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

Lower De Grey and Yule groundwater allocation limits report

Background information and method used to set an allocation limit for the De Grey and Yule alluvial aquifers

October 2012

Looking after all our water needs

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Department of Water

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Summary

This report explains how the Department of Water revised the allocation limits for the lower De Grey and Yule alluvial aquifers. It supports the *Pilbara groundwater allocation plan*.

The De Grey and Yule alluvial aquifers are in the Ashburton subarea of the Pilbara groundwater area. Bore fields on both aquifers supply the Port Hedland Regional Water Supply Scheme.

This report summarises available hydrogeological, environmental, cultural and social information for both aquifers and describes the methods used to review aquifer and groundwater subarea boundaries and to set allocation limits.

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

The department has set an allocation limit of 10.15 GL/yr for the De Grey alluvial aquifer and 10.56 GL/yr for the Yule alluvial aquifer.

The allocation limits were based on the best available information and will meet short-term regional demand for water to support population growth, pastoral diversification and both local and remote mining operations.

Details of how the department will manage water resources using the allocation limits are included in the *Pilbara groundwater allocation plan*.

1 Introduction

1.1 Water allocation planning in the Pilbara region

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

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

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

This report describes how we have used the best information available to set allocation limits for the De Grey and Yule alluvial aquifers, two of the aquifers covered by the plan area. We prepared this document to make the process used in setting allocation limits transparent and publically available.

1.2 Resource area and location

The De Grey alluvial aquifer is located along the De Grey River, east of Port Hedland, in the Pilbara region of Western Australia (Figure 1). The catchment of the river extends 360 km inland and covers an area of about 56 900 km^2. The De Grey River is the largest river by volume in the region, based on mean annual flow. The area of the De Grey alluvial aquifer assessed for the plan extends approximately 65 km south from the coast along the De Grey River.

The Yule alluvial aquifer is located along the Yule River, about 40 km south-west of Port Hedland (Figure 1). The Yule River is approximately 217 km long and has a catchment area of about 12 000 km^2. The area of the Yule alluvial aquifer assessed for the plan extends approximately 65 km south from the coast along the Yule River.

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

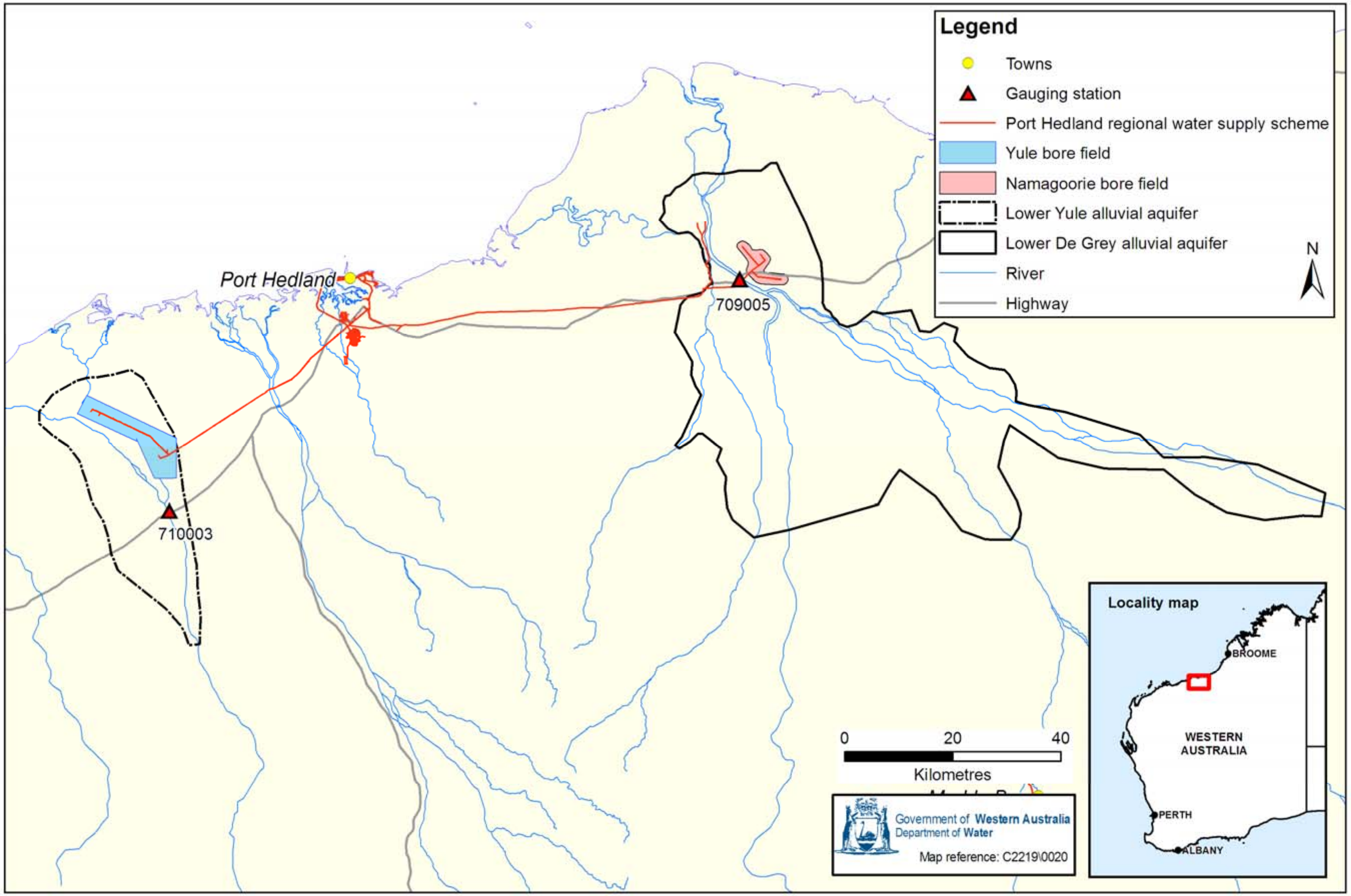


Figure 1 Location of De Grey and Yule alluvial aquifers

1.3 Allocation limits

Definition of an allocation limit

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

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

In the De Grey and Yule alluvial aquifers the allocation limits include water that is currently licensed for public water supply and water used for stock and domestic purposes that is exempt from licensing. These uses take up the full amount, so no water is set aside for general licensing.

Previous allocation limits and approach

The De Grey and Yule aquifers were previously part of the larger Pilbara coastal alluvial aquifer and so individual aquifer boundaries and allocation limits had not been set. In 2009, the department created administrative subareas within the Pilbara coastal alluvial aquifer to allow water from each aquifer to be reserved for future public water supply.

De Grey aquifer

The Namagoorie bore field on the lower De Grey River has operated as part of the Port Hedland Regional Water Supply Scheme since 1979. The total licensed abstraction for the bore field (before review in 2012) was 7 GL/yr. In 2009 an additional 6 GL/yr was reserved for public water supply to meet the future growth of Port Hedland. We have refined this estimate and removed the reserve (now fully licensed) due to increased demand and public water supply (see section 3.2).

Previous estimates of possible yield and the amount of water available for licensing from the De Grey alluvial aquifer were based on average annual recharge. These estimates did not take into account the amount of water required to maintain groundwater-dependent social, cultural and ecological values.

Yule aquifer

The Yule bore field on the lower Yule River has operated as part of the Port Hedland Regional Water Supply Scheme since 1967. In 2004–05, the department increased the licensed entitlement from the aquifer from 6.5 GL/yr to 8.5 GL/yr. In 2009 the department also reserved an additional 1.5 GL/yr for public water supply to meet future growth of Port Hedland. We have refined this estimate and removed the reserve (now fully licensed) due to increased demand and public water supply (see sections 3.2).

Previous estimates of potential yield and the amount of water available for licensing from the Yule alluvial aquifer were based on work by Davidson (1976) following investigative drilling, monitoring and hydrogeological assessment.

1.4 Allocation planning

The Department of Water follows the process shown in Figure 2 when developing a water allocation plan and to set allocation limits. This report describes how we assessed the information available on the De Grey and Yule alluvial aquifers (Section 2), how we set the objectives and allocation limits (Section 3) and how we defined our management approach (Section 4).

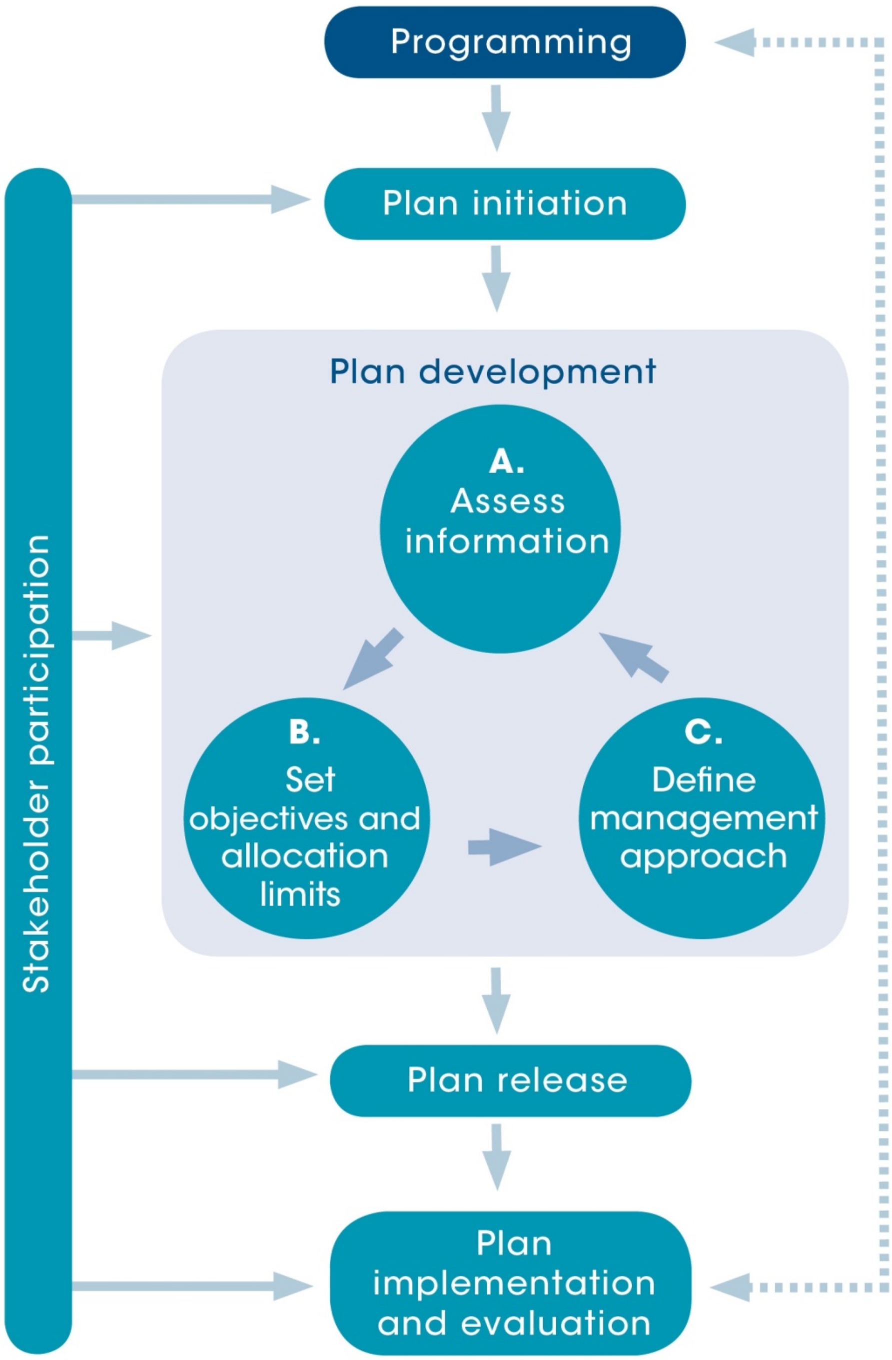


Figure 2 Water allocation planning process

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

1.5 Working with water users and other stakeholders

The Department of Water consulted with pastoralists, industry and the Water Corporation about the De Grey and Yule alluvial aquifers and water resource issues. We met with traditional owner groups in 2002 to discuss cultural values of Pilbara waterways, and in more recent years (2007 to 2012) on issues related specifically to the lower De Grey and Yule rivers. See Section 2.2 for more information.

The initial round of stakeholder engagement for the plan was followed by the completion of the Water for the Future program investigations in 2010. We met with the Water Corporation and industry to discuss water resource issues and identify future water demands. We also met with pastoralists about existing issues.

The main concerns identified by stakeholders were:

- water availability
- water quality
- managing any adverse effects on other users resulting from a particular water use
- water related environmental values
- water related Indigenous cultural values.

The Water Corporation was consulted extensively during 2011 about potential allocation options to ensure these were feasible and practical for use in groundwater models.

In 2012 we met with stakeholders again to discuss the allocation limits we have set. We also worked closely with the Water Corporation to develop policy.

We were able to use this understanding of how water is used and valued by the community when we were setting objectives and allocation limits and when developing the management approach for the De Grey and Yule alluvial aquifers. See Section 2.2 for more information.

There will be further opportunities for stakeholders to contribute to the planning process when we finalise the *Pilbara groundwater allocation plan* in 2013.

2 Assessing information

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

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

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

2.1 Understanding the resource

Resource boundaries

We reviewed the existing resource boundaries (Figure 3 and Figure 4) and defined the De Grey and Yule alluvial aquifer boundaries within the Ashburton subarea (Figure 5 and Figure 6). This allowed us to apply specific allocation limits and management approaches to the individual aquifers. This is important now that the allocation limits have increased and the degree of management needs to increase as a result.

Before this review, the De Grey and Yule alluvial aquifers were part of the Pilbara alluvial aquifer and were distinguished as individual subareas (as an interim measure in 2009 when reserves for future public water supply were established).

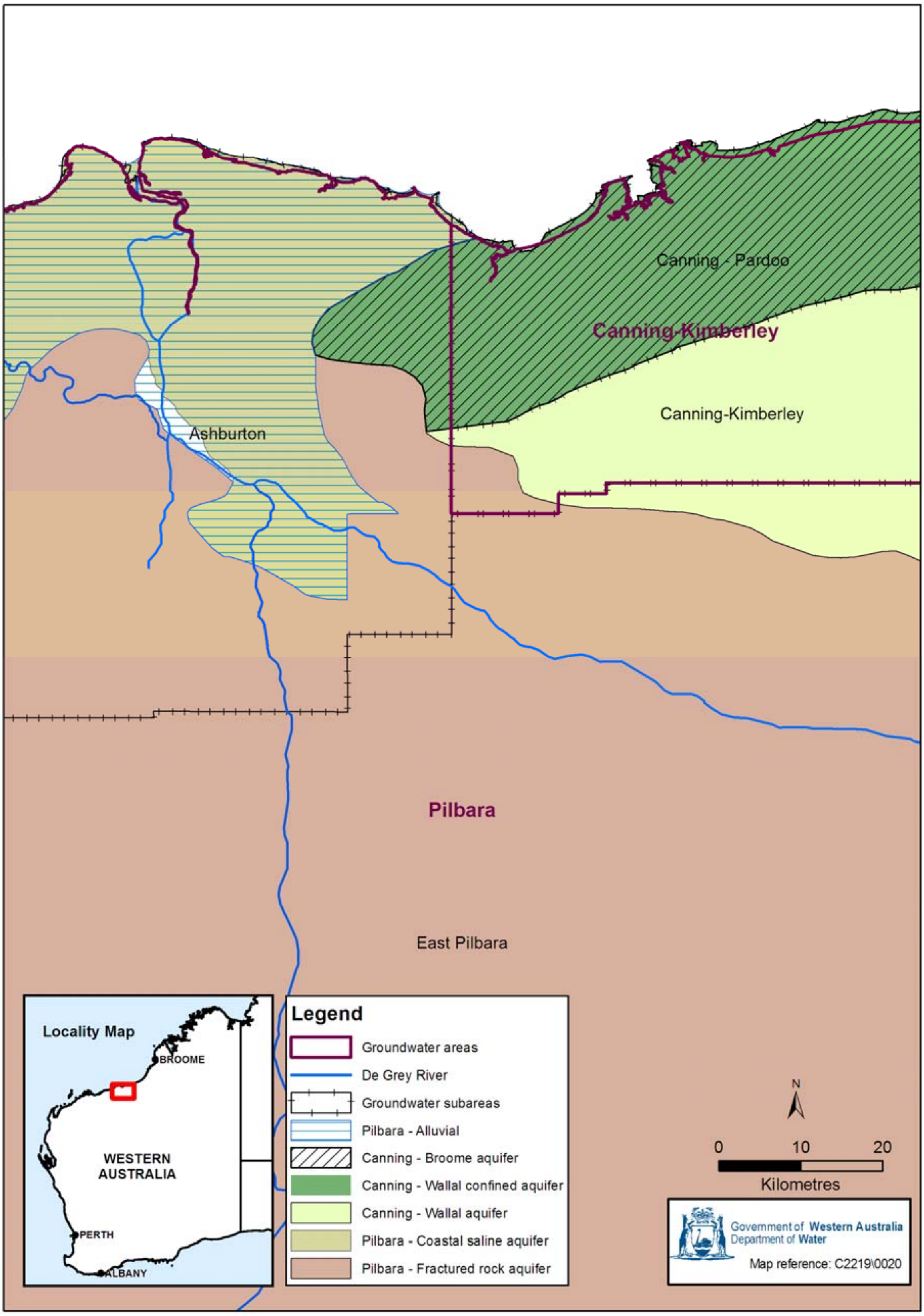


Figure 3 De Grey aquifer previous subarea and aquifer boundaries

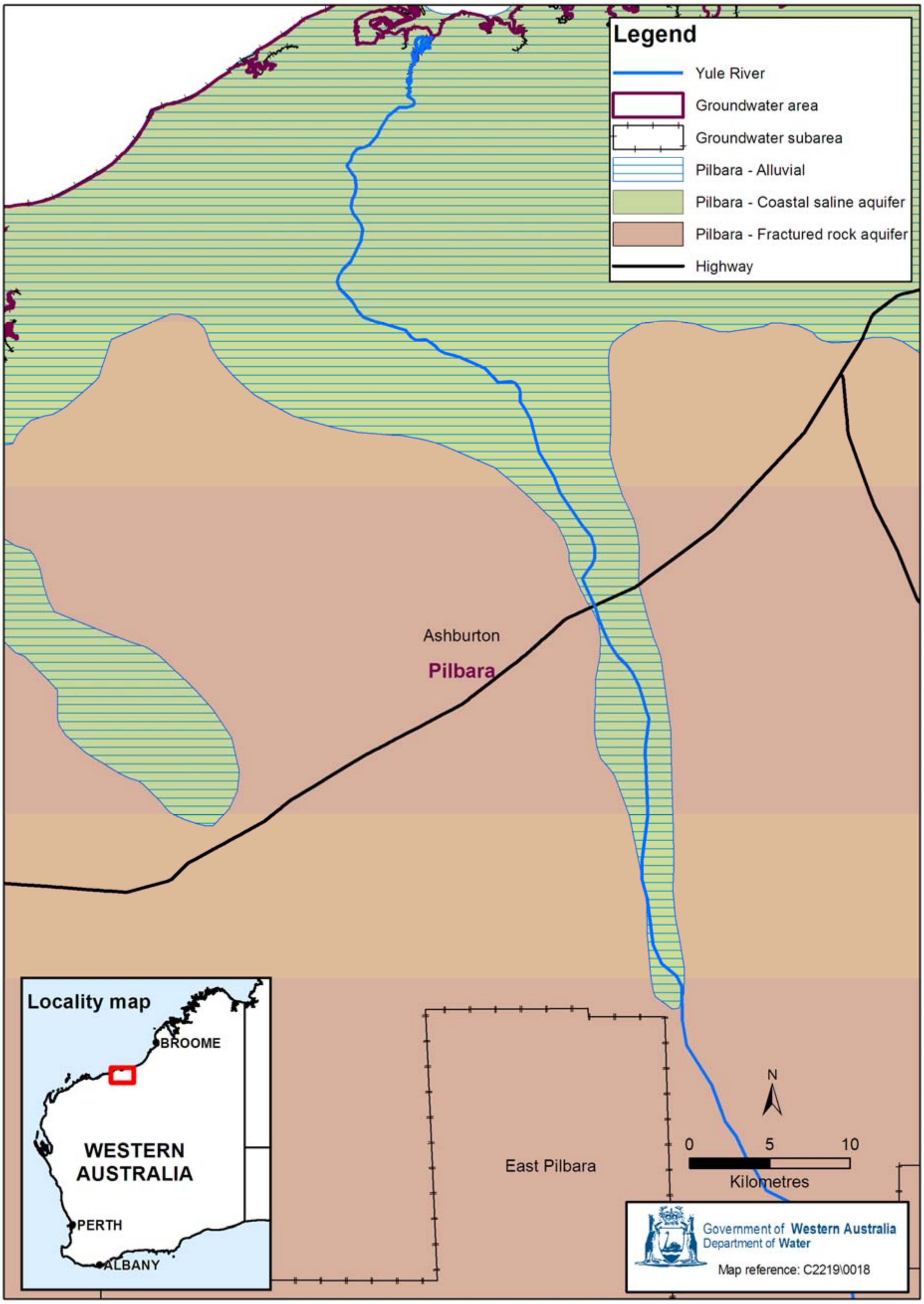


Figure 4 Yule aquifer previous subarea and aquifer boundaries

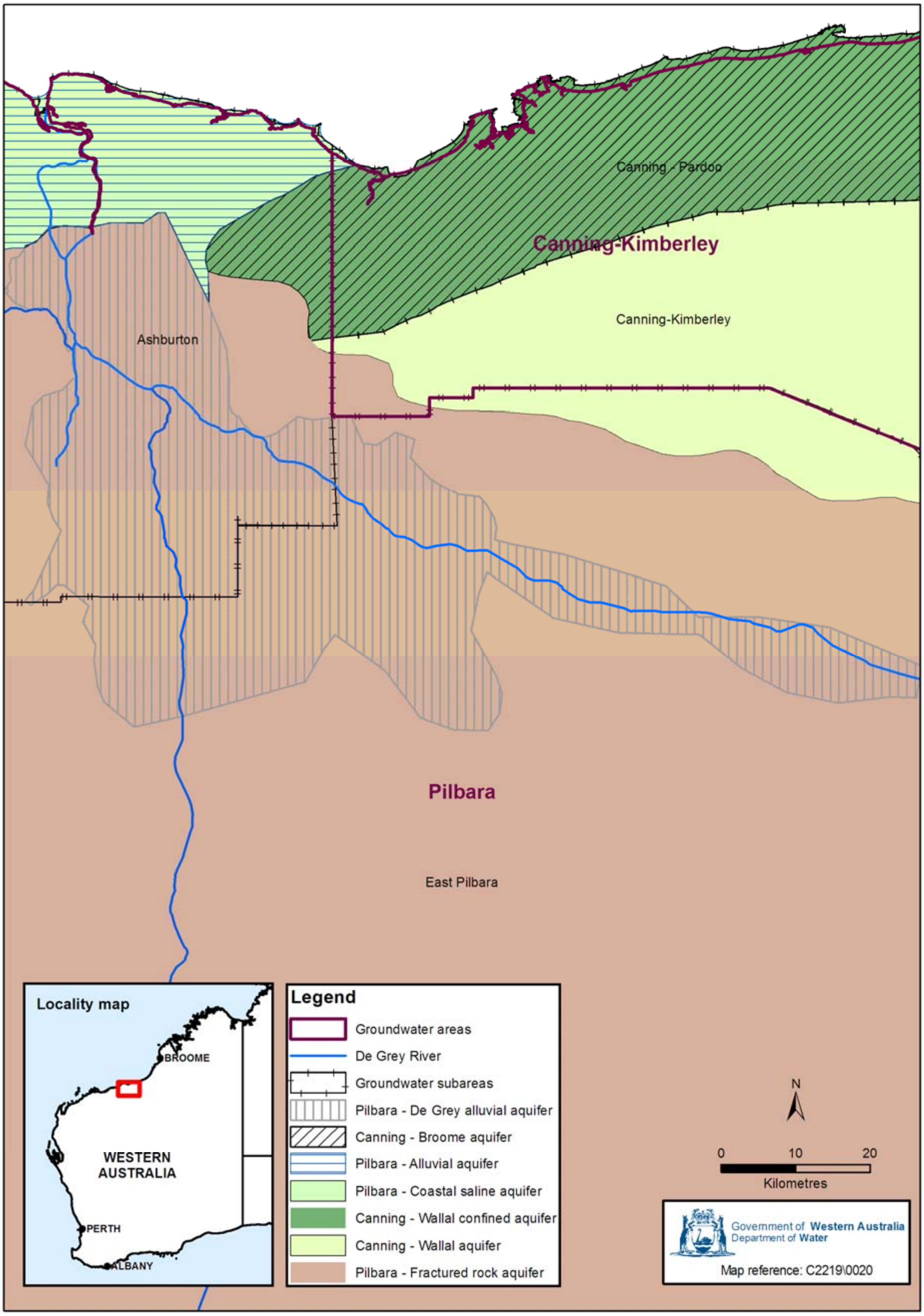


Figure 5 De Grey aquifer revised subarea and aquifer boundaries

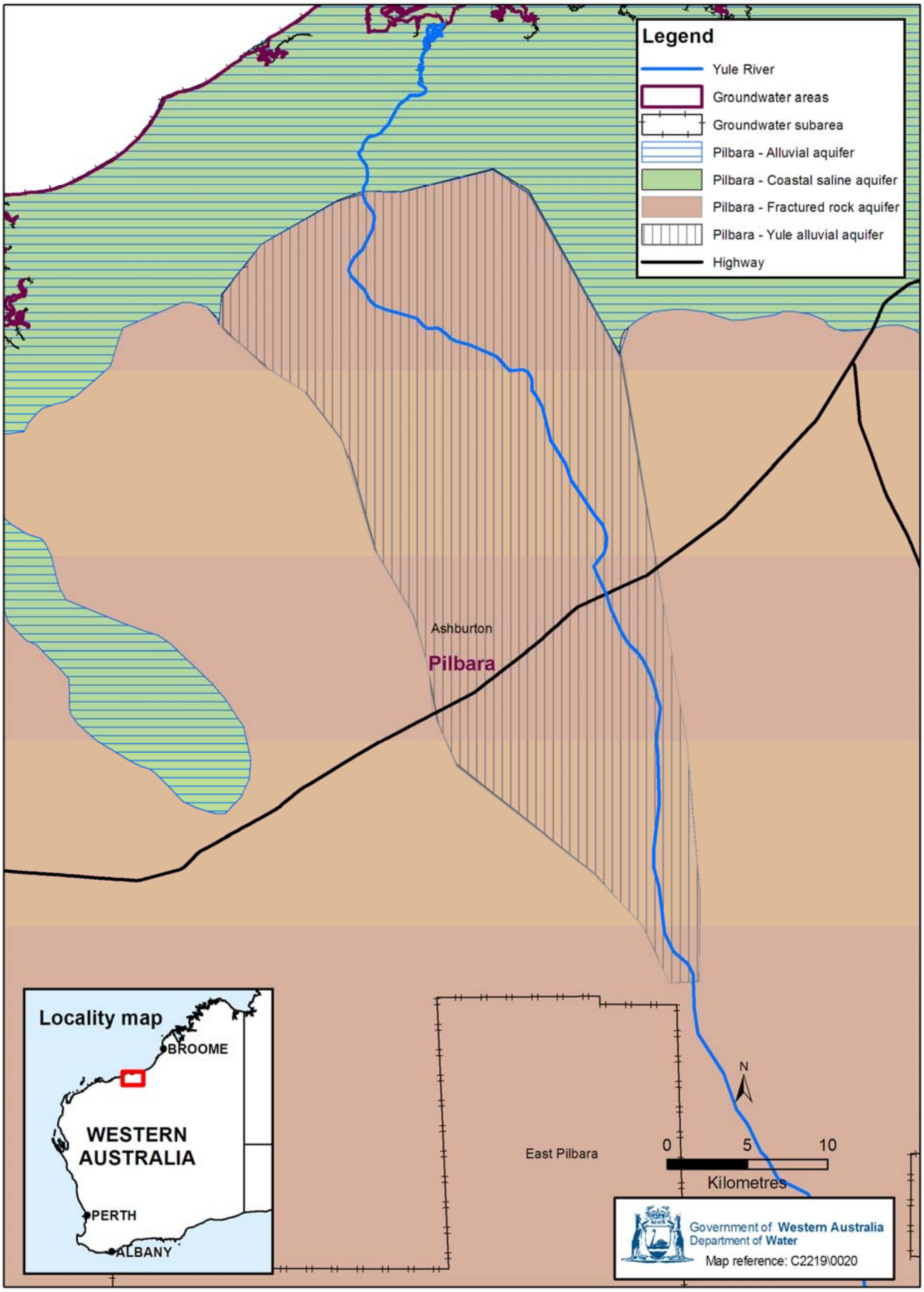


Figure 6 Yule aquifer revised subarea and aquifer boundaries

The new boundaries better reflect the local hydrogeology. They are based on the extent of the aquifers, which were redefined as part of the hydrogeological assessments for the De Grey and Yule groundwater models (SKM 2010; MWH 2010). These changes mean that resource names on licences will be updated when we reissue existing licences.

Climate and rainfall

The Pilbara region's climate is classified as semi-arid to arid with hot, dry conditions most of the year. Average evaporation greatly exceeds rainfall, causing an extreme moisture deficit.

Rainfall is highly variable and largely results from cyclonic events and localised thunderstorms between December and March. Rainfall data is recorded at Bureau of Meteorology (BoM) stations at Pardoo Station (BoM station 04028), near the De Grey River and at Mundabullangana Station (BoM station 04024), on the Yule River (Table 1).

Annual average and median rainfall for the period 1900 to 2012 are similar at the two sites. Some rain has been recorded every year at Mundabullangana while Pardoo has four years with no recorded rainfall. Maximum rainfall was more variable, ranging from 815 mm at Pardoo (De Grey) to 778 mm at Mundabullangana (Yule). The long-term annual average evaporation at Port Hedland (BoM station 04032) is 3357 mm.

Table 1 De Grey and Yule rainfall data summary (1900 to 2012)

	De Grey River Pardoo Station BoM station 04028	**Yule River Mundabullangana Station BoM station 04024**
Average annual rainfall	300	318
Median annual rainfall	289	297
Maximum annual rainfall	815	778
Minimum annual rainfall	0	6
Number of no rainfall years	4	0

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

Hydrology

De Grey River

The De Grey River catchment covers approximately 57 000 km^2 and is the second largest catchment in the Pilbara region (Table 2). The river flows to the north-west, joining with the Shaw, Strelley, Coongan, Oakover and Nullagine rivers. In the lower catchment the De Grey River widens to approximately 1 km into a broad alluvial valley which drains to the coast. Within the lower De Grey alluvial aquifer, the Strelley east and west branches feed the Ridley River, which wraps around the Ord Ranges before draining north-west.

Based on streamflow recorded at Coolenar Pool gauging Station (AWRC reference 710003) since 1974 (excluding 1980 to 1982) the De Grey River flows almost every year (34 out of 35 years of record). In comparison to other gauged rivers in the Pilbara this makes it the most reliable in the region. Based on mean and median annual flows it is also the largest (Table 2). Median annual flow from 1974 to 2010 (1062 GL) is significantly higher than the next largest rivers in the region: the Ashburton (534 GL) and the Yule (136 GL), despite similar rainfall. This is due to the catchment size, spread and orientation.

Table 2 Major river flows in the Pilbara region

River	Gauging station	Catchment area km^2	Mean annual rainfall mm	Mean annual flow GL	Median annual flow GL
De Grey	**710003**	**56 890**	**400**	**1342**	**1062**
Ashburton	706003	71 387	300	952	534
Yule	**709005**	**8 427**	**400**	**363**	**136**
Fortescue[1]	708002	14 629	450	227	51
Fortescue[2]	708015	18 371	400	224	97
Shaw	710229	6 501	400	221	151
Sherlock	709003	4 581	400	164	40
Robe	707002	7 104	500	125	18
Coongan	710204	3 736	400	118	68
Cane	707005	2 326	400	82	65
Maitland	709004	1 948	375	48	14
Harding	709001	1 058	400	39	23
Turner	709010	885	400	33	5

[1]Gauging station 708002 at Gregory Gorge

[2]Gauging station 708015 at Bilanoo

Yule River

The Yule River drains from the Chichester and Mungaroo ranges to the coast. It is an ephemeral system characterised by a highly variable flow regime.

River flow has been recorded at the Jelliabidina Well gauging station (AWRC reference 710005) since 1973 (except for 2003 and 2004) with zero flow in one out of four years. The longest period of no flow was 37 months. Recorded median annual flow is 136 GL. The maximum annual discharge of 1823 GL was recorded in 2000.

Hydrogeology

De Grey alluvial aquifer

All investigative and assessment work on the De Grey alluvial aquifer for the *Pilbara groundwater allocation plan* has focused on the area downstream of the confluence with the Coongan River (Loomes 2012).

The hydrogeology of the lower De Grey area was first investigated in the 1970s when work was done for water supply for the Goldsworthy Mine (Davidson 1974). The Water Corporation has carried out further work since 1979 (WorleyParsons 2005; GHD 2010; SKM 2011). The results of the pre-2009 investigations are summarised in Haig (2009).

Recent investigations (2007 to 2010) include work commissioned by the Department of Water as part of the *Water for the Future* program. This work used existing information and undertook geophysical investigations (FUGRO 2009) and LiDAR (light detection and ranging) surveys to support the development of a numerical groundwater model for the lower section of the De Grey River (SKM 2010).

The present day lower De Grey River valley is situated on the eastern edge of the Pilbara Craton adjacent to the West Canning Basin. A deep valley was cut into the Archaean and Mesozoic formations during the Tertiary that has been infilled with alluvium. The alluvium comprises interbedded sequences of sands and gravels grading to silty clay and clay and its thickness ranges from a few metres up to 75 m (Davidson 1974). Kankar/calcrete has formed in the upper part of the sequence and at the base of the palaeochannel as a result of basement weathering. The older alluvium is overlain by a thin layer of Quaternary alluvium and colluvium currently deposited within the present day De Grey River valley.

The palaeochannel generally follows the current De Grey River to the Shaw River confluence, then runs to the south-west parallel to and east of the De Grey River, finally crossing beneath the river channel and running north-west towards the coast.

The De Grey alluvial aquifer is broadly defined here as both the infilled palaeochannel and overlying Quaternary alluvium within the De Grey River valley. There are three broad layers within the palaeochannel which make up the aquifer:

- an unconfined upper sand aquifer
- a sandy–clay to clayey–sand leaky aquiclude with minor water bearing sands
- a basal gravel and sand aquifer (WorleyParsons 2005).

Confining layers are discontinuous across the aquifer, ranging from largely unconfined downstream near the homestead to confined upstream (Rockwater 2006). Where the aquifer is unconfined, there is good vertical connectivity between layers with transmissivity ranging from 58 m^2/day to 1400 m^2/day with an average of 560 m^2/day (WorleyParsons 2005). No storage coefficient has been calculated, but it has been estimated to be between 0.0005 and 0.1 depending on the level of aquifer confinement (Davidson 1974).

Based on hydrograph responses, relative changes in groundwater level correspond well with streamflow from the De Grey River and its tributaries. Streamflow is considered the primary source of recharge to this system, with a limited contribution from direct infiltration of rainfall.

Yule alluvial aquifer

The hydrogeology of the lower Yule River area has been well investigated (Whincup 1967, Forth 1972 and Davidson 1976) and the results summarised (Haig 2009). Most recently, geophysical surveys were undertaken (FUGRO 2010), a LiDAR survey completed and a groundwater model developed (MWH 2010).

The Yule River is situated on the Pilbara Craton. The Archaean and Proterozoic fractured rock basement is weathered variably and cut into by a palaeochannel. The palaeochannel is filled with more recent alluvium of clay, silt, sand and gravel with minor calcrete. The main palaeochannel runs north-east, crossing from the west to the eastern side of the current Yule River beneath the current Yule bore field.

The Yule alluvial aquifer is defined here as the alluvial sediments infilling and overlying the palaeochannel. There is an unconfined upper sand and gravel aquifer up to 20 m thick, underlain by a leaky discontinuous aquiclude of up to 25 m of silts and clays, and a deeper sand aquifer. The alluvium ranges from 12 m in the upper catchment up to 80 m thick in the deepest parts to potentially more than 80 m north of the Water Corporation bore field.

As with the De Grey confining layers are discontinuous across the aquifer ranging from largely unconfined to confined with estimated transmissivity of 155 m^2/day to 550 m^2/day and up to 1200 m^2/day. Most production bores have targeted the deeper sediments within the palaeochannel.

Groundwater is recharged primarily by Yule River streamflow. Current groundwater modelling suggests up to 28 GL/yr potential recharge to the aquifer from streamflow. Recharge is highly variable due to the variability in flow of the Yule River and to the occurrence of drought or no flow periods.

Groundwater salinity

Salinity in the De Grey and Yule alluvial aquifers is generally lowest near the active river channel and increases with distance away from the rivers and tributaries because of decreasing recharge and throughflow (Figure 7 and Figure 8). Some fresh water is available away from the current river channel where the course of the palaeochannels deviate from the river. Variations also occur with depth, with salinities in shallow areas of the aquifers relatively high and decreasing with depth (Haig 2009). The higher salinity at depth may be due to the flushing down of salt residue from the surface during recharge events, dissolving of salts from oxidation within the capillary fringe or by concentration of salts due to evapotranspiration (Haig 2009).

Measured salinity in De Grey production bores ranges from fresh – less than 500 mg/L total dissolved solids (TDS), to 2000 mg/L TDS. Groundwater salinity in many bores has increased marginally since abstraction began in 1979. Salinity has increased by up to 400 mg/L in some cases, but mostly by around 200 mg/L in abstraction bores.

Water quality in groundwater fed pools has not been widely reported, although sampling has been done as part of ecological surveys (van Dam et al. 2005; Morgan et al. 2009; Pinder & Leung 2009). Unlike other river systems in which salinity in pools increases with distance downstream, the situation in the De Grey River is much more variable, with pool water quality reflecting that of local groundwater (Dames & Moore 1978).

Measured groundwater salinity in several Yule production bores is increasing steadily. However, the water is still fresh (<500 mg/L). Across the bore field, the groundwater salinity is generally stable.

The De Grey and Yule alluvial aquifers are close to the coast and hence can be influenced by seawater intrusion. Groundwater throughflow from the aquifers towards the coast creates a seawater wedge or interface. The position of the seawater interfaces remain relatively stable but can move inland into the aquifers when groundwater throughflow declines due to abstraction or failed recharge.

The seawater interface at the De Grey is currently 16 km north of the most northerly production bore and 18 km from the coast. At the Yule, the seawater interface is approximately 35 km north of the North West Coastal Highway and 5 to 10 km from the coast.

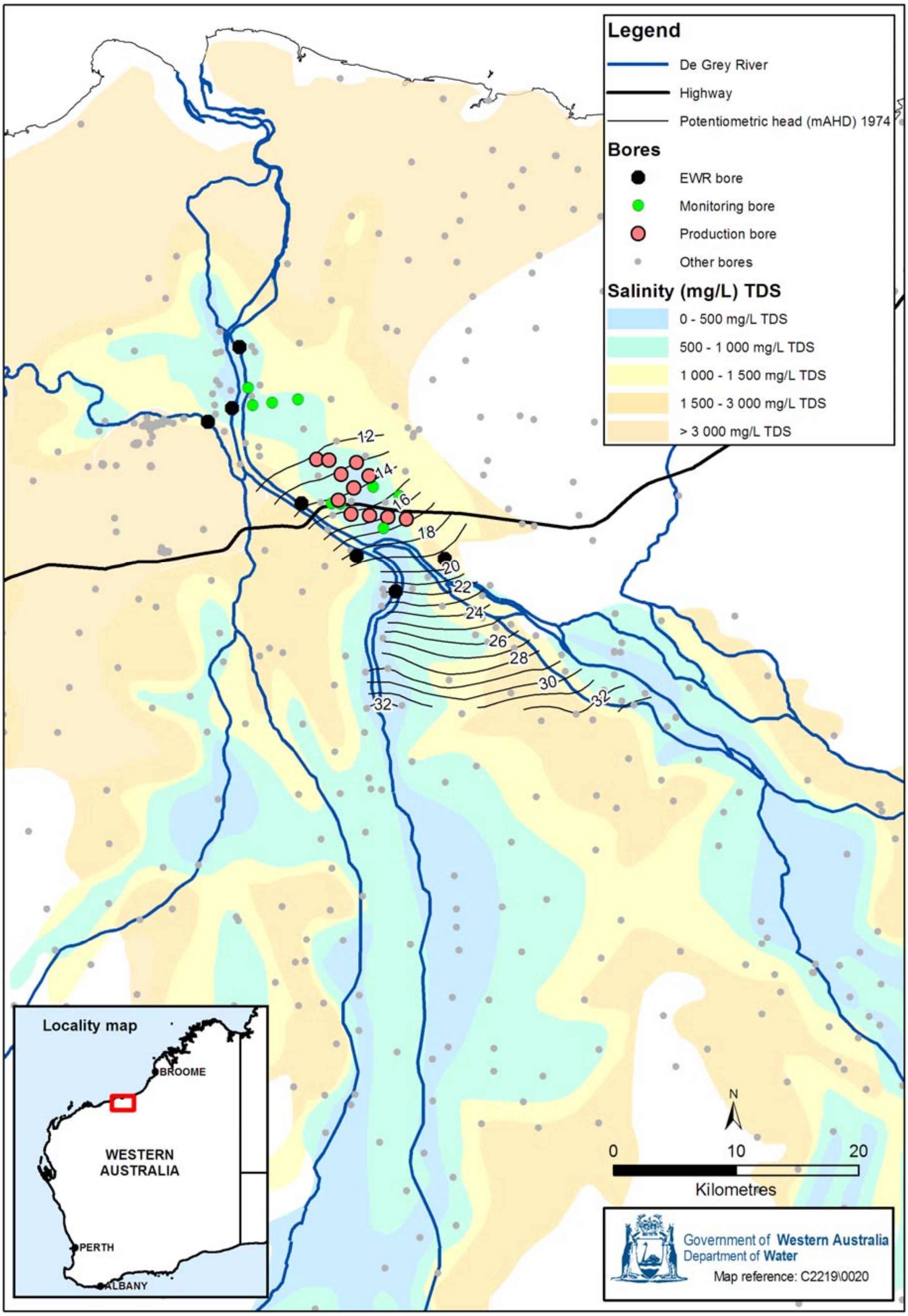


Figure 7 De Grey alluvial aquifer salinity levels

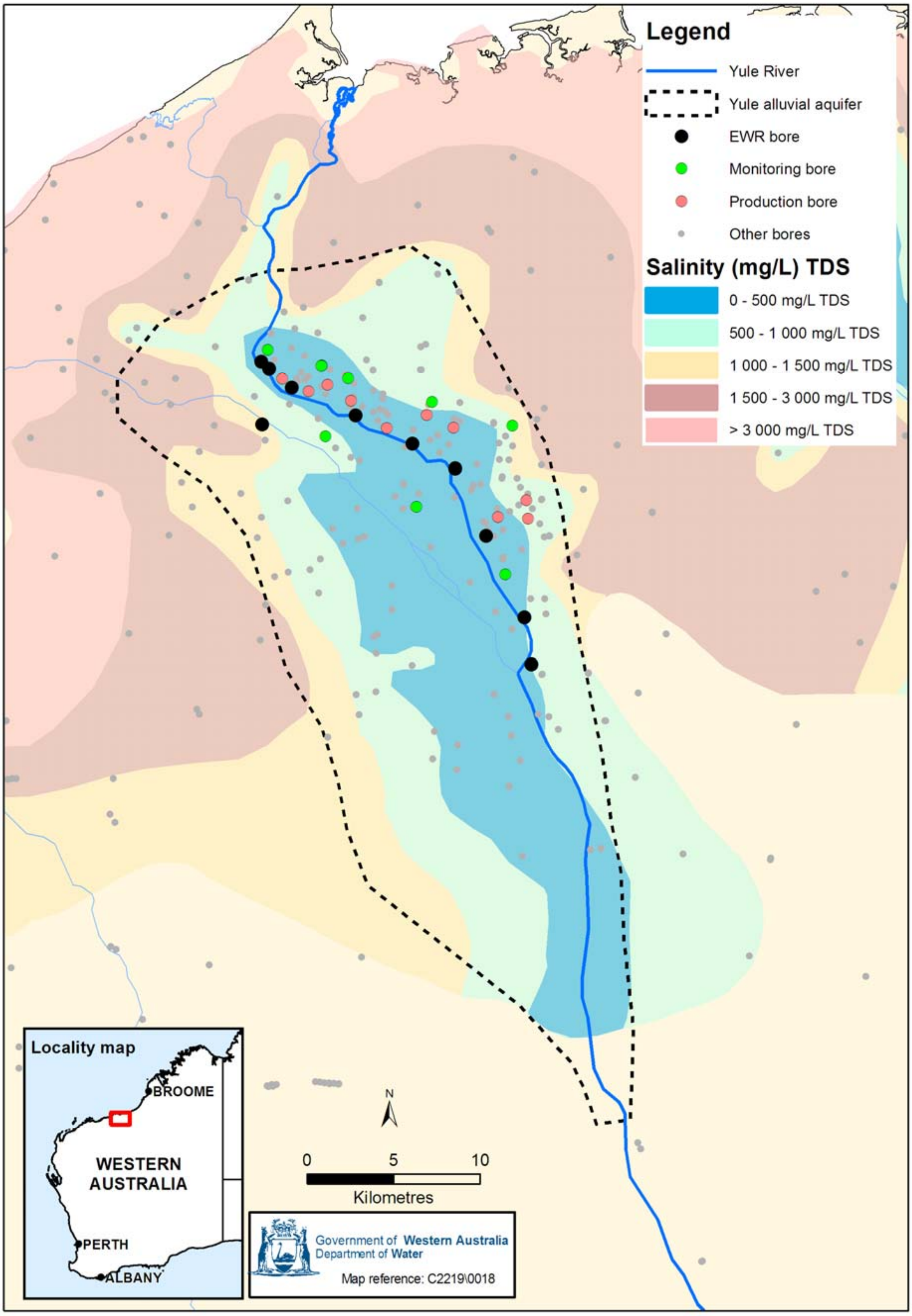


Figure 8   Yule alluvial aquifer salinity levels

Surface water and groundwater interaction

Pools of varying permanency occur in the current river channels of the De Grey and Yule rivers. Some pools are connected to and interact with the underlying alluvial aquifers. When the rivers are in flood the pools, floodplains and riparian zone are connected, allowing biota and nutrients to move though the system (Braimbridge 2010). During river flow events, groundwater is recharged and the watertable rises.

During periods of no flow the groundwater movement reverses and discharges into the pools. Without flow, intermittent pools begin to dry out as the watertable drops below the base of the pools and the groundwater becomes disconnected.

During extended periods of no flow (drought conditions) continued groundwater declines result in shallower pool depths and semi-permanent pools may become disconnected from the groundwater.

In both the De Grey and Yule rivers permanent pools occur where the river channel is deep enough to remain connected to groundwater through drought periods. These pools are critical refuges for aquatic (and terrestrial) ecosystems during drought periods.

Groundwater models

In 2010, numerical groundwater models were completed for the De Grey (SKM 2010) and Yule (MWH 2010) alluvial aquifers with funding from the Australian Government's *Water for the Future* program.

The groundwater models were built using FEFLOW (a finite element numerical model) and following guidelines for numerical groundwater models for the Murray–Darling Basin (MDBC 2001). In accordance with these guidelines the models were calibrated to achieve a RMS (normalised root mean square) error of <10%, in this case RMS error was 4.3% for the De Grey model (SKM 2010) and 2.1% for the Yule model (MWH 2010).

The models were used to assess potential effects of future allocation options on the alluvial aquifers. This included effects on the groundwater-dependent ecosystems of the aquifers and risks of changes in water quality.

De Grey groundwater model

The lower De Grey groundwater model covers the area from upstream of the existing bore field to the ocean (SKM 2010) (Figure 9).

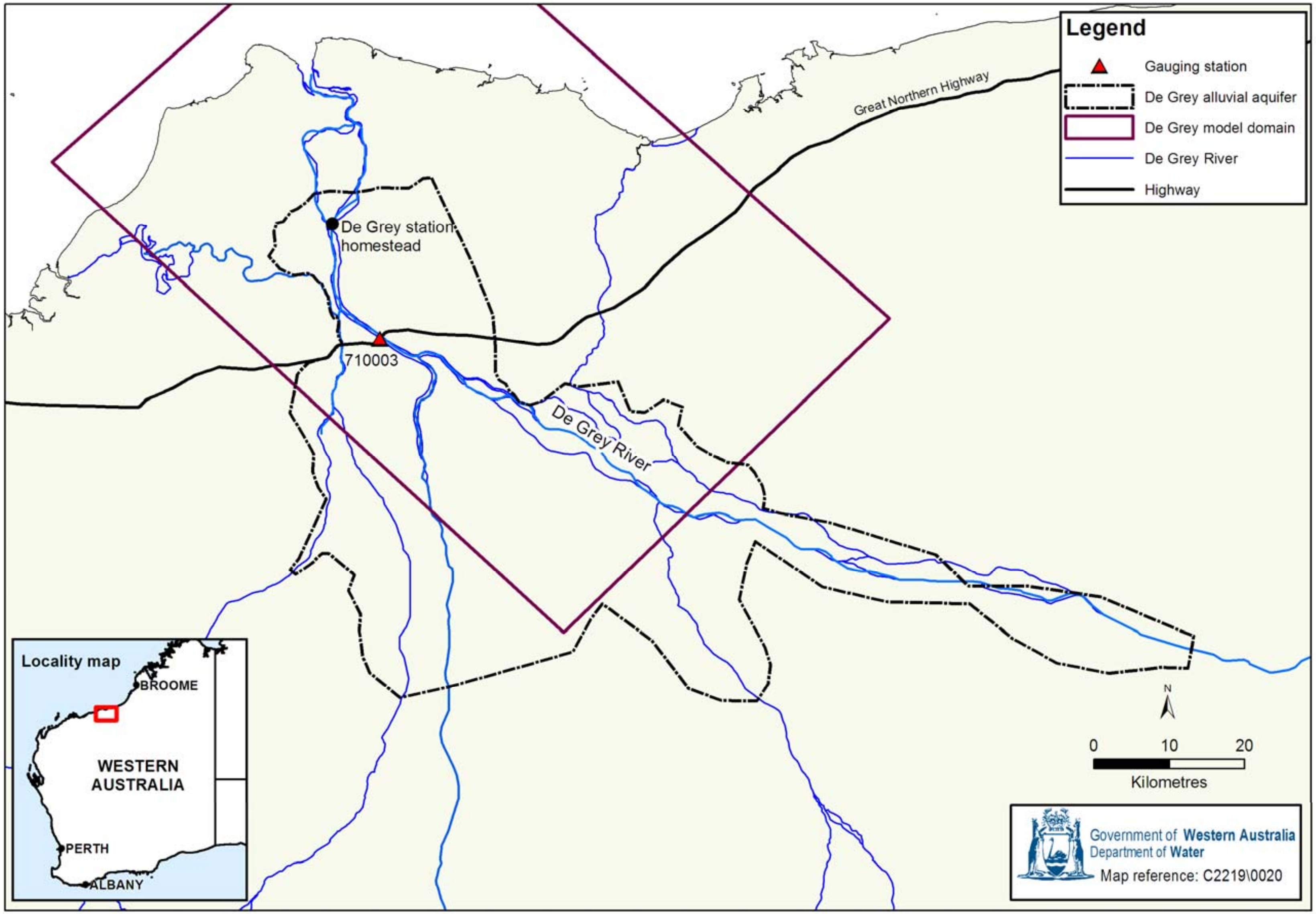


Figure 9 De Grey groundwater model area

The De Grey model used information from previous hydrogeological and geophysical investigations including:

- daily streamflow and stage height data measured at Coolenar Pool (709003) from January 1974 to May 2009 (7/1/1980 to 13/11/1982 missing)
- groundwater data from 24 monitoring bores from the 1970s
- additional, one-off groundwater level readings from 279 bores in the vicinity of the model area
- bore logs for 83 bores
- surface water levels from 5 river pools from 2000–01 to 2009
- bore field abstraction volumes for 1980 to 2009 (1989 to 1995 missing, but calculated using annual Port Hedland supply and Yule abstraction data)
- results of aerial geophysics survey
- LiDAR survey
- summaries from drilling and pump tests
- rainfall data
- previous hydrogeological assessments including Davidson (1974) and Haig (2009).

Modelled allocation options and outputs are presented in Section 3.2.

Yule groundwater model

A groundwater model of the lower Yule River was developed in 2010. The model covers an area from 20 km south of the North West Coastal Highway and north to the coast, including the existing bore field north of the highway (Figure 10).

The Yule model used information from previous hydrogeological and geophysical investigations including:

- daily streamflow and stage height data measured at Jelliabidina Well (709005) from 1972 to May 2009 (several periods of missing data)
- groundwater data from 31 monitoring bores from as early as late 1960s (1988 to 1998 data missing)
- additional, one-off groundwater level readings from 311 bores in the vicinity of the model area (data pre-1985 to remove the effects of abstraction)
- all available borehole logs
- surface water levels from Li Lin Pool from 2004 to 2009
- bore field abstraction volumes for 1968 to 2008 (1971 to 1981 missing, poor data 1989 to 1995).
- results of aerial geophysics survey
- LiDAR survey
- summaries from drilling and pump tests
- rainfall data
- previous hydrogeological assessments including Whincup (1967), Forth (1972), Davidson (1976) and Haig (2009).

Modelled allocation options and outputs are presented in Section 3.2.

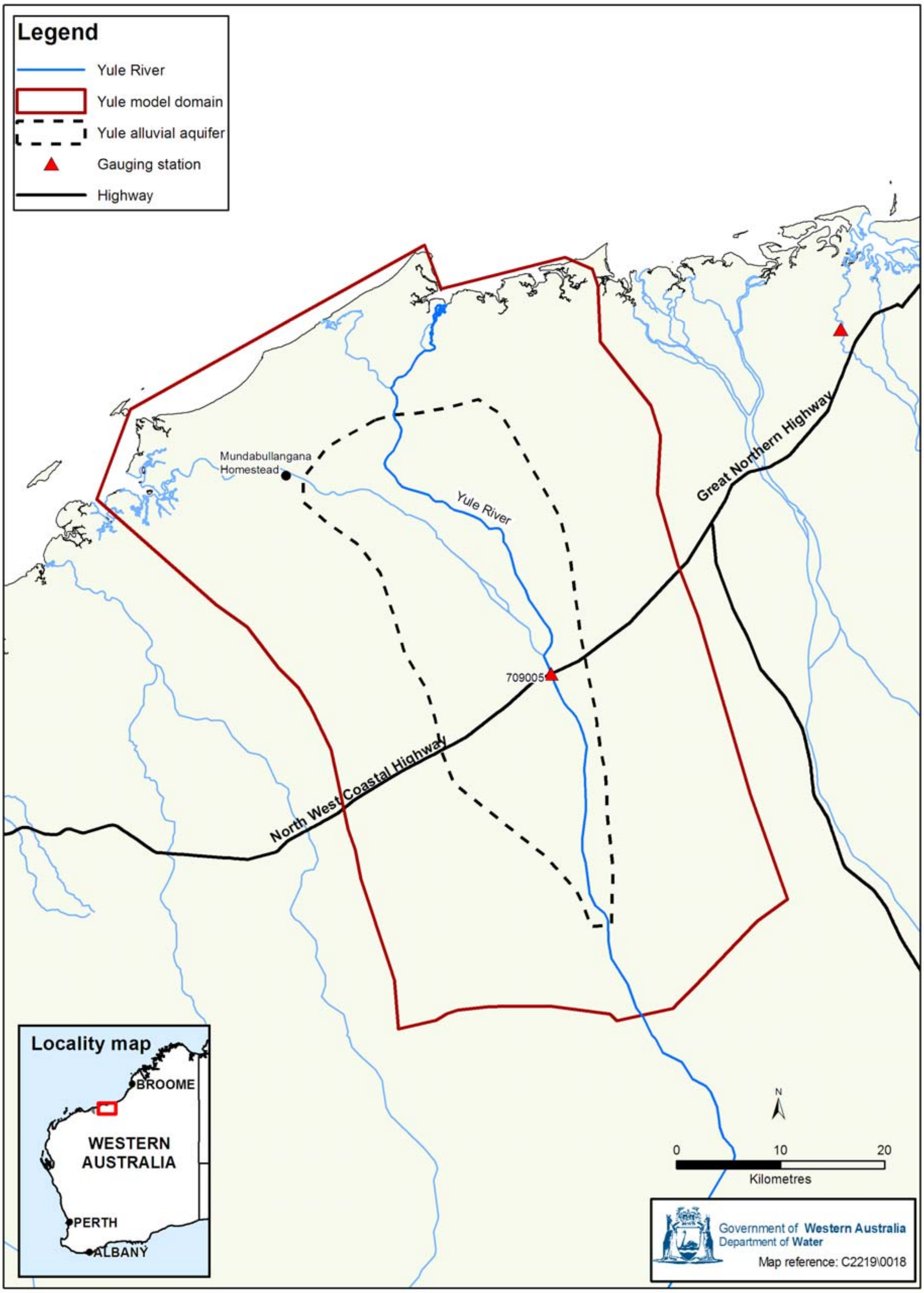


Figure 10 Yule groundwater model area

2.2 Water for the environment

The starting point for deciding on an allocation limit is to estimate the resource yield. We consider the yield as the amount of water that can be taken out, once in situ groundwater requirements are met. To do this we consider the groundwater needed to support:

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

Maintaining the productivity of the resource

It is essential to maintain water quantity (storage capacity) and quality, sometimes referred to as aquifer integrity. An important consideration for maintaining the long-term productivity of the aquifers is to prevent inland movement of the seawater interface. Too much abstraction from these resources could allow the interface to move inland and reduce groundwater quality. This could mean less water being available for consumption. In alluvial aquifers in the Pilbara, recharge and therefore groundwater levels are naturally variable. There is an underlying range or limit to this variability and this will shift as a result of increased abstraction. If a new range becomes established and the aquifer does not continue to decline, then it is likely that the new level of abstraction can be sustained.

Deterioration of water quality caused by increasing salinity is a significant constraint in both aquifers. This can be at the seawater interfaces and along the sides of the aquifers. To maintain potable water quality, we need to maintain adequate throughflow and watertable level gradients within the aquifers.

The seawater interface in the De Grey area is currently about 15 to 20 km south of the coast and 5 to 10 km north of the De Grey Station homestead. In the Yule area, the interface is about 5 to 10 km south of the coast. Adequate freshwater throughflow downstream toward the coast is needed to maintain the position of the seawater interfaces and water quality in the aquifers.

Salinity in both aquifers also increases laterally away from the rivers (Figures 7 and 8), which are the main source of freshwater recharge. To prevent declines in water quality, freshwater volumes need to be maintained to stop saltwater moving in from the aquifer sides.

Water-dependent ecosystems and values

The De Grey and Yule alluvial aquifers support river pools, fringing riparian vegetation communities and stygofauna, all of which depend on groundwater to meet their water needs to some extent (Figures 11 and 12).

As part of the *Water for the Future* program we reviewed available information on ecosystems dependent on the De Grey and Yule aquifers. We also:

- updated groundwater-dependent ecosystem mapping (vegetation and river pools)
- reassessed the health of riparian vegetation on existing monitoring transects
- compared fish on the lower Yule River to those in regional datasets
- compared aquatic macroinvertebrates of the lower Yule and De Grey rivers to water quality and habitat characteristics
- investigated how riparian vegetation responds to changes in water availability on the Yule River
- calculated water level ranges of important riparian species at both sites and compared to regional resources
- developed depth to groundwater maps for both systems.

We used this work to describe the groundwater-dependent ecosystems and to develop conceptual models of links between ecosystems and hydrogeology in ecological values and issues papers (Braimbridge 2010; Loomes & Braimbridge 2010). We then described ecological water requirements (EWRs) which are the water regimes required to maintain the groundwater-dependent ecosystems at a low level of risk (Braimbridge 2012; Loomes 2012). The EWRs are expressed as water levels in the aquifers.

The river pools support aquatic ecosystems of freshwater and marine fish species, macroinvertebrates, waterbirds, frogs, reptiles and aquatic flora. Deep pools maintain connectivity with the groundwater throughout the dry season and are critical refuges, from which aquatic fauna will repopulate when the river floods return. Continued input of groundwater to permanent pools is critical for maintaining adequate habitat and water quality during the dry season and extended droughts.

Riparian vegetation provides habitat for native fauna, acts as wildlife corridors, helps control erosion and is generally more productive than the surrounding landscape. Riparian communities along both rivers are dominated by the tree species *Eucalyptus camaldulensis* (river red gum), *Melaleuca argentea* (cadjeput) and *E. victrix* (coolibah) which are phreatophytic (groundwater-dependent) at these sites.

Vegetation mapping at both rivers shows that riparian communities are restricted to areas of shallow groundwater (<10 m). The shallow depth to groundwater in the alluvium along the rivers provides areas where deep rooted vegetation can reach groundwater, which sustains these communities in the absence of rainfall and/or surface water flow.

Stygofauna are also known to occur in both alluvial aquifers (Eberhard et al. 2005). As there is little specific information on their ecology and tolerances to water level changes our ecological investigations have focused on river pools and riparian vegetation. We have assumed that the ecological water requirements we have established for other groundwater-dependent ecosystems will also provide adequate habitat for stygofauna and act as surrogate requirements.

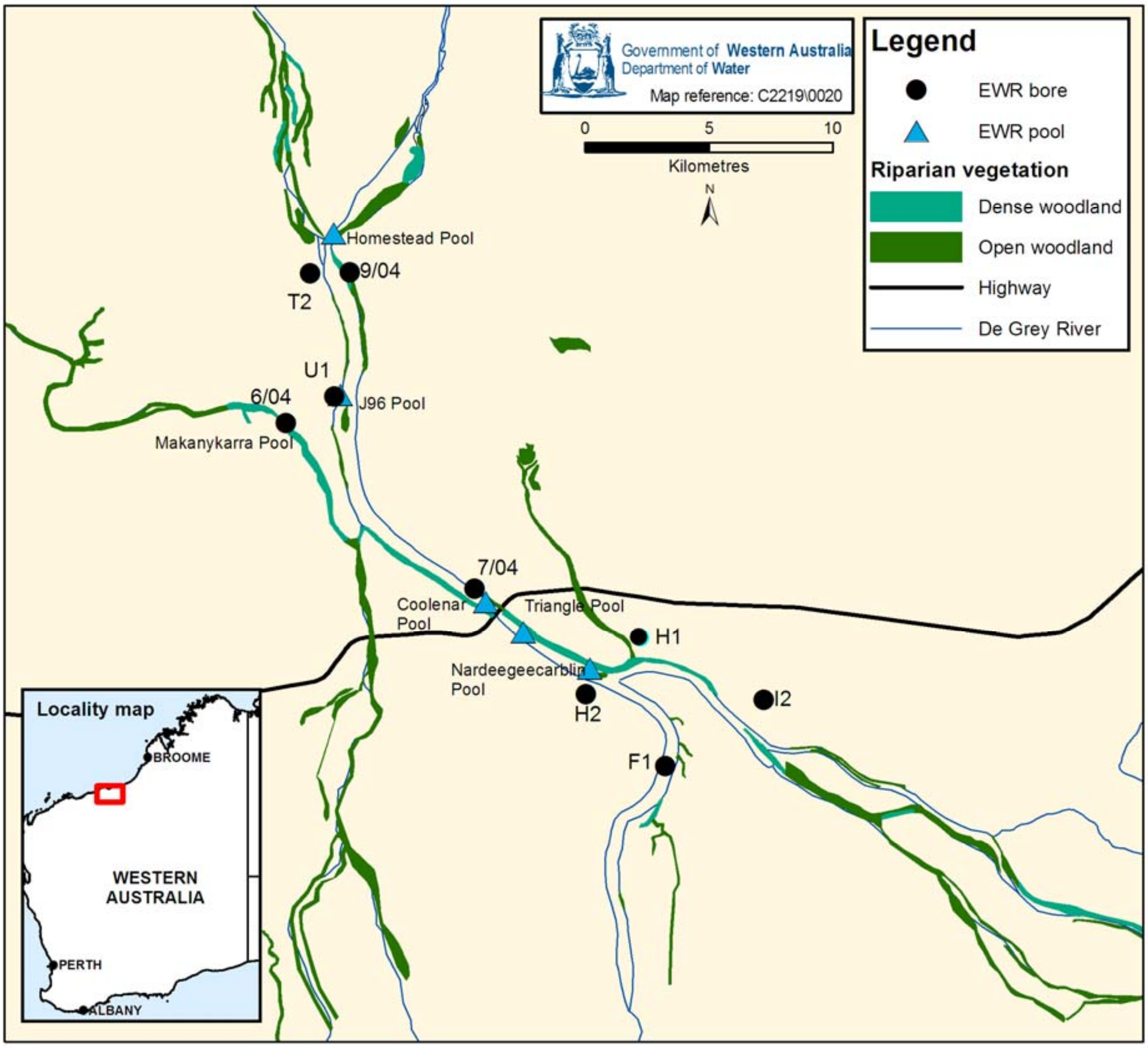


Figure 11 River pools and riparian vegetation of the lower De Grey River

The environmental values of the De Grey River are considered to be high due to the good to very good condition of the riparian zone and river pools (despite grazing pressure). The De Grey River, from the confluence of the Nullagine and Oakover rivers to the mouth is listed in the *Directory of important wetlands in Australia* (Environment Australia 2001). The river meets three of the six criteria for inclusion in the directory, namely:

- it is a good example of a wetland type occurring within a biogeographical region of Australia
- it plays an important ecological and hydrogeological role
- it has outstanding historical and cultural significance.

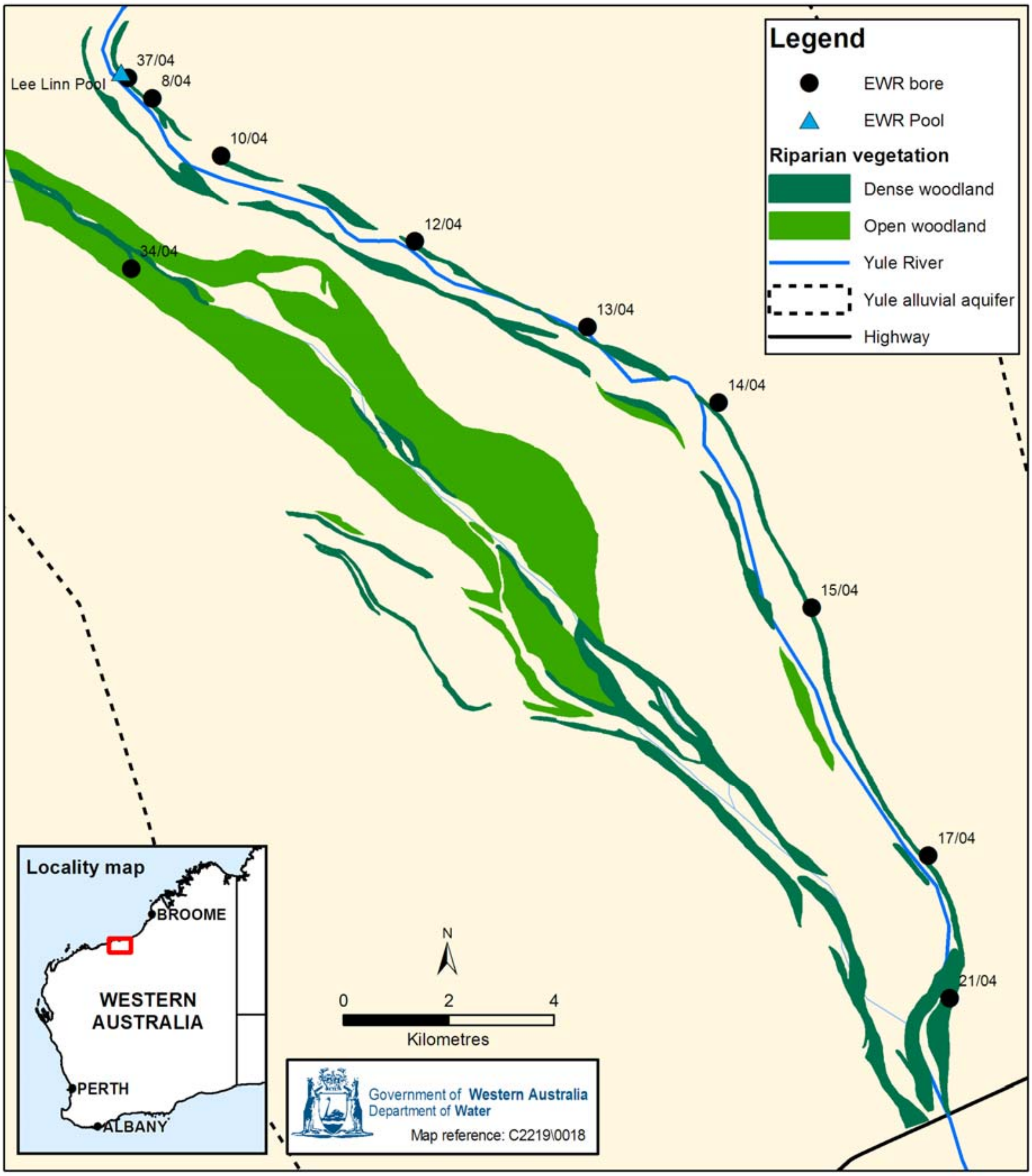


Figure 12 River pools and riparian vegetation of the lower Yule River

The Yule River has lower ecological values due to the adverse effects of grazing and to weed invasion. However, it is still considered to be of local conservation significance due to the presence of permanent river pools and riparian vegetation (Kendrick & Stanley 2002). Riverine and riparian ecosystems in the Pilbara have been found to be critical habitats for a number of fauna species.

Water related cultural and social values

In 2004, the former Water and Rivers Commission commissioned the study and report *'We Used to Get our Water Free…' – Identification and protection of Aboriginal* *cultural values of the Pilbara Region* (Rumley & Barber 2004). The excerpt below is taken from the report.

> Aboriginal people in the Pilbara region of Western Australia have strongly articulated cultural beliefs about water sources in their country based on their traditional religion. This religion, or cultural belief system, stems from the Dreamtime when it is believed that the landscape and all geographical features within it, including surface and groundwater sources as well as all species of flora and fauna, were created by Dreamtime beings. All these features are important to Aboriginal people in a variety of cultural, social and economic ways.
>
> … it is traditionally believed that the Dreamtime beings left part of their mythical essence in all the features and flora and fauna which they created. As far as water sources in the Pilbara region are concerned, this mythical essence is believed to remain in all water sources, rivers, creeks, soaks, pools and springs and takes the form of a water snake or water serpent.

The Department of Water's approach to engagement with Aboriginal people in the Pilbara has been shaped by these themes. We see water allocation planning work as more than an identification and documentation of sites of significance but rather an opportunity to build longer term water management partnerships with traditional owners in the Pilbara.

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

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

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

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

Cultural values of the lower De Grey River

The lower De Grey River is located within the boundaries of the Ngarla Determination Area (Montenegro 2010).

The initial meeting with the representatives of the Ngarla community was in October 2009. This was followed up with an on-country visit by department staff and members of the Ngarla group in June 2010.

The lower De Grey River contains a series of Aboriginal sites which are interrelated and of great significance to the Ngarla community (Torres-Montenegro 2010). The permanent river pools are of special significance because of the abundance of fish, particularly barramundi. Further evidence of the importance of the river pools is given by the fact that they are named and the names are still in use today. Additionally, three pools are listed with the Department of Indigenous Affairs as containing cultural or archaeological heritage. The area is also rich in bush tucker (Torres-Montenegro 2010).

The Ngarmal and Warram group determination areas are further upstream, beyond the boundary of the De Grey alluvial aquifer allocation area. Meetings with representatives of the Ngarmal and Warram groups were conducted in 2009 and 2010 respectively.

We will continue to consult with the Ngarla, Ngarmal and Warram groups as we finalise the *Pilbara groundwater allocation plan*.

Cultural values of the lower Yule River

The lower Yule River is located within the boundaries of the Kariyarra people native title claim (Morgan 2010).

The initial meeting with the representatives of the Kariyarra people was in June 2009. This was followed up with an on-country visit by department staff and members of the Kariyarra people in March 2010.

The significance of river pools and healthy riparian vegetation to the traditional owners was expressed during both meetings. In addition, two sites on the lower Yule River are listed on the Department of Aboriginal Affairs site database (Morgan 2010).

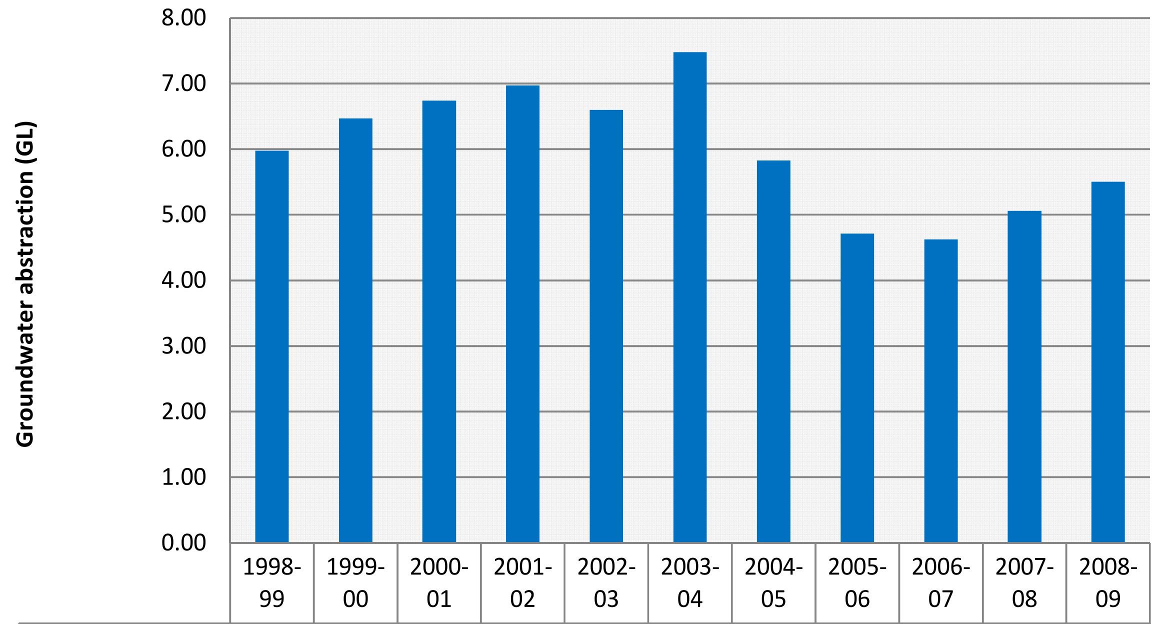
We will continue to consult with the Kariyarra people as we finalise the *Pilbara groundwater allocation plan*.

2.3 Understanding water demand and trends

How water is abstracted and used in the area

De Grey

The Namagoorie bore field is on the east side of the De Grey River, north of the North West Coastal Highway (Figure 9). It was commissioned in 1979 to supplement supply to the Port Hedland Regional Water Supply Scheme. The Water Corporation has had a licence to abstract 7 GL/yr since 1995. Actual abstraction since 1981 has averaged 5.8 GL/yr with a maximum of 7.2 GL/yr in 2003 (Figure 13).



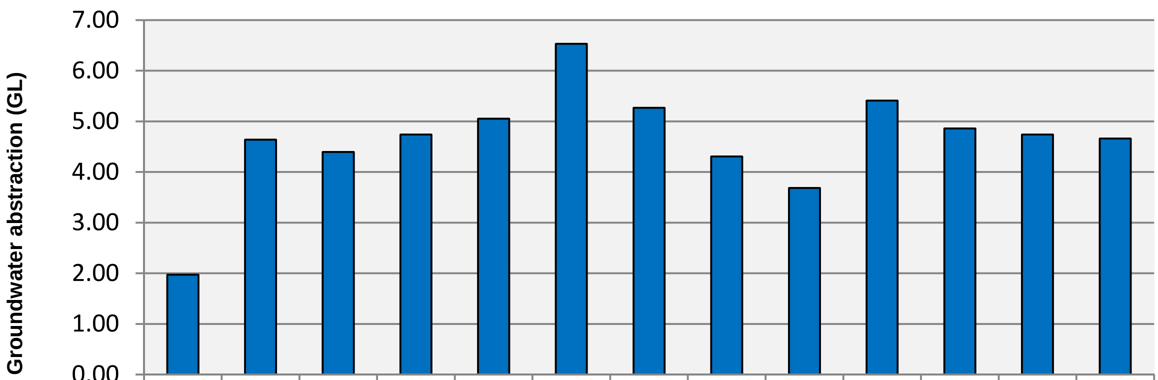
	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Total abstraction	5.97	6.47	6.74	6.97	6.60	7.48	5.83	4.71	4.63	5.06	5.50

Figure 13 Total annual abstraction (water year) from the De Grey (Namagoorie) bore field

De Grey Station also uses groundwater from the alluvial aquifer for stock and domestic purposes. Based on the average cattle carrying capacity in the Pilbara groundwater area, stock water use was estimated at 0.15 GL/yr from the De Grey alluvial aquifer. This is exempt from licensing.

Yule

A bore field has been in operation on the Yule River since 1967, also to supply the Port Hedland Regional Water Supply Scheme. There are currently 10 bores in operation on the north-east side of the river. Since 2003 the Water Corporation's licensed entitlement for the Yule bore field has been 6.5 GL/yr with an additional temporary licence of 2 GL/yr. Actual abstraction from the bore field since 1999 has not exceeded 6.5 GL/yr and has averaged 4.8 GL/yr (Figure 14).



	98-99	99-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Total abstraction	1.97	4.64	4.40	4.74	5.05	6.53	5.27	4.31	3.68	5.41	4.86	4.74	4.66

Figure 14 Total abstraction (water year) from the Yule bore field

Mundabullangana Station also uses groundwater from the alluvial aquifer for stock and domestic purposes. Based on the average cattle carrying capacity in the Pilbara groundwater area, stock water use was estimated at 0.06 GL yr from the Yule alluvial aquifer. This is exempt from licensing.

Future demand

The Water Corporation has proposed to expand the Port Hedland Regional Water Supply Scheme to meet the expected growth of the town and the increase in iron ore production. The Water Corporation has recently been granted increased licences for both resources as an outcome of this allocation process. If expected population and industry growth occurs, total demand (town and ports) is predicted to reach around 21 GL/yr by 2016 and 33.5 GL/yr by 2031.

2.4 Points to consider from assessing information

From the information we had on the De Grey and Yule alluvial aquifers, we identified a number of points to consider when setting objectives and allocation limits:

- In terms of flow, the De Grey River is the most reliable and largest of the gauged Pilbara rivers.
- The Namagoorie (De Grey) and the Yule bore fields have been important sources for the Port Hedland Regional Water Supply Scheme since 1979 and 1967 respectively.
- Current groundwater use from the bore fields averages 5.8 GL/yr from the De Grey resource and 4.8 GL/yr from the Yule.
- Demand for water in Port Hedland is projected to reach 33.5 GL/yr by 2021, well above the volume of water available from the De Grey and Yule bore fields.

- We have groundwater models to assess the potential effects of abstraction from the De Grey and Yule aquifers.
- Both aquifers support river pools and riparian vegetation communities. On the De Grey River these are of recognised high ecological and cultural significance. On the Yule River the ecological significance may be lower.

3 Setting objectives and allocation limits

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

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

3.1 Setting objectives

In administering the *Rights in Water and Irrigation Act 1914*, the Department of Water provides for both the sustainable use and development of water resources and the protection of ecosystems associated with water resources. We set outcomes and objectives in accordance with this, to guide our allocation decisions.

Outcomes

Our desired outcomes from managing the De Grey and Yule alluvial aquifers are that:

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

Resource objectives

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

The water resource objectives for the De Grey and Yule alluvial aquifers are:

- prevent saltwater intrusion into the aquifers caused by abstraction
- maintain water quality for the most beneficial use (potable water supply)
- maintain groundwater and pool levels within a target range, to maintain aquatic habitat and riparian vegetation dependent on groundwater and protect the values of the De Grey River as listed in the *Directory of important wetlands of Australia* (Environment Australia 2001).

3.2 Assessing allocation limits

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

Allocation options

The department used the De Grey and Yule groundwater models (see Section 2.1), hydrogeological assessments and monitoring data to assess a range of allocation options (Table 3 and Table 4). Six allocation options were modelled for each resource. Options were based on current and historical levels of use and projected demand. We used previous modelling runs to focus in on the likely range of allocation limits.

Models were run using a set of synthetic climate scenarios that were statistically generated from recorded historical climate data (Appendix A). These extended the time period we could model and assumed that climate in the Pilbara will remain approximately the same as in recent history. We took this approach:

- because the climate change predictions for the Pilbara at the time of modelling were not consistent (Loo & Humphreys 2009).
- to enable allocation limits to be set using a consistent set of climate inputs that covered the same period across multiple aquifers.

We used the modelled allocation option outputs and other information (such as monitoring data) to assess the risk to the resource (hydrogeological) and against the objectives listed in Section 3.1.

De Grey aquifer

All options for the De Grey aquifer, except Option 1 (no abstraction), included non-licensed stock and domestic use of 0.2 GL/yr (Table 3). Climate input for all options were based on the climate scenarios described above.

Option 2 represented a ‘business as usual case’ using the then current annual rate of abstraction (7 GL/yr).

Under options 3-1 and 3-2 abstraction from the current bore field was increased to 8 GL/yr, but streamflow was reduced by 10% in Option 3-2 to represent dry conditions.

Abstraction was increased to 10 GL/yr under options 4 and 5. In Option 4 the total volume was taken from the current bore field. In Option 5, 8 GL/yr was taken from the current bore field and 2 GL/yr from additional hypothetical bores south of the current bore field near the junction of the De Grey and Shaw rivers.

Table 3 Allocation options modelled for the De Grey alluvial aquifer

Option	Climate		Abstraction					
	Based on historical climate	**Dry climate**	**None**	**Stock and domestic 0.2 GL/yr**	**Existing bore field 7 GL/yr**	**Existing bore field 8 GL/yr**	**Existing bore field 10 GL/yr**	**Expanded bore field[1] 2 GL/yr**
1	*		*					
2	*			*	*			
3-1	*			*		*		
3-2		*		*		*		
4	*			*			*	
5	*			*		*		*

[1]Additional hypothetical bores located near the Shaw and De Grey confluence

Yule aquifer

The allocation options for the Yule aquifer were based on preliminary results of a drilling program completed by the Water Corporation to investigate potential bore field expansion.

All options except Option 0, a no abstraction option, included non-licensed stock and domestic use of 0.2 GL/yr (Table 4). Climate input for all options was based on the climate scenarios described above.

Options 2 and 3 included additional hypothetical bores on the eastern side of the river as an extension of the existing bore field.

Options 4 and 5 included bores located on the western side of the river in a new bore field.

Option 6 represented a business as usual case using the then current annual abstraction rate of 4.8 GL/yr.

Table 4 Allocation options modelled for the Yule alluvial aquifer

Option	Climate	Abstraction						
			Existing bore field					
	Based on historical climate	Stock and domestic 0.2 GL/yr	8.5 GL/yr	plus 3 bores at 8.5 GL/yr	plus 3 bores at 10.5 GL/yr	plus 7 bores at 10.5 GL/yr (including bores on western side of river)	plus 7 bores at 12 GL/yr (including bores on western side of river)	Existing bore use 4.8 GL/yr
0	*							
1	*	*	*					
2	*	*		*				
3	*	*			*			
4	*	*				*		
5	*	*					*	
6	*	*						*

Assessing model results

Hydrogeological and environmental factors described in Section 2.2 were considered to determine how much water we need to leave in the aquifers to meet environmental requirements.

Hydrogeological assessment

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

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

The risks of seawater intrusion (Table 5) and potential effects from the sides of the aquifer (Table 6) for each option were classified qualitatively as high, medium or low.

Table 5 Definitions of categories for seawater intrusion risks for De Grey and Yule alluvial aquifers

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

Table 6 Definitions of categories for risk of water quality effects from the sides of the De Grey and Yule alluvial aquifers

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

De Grey aquifer

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

Predictive model outputs showed some difference in groundwater levels and duration of low levels at most bores between the no abstraction option (Option 1) and all other options. That is, there was some sustained drawdown of water levels in parts of the aquifer under all the allocation options.

Although localised aquifer levels declined in response to abstraction for the first 12 years, they equalised and then appeared to recharge completely for all options. This is due to the reliability of recharge events (frequency of river flow) on the De Grey River. Despite reliable recharge drawdown did occur after 50 years. This coincided with a dry period in the synthetic climate sequence.

Maximum drawdown for each option was dependent on bore field configuration and volume abstracted (Table 7).

Due to the localised drawdown around the bore field, some reduction in discharge to the river pools was predicted.

Table 7 De Grey aquifer allocation option results: maximum drawdown

Option	Volume and bore field GL/yr	Maximum drawdown at 50 years m	Location of drawdown (bore or pool)*
1	0	0.47	F1 – south (upstream) of proposed bore field expansion
2	7.2 from existing bore field	1.24	H1 – on southern boundary of existing bore field
3-1	8.2 from existing bore field	1.60	H1 – as above
3-2	8.2 from existing bore field (dry climate)	1.65	H1 – as above
4	10.2 from existing bore field	2.78	Nardeegeecarblin Pool – on southern boundary of existing bore field
5	10.2 from expanded bore field	2.30	Nardeegeecarblin Pool – as above

**see Figure 11*

The seawater interface is currently 16 km north of the northernmost production bore. Modelling results showed that the position of the seawater interface will not change under any of the allocation options. It should be noted that there is less data (drilling and monitoring) in the northern part of the De Grey aquifer and hence the model results in this area need to be assessed with caution. Ongoing monitoring of water quality is required to manage potential movement of the seawater interface.

The effects on water quality along the sides of the aquifer are considered a short to medium term issue that will need monitoring and management.

The hydrogeological assessment concluded that all allocation options represented a low risk to the De Grey aquifer.

Yule aquifer

A review of the model showed that a no recharge sequence had been included in the synthetic climate input data, and that it lasted in excess of six years (2020 to 2026).This period had a large effect on the model outputs. We reviewed the data and found that such sustained low flows were not replicated historically. The maximum period of low (<1500 ML/day) flow in the recorded data set was 1328 days compared to 2444 days in the synthetic record. So while the synthetic sequence is based on historical data, and the mean annual flow and recharge are comparable, analysis of recorded data predicts a very low probability of such an event occurring.

Left in the model, this dry period could lead to a very conservative allocation limit. It was therefore removed and we instead used the last 22 years of the 50 year modelled climate sequence (2041 to 2063). The maximum low flow period in this data set is 732 days. Periods of low flow equal to or longer than 700 days have been recorded four times between 1972 and 2010.

Recharge to the Yule aquifer is less reliable than to the De Grey and this needs to be considered in allocation decisions. We looked at recovery of the aquifer following ‘typical’ recharge events, which streamflow records show have a probability of occurring once every two years. We selected two representative recharge events from the climate sequence and assessed the modelled groundwater contours for recovery. This gave us an idea of the aquifer’s capacity to recover from sustained pumping and the risk of adverse effects on water quality.

Model outputs were also compared with recorded data and aquifer throughflow estimates. This helped to reduce some of the uncertainty in the modelling.

The results showed a partial recovery of water level gradients following the two selected recharge events. However, there would be some permanent reduction at the downstream end of the resource as a result of increased abstraction.

There was also some predicted drawdown around the bore field that did not fully recover. Under allocation options with abstraction of 8.5 GL/yr and above, this drawdown extended into the higher salinity areas of the aquifer (Table 8).

Table 8 Yule allocation option results: maximum drawdown

Option	**Volume and bore field GL/yr**	**Maximum drawdown at 50 years m**	**Location of drawdown (bore)***
0	0	n/a	n/a
1	8.5 from existing bore field	5	3/96 and 1/96 – most southern abstraction bores
2	8.5 from bore field extended east of river	10	18/04 – east of existing bore field
3	10.5 from bore field extended east of river	10	18/04 and 19/04 – east of existing bore field
4	10.5 from bore field extended east and west of river	7	18/04 and 19/04 – east of existing bore field
5	10.5 from bore field extended east and west of river	8	18/04 and 19/04 – east of existing bore field
6	4.8 ‘business as usual’	1	3/96 and 1/96 – most southern abstraction bores

**see Figure 12*
n/a – not applicable

Changes to the position of the seawater interface will occur in the long term (>20 years) as the aquifer establishes a new equilibrium after the increased abstraction. This is considered to be no worse than a moderate risk to the aquifer in the long term and could be managed. Adverse effects on water quality along the sides of the aquifer are considered a more short to medium term issue that will need monitoring and management.

The assessment concluded that abstraction of 8.5 GL/yr represented a low to moderate risk to the aquifer and abstraction at higher rates, of 10.5 GL/yr and above, represented a moderate risk.

Ecological assessment

Ecological water requirements

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

For the lower De Grey and Yule alluvial aquifers we have described EWRs as pool or groundwater levels required to support river pool and riparian vegetation ecosystems (Loomes 2012 and Braimbridge 2012). We have not set an EWR for stygofauna communities because of uncertainties about habitat requirements, tolerances and responses to water regime change.

Seven sites were selected across the De Grey alluvial aquifer (Figure 11) and eight across the Yule (Figure 12) as being representative of river pools and/ or riparian vegetation ecosystems. Site selection was based on the degree of groundwater dependence, hydrological and ecological data availability and location of the site within or close to existing bore fields. We also selected two sites upstream of the Yule bore field, beyond the influence of abstraction, as reference sites.

To describe EWRs for both resources, we used the results of a pumping trial conducted at the Yule bore field, information from previous studies in the Pilbara and results from statistical analyses of local hydrological data.

Using the Yule bore field drawdown trial results we identified two thresholds of vegetation responses to changes in groundwater level:

- Moderate risk of adverse effects based on an initial physiological response in the vegetation.
- High risk of adverse effects when a more severe response and tree deaths were observed.

The thresholds equated to the 20th (moderate risk) and 5th (high risk) percentiles of groundwater level distributions at the Yule bore field. The use of percentiles made the thresholds relative instead of using absolute measures and let us transfer them to other resources (e.g. the De Grey aquifer) and to identify site specific water level thresholds.

The moderate and high risk thresholds allowed us to describe EWRs that reflect the Pilbara's varying water availability conditions rather than rigid water levels. We also described EWRs to represent higher water levels needed for periods of recovery and regeneration. This was equivalent to the 50th percentile.

Ecological water requirement thresholds to maintain river pool ecosystems were also described and were based on the 5th, 20th and 50th percentiles of pool levels data. While these EWRs were not based on observed ecological responses, the approach is consistent with previous studies on the aquatic ecosystems on the De Grey River (van Dam; Storey et al. 2005), which also used analysis of hydrological data to determine thresholds.

The EWRs for both systems were therefore based on 5th, 20th and 50th percentiles of groundwater and pool levels. These relate to four water availability conditions – drought, dry, average and above average, and therefore to recent climate conditions.

This approach recognises that a range of water levels are needed to maintain productive ecosystems and means we can manage the resources using a variable set of triggers (and responses) based on recent climate conditions. See Appendix B for ecological water requirements for the De Grey and Yule aquifers and see Loomes (2012) and Braimbridge (2012) for further details of ecological water requirements.

Ecological risk assessment

Model outputs were used to assess the ecological risk of each allocation option on groundwater-dependent ecosystems. To do this we recalculated the 5th, 20th and 50th percentiles using modelled data rather than using recorded data. This let us deal with the errors in predicting absolute water levels typical of outputs from numerical groundwater models (for example for the De Grey percentiles varied by 0.30 to 1.30 m between modelled and recorded data). By transferring thresholds across into modelled data we dealt with relative changes in groundwater levels that groundwater models predict with greater accuracy.

The ecological risk assessment focused on the duration and magnitude of water levels beyond drought ecological water requirement thresholds (5th percentile). The duration of low water levels beyond a threshold is a major factor affecting ecological response (Roberts et al. 2000). That is, the longer a low level is sustained, the greater the risk of adverse effects. The magnitude by which a threshold is exceeded is also important (Roberts et al. 2000). The drought EWR threshold represents the highest risk to ecosystems. We use the following categories for duration and magnitude:

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

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

B. Magnitude of exceedance by:

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

De Grey aquifer

For the De Grey aquifer we recalculated ecological water requirement thresholds (percentiles) using modelled historical data (1978 to 2008) for bores 7/04, U1, and Muccangarra and J96 pools and compared these to the predicted groundwater levels for each allocation option.

Additional sites upstream of the current bore field (at Nardeegeecarblin and Triangle pools and bores H1, H2 and F1) were assessed to examine potential effects of the bore field expansion proposed under allocation Option 5 (10 GL/yr – expanded bore field). Historical modelled or monitoring data were not available for these sites. We therefore used model outputs from Option 2 (current use – 7 GL/yr) to represent a historical base case and calculated thresholds from these data. The lack of historical data meant the model was not well calibrated at Nardeegeecarblin and Triangle pools and so results need to be treated with caution.

Ecological risk assessment results are shown in Appendix C.

The assessments showed that predicted groundwater levels were sensitive to the overall rate and distribution of abstraction. The duration of groundwater levels below the drought EWR threshold (Figure C.1) were consistently greatest at the site closest to the current bore field, bore H1. In Option 2 (7 GL/yr) this occurred for about 22% of the model period and was assessed as a moderate risk. This increased to approximately 40% under Option 5 (10 GL/yr – expanded bore field) and was therefore classed as high risk. Under allocation options 4 (10 GL/yr – current bore field) and 5, groundwater levels for Nardeegeecarblin Pool were predicted to fall below the drought EWR for approximately 40% of the model period. Levels at all other sites fell below the drought EWR threshold for less than 25% of the time under all scenarios.

In terms of magnitude, drought thresholds were exceeded by up to 1.0 m and 2.5 m (for allocation options of 8.0 GL/yr and greater) with the magnitude of exceedance increasing with greater abstraction (Figure C.2).

Allocation options were assigned a qualitative overall risk based on an ‘average’ of risk categories for representative sites.

Overall there was little difference in duration and magnitude of high risk categories between 8.0 GL/yr (Option 3) and 10 GL/yr if the latter is taken from an expanded bore field (Option 5).

Yule aquifer

This assessment followed a similar approach to that used for the De Grey aquifer, although thresholds were calculated from two modelled data sets. We also recalculated thresholds based on modelled data rather than use thresholds calculated using recorded data.

Thresholds were calculated using modelled historical data over the period 2005 to 2010 and also from modelled groundwater data from the business as usual allocation option (Option 6 for the period 2041 to 2063). Option 6 used a constant rate of abstraction of 4.8 GL/yr which is the mean annual abstraction recorded for the bore field. We included a second set of thresholds to test the sensitivity of the analysis. Modelled abstraction options were evaluated using both sets of thresholds as Evaluation 1 (modelled historical thresholds) and Evaluation 2 (business as usual Option 6 thresholds).

Ecological risk assessment results are shown in Appendix C.

In both evaluations, modelled groundwater levels were sensitive to overall rate and distribution of abstraction. Under Evaluation 1, levels fell below the drought EWR threshold for the majority of time (>50%) for seven of the eight sites under a 12 GL/yr allocation option (Option 5) and six of the eight sites for Option 4 (10.5 GL/yr from proposed bore field extending across to western side of the river). Allocation options 1, 3, 4 and 5 were classed as having a high risk of adverse effects on groundwater-dependent ecosystems based on these results.

Under the business as usual option (Option 6), water levels at two sites fell below the drought threshold for 50% or more of modelled period and at five sites for 25% of the time. Under Evaluation 1, Option 6 was classed as moderate to high risk. This suggested that the evaluation was too conservative, as a continuation of (approximately) the current abstraction posed a moderate to high risk that hasn't been demonstrated under historical rates of pumping.

Evaluation 2 was less conservative, with groundwater levels under Option 6 predicted to only exceed the drought threshold for approximately 10% of the modelled period at all sites. All sites were therefore classed as being at a low risk of suffering adverse effects under this allocation option.

Under Evaluation 2 there were still extended periods of time when modelled groundwater levels fell below the threshold for rates of abstraction of 8.5 GL/yr or greater. At high rates of abstraction (10.5 and 12 GL/yr allocation options) this was predicted to occur for up to 80% of the modelled period. Under allocation options 5 (12 GL/yr) and 3 (10.5 GL/yr) all sites except the reference site were classified as being at high risk of suffering adverse effects.

The distribution of abstraction was an important factor affecting ecological risk. This indicates that controlling where abstraction is to take place will be an important risk management tool. The overall risk to ecosystems from both 10.5 GL/yr options (options 3 and 4) was similar. Spreading abstraction across an expanded bore field (Option 4) reduced the duration of time that water levels were below the drought threshold for five of the seven effected sites. This included bore 37/04 which is located next to Li Lin Pool, the main semi-permanent pool within the bore field.

The magnitude by which water level decreases exceeded the high risk threshold also differed between the evaluations. However, both showed increased abstraction (8.5 GL/yr and greater) would result in the drought ecological water requirements being exceeded periodically by 1 m to over 3 m. This was considered to be of high risk to groundwater-dependent ecosystems.

The distribution of abstraction was important to the magnitude of breaches as well as the duration. Evaluation 2 thresholds showed a similar pattern (to duration) of reduced risk of adverse effects between allocation options 3 and 4. That is, spreading abstraction across a greater area reduced the magnitude by which water levels exceeded the drought EWR threshold at five of the seven effected sites.

Ecological and hydrogeological assessment results

To determine an overall level of combined ecological and hydrogeological risk (low, medium or high) for each allocation option we reviewed the results of the ecological and hydrological assessments, giving equal weightings to both assessments. Specifically, for each option we looked at the number of sites which fell within each ecological risk category then combined this with the hydrogeological assessment. The results for each resource are discussed below.

De Grey aquifer assessment results

The hydrogeological assessment concluded that all allocation options represented a low hydrogeological risk to the De Grey aquifer (Table 9).

The ecological assessment concluded that 8 GL/yr from the existing bore field presented a low to medium risk to groundwater-dependent ecosystems and 10 GL/yr presented a medium risk. If 10 GL/yr is spread across the expanded borefield, and adequate monitoring and review mechanisms are put in place, risk is reduced to low to medium (Table 9). Management and monitoring mechanisms are described in the *Pilbara groundwater allocation plan* and monitoring program (Department of Water in preparation b).

Table 9 Summary of risk assessment of modelled De Grey aquifer allocation options

Option		**Hydrogeological risk**	**Ecological risk**	**Combined risk**
1	0 GL/yr	Low	Low	Low
2	7 GL/yr existing bore field	Low	Low	Low
3-1	8 GL/yr existing bore field	Low	Low–medium	Low
3-2	8 GL/yr existing bore field, dry climate	Low	Low–medium	Low
4	10 GL/yr existing bore field	Low	Medium	Medium
5	10 GL/yr expanded bore field	Low	Low–medium	Low

Yule aquifer assessment results

The hydrogeological assessment concluded that all allocation options represented a low to medium risk to the Yule aquifer. An important consideration was the predicted timeframe of seawater intrusion and aquifer water quality changes and the ability to manage these risks.

The risk to groundwater-dependent ecosystems depended on the volume of abstraction and also the bore field configuration. We concluded that 8.5 GL/yr presented a medium risk to ecosystems and 10.5 GL/yr presented a medium–high risk if spread across existing and additional proposed production wells (Table 10).

Table 10 Summary of risk assessment of modelled Yule aquifer allocation options

Option		Hydrogeological	Ecological	Combined
0	0 GL/yr	Low	Low	Low
1	8 GL/yr existing bore field	Low–medium	High	Medium
2	8.5 GL/yr expanded bore field east	Low–medium	Medium	Medium
3	10.5 GL/yr expanded bore field east	Medium	Medium–high	Medium–high
4	10.5 GL/yr expanded bore field east and west	Medium	Medium–high	Medium–high
5	12 GL/yr expanded bore field east and west	Medium	High	Medium–high
6	4.8 GL/yr existing bore field	Low	Low	Low

Stock and domestic use

Before we set the allocation limits, the stock and domestic use included in the groundwater model was revised. This was based on the recommended stock carrying capacity (head of cattle per hectare) for each station in the resource area and an annual daily water use per animal (P Smith pers. comm., March 2012).

The estimated stock and domestic use for the De Grey alluvial aquifer was 0.15 GL/yr and for the Yule alluvial aquifer 0.06 GL/yr. These estimates were lower than the 0.20 GL/yr applied in the groundwater models.

3.3 Deciding allocation limits

Table 11 shows the allocation limits set after following the process described above. The sections after the table give some comments on the limits chosen.

Table 11 Allocation limit components for the De Grey and Yule alluvial aquifers

Aquifer	Allocation limit GL/ yr	Licensable components GL/ yr		Un-licensable component GL/ yr
		General licensing	Public water supply	Unlicensed use (stock and domestic)
De Grey	10.15	n/a	10.00	0.15
Yule	10.56	n/a	10.50	0.06

De Grey aquifer

The department set the allocation limit for the De Grey alluvial aquifer at 10.15 GL/yr (including 0.15 GL/yr for stock and domestic use) (Table 11). The decision was based on:

- predicted low to medium risk to high value groundwater-dependent ecosystems
- predicted low risk to groundwater quality

- predicted short to medium term demand
- high reliability of recharge
- high ecological values.

The environmental values for the De Grey resource are considered high compared to other resources covered in the plan. This is due to the good to very good condition of the riparian zone and river pools (despite grazing pressure) and listing in the *Directory of important wetlands of Australia* (Environment Australia 2001). As a result we have set allocation limits that maintain a low level of risk.

The main risks associated with taking 10.15 GL/yr from the De Grey alluvial aquifer are therefore the effects on ecologically and culturally significant river pools and groundwater-dependent riparian vegetation.

The distribution of abstraction is important in managing risk to ecosystems and the aquifer. Therefore, through our licensing assessment, we will allow 8.00 GL/ yr to be taken from the current bore field, 0.15 GL/yr from existing stock watering points and an additional 2.00 GL/yr from an additional bore field. In the allocation options this was modelled as additional bores to the south of the current bore field. The configuration and management of abstraction from of an additional bore field would need to be investigated and proven up through our licensing process.

Given that the historical production from the existing bore field has not exceeded 7.2 GL/yr with an average of 5.6 GL/yr since 2001, increases in abstraction and their effects need to be monitored and managed carefully. This will include checking the actual new water levels against the predicted ones as abstraction increases and monitoring results become available.

Yule aquifer

Based on the information available when this report was being prepared the environmental values for the Yule area were considered to be relatively low compared to other resources assessed as part of the Pilbara planning project. This is due to the poor condition of the riparian zone and river pools which have been relatively heavily affected by grazing. In setting the allocation limit we considered these low ecological values along with the importance of the resource as a water supply for Port Hedland.

The department set the allocation limit for the aquifer at 10.56 GL/yr (including 0.06 GL/yr for stock and domestic use) (Table 11). In accordance with our considerations above and resource objectives (Section 3.1) we have set an allocation limit that poses a greater risk to the Yule’s groundwater-dependent values and the long-term productivity of the resource than we have for the De Grey aquifer. The final decision was based on:

- predicted medium to high risk to groundwater-dependent values
- predicted low to medium risk to groundwater quality
- predicted short to medium term demand
- low ecological values.

The distribution of abstraction is important in managing risk to ecosystems and the aquifer. In the allocation options this was modelled as additional bores on the western side of the Yule River. Spreading the take from the aquifer spatially will be essential to reducing the risk.

Given that the allocation limit is significantly greater than historical production from the bore field, which has not exceeded 6.5 GL/yr and has averaged only 4.7 GL/yr since 2000, increases in abstraction need to be monitored and managed carefully. This will include checking the actual new water levels against the predicted ones as abstraction increases and monitoring results become available and, if necessary, reviewing the abstraction management.

4 Defining management approach

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

At the aquifer scale the allocation limits, as described in this report, will help us meet the resource objectives to prevent seawater intrusion, maintain water quality and maintain groundwater and pool levels within a target range.

At the local scale, the department will use licensing policy and monitoring. Licensing policy helps us assess groundwater licence applications and manage licences on a case-by-case basis. Monitoring allows us to understand how resources are performing over time and in particular how the aquifers and the environment are responding to increased abstraction.

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

4.1 Licensing policy

Before abstraction can be increased to the maximum permitted under the allocation limits we will require the proponent (the Water Corporation) to test aquifer response to prolonged periods of abstraction above the historical average (5.6 GL/yr for the De Grey aquifer, 4.8 GL/yr for the Yule) at rates of 8.0 GL/yr from the De Grey and 8.5 GL/yr from the Yule.

The ability to abstract the full allocations from both resources and not cause significant adverse effects on hydrogeological, environmental and cultural values is also dependent on the spread of the abstraction. The Water Corporation will be required to develop new bore fields or expand existing ones to ensure that values are protected.

To maximise take while maintaining environmental and cultural values the department has set up licensing policy that links management to the recharge that the alluvial aquifers receive.

As the maximum allocation limit for the Yule aquifer poses risks to the groundwater-dependent values and long-term quality of the resource – particularly in years when recharge is limited or has not occurred – a high level of management is needed.

We will work with the proponent to ensure that:

- the resources can be managed to provide Port Hedland with a reliable water supply
- the resources remain productive in the long-term
- any adverse effects on groundwater-dependent ecosystems are minimised
- effects to groundwater-dependent ecosystems are anticipated.

Operating strategies associated with licences will also include the requirement for longer term hydrological and ecological monitoring, assessment and reviews to ensure the resources can be used sustainably.

4.2 Monitoring – trigger and response framework

Risks from increased abstraction to both aquifers will be managed through a trigger and response framework. This means that water level triggers will be used to manage effects on the environment and cultural values and on the resource. When reached, the water levels trigger a response so that management can be adapted and any adverse effects can be minimised. Trigger levels ensure adequate water is left in the alluvial aquifers based on the ecological water requirements (see Section 3.2). Trigger levels for water quality will be developed for operating strategies.

The framework has trigger, criteria and target water levels. A trigger is an early warning which indicates that a water level is declining and approaching the critical criteria level. Criteria levels have been set to meet water resource objectives and should not be breached. Management responses are triggered with increasing levels of effort as water levels continue to decline.

Target levels are higher water levels that should be met under average and wet conditions to reflect periods of greater recharge. Target levels are not imposed with the same level of management and response required by a trigger or criteria level.

How we set trigger, criteria and target levels

Because we need to balance demand for water with how much water is left in the aquifers to support the environment and aquifer productivity, the full EWRs cannot be met in full in all cases. We have therefore determined environmental water provisions (EWPs) that are a compromise between the EWRs and the water levels predicted under full allocation options (10 GL/yr at De Grey, 10.5 GL/yr at Yule). The EWPs represent post-abstraction water levels. We recognise that this poses a risk to the environment but think these risks are either manageable or consistent with the resource objectives.

Trigger levels in the management framework are equal to the EWR thresholds described in Section 3.2. Target levels are also based on EWRs. Criteria levels for drought and dry conditions are the EWPs, which were derived from the EWRs. For average conditions we have set the criteria as the 20th percentile EWR.

The approaches used to set the criteria levels varied slightly between the two resources because of differences in what we know about values, risks and available data.

De Grey aquifer

EWRs were based on the 5th, 20th and 50th percentile groundwater levels at the seven relevant groundwater bores. The 5th and 20th percentiles have been used as trigger levels in the trigger and response framework. To set criteria levels (EWPs) or drought and dry conditions we used:

- modelled historical groundwater levels from 1983 to 2008 to calculate EWRs in the model domain
- modelled groundwater levels predicted for 2012 to 2062 as representative of groundwater under the 10 GL/yr allocation option
- actual observed historical groundwater levels to 2008 to calculate actual EWRs.

We then:

1 calculated the 5th and 20th percentiles for the modelled predicted and modelled historical groundwater levels

2 found the difference between modelled predicted percentiles and modelled historical percentiles

3 added the difference (from step 2) to the observed historical percentiles.

The 5th and 20th percentile levels from step 3 became the criteria levels. An example of this process is shown in Table 12.

The difference at step 2 represents the amount by which we have accepted EWRs will not be met under the new allocation limit. It is the trade-off that is made when meeting the projected demand compared to meeting the EWRs in full. The 50th percentiles have been applied/ used as targets in the trigger and response framework.

Table 12 Example of De Grey aquifer threshold calculation

Percentile	Modelled data			Observed data	
	EWR (mAHD) based on historical abstraction	**Predicted EWR based on 10 GL/yr abstraction mAHD**	**Difference m**	**Trigger (EWR mAHD)**	**Criteria (EWP mAHD) (EWR + difference)**
5th	8.81	8.69	0.11	9.26	9.15
20th	9.01	8.97	0.04	9.65	9.61

Yule aquifer

The process for determining criteria values for the Yule River aquifer was similar to that used for De Grey. EWR thresholds (5th, 20th and 50th percentiles) were used as triggers and model outputs from the accepted allocation limit option (10.5 GL/yr) were used to calculate criteria levels. Because of the sensitivity to droughts (failed recharge) and distribution of pumping for the Yule aquifer we used an average difference across our EWR sites instead of applying differences calculated for each site.

The average difference was calculated using predicted water levels for nine bores (17/04, 21/04, 37/04, 20/04, 14/04, 12/04, 11/04, 10/04 and 8/04) and calculating the difference in percentiles between allocation Option 3 (10.5 GL/yr) and Option 6 (4.8 GL/yr). The time period used to calculate the difference was 2041 to 2063 which is consistent with the timeframe used in assessing the allocation options.

The average difference of 1 m was applied to the EWR for each EWR investigation site to calculate the criteria values.

Applying trigger, criteria and target levels

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

As the flow regimes of the rivers are different we looked at various hydrological parameters to find the one with the strongest relationship to groundwater recharge. We looked at the relationship between groundwater levels and annual river flow volume, wet season flow volume, river height, duration of flow and time since last flow.

For both the De Grey and Yule aquifers we found that the total wet season flow was the best parameter for estimating recharge. The wet season was defined as being from October to April.

The overall approach we followed to derive the recharge classes was:

1. Calculate total wet season flow volumes for 1975 to 2011 (where data available) for the:
   - De Grey River at Coolenar Pool gauging station
   - Yule River at Jellabidina Pool gauging station.
2. For each resource, rank years by flow volume from lowest to highest.
3. For each resource, assign each year to one of four recharge classes based on the probability distribution of total wet season flows.

The flow volumes and water availability conditions for each class are shown in Table 13 and Table 14. More detail on recharge classes is provided in Loomes (2012) and Braimbridge (2012).

Table 13 De Grey aquifer recharge classes

Recharge class	Water availability conditions	Total wet season flow (Oct-Apr) ML
1	Drought	<100 000
2	Dry	100 000 – 450 000
3	Average	450 000 – 2 000 000
4	Above average/wet	>2 000 000

Table 14 Yule aquifer recharge classes

Recharge class	Water availability conditions	Total wet season flow (Oct-Apr) ML
1	Drought	<3000
2	Dry	3000 – 50 000
3	Average	50 000 – 500 000
4	Above average/wet	>500 000

The water levels applicable to each recharge class (for both resources) are shown in Table 15. To apply the trigger, criteria and target levels we determine the recharge class and then decide which levels are applicable.

For example, if the total De Grey River wet season flow is 300 000 ML, it is a recharge class 2 year and the trigger and criteria levels are based on the 20th percentile water levels. If the flow is greater than 2 000 000 ML, it is recharge class 4 and water levels should remain above the target level.

Table 15 Applying trigger, criteria and target water levels

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

For the Yule and De Grey aquifers the triggers, criteria and targets have been incorporated into a trigger and response framework for the Port Hedland Regional Water Supply Scheme. The framework incorporates reporting, monitoring and responses in management of take from the bore fields with increasing levels of effort towards the most critical drought thresholds.

This framework will be implemented as part of an operating strategy developed as a condition on the licences held by the Water Corporation for both aquifers.

Details of the trigger and response framework and actual trigger, criteria and target water levels are included in plan.

Appendices

Appendix A — Pilbara groundwater area synthetic 100 year climate sequences

De Grey and Yule groundwater models were run using 50 year subsets of a 100 year climate option generated by the department using a ‘bootstrapping’ approach to historical climate data. The bootstrapping method uses repetitive random sampling of the historical time series on an annual basis and joining them end to end to build up the 100 years of synthetic time series. The 100 year sequence was statistically similar to the recorded historical climate. This therefore assumes that the climate in the Pilbara will remain approximately the same as recent history. We took this approach to modelling because the climate predictions for the Pilbara at the time of modelling did not indicate a consistent predicted change (Loo & Humphreys 2009). The 50 year subset was used instead of the full 100 years to reduce model run times.

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

Introduction

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

The data has been generated for use as input to groundwater models that predict aquifer yields to guide allocation planning. The 100 year sequences were generated on a daily timestep using a bootstrapping method following the procedure used by DHI (2009) for the Millstream groundwater model area. Data in the 100 year sequence was sampled from a 22-year period of historical record for which streamflow data was available in all six areas (from October 1987 to September 2009).

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

Historical data

Rainfall

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

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

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

Streamflow

Streamflow data was obtained from the Department of Water HYDSYS database in October 2010 for each area. The streamflow gauges used for each model area are listed in Table A1.

Adjustments were made to the streamflow records to fill gaps and replace some questionable data, details of which follow.

Table A1 Rainfall and streamflow data sources

Groundwater model area	SILO grid Easting	SILO grid Northing	Streamflow gauge location	Streamflow gauge AWRC reference
Yule	118.25	20.65	Yule River – Jelliabidina	709005
De Grey	119.40	20.25	De Grey River – Coolenar	710003

Yule River – Jelliabidina

Data for the following dates was questionable, having repeated values for daily streamflow for periods of weeks or more: 1/10/87–27/3/88; 19/7/88–18/12/88; 31/12/88–23/2/89; 16/11/89–4/2/93. The daily streamflow for these periods was replaced with periods of no flow.

Gaps in the streamflow record were filled with data from other periods with similar rainfall. Streamflow data for 25/1/03–30/4/03 filled with data copied from 29/3/88–2/7/88. Streamflow data for 1/5/03–8/12/04 filled with data copied from 1/5/95–8/12/96.

De Grey River – Coolenar Pool

Data for the following dates was questionable, having repeated values for daily streamflow for periods of weeks or more: 31/12/91–1/2/92; 23/2/92–3/2/93. The daily streamflow for these periods was replaced with periods of no flow.

Water depth

Water depth data was obtained from the Department of Water HYDSYS database in June 2011 for both areas. The water depths reported in the synthetic data sequences are at the gauges listed in Table A1.

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

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

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

Adjustments were made to the water depth records to fill gaps and replace some questionable data, details of which follow.

Yule River – Jelliabidina

Data for the following dates was questionable, having repeated values for daily streamflow for periods of weeks or more: 1/10/87–27/3/88; 19/7/88–18/12/88; 31/12/88–23/2/89; 16/11/89–4/2/93. The daily water depth for these periods was replaced with periods with depth set to zero.

Gaps in the depth record were filled with data from other periods with similar rainfall. Water depth data for 25/1/03–30/4/03 filled with data copied from 29/3/88–2/7/88. Water depth data for 1/5/03–8/12/04 filled with data copied from 1/5/95–8/12/96.

De Grey River–Coolenar Pool

Data for the following dates was questionable, having repeated values for daily streamflow for periods of weeks or more: 31/12/91–1/2/92; 23/2/92–3/2/93. The daily water depth for these periods was replaced with the water depth at the start of that period.

Period of record

A period of years from which to sample streamflow and rainfall data was chosen based on the shortest streamflow record being the Fortescue River Bilanoo gauge, from 1987 to 2009. Having the same period of years from which to sample data should give synthetic sequences that represent the same climate.

Current climate synthetic series generation

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

Dry climate synthetic series generation

A dry climate synthetic series was generated for each area using the same method as DHI (2009). Randomly selected years in the current climate synthetic series (for rainfall and streamflow) were replaced with the low flow years listed in Table A2 . Low flow years were selected from those with total water year streamflow in the lowest 10th percentile in the 1987 to 2009 period. Years were replaced until the average annual flow was approximately 10% lower than for the current climate series.

Close to a 10% reduction in average annual streamflow was achieved for the De Grey River. For the Yule River, replacing seven years yielded a 7% reduction and replacing eight years yielded a 14% reduction. The synthetic series with a 14% reduction in average annual streamflow was chosen as the more conservative of the two.

Table A2 Low flow water year used to build dry climate synthetic series

Groundwater model area	Water year used to replace random years for dry climate synthetic series
Yule	October 1995 to September 1996
De Grey	October 1989 to September 1990

Appendix B — De Grey and Yule ecological water requirements

Table B1 Ecological water requirements or De Grey river pools and bores representing riparian vegetation

Percentile	River pool	EWR water level mAHD	Bore	EWR water level mAHD
	Coolenar Pool[1]		7/04	
5th		15.50		14.27
20th		15.73		14.47
50th		15.99		14.96
	Homestead Pool		9/04[1]	
5th		6.54		7.05
20th		6.77		7.38
50th		7.10		7.72
	96 Pool		U1	
5th		9.86		9.26
20th		10.16		9.65
50th		10.62		10.06
	Makanykarra Pool		6/04[1]	
5th		8.53		7.87
20th		8.81		8.48
50th		9.62		9.14
	Triangle Pool[2]		Cuttangunah Well[2]	
5th		14.28		15.84
20th		14.94		16.06
50th		15.88		16.49
	Nardeegeecarblin Pool[2]		Bore H2	
5th		15.50		19.05
20th		16.19		19.32
50th		17.16		19.72
			Bore F1	
5th	n/a	-		24.13
20th		-		24.57
50th				25.04
			Bore I2	
5th	n/a	-		20.21
20th		-		20.59
50th		-		20.97

[1] site not modelled

[2]modelled data only

n/a – not applicable

Table B2 Ecological water requirements for Yule groundwater monitoring bores representing riparian vegetation

Percentile	Bore	EWR water level mAHD
5th	8/04	8.27
20th		9.23
50th		10.78
5th	10/04	8.47
20th		9.56
50th		12.18
5th	12/04	12.10
20th		14.30
50th		15.39
5th	13/04	15.59
20th		17.53
50th		18.34
5th	14/04	17.44
20th		18.77
50th		19.82
5th	15/04	22.35
20th		23.12
50th		24.22
5th	34/04	9.41
20th		10.06
50th		10.68
5th	37/04	8.18
20th		8.87
50th		10.32
5th	17/04	28.28
20th		28.96
50th		29.48
5th	21/04	31.45
20th		32.03
50th		32.48

Appendix C — Ecological risk assessment results

Figure C1 Duration of threshold exceedance at De Grey assessment sites as per cent of total model period (50 years) for options 1 (a), 2 (b), 3-1 (c), 3-2 (d), 4 (e) and 5 (f). L, M and H in red text boxes represent overall level of risk

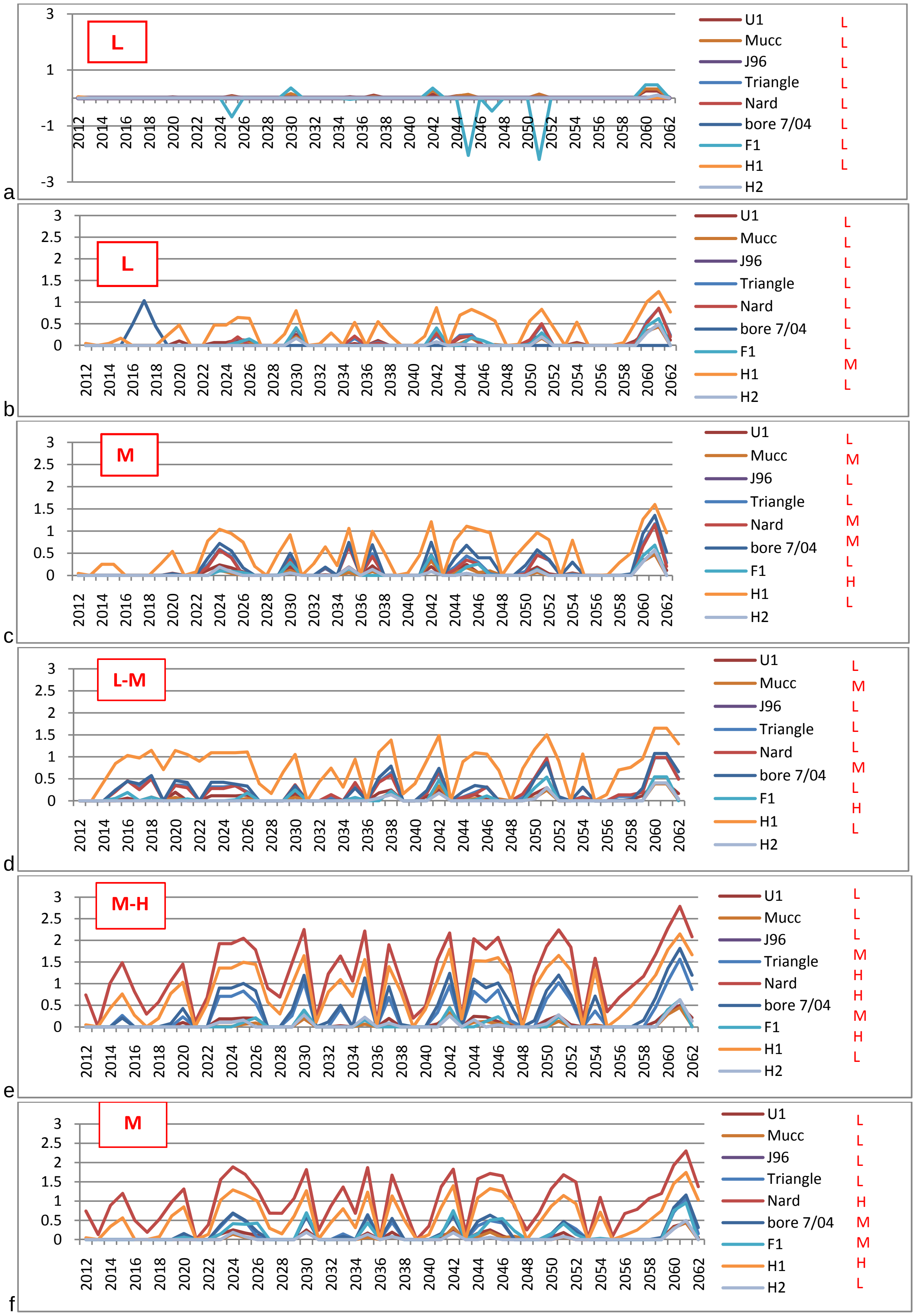


Figure C2 Magnitude of drought EWR (recharge class 1) exceedance at all De Grey sites for options 1 (a), 2 (b), 3-1 (c), 3-2 (d), 4 (e) and 5 (f)

Figure C3 Evaluation 1 of duration that water levels are exceeded at Yule assessment sites as per cent of total model period (50 years) for options 0 (a), 1 (b), 2 (c), 3 (d), 4 (e), 5 (f) and 6 (g)

Figure C4 Evaluation 2 of duration that water levels at Yule assessment sites were exceeded as per cent of total model period (50 years) for options 0 (a), 1 (b), 2 (c), 3 (d), 4 (e), 5 (f) and 6 (g)

Figure C5 Evaluation 1 of magnitude of drought EWR exceedance for options 0 (a), 1 (b), 2 (c), 3 (d), 4 (e), 5 (f) and 6 (g)

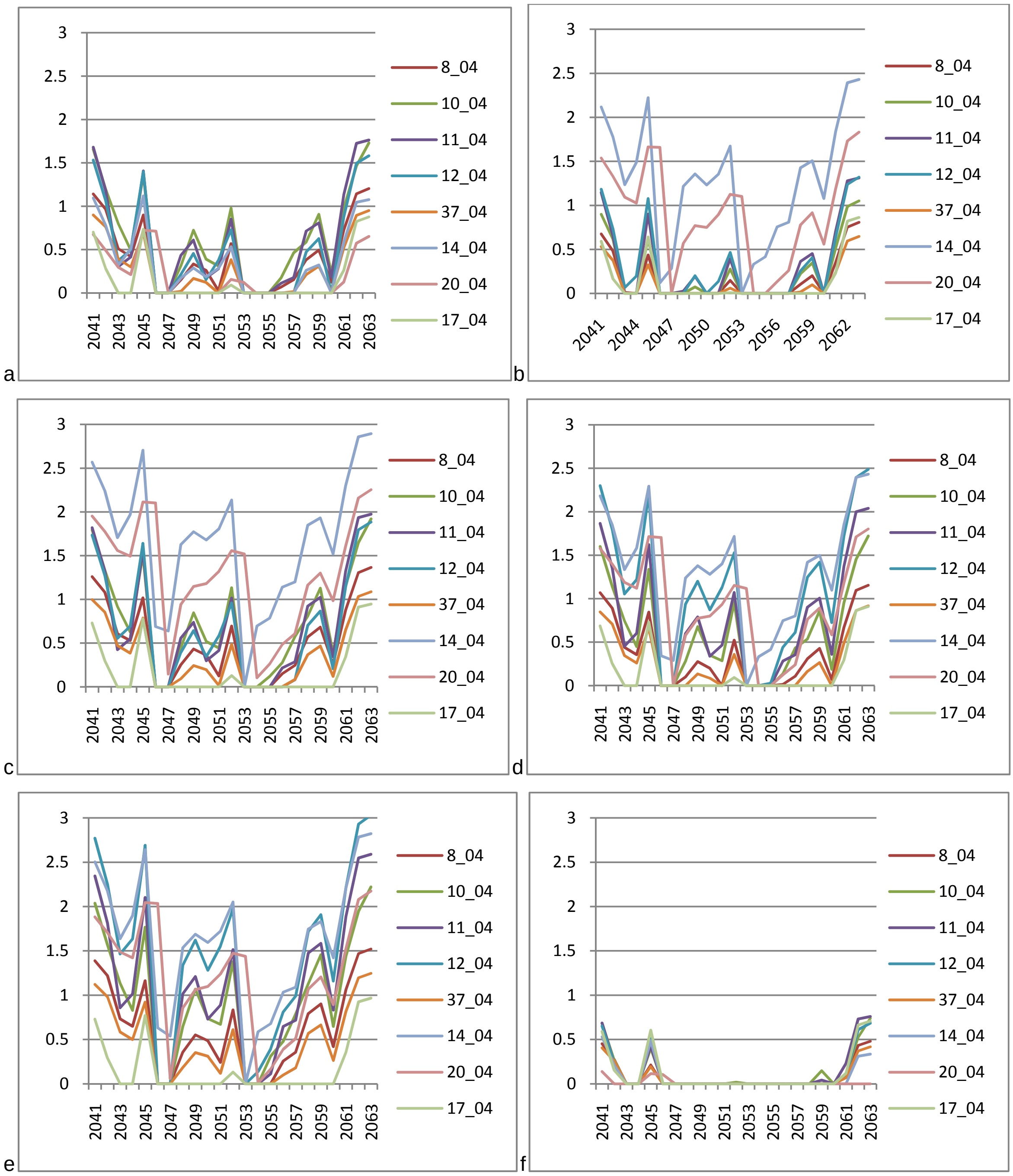


Figure C6 Evaluation 2 of magnitude of drought EWR exceedance for options 0 (a), 1 (b), 2 (c), 3 (d), 4 (e), 5 (f) and 6 (g)

Appendix D — Map information and disclaimer

Datum and projection information

Vertical datum: Australian Height Datum (AHD)

Horizontal datum: Geocentric Datum of Australia 94

Projection: MGA 94 Zone 50

Spheroid: Australian National Spheroid

Project information

Client: Robyn Loomes

Map Author: Michelle Antao

Filepath:

a) J:\gisprojects\Project\C_series\C2219\0020_DeGrey_Maps\mxd\methods report

b) J:\gisprojects\Project\C_series\C2219\0018_Yule_Maps\mxd\methods report

Filename:

a) 120607_Degrey_GDE.mxd
   120814_Degrey_Yule_Location_Map.mxd
   120607_Degrey_Model_Domain.mxd
   120607_Degrey_revised_boundary.mxd
   120607_Degrey_salinity.mxd
   120607_Degrey_current_boundaries.mxd

b) 120607_Yule_GDE.mxd
   120607_Yule_Model_Domain.mxd
   120607_Yule_revised_boundary.mxd
   120607_Yule_salinity.mxd
   120607_Yule_current_boundaries.mxd

Compilation date: June 2012
August 2012

Disclaimer

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

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Sources

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

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

Pilbara Pool Mapping – DoW – 2009

Road Centrelines – DoW – Current

Towns –DLI – Current

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

Main Roads, DLI, 2010

Pilbara Monitoring Program, DoW project specific data, 2012

WIN surface water sites – stream gauging, DoW, 2012

WIN groundwater sites – all, DoW, 2012

DWAID Aquifers, DoW

DWAID Groundwater areas, DoW

DWAID Subareas, DoW

Water Corporation pipes – WC – Current

Shortened forms

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

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 gigalitre	(GL)

Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Allocation limit	Annual volume of water set aside for consumptive use from a water resource.
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. Aquifer types include unconfined, confined and artesian.
Australian Height Datum	The datum used for the determination of elevations in Australia. The determination used a national network of bench marks and tide gauges, and set mean sea level as zero elevation.
BoM	Bureau of Meteorology
Bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer.
Bore field	A group of bores to monitor or withdraw groundwater.
Consumptive use	The use of water for private benefit consumptive purposes including irrigation, industry, urban and stock and domestic use.
Criteria level	A groundwater or pool level that should not be breached. This is to meet water resource objectives, usually relating to maintaining water quality, aquifer productivity and/or water for ecology.
Discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants or engineering.
Drawdown	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure.
Environmental water provision	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.

Ecological water requirement	Water regime needed to maintain the ecological values of water-dependent ecosystems (including assets, functions and processes) at a low level of risk.
FEFLOW	(Finite Element subsurface FLOW system) is a computer program for modeling groundwater flow.
Groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.
Groundwater area	Boundaries that are proclaimed under the *Rights in Water and Irrigation Act 1914* and used for water allocation planning and management.
Groundwater subarea	Areas defined by the Department of Water within a groundwater area, used for water allocation planning and management.
Hydrogeology	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
HYDSYS	Database used by the Department of Water to hold hydrographic records.
Licence	A formal permit which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source.
LiDAR	Remote sensing technology that can be used to develop ground contours by measuring the distance to on-ground objects
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Salinity	The measure of total soluble salt or mineral constituents in water. Water resources are usually classified by salinity in terms of total dissolved salts (TDS).
Stock and domestic water use	Water that is used for ordinary domestic purposes associated with a dwelling, such as: water for cattle or stock other than those being raised under intensive conditions; water for up to 0.2 hectares (if groundwater) or 2 hectares (if surface water) of garden from which no produce is sold. This take is generally considered a basic right.
Subarea	A sub-division within a Surface or Groundwater Area, defined for the purpose of managing the allocation of groundwater resources. Subareas are not proclaimed and can therefore be changed internally without being gazetted.

Target level A groundwater or pool level that is a goal to meet in average or above average years for allowing some recovery of the aquifer or ecosystem to occur.

Trigger level A groundwater or pool level that triggers management actions or responses to be implemented so that the risk of abstraction impacting on the water resource and dependent values is reduced.

Yield The amount of water that can be abstracted out of the system, after environmental water is met.

References

Braimbridge, M 2010, *Yule River – ecological values and issues,* Environmental water report series, report no. 18, Department of Water, Perth.

——2012, *Ecological water requirements of groundwater dependent ecosystems of the lower Yule River,* Environmental water report series, Report no. 24, Department of Water, Perth.

Dames & Moore 1978, *Environmental review and management program – De Grey River bore field, Port Hedland, Western Australia,* Perth.

Davidson, WA 1974, *Hydrogeology of the De Grey River area,* Record 1973/27, Geological Survey of Western Australia, Perth.

——1996, *Yule River groundwater assessment*, Record 1976/10, Geological Survey of Western Australia, Perth.

Department of Environment and Resource Management (DERM) Queensland 2009, *DERM Enhanced meteorological datasets: SILO Data Drill,* viewed 13 September 2012, <www.longpaddock.qld.gov.au/silo >.

Department of Water 2011, *Water allocation planning in Western Australia: a guide to our process*, Department of Water, Perth.

——2012 *Pilbara groundwater allocation plan: for public comment*, Water resource allocation and planning report series, Department of Water, Perth.

——in preparation a, *Pilbara groundwater allocation plan final*, Department of Water, Perth.

——in preparation b, *Monitoring program to support the Pilbara groundwater allocation plan*, Department of Water, Perth.

DHI 2009, *Letter report* 27/8/2009*: Fortescue River flow data generation for Millstream MIKE11/MODFLOW model*, DHI, Queensland.

Eberhard, SM, Halse SA & Humphreys WF 2005, 'Stygofauna in the Pilbara region, north-west Western Australia: a review', *Journal of the Royal Society of Western Australia,* 88, 167–176.

Environment Australia 2001, *A* d*irectory of important wetlands in Australia, 3rd edition,* Environment Australia, Canberra.

Forth, JR 1972, *A reappraisal of the Yule River area – Port Hedland town water supply,* Report 2, Geological Survey of Western Australian, pp. 35–62.

Fugro 2009, *Interpretation of airborne electromagnetic, magnetic and FALCON gravity gradiometer data*, Fugro Airborne Surveys Pty, Perth.

GHD 2010, *Report for Port Hedland water supply – Namagoorie bore field capacity review,* a report to the Water Corporation, GHD, Perth.

Haig, T 2009, *The Pilbara coast water study*, Hydrogeological record series, Report no. HG34, Department of Water, Perth, pp. 183.

Hodgkinson, JH, Littleboy, A Howden, M, Moffat, K & Loechel, B 2010, *Climate adaptation in the Australian mining and exploration industries*, CSIRO Climate Adaptation Flagship working paper no. 5, viewed 13 September 2012, <www.csiro.au/resources/CAF-working-papers.html>.

Kendrick, P & Stanley, F 2002, 'Pilbara 4 PIL 4 – Roebourne synopsis', In *A biodiversity audit of Western Australia's 53 biogeographical subregions in 2002,* Department of Conservation and Land Management, Perth.

Loo, I & Humphreys, L 2009, *The Indian Ocean Climate Initiative stage 3 2009 workshop report*, Indian Ocean Climate Initiative, Perth.

Loomes R 2012, *Ecological water requirements of the lower De Grey River*, Environmental water report series report no. 20, Department of Water, Perth.

——& Braimbridge, M 2010, *Lower De Grey River – ecological values and issues,* Environmental water report series report no. 12, Department of Water, Perth.

MDBC 2001, *Groundwater flow modelling guideline*, prepared for the Murray-Darling Basin Commission by Aquaterra Consulting PL, Adelaide.

Morgan, S 2010, *A report on a consultation with traditional owners in the lower Turner and lower Yule rivers,* a report prepared for the Department of Water, Yamatji Marlpa Aboriginal Corporation, South Hedland.

Morgan, D, Ebner, B & Beatty S 2009, *Fishes in groundwater dependent pools of the Fortescue and Yule rivers, Pilbara, Western Australia*, *Perth*, Centre for Fish and Fisheries Research, Murdoch University.

MWH 2010, *Development of a subregional scale numerical groundwater model of the Lower Yule catchment*, prepared for the Department of Water, Perth.

Pinder, AM & Leung, A 2009, *Conservation status and habitat associations of aquatic invertebrates in Pilbara coastal river pools*, A report to the Department of Water by the Science Division, Department of Environment and Conservation, Perth.

Roberts, J, Young, B & Marston F 2000, *Estimating the water requirements of floodplain wetlands: a guide,* occasional paper 04/00, Land and Water Resources Research and Development Corporation, Canberra.

Rockwater, 2006, *West Pilbara drought relief investigation, results of groundwater exploration and testing program and assessment of water-supply potential,* a report to the Water Corporation, Perth.

Rumley, H & Barber, K 2004, '*We used to get our water free…' – Identification and protection of Aboriginal cultural values of the Pilbara Region,* a report to the Water and Rivers Commission, Perth.

SKM 2010, *Lower De Grey groundwater model*, prepared for the Department of Water, SKM, Perth.

——2011, *Lower De Grey River groundwater model – predictive scenarios,* SKM, Perth.

Torres-Montenegro N 2010, *Ethnographic report on the lower De Grey River,* a report prepared for the Department of Water*,* Yamatji Marlpa Aboriginal Corporation, South Hedland.

van Dam, R, Storey, A, Humphrey, C, Pidgeon, B, Luxon, R & Hanley, J 2005, *Bulgarene borefield (De Grey River) Port Hedland water supply aquatic ecosystems study,* National Centre for Tropical Wetland Research, Darwin.

Water and Rivers Commission 2000, *Environmental water provisions policy for Western Australia,* Statewide Policy No. 5, Water and Rivers Commission Perth.

Whincup, A 1967, *Port Hedland town water supply – hydrogeological investigation,* Annual report 1966, Geological Survey of Western Australian, pp. 13–18.

WorleyParsons, 2005, *De Grey groundwater resources: Bulgarene bore field model, volume 1 – model development and calibration*, Perth.

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