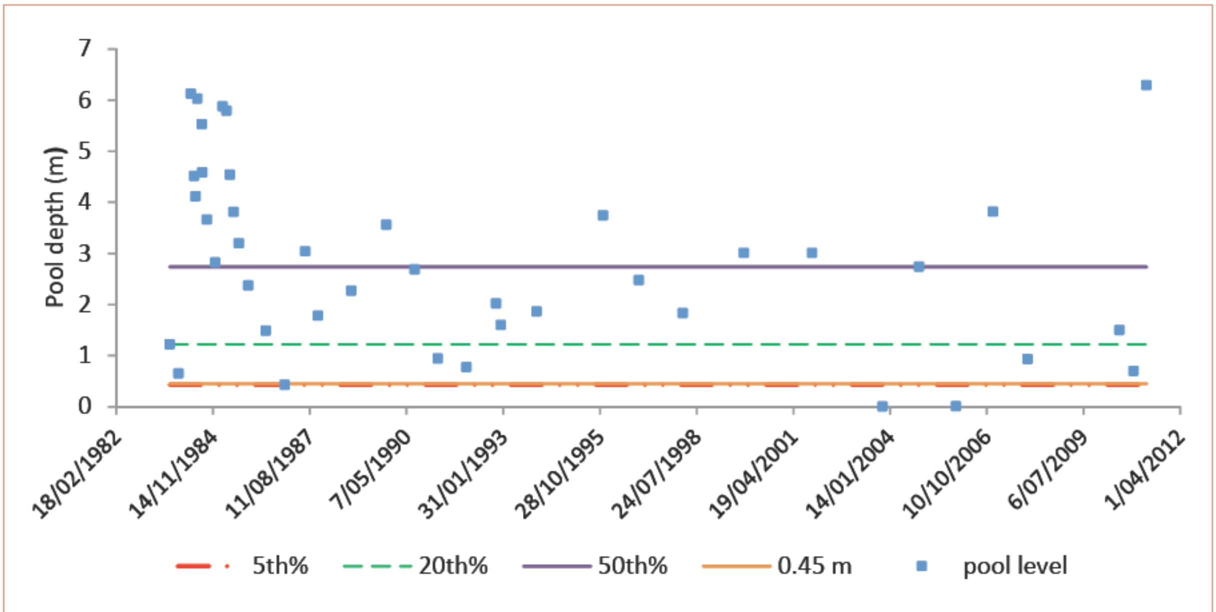

Figure 9
Extrapolated pool depth percentiles and 1.5 m depth at Jilan Jilan Pool

3.5 Linkage 4: sufficient depth in deeper pools to maintain water quality

The pool depth requirements established for linkage 3 should also maintain water quality. So we therefore have used a depth of 1.50 m as the minimum depth for maintaining water quality.

3.6 Linkage 5: depth to groundwater within range required by phreatophytic riparian vegetation

Each of the five representative sites supports some riparian species that are known to use groundwater to meet their water requirements between periods of soil water recharge (Muir Environmental 1995; Humphreys 2000).

Approach

The Yule borefield drawdown trial identified the responses of vegetation to altered water availability at thresholds of 5th and 20th groundwater level percentiles (Braimbridge 2012). Trial results showed a distinct eco-physiological water stress response in vegetation when the levels were exceeded, but overall the vegetation recovered.

We used observed groundwater data from bores 2B (Stewart Pool), 8A (Jilan Jilan Pool), 15A (North Jilan Jilan Pool) and 22A (Mungajee Pool) to calculate 5th, 20th and 50th percentiles. We analysed data further to determine how often the 5th percentile was not reached in the past. We also calculated the frequency of periods above the 20th and 50th percentiles and used these data to refine thresholds. That is, how often the minimum or the 5th percentile can be breached and how often the higher levels of the 20th and 50th percentiles should be met.

Bores for the EWR sites are between 50 m and 2000 m from the pools and vegetation. To better represent the actual depths to groundwater (dtgw) experienced by the vegetation, depths were extrapolated from bores using elevation data derived from LiDAR.

We extracted elevations from LiDAR along transects running from the bore to the associated pool (e.g. bore 8A to Jilan Jilan Pool) at four sites; Stewart, Jilan Jilan, Nor th Jilan Jilan and Mungajee pools. Groundwater levels recorded at each relevant bore were extrapolated along the transect (Figure 10). Where riparian vegetation was present on a transect (mapped previously), elevations and percentile groundwater levels were used to determine the range in depth to groundwater at that site. As there is not a bore in close proximity to Bilanoo Pool, it was not included in this assessment.

Results

Figure 10 shows the groundwater percentile levels extrapolated across the transects, highlighting areas where they intersect riparian vegetation. Percentiles and frequencies of groundwater levels at each bore are summarised in Table 6 along with the extrapolated depth to groundwater range of the riparian vegetation.

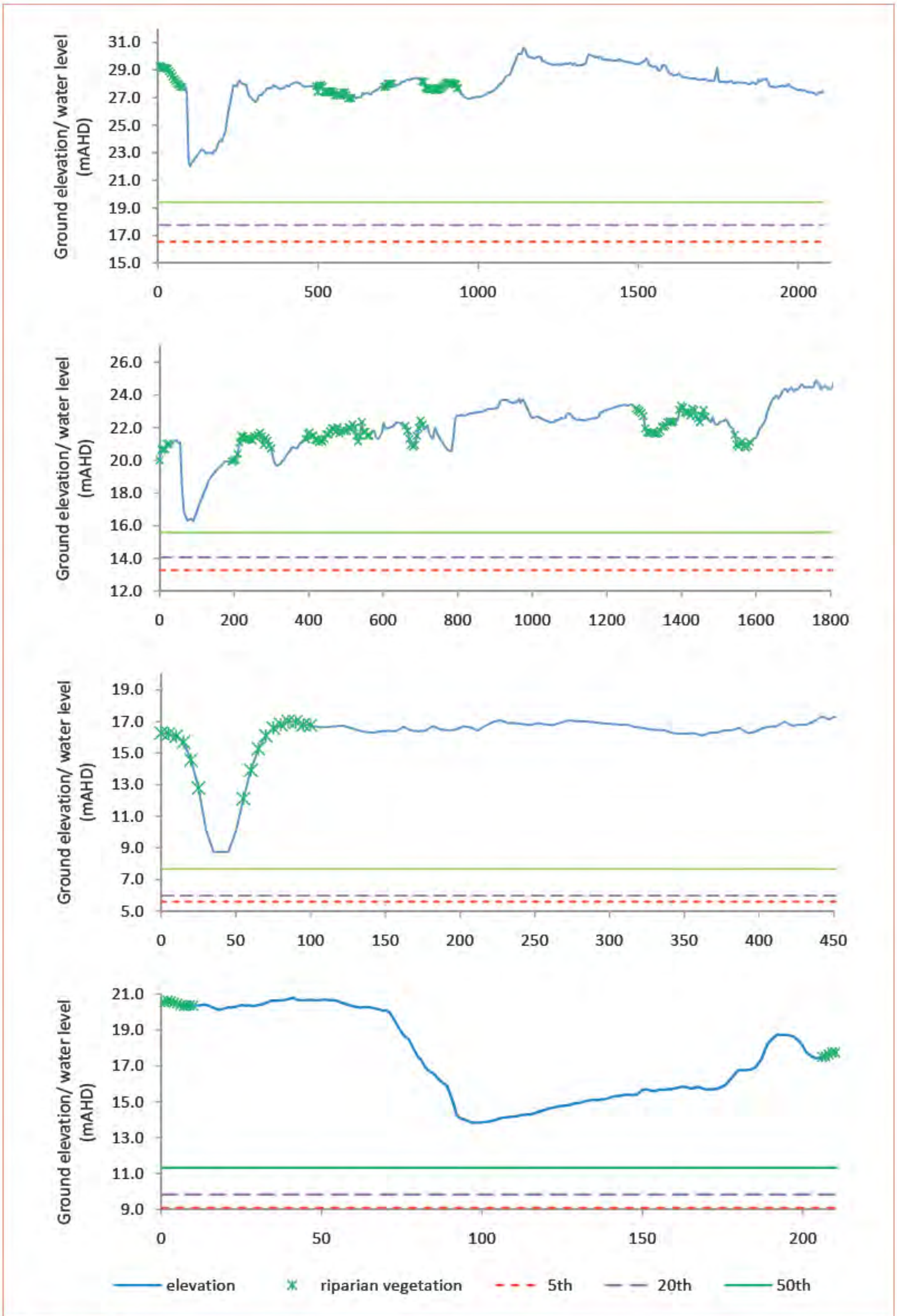

Figure 10

Groundwater levels extrapolated across transects from bores to associated pools a) bore 2B, b) bore 8A c) bore 22A and d) bore 15A.

Table 6
Observed groundwater level percentiles, frequency they were exceeded or not met and riparian vegetation dtgw ranges

Pool and associated bore	Percentile	Groundwater level at bore mAHD	Frequency that level or depth was met*	Riparian vegetation dtgw range
Stewart 2B	5th	16.55	2	10.39–12.74
	20th	17.75	6	9.19–11.54
	50th	19.41	7	7.53–9.88
Jilan Jilan 8A	5th	13.28	3	6.65–10.06
	20th	14.07	7	5.86–9.27
	50th	15.59	7	4.35–7.76
Nth Jilan Jilan 15A	5th	9.10	2	4.52–11.50
	20th	9.83	7	3.61–10.59
	50th	11.33	7	2.87–9.85
Mungajee 22A	5th	5.59	6	6.53–11.42
	20th	5.97	7	6.15–11.04
	50th	7.66	3	4.46–9.35

*number of times water levels exceeded 20th and 50th percentiles or fell below 5th percentile

Recommendations

Minimum dry season groundwater levels should remain above the 5th percentile, as shown below, to meet requirements of linkage 5 in drought years.

- bore 2B 16.55 mAHD
- bore 8A 13.28 mAHD
- bore 15A 9.10 mAHD
- bore 22A 5.59 mAHD.

In dry years the groundwater level should not be lower than the 20th percentile.

- bore 2B 17.75 mAHD
- bore 8A 14.07 mAHD
- bore 15A 9.8 mAHD
- bore 22A 5.97 mAHD.

In years of average or above average water availability, the groundwater level should be at or above the 50th percentile.

- bore 2B 19.41 mAHD
- bore 8A 15.59 mAHD
- bore 15A 11.33 mAHD
- bore 22A 7.66 mAHD.

3.7 Linkage 6: Periods of high water availability to maintain established vegetation and allow establishment of new vegetation

As mentioned previously, the requirements for linkage 6 are provided by flood flows and since these are not affected by groundwater abstraction, they have not been considered further as part of this study.

3.8 Recommendation for pool level monitoring and surveys of pool bathymetry

For the pools that we were not able to study due to lack of data or bores being too far away – Stewart, Mungajee and North Jilan Jilan pools – we recommend that the department or licensees set up pool level monitoring and carry out surveys of pool bathymetry. This will provide data on pool permanence and depth and enable us to establish EWRs and monitor any changes in water levels related to increases in abstraction.

And although we were able to assess Bilanoo and Jilan Jilan pools using existing data, we recommend that pool level monitoring and a survey of pool bathymetry be established for these as well.

Because we established ecological water requirements for three levels of water availability, we needed a way to determine which level would apply for a given year.

The amount of recharge to pools and groundwater is determined by the magnitude, duration and frequency of river flows. We examined different flow parameters to see which single parameter, or combination of parameters, gave the best indication of recharge along the lower Fortescue River.

Analyses of correlations showed that flow volume (magnitude) influenced groundwater levels in the study area more than the frequency or duration of flow. We found that wet season flow (January to April) had the strongest correlation with groundwater levels in the following water year (May to April).

We therefore used the river flow during the previous wet season as the indicator of water availability.

We ranked total wet season flows for years 1987–2011, by volume from lowest to highest to establish 'recharge classes' or levels of availability of water. We then assigned each year to one of four recharge classes based on probability distribution (Figure 11):

- Class 1 – drought: total wet season flow <1000 ML
- Class 2 – dry: total wet season flow 1000 to 50 000 ML
- Class 3 – average: total wet season flow 50 000 to 600 000 ML
- Class 4 – above average: total wet season flow >600 000 ML.

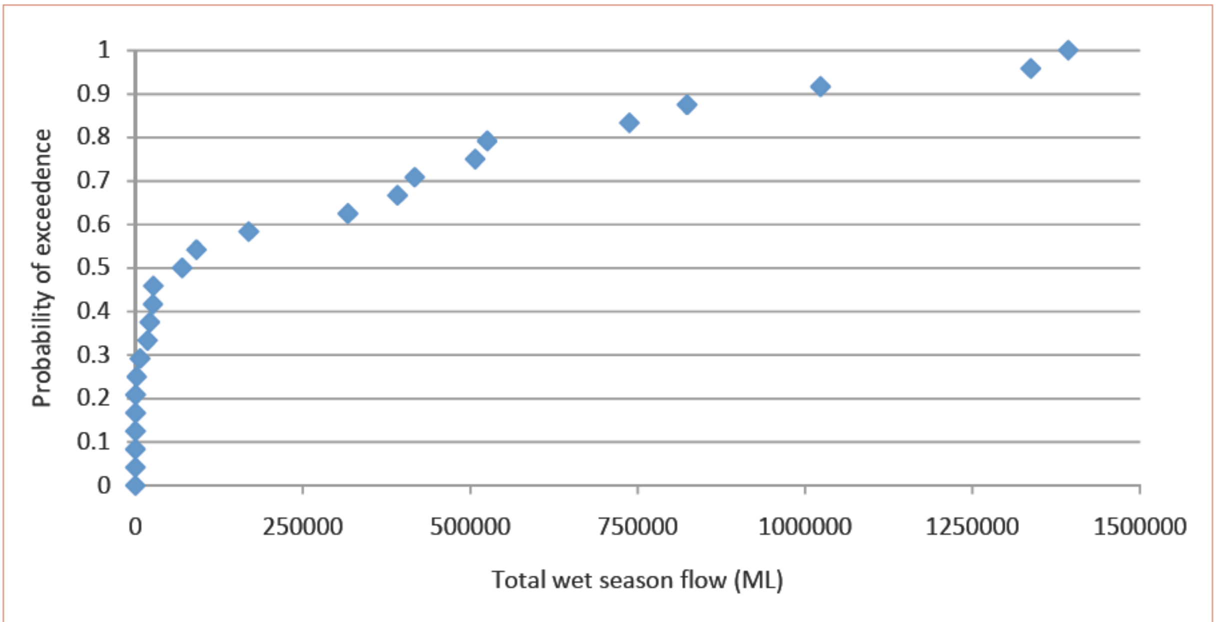

Figure 11
Wet season flow probability distributions (1987–2011)

To apply the appropriate thresholds to a given water year (May to April), the total volume of the previous wet season's flow (January to April) is calculated and the water year is allocated to a recharge class. The appropriate ecological water requirement is then chosen from Section 5. They thus will vary from year to year, based on water availability.

We tested how the recharge classes compared to observed groundwater levels. Figure 12 shows the range in annual minimum groundwater levels observed at each of the four study sites in each recharge class. The 5th (red), 20th (green) and 50th (purple) groundwater level percentiles are also shown.

As expected, minimum groundwater water levels were related to the recharge classes, with the lowest levels corresponding to recharge class 1 and the highest to recharge class 4. The percentile levels also fell where predicted. That is, the 5th and 20th percentiles generally fell close to the minimum levels of recharge class 1 and 2 respectively. These findings support the idea that recharge classes are representative of actual water availability conditions.

Note that, for the purpose of choosing the appropriate ecological water requirements, recharge classes 3 and 4 have been combined into a single 'water availability' category of 'average–above average'.

As an example of recharge class application – if total wet season flow in 2013 is less than 1000 ML it falls into recharge class 1: drought conditions. Minimum groundwater levels at bore 8A representing Jilan Jilan Pool, should not fall below 13.28 mAHD (the drought condition EWR) for the specified time period described in Section 5 below. As the minimum level recorded at bore 8A has historically ranged from 11.81 and 14.63 mAHD (Figure 12), it is likely to remain within that range over the following water year (i.e. to the end of the following April).

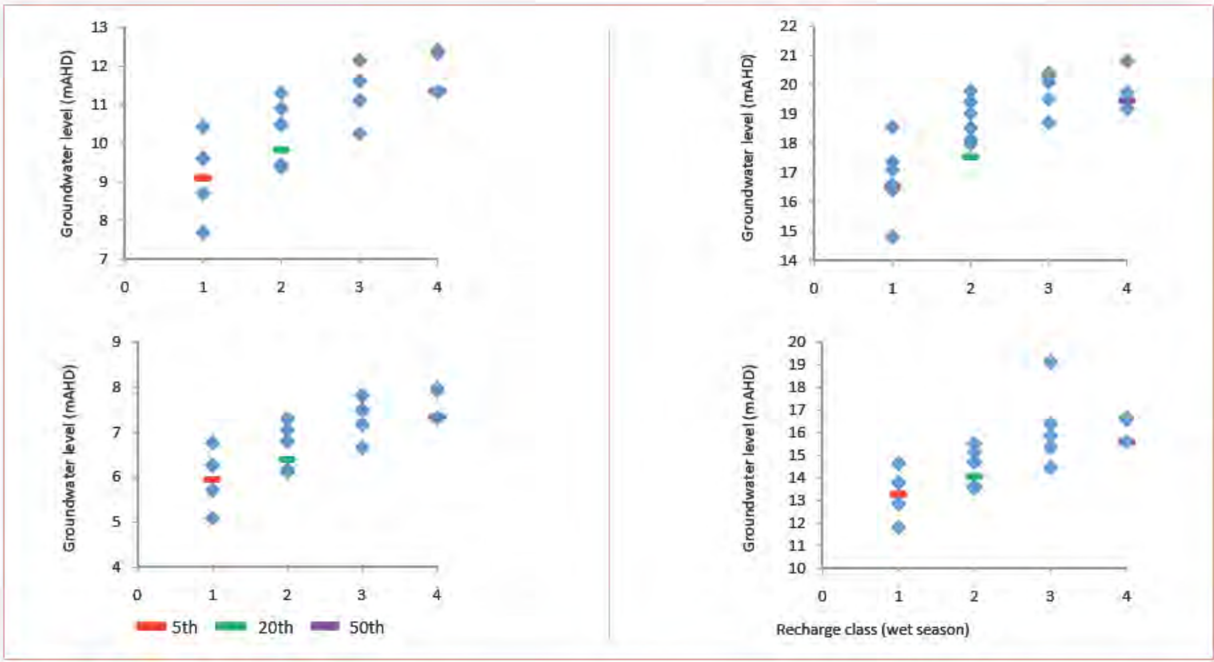

Figure 12

Observed minimum annual groundwater levels for each recharge class at a) bore 2B, b) bore 8A, c) bore 15A and d) bore 22A

The water levels and/or depths required to meet some hydro-ecological linkages should also meet others. For example a minimum pool depth of 1.50 m required to provide fauna habitat also meets the requirement for water quality.

At Jilan Jilan Pool the 1.50 m depth requirement is only met during average (50th percentile) water availability conditions, as represented by groundwater levels measured at bore 8A. However the 0.45 m requirement is also met under dry and drought conditions. The 5th percentile equates to 0.45 m and is therefore recommended for drought conditions.

We have recommended the 20th and 50th percentiles for dry and average-above average conditions respectively. This will maintain variation in pool depth and habitat during periods of higher water availability.

We have recommended 5th percentile groundwater levels for riparian vegetation during drought periods. Although riparian vegetation communities will tolerate drought conditions, they are unlikely to remain healthy and productive if low water availability persists for extended periods. The 20th and 50th percentiles have therefore been recommended for dry and average–above average conditions respectively.

We have allowed for inter-annual variation in river flow and water availability by setting the frequency and duration of recommended levels over a five-year period. Because groundwater has been monitored relatively infrequently it was not possible to determine the duration of low water level events. Therefore the duration of events in dry and average conditions were based on those calculated for a similar EWR study for the De Grey River. Frequencies for drought conditions were also based on the De Grey study.

The EWR reflects the region's dynamic climate. Groundwater levels in the Fortescue alluvial aquifer fluctuate – falling with droughts and recovering during wet periods – and ecosystems have adapted to cope with these fluctuations.

Bilanoo Pool

Drought conditions

- Pool level (stage height) of 9.27 m measured at the gauging station.

Dry conditions

- Pool level (stage height) of 9.28 m measured at the gauging station.

Average-above average conditions

- Pool level (stage height) of 9.63 m measured at the gauging station.

Stewart Pool

Drought conditions

- Groundwater level at bore 2B not to be lower than 16.55 mAHD more than three times for a total duration of more than one month in a five-year period.

Dry conditions

- Groundwater level of 17.75 mAHD at bore 2B to be reached more than four times for a total duration of nine months in a five-year period.

Average-above average conditions

- Groundwater level of 19.41 mAHD at bore 2B to be reached more than four times for a total duration of six months in a five-year period.

Jilan Jilan Pool

Drought conditions

- Groundwater level at bore 8A not to be lower than 13.28 mAHD more than three times for a total duration of more than one month in a five-year period.

Dry conditions

- Groundwater level of 14.07 mAHD at bore 8A to be reached more than four times for a total duration of nine months in a five-year period.

Average-above average conditions

- Groundwater level of 15.59 mAHD at bore 8A to be reached more than four times for a total duration of six months in a five-year period.

North Jilan Jilan Pool

Drought conditions

- Groundwater level at bore 15A not to be lower than 9.10 mAHD more than three times for a total duration of more than one month in a five-year period.

Dry conditions

- Groundwater level of 9.83 mAHD at bore 15A to be reached more than four times for a total duration of nine months in a five-year period.

Average-above average conditions

- Groundwater level of 11.33 mAHD at bore 15A to be reached more than four times for a total duration of six months in a five-year period.

Mungajee Pool

Drought conditions

- Groundwater level at bore 22A not to be lower than 5.59 mAHD more than three times for a total duration of more than one month in a five-year period.

Dry conditions

- Groundwater level of 5.97 mAHD at bore 22A to be reached more than four times for a total duration of nine months in a five-year period.

Average-above average conditions

- Groundwater level of 7.66 mAHD at bore 22A to be reached more than four times for a total duration of six months in a five-year period.

Appendicies

Appendix A — Relationship between groundwater levels

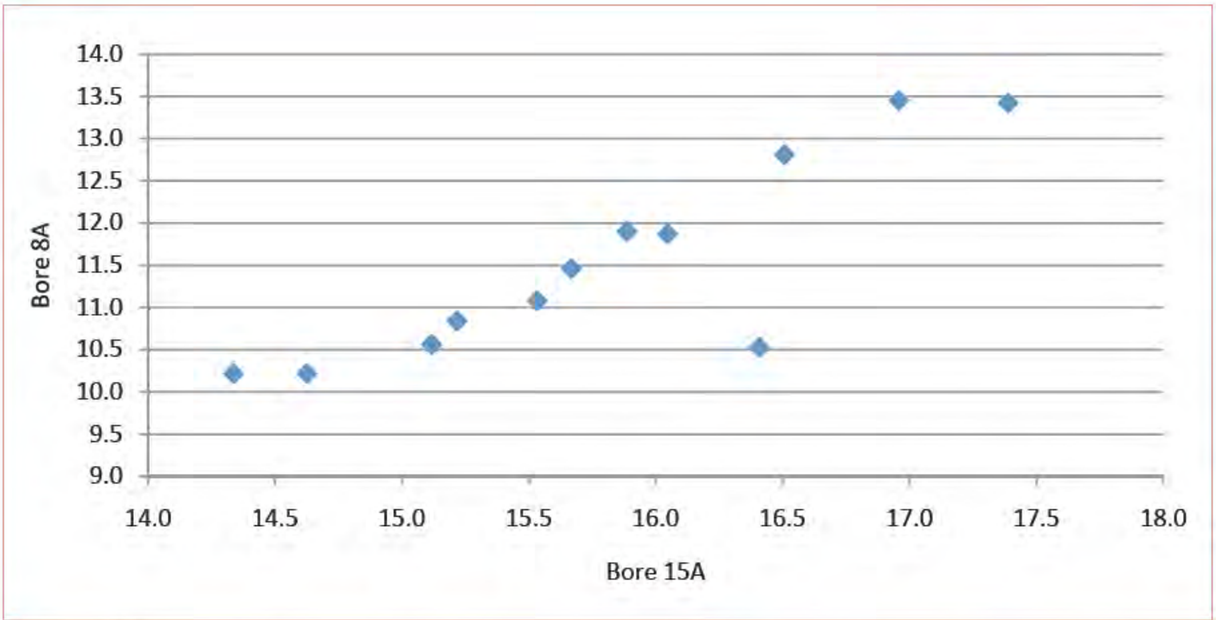

Figure A1

Relationship between groundwater levels at bores 8A and 15A

Figure A2

Groundwater levels at bore 15A extrapolated using relationship from Figure A1

Appendix B — Total annual wet season flow volume, probability of exceedence, recharge classes and water availability condition

Year	Flow volume ML	Probability	Recharge class	Water availability
2002	0	0.000	1	drought
2003	0	0.042	1	
2005	0	0.083	1	
2007	70	0.125	1	
1991	120	0.167	1	
1987	220	0.208	1	
1992	1820	0.250	2	drought
2010	6910	0.292	2	
1998	18020	0.333	2	
1994	21520	0.375	2	
1988	26210	0.417	2	
1990	26610	0.458	2	
1989	69670	0.500	3	>average
1996	91140	0.542	3	
2008	169270	0.583	3	
1997	317370	0.625	3	
2011	391450	0.667	3	
2001	417119	0.708	3	
1993	507390	0.750	3	
1999	525460	0.792	3	
2000	737690	0.833	4	wet
1995	824040	0.875	4	
2009	1023300	0.917	4	
2006	1337340	0.958	4	
2004	1393320	1.000	4	

Shortened forms

AHD	Australian Height Datum
dtgw	Depths to groundwater
ELOHA	Ecological limits of hydrologic alteration
EWR	Ecological water requirements
LiDAR	Light detection and ranging
WRC	Water and Rivers Commission
WRM	Wetlands 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 threshold	The point below which a change in water availability may cause a negative change in an ecosystem.
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 m3/second, m3/day or ML/annum. 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 is dependent 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 presences of predators.
Hydro-ecological linkage	Surface or groundwater regime or levels needed to maintain ecological components or processes of a water dependent ecosystem.
Hydrology	The study of water, its properties, movement, distribution and utilisation 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.
LiDAR	A remote sensing technology that uses laser scanning to collect height or elevation data.
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.
Macroinvertebrate (aquatic)	An animal without a backbone that is visible with the naked eye and spends all or part of their life in water.
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 where the depth at low tide does not exceed 6 m.

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