GOVERNMENT OF WESTERN AUSTRALIA
Department of **Water**
Department of **Regional Development**
ROYALTIES FOR REGIONS

Securing Western Australia's water future

Groundwater assessment of the north-west Hamersley Range

Hydrogeological record series

Report no. HG62
August 2016

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August 2016

ISBN [978-1-925387-82-7] (print)
ISBN [978-1-925387-83-4] (online)

Acknowledgements

The Department of Water thanks the following for their contribution to this publication. This summary document was prepared by Seth Johnson of HydroConcept Pty Ltd, based on a more comprehensive, technical report. Review and editing was undertaken by James Milne, Sandie McHugh, Gary Humphreys, Kevin Hopkinson and Alex Waterhouse.

This project is made possible by the State Government's Royalties for Regions program. For more information, visit http://www.drd.wa.gov.au.

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Cover photograph: Riverine pool within Robe River

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Summary

A desktop groundwater resources assessment has identified seven prospective areas with the potential to supply low-salinity, fit-for-purpose groundwater for West Pilbara towns, industry and irrigated horticulture.

The aquifers in the **Upper Bungaroo**, **Weelumurra West** and **Caliwingina Creek** systems are the most prospective water resources in the north-west Hamersley Range. They are made up of channel-iron deposits and calcrete overlain by valley-fill material. The aquifers generally contain fresh water, have large storages, and are close to existing infrastructure. Estimates of minimum and maximum recharge and storage for each of the seven prospective aquifers give a preliminary indication of the size of renewable resources that could be developed. These are summarised in Table 1.

The **Kumina Confluence** has moderate potential as it is positioned close to existing infrastructure and has additional recharge that could be captured via stream diversion, providing this did not cause adverse downstream environmental impacts. The western options of **Yanks Bore** and **Urandy Creek** require more investigation to refine their potential. However, they may be strategically important for supplying Onslow and other nearby places.

The **Buckland** option is relatively too small for further consideration.

Table 1 Ranked groundwater supply options

Water supply option	Storage (GL)	Minimum recharge (GL/yr)	Maximum recharge (GL/yr)	Average recharge (GL/yr)
Upper Bungaroo	108	3.3	13.1	9.8
Weelumurra West	95	2.0	11.8	7.8
Caliwingina	94	2.6	10.5	7.8
Kumina Confluence	72	1.3	7.6	5.1
Yanks Bore	67	1.4	8.2	4.7
Urandy Creek	75	1.4	5.8	3.4
Buckland	23	1.2	7.1	3.1

1 Introduction

1.1 Background

The Pilbara region has seen tremendous growth in the past decade because of the 'iron-ore boom'. In the north-west Hamersley Range, most mineral exploration iron-ore mining activities are associated with channel-iron deposits (CID). These ancient, iron-rich alluvial sediments of Miocene age occupy meandering palaeochannels incised into basement rocks. These palaeochannels are also important regional aquifer systems containing valuable low-salinity groundwater.

The lack of low-salinity water resources on the Pilbara coast and high cost of desalination spurred an improved understanding of groundwater resources in the north-west Hamersley Range. The development of the Bungaroo Borefield highlighted the water supply potential from unexplored CID and valley-fill aquifers and provided focus for this assessment.

1.2 Scope and purpose

This desktop assessment aims to identify and quantify the prospectivity of groundwater sources in the north-west Hamersley Range for low-salinity, fit-for-purpose water.

The assessment collated, reviewed, analysed and verified data from the Department of Water, Department of Mines and Petroleum, mining companies and other sources to identify any potential groundwater sources. Each potential source is described in terms of its hydrology and hydrogeology. Any considerations for groundwater development are highlighted: including traditional owner/cultural sensitivities, impacts on existing groundwater users and groundwater-dependent ecosystems. The prospective areas have been ranked so that investigations to refine the findings of this assessment can be prioritised.

2 Study area

2.1 Location

The project area covers the north-western portion of the Hamersley Range (Figure 1). It extends from Weelumurra Creek and Fortescue Metals Group's Solomon operations in the east to Robe River and Pannawonica in the north-west and the Mount Stuart pastoral station in the south-west. The north-west Hamersley Range is located between the Fortescue River in the north and tributaries of the Ashburton River in the south.

This assessment focused on some important creek systems that drain from the Hamersley Range. Bungaroo, Kumina, Caliwingina and Weelumurra creeks are north-flowing drainages that discharge into the Fortescue River valley. Red Hill and Urandy creeks are west-flowing drainages with ephemeral discharges into the Robe and Ashburton rivers respectively.

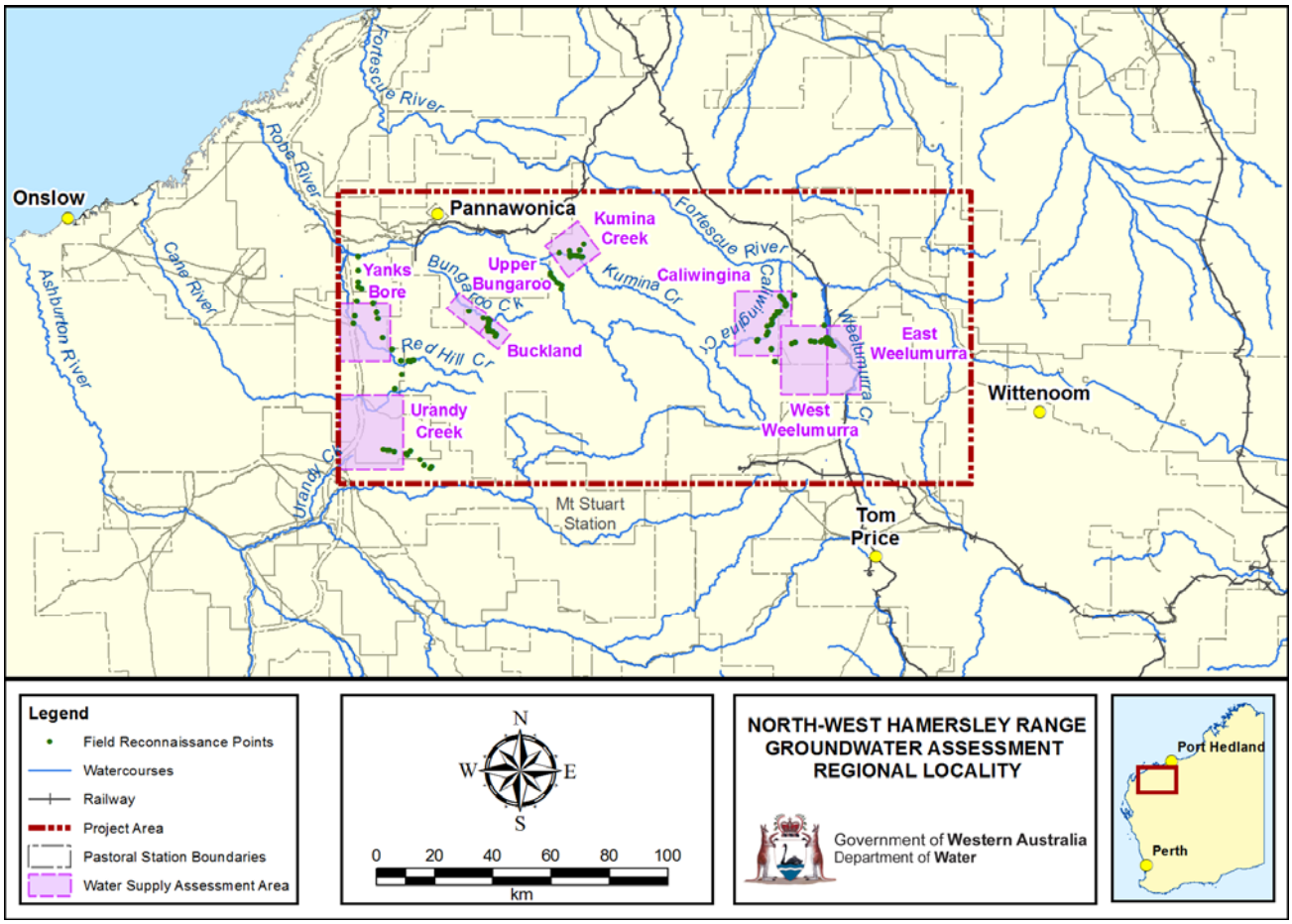


Figure 1 Study area location plan

2.2 Climate

The north-west Pilbara area has an arid-tropical climate with hot summers (wet season) from October to April and mild winters (dry season) from May to September (Gentilli 1972).

Average rainfall is less than 300 mm/year with most falling between December and April. Annual rainfall statistics can vary dramatically depending on the influence of thunderstorms and cyclone activity, which can bring events of up to 600 mm, as Cyclone Joan did in 1975. Rainfall data from single monitoring sites are not representative of an entire catchment.

In the past decade, parts of the Pilbara have experienced above-average annual rainfall associated with increased cyclonic activity. In fact, CSIRO's climate change projections with high confidence are for increased intensity of extreme rainfall events in the Northern Rangelands (CSIRO 2015). However, there is no consistency in the direction of global climate modelling results for the region as a whole with both warmer wetter and warmer drier climates possible (Department of Water 2015).

Mean annual evaporation is extremely high, usually more than 3000 mm/yr, or about ten times annual rainfall. This ensures that the landscape is arid and areas of permanent surface water are rare.

2.3 Physiography

The Hamersley Range dominates the landscape, rising 150 to 400 m above the Fortescue River valley, with local peaks of up to 800 m AHD. The Chichester Range in the north-eastern portion of the project area has gentle southern slopes with minor alluvial fans and well-defined, but narrow, drainage channels.

The ancestral Fortescue River was a significant surface water feature that flowed westward between the Hamersley and Chichester ranges during the Tertiary period. Over time, the river system filled and diverted to the north-west at Millstream and dissected to the west forming the modern-day Robe River.

Important creeks draining the Hamersley Range include the Bungaroo, Kumina, Caliwingina and Weelumurra creeks. In the south-west the Duck, Caves and Urandy creeks drain into the Ashburton River.

2.4 Environment

The ecosystems in the Pilbara have adapted to the unpredictable climate. The plants are typically low with larger trees only found along drainage features or in shallow basin areas. The animals of the Pilbara are small and able to hide in crevasses and shady places to avoid the hot, arid conditions. Wetlands and water holes are found in deep gorges as well as intermittent springs and pools of varying permanency.

Stygofauna, or groundwater-dwelling crustaceans, were first studied in the Pilbara during the 1990s (Humphreys 2001).

The Pilbara Region Biological Survey (Department of Environment and Conservation 2009) mapped the distribution of stygofauna in many different aquifer types across the Pilbara. This survey showed that stygofauna are abundant in the region and, while there is limited data on their distribution in the study area, the CID and valley-fill aquifers are thought to be good habitats.

2.5 Land use

The north-west Hamersley Range (this project area) is mainly used for iron-ore mineral exploration and mining. There are large mines at Mesa J in the north-west of the project area and at Solomon in the east. There is little pastoral activity due to limited areas for stock grazing. There are few towns, with the largest being Pannawonica that supports the Mesa J mine. The population is mostly 'fly-in/fly-out' to the mines, but Pannawonica and Tom Price (just south of the project area) have significant residential populations.

2.6 Demand for water

Growth in mining production is expected to continue as existing iron-ore projects expand. The increased demand for water at minesites is expected to be largely met by excess dewater as expanding projects develop below the watertable.

Most of the water used by coastal towns and ports adjacent to the project area is currently provided by the West Pilbara Water Supply Scheme (WPWSS). Inland towns like Pannawonica are serviced by local schemes managed by mining companies.

The WPWSS is now supported by the additional source at Bungaroo, and therefore supply in the West Pilbara ports is delivered from a combination of Bungaroo, Harding Dam and Millstream for the medium-term future. Many new mines opening within or close to the Hamersley Range project area are water-surplus mines so mining industry demand is not likely to put demand pressure on these sources except if they become active mining areas.

A major challenge for the future will be to provide low-salinity, fit-for-purpose water for the coastal region between Onslow and Dampier. Groundwater resources in the north-west Hamersley Range could meet this need.

3 Methods

This desktop assessment collected, reviewed, analysed and field-verified relevant data and information from nearly 200 reports from the Department of Water's External Report database, from other government agencies, mining companies and consultants. Most of the groundwater resource assessments of CID aquifers were restricted to proposed and existing mining operations along the Robe River upper Weelumurra Creek, and the Bungaroo Borefield (information taken from unpublished, confidential company reports provided to the Department of Water).

About 840 Western Australian Mineral Exploration database open-file reports were reviewed. Of these, only 98 contained useful data, mostly to do with geological mapping of CID outcrop and lithological logging from mineral exploration drilling. Only four mineral exploration reports contained any depth-to-water and groundwater level data.

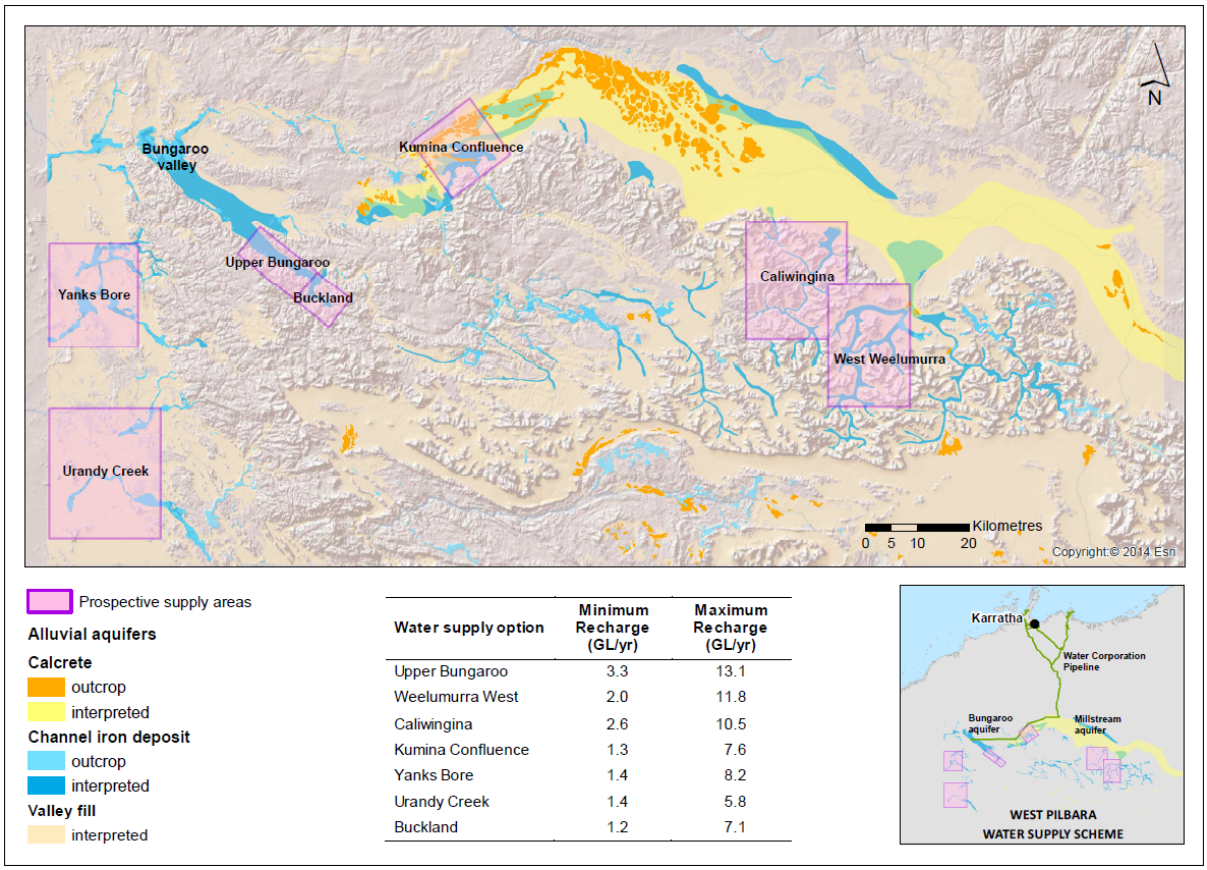
From this research, seven water supply options were chosen for individual assessment to provide a thorough understanding of their water supply potentials.

3.1 Groundwater resource assessment

Mapping the distribution of CID and valley-fill aquifers throughout the north-west Hamersley Range (Figure 2) was used as the basis for selecting the seven prospective targets for water supply development. All supply options had to meet the minimum criteria of having 20 GL groundwater storage and large up-gradient catchment areas with good recharge potential from streamflow infiltration.

The Southern Fortescue Palaeochannel may have stored groundwater but was not chosen because recharge could be unreliable. Groundwater resources on the southern side of the Hamersley Range were also not chosen because of the high cost of piping water to coastal towns and ports.

The groundwater resources near Rio Tinto Iron Ore's (RTIO) Mesa A and Mesa J are currently licenced to produce about 32 GL/yr in mine dewatering and these areas are already well understood and associated with active mining operations. So it was decided not to focus on these areas for this assessment.



Water supply option	Minimum Recharge (GL/yr)	Maximum Recharge (GL/yr)
Upper Bungaroo	3.3	13.1
Weelumurra West	2.0	11.8
Caliwingina	2.6	10.5
Kumina Confluence	1.3	7.6
Yanks Bore	1.4	8.2
Urandy Creek	1.4	5.8
Buckland	1.2	7.1

Figure 2 Aquifer distribution in the north-west Hamersley Range

Recharge estimation

Groundwater in the Pilbara recharges mostly from streamflow and flooding events. Most traditional estimations are expressed in terms of average annual rainfall across a catchment area but these approaches may provide estimates that are unrepresentative of the dominant recharge process.

More accurate estimates of groundwater recharge need high-quality and high-resolution rainfall, streamflow and groundwater level measurements but that information was not available for this project. Instead, we used a streamflow infiltration hydrographic approach, based on Dahan et al. (2007), to estimate the volume of vertical infiltration from streamflow events for each water supply option area. In some areas, complementary approaches, such as change in groundwater storage after specific rainfall or streamflow events, were used.

Creating a model for storage estimation

Groundwater storage volumes were estimated using ArcGIS and the 3D Analyst extension to create a low-resolution geological model with layers that included elevation (a digital elevation model derived from ASTER satellite information), lithology, and a regional watertable. The model was used to calculate the saturated volumes of groundwater storage in the valley-fill and CID aquifers, which were then

multiplied by specific yield of 0.05 for valley-fill and 0.15 for CID. The process and workflow employed is outlined in Figure 3.

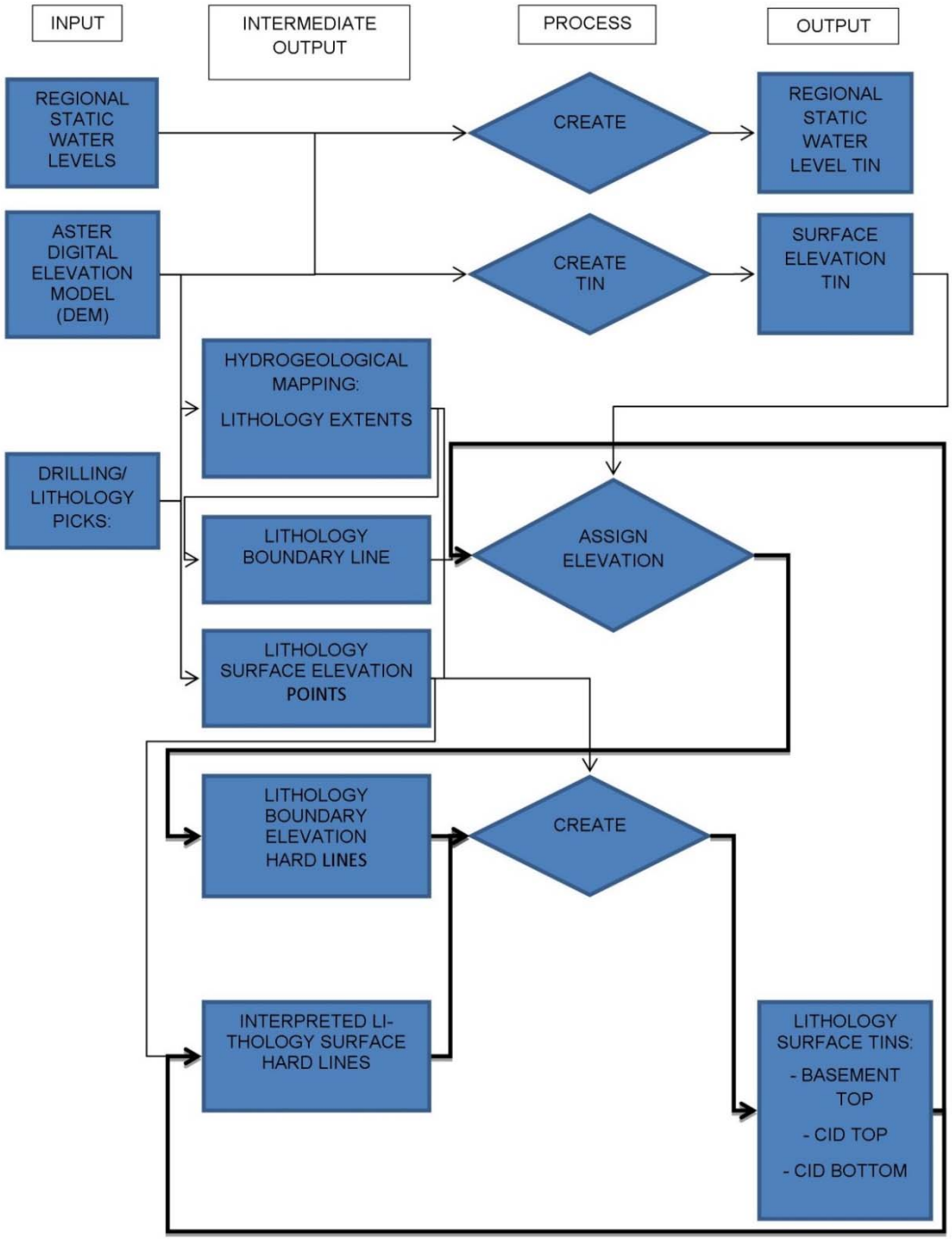


Figure 3 Layer generation workflow (Note: dark lines highlight refinement and review stages)

3.2 Surface water assessment

The aim of the surface water assessments was to estimate how much rainfall was needed to generate streamflow within the study area. Before undertaking the surface water assessments, catchment boundaries were reviewed using updated elevation information and cyclone data was analysed to understand rainfall variability.

With streamflow and rainfall monitoring in the entire Pilbara region limited and the spatial variability of thunderstorms, the assessments had to be done on relatively small catchments to ensure the observed rainfall information adequately represented the rainfall over the entire catchment. The Palra Springs (DOW 707001) streamflow monitoring site, in the headwaters of the Robe River, was identified as suitable for this purpose.

The streamflow information shows that there is some baseflow from groundwater discharge within the gauging reach. The moderate to high flows were analysed and related to rainfall to establish the minimum daily rainfall required to generate streamflow. An assessment of sixteen flow events found an average of 40 mm of rainfall was required to produce runoff at the Palra Springs streamflow gauge. The amount of rainfall required to generate streamflow varied depending on the catchment wetness before the rainfall event. A minimum of 55 mm of rainfall over 24 hours was needed to generate streamflow on a dry catchment but only 20 mm on a wet catchment.

The average duration of the flow events varied by 10–38 days at the Palra Springs streamflow gauge on the Robe River. Flow durations for the Cane River at the Toolunga streamflow gauge and Bungaroo Creek gauge were found to be 10–19 days. An average flow duration of 14 days was adopted for recharge estimation using the streamflow hydrograph approach.

4 Hydrogeology

The regional hydrogeology of the central Pilbara, which includes the south-eastern portion of the project area, is described by Johnson and Wright (2001). Barnett and Commander (1986) detailed the hydrogeology of the western Fortescue River valley with a focus on the distribution and potential of the calcrete aquifer which was later summarised by Haig (2009).

Groundwater occurs throughout the north-west Hamersley Range in the Cainozoic deposits and Archean to Lower Proterozoic basement rocks. It originates from direct rainfall recharge into basement rock outcrops and indirect recharge into the sediments via streamflow infiltration. The quantity and quality of the groundwater held in the various aquifers vary considerably.

The most prospective aquifers have been grouped into four types, as detailed in Table 2. The focus of this assessment is the valley-fill, calcrete and channel-iron deposit (CID) aquifers, as the basement rock aquifers are considered to have only localised groundwater resources.

Table 2 Most prospective aquifers

Aquifer type	Geological unit	Max. saturated thickness (m)	Bore yield (kL/day)	Aquifer potential
Valley-fill	Alluvium	15	<500	Minor
	Colluvium	20	<500	Minor
	Kumina Conglomerate	70	1500	Major
	Detritals	25	<1000	Minor
Calcrete	Calcrete	50	2000	Major
Channel-iron deposits (CID)	Channel-iron deposits	100	1500	Major
Fractured-rock	Hamersley Basin			
BIF	Brockman Iron Fm Marra Mamba Iron Fm	-	<500	Local
Dolomite	Wittenoom Formation	-	2000	Major

4.1 Valley-fill aquifer

The valley-fill aquifer comprises alluvium, colluvium, and shingles of the Kumina Conglomerate and detrital iron-ore deposits. The sedimentary sequence is often complex, reflecting various periods and modes of deposition, as well as reworking the underlying CID.

The alluvium has sand and gravel lenses that are interfingered with silty clay and clay layers. The colluvium comprises cobble-sized detritals within a clay matrix. The Kumina Conglomerate is a shingle-like alluvial deposit with granular- to boulder-sized clasts in a clayey to silty matrix. The lower part of the valley-fill is mostly detrital iron-ore deposits that are more common in the tributaries and are important for capturing runoff from basement rocks.

The valley-fill can be up to 150 m thick near RTIO's Homestead operations, but is mostly less than 50 m thick beneath the creek systems within the Hamersley Range.

The valley-fill forms the major unconfined or watertable aquifer but may be locally confined to semi-confined by sediments of low permeability. Groundwater is contained in the primary porosity of the clastic sediments. Variations in hydraulic conductivity are common owing to its heterogeneous nature, with significant increases seen in permeable sand and gravel horizons, and where the Kumina Conglomerate is found.

There is likely to be a good hydraulic connection between the valley-fill and the calcrete aquifer, but not the CID aquifer where there are clay layers at the base of the valley-fill and/or top of the CID. It is possible that detrital deposits could allow recharge pathways into the CID aquifer.

The watertable is usually 10–20 m below ground level (bgl) but can be up to 50 m deep. In places, the watertable is at the ground surface, forming riverine pools and springs. There may also be some localised perched groundwater associated with shallow, intermittent clay horizons.

The variability in depth to watertable affects the saturated thickness of the valley-fill aquifer which tends to increase in the thalweg.

Groundwater flow is away from the recharge areas, along the valley sides or centres, and down-gradient in the direction of surface water flow. Groundwater discharge is by outflow to river springs and pools, evapotranspiration from vegetation, and evaporation through the unsaturated zone where the watertable is shallow.

Barnett and Commander (1986) suggested alluvium in the Fortescue River valley has low bore yields of 50–80 kL/day, and low hydraulic conductivity 0.1–3 m/day owing to high clay content and poor sorting. Aquifer testing of the valley-fill aquifer at Bungaroo indicated variable hydraulic conductivity between 0.5 and 100 m/day (information taken from unpublished, confidential company reports provided to the Department of Water). Individual bore yields from the more permeable Kumina Conglomerate may be up to 1500 kL/day.

The valley-fill aquifer is hydrogeologically important because of the volume of stored groundwater and its hydraulic connection with the environment and surface water features. Nevertheless, except for areas of Kumina Conglomerate, the aquifer has limited potential for direct utilisation, and most groundwater will be obtained via leakage into underlying calcrete and CID aquifers.

4.2 Calcrete aquifer

Calcrete occurs as exposed mounds within the Fortescue River valley and thin discrete layers between the CID and valley-fill aquifers in the palaeotributaries. The calcrete can be up to 50 m thick at Millstream (Barnett & Commander 1986) but is generally less than 10 m thick.

The calcrete is characterised by secondary porosity with karstic features developed through the partial dissolution of the calcrete. Calcrete is an important aquifer capable of supplying shallow, fresh to brackish groundwater for use in town water schemes, horticultural developments and mining. The calcrete aquifer at Millstream has provided groundwater resources into the West Pilbara Water Supply Scheme for more than forty years. Recently, this has been augmented by the Bungaroo Borefield owing to concerns about abstraction impacts on groundwater-dependent ecosystems.

4.3 Channel-iron deposit (CID) aquifer

CIDs form a significant regional aquifer where they are found close to and beneath drainage lines. The greatest aquifer potential is where it fills channels cut into basement rocks and is overlain by a saturated valley-fill aquifer. Where the CID is outcropping as mesa landforms in the west of the project area, it is elevated and unsaturated. The aquifer is 40 to 50 m thick in most palaeotributaries within the Hamersley Range but is up to 125 m thick towards the headwaters of Bungaroo Creek (Iron Ore Holdings 2013). In western areas, the CID is typically thinner as the upper and lower CID has been eroded.

The distribution of the CID aquifer varies across the Hamersley Range. In the tributaries, it usually forms a continuous sequence but there are places where the CID has been deeply incised by modern drainages to form disconnected bodies. Around the ancestral Fortescue River, distribution is irregular owing to multiple periods of erosion. In the west, the CID has been topographically inverted to form discontinuous and isolated mesa outcrops.

The aquifer has a goethitic zone that is highly porous and vuggy; these vugs can fill with clay, reducing the permeability of the CID. Areas of hardened goethite can also have lower permeability and bore yields. The lower CID is most prospective because it is more permeable, being friable and granular with minor cementation and less clay. A clay layer up to 10 m thick at the top of some parts of the CID could be a semi-confining aquitard overlying the CID aquifer.

Many aquifer tests over the past decade have shown that in the Weelumurra area to the east, the CID aquifer has hydraulic conductivities between 30 and 120 m/day and storativity values between 2 x 10^{-6} and 0.02. The hydraulic conductivity of the CID aquifer beneath the Bungaroo Creek varied between 0.5 and 10 m/day in the overlying hardcap CID and basal clay, and up to about 70 m/day in the friable lower CID (information taken from unpublished, confidential company reports provided to the Department of Water). The CID aquifer often responds as a dual porosity, fractured-rock aquifer with initial inflow from storage in the vugs and fractures, followed by inflow from the saturated matrix (FMG 2011).

The CID contains significant stored groundwater resources. Long-term pumping could cause leakage from overlying and surrounding lithologies adding to bore yields which can be more than 1500 kL/day. Groundwater is mostly fresh and potable, particularly where positioned beneath modern-day drainages.

4.4 Fractured-rock aquifer

Fractured-rock aquifers are found in many different basement rocks. Groundwater occurs where secondary porosity has developed in fractured and weathered zones or along bedding plane partings or joints. The tight basement rocks outside these areas contain little or no groundwater. Although many geological formations in the Pilbara are actually sedimentary rocks, they have been greatly altered over geological time so they no longer have a primary porosity but behave in hydrogeological terms like fractured rocks.

Banded iron-formation (BIF) aquifers exist in the Brockman and Marra Mamba Iron formations. The rocks are brittle, relatively resistant and are preserved as ridges that dominate the landscape. Groundwater storage potential in the BIF is linked to fractures and ore mineralisation, is only ever localised, but can yield up to 1000 kL/day.

Town and mine water supplies in the central Pilbara mostly come from the dolomitic aquifers in the Wittenoom Formation (Johnson & Wright 2001). Bore yields can be up to 2000 kL/day, depending on the intersected fracture and cavern density. Yields may be higher in the valley centres where the dolomite is well fractured and cavernous but lower near valley sides where the dolomite is mostly massive, hard and un-fractured.

4.5 Recharge

The following discussion does not include sufficient data to analyse each of the aquifer types described in Sections 4.1–4.4. Groundwater is recharged from surface water runoff and streamflow after significant rainfall events and flooding, especially around modern drainages. Aquifers in the north-west Hamersley Range also recharge through runoff infiltration along the valley margins, downward leakage into underlying aquifers, sheet flow across alluvial fans and scree slopes at the base of the ranges, and through direct rainfall infiltration.

Recharge is higher where the watertable is deep and the valley-fill aquifer is unsaturated (Winter et al. 1998). The rate of recharge infiltration from creeks could be affected by near-surface clay layers in the alluvium, as well as areas of shallow watertable.

Outcropping basement rocks on the valley flanks have limited infiltration capacity, so a high proportion of rainfall becomes runoff which reaches the valley floors. At the edges of the valleys are scree slopes of colluvium and detrital deposits that can absorb this runoff. This recharge process works better where the valleys are narrower and scree slopes are well developed.

Because the CID aquifer is buried, it recharges by leakage from overlying aquifers and lithologies throughout most of the tributaries. This leakage would be most likely where there is no clay layer – at the flanks where detrital deposits are overlain by permeable Kumina Conglomerate.

Groundwater levels rise rapidly from streamflow infiltration and drop during dry periods. Rainfall alone does not often directly affect groundwater levels (information taken from unpublished, confidential company reports provided to the Department of Water).

The deep watertable suggests that there is much capacity to take water from recharge events, though this depends on how well creek beds and the valley-fill aquifer can absorb the water. So some areas of shallow or near-surface watertable may lack capacity to absorb water during recharge events. Pumping water from these aquifers would generate space for recharge from future streamflow events.

4.6 Groundwater quality

Groundwater in the valley-fill and CID aquifers is fresh and its salinity in the upper reaches of some of the tributaries, such as Bungaroo and Weelumurra creeks, can be less than 200 mg/L total dissolved solids (TDS). The fresh groundwater suggests that there is active, modern groundwater recharge beneath the drainages.

Low salinity groundwater mounds have been observed beneath Bungaroo and Kumina creeks. This shows that groundwater recharge through the creek bed is an active and important process for improving and maintaining the fresh groundwater. The salinity of Kumina Creek increases slightly away from the drainage.

Groundwater pH tends to be neutral to slightly alkaline with pH 7.0–8.0. In places, the groundwater can be hard to very hard with up to 400 mg/L $CaCO_3$. Nitrate levels vary but are usually less than 5 mg/L NO_3. Some samples suggest that groundwater salinity may be improving as a result of increased recharge over the past decade after more intense and frequent rainfall events.

4.7 Resource potential

The CID aquifer is a regionally significant groundwater resource with development potential for water supplies. This aquifer is also an important water source for RTIO's Robe River operations and FMG's Solomon operations.

The CID aquifer is readily recharged by the infiltration of streamflow. It is most prospective where it is concealed and buried beneath saturated valley-fill and calcrete aquifers. Groundwater can be directly pumped at more than 1500 kL/day, with some recharge through leakage from overlying lithologies after long-term pumping. The groundwater quality is typically fresh and potable, particularly where positioned beneath modern-day drainages.

Most CIDs have exploration leases on them and/or are being considered for iron-ore mine development. There is potential competition between preserving the CID as a groundwater resource for water supply and mining it for iron ore.

The calcrete could provide large supplies of shallow, fresh to brackish groundwater. The Millstream Borefield provided groundwater into the West Pilbara Water Supply Scheme for more than forty years but has recently been augmented by the Bungaroo Borefield to reduce the impacts on groundwater-dependent ecosystems. Brackish groundwater resources in the eastern Fortescue River valley can be developed with minimal impact on the riverine pools at Millstream.

The valley-fill aquifer contains stored groundwater but has limited potential for direct use owing to its low permeability. There is localised and limited potential where the Kumina Conglomerate is thick and positioned under modern drainages. In fact, most groundwater in the valley-fill would be accessed after it leaks into underlying calcrete and CID aquifers. Pumping this water though could affect surface water features and the environment because of their hydraulic connections to the valley-fill aquifer.

Dolomite in the Wittenoom Formation and mineralised sections of the Marra Mamba Iron Formation forms significant local **fractured-rock aquifers**. For many years, the high-yielding Wittenoom Formation was the primary groundwater target in the Central Pilbara owing to its well-developed secondary porosity and high permeability. However, in recent years, increased mine dewatering from mineralised sections of the Marra Mamba Iron Formation, are potentially reducing yields.

5 Upper Bungaroo

5.1 Overview

The Upper Bungaroo area is prospective for water resource development with its thick, permeable valley-fill and CID aquifer system that is recharged by the substantial surface water stream flow of Bungaroo Creek.

The Bungaroo Borefield established in 2010, just north of the proposed Upper Bungaroo area, provides extra capacity and reliability into the West Pilbara Water Supply Scheme (WPWSS) and for dust suppression needs at Cape Lambert port facility (information taken from unpublished, confidential company reports provided to the Department of Water). The borefield has shown further potential as a groundwater resource in the upper Bungaroo Creek, as well as similar hydrogeological settings across the north-west Hamersley Range.

The Upper Bungaroo area is located about 40 km south-east of Pannawonica and 35 km south-east of the RTIO Mesa J iron-ore mine. It is associated with Bungaroo Creek, which flows northward into the Robe River, and sits within the basement rocks of the north-western Hamersley Range.

The main valley of the Bungaroo Creek above its junction with Jimmawurrada Creek extends about 17 km in an east-south-east direction, and is incised into the Hamersley Range. It has many braided creeks that flood often during the wet season. The creek bed is quite flat with the surrounding ridges rising sharply to elevations between 60 and 140 m above the valley floor. Its upper catchment is quite rugged terrain with watercourses incised into the Hamersley Range.

The catchment above the Jimmawurrada Creek junction includes the Bungaroo valley and minor catchments entering from the valley sides. The catchment area above the head of the main valley, where the two main tributaries come together, is 514 km² – this area also includes the prospective water supply at Buckland.

The CID and overlying valley-fill aquifers in the Upper Bungaroo have potential for water supply development. The CID aquifer is thick and well preserved beneath a thick sequence of highly permeable valley-fill deposits. Groundwater is fresh and potable with potentially large bore yields. The many completed high-quality surface water and groundwater resource studies of the Bungaroo Valley provide confidence for this assessment.

5.2 Renewable resources

The hydrographic approach was used to estimate groundwater recharge in terms of potential infiltration related to streamflow events. The main assumptions for Upper Bungaroo are a flooded creek width of 200 m; creek and southern tributary length (sitting on the aquifer) of 17 km; flow event duration of 14 days; and number of flow events per year being an average of 1.5 events per year (0.5 events at 25%

percentile and two events at 75% percentile). The average potential groundwater recharge may be 9.8 GL/yr with a range between 3.3 and 13.1 GL/yr.

Aquaterra (2003) estimated groundwater throughflow to be 0.6 GL/yr in the Upper Bungaroo. This increased to 1.8 GL/yr at the confluence of the Bungaroo and Jimmawurrada groundwater systems. The groundwater throughflow estimates have been refined, based on improved 3-D appreciation of the aquifer cross-sectional area and water level fluctuations, to range between 1.8 and 3.8 GL/yr (information taken from unpublished, confidential company reports provided to the Department of Water).

5.3 Stored resources

The total stored groundwater resources in the valley-fill (42 GL) and CID (112 GL) aquifers associated with the Upper Bungaroo are estimated at 154 GL. Groundwater resources in the CID aquifer are much greater, although the valley-fill estimate is considered conservative and the shingle material would provide groundwater recharge in the entire aquifer system. The largest resources are towards the valley centre where the saturated thickness is greater.

5.4 Resource development

There are fresh groundwater resources in the Upper Bungaroo. It has high potential as a groundwater resource because of its saturated thickness, permeable aquifers (both shingle alluvium and CID), and streamflow infiltration recharge from Bungaroo Creek.

The sustainable yield of the aquifer will be limited by the frequency and amount of recharge from flow events. The potential yield is estimated at about 10 GL/yr and would depend on the extent of aquifer used. Increases in aquifer infiltration capacity may be achieved through lowering the watertable near the creek line to generate added storage.

Individual bores could yield more than 1000 kL/day if bore spacing is about 1–1.5 km to minimise drawdown impacts and interference. This is a similar configuration to that in the existing Bungaroo Borefield (information taken from unpublished, confidential company reports provided to the Department of Water).

Further work is required to establish the sustainable yield of the groundwater system and thoroughly assess the impacts of water supply development. This is important as the Upper Bungaroo is subject to development by two nearby mines. Further abstraction from the Upper Bungaroo has potential to reduce the yield from the existing approved and licensed Bungaroo Borefield. Cumulative impacts on the groundwater resource with respect to this borefield should be further assessed.

6 Weelumurra

6.1 Overview

The Weelumurra area is prospective for groundwater resource development with its thick, permeable valley-fill and CID aquifers that are recharged by the Weelumurra Creek surface stream flow. The development of FMG's Solomon mine in the CID to the east of Weelumurra has highlighted the potential of the CID as a regionally extensive and high-yielding aquifer.

The Weelumurra area, 100 km north-west of Tom Price and 75 km south-east of the Millstream National Park, is within the Hamersley Range and south of the Fortescue River valley. It is surrounded by a number of prospective mineral resources including RTIO's Caliwingina deposit to the west, Flinders Mines' Blacksmith deposits to the south-west, FMG's Serenity and Mt Shelia deposits to the south, and FMG's Firetail and Solomon deposits to the east.

Since the late 1970s, various companies have undertaken mineral exploration in the Weelumurra area. BHP (1978a & b) completed a geophysical survey and drilling program that found a buried CID palaeochannel though the thick overlying sequence of alluvium and colluvium stopped further investigation. Mining companies are now focussing more on buried CIDs because high-quality haematite iron-ore deposits are being depleted (Petts et al. 2011).

The CID and overlying valley-fill aquifers could provide good water supplies. There is a continuous CID aquifer buried beneath a thick sequence of permeable valley-fill deposits. Minor aquifers are associated with calcrete and silcrete layers that occur at the base of the valley-fill aquifer. The presence of a clay aquitard between the valley-fill and CID aquifers will result in some hydraulic separation. The groundwater appears to be fresh and potable with potentially large bore yields.

6.2 Renewable resources

Groundwater recharge has been estimated using the streamflow infiltration hydrograph approach. This has been based on vertical infiltration of streamflow along 15 km and 31 km of aquifer in Weelumurra West and Weelumurra East respectively, and an average creek width of 200 m. The number of days that exceeded 40 mm rainfall, as recorded at the Bureau of Meteorology's 005005 Hamersley Rainfall Station in the south, was used as a proxy for calculating the number of streamflow events.

Based on an average of two flow events per year (0.5 events at the 25% percentile and three events at the 75% percentile), the average potential groundwater recharge is 9.8 GL/yr (ranging from 4.1 to 14.2 GL/yr) for Weelumurra East and 7.8 GL/yr (2 to 11.8 GL/yr) for Weelumurra West.

FMG (2011) estimated groundwater throughflow for several sections of the Solomon CID deposit ranging from 0.16 ML/day in the headwaters to 2.16 ML/day at the

discharge outlet into Weelumurra Creek. Using a similar approach, a groundwater throughflow of 2.5 ML/day was estimated for the Serenity area. These estimates represent groundwater throughflow in the Weelumurra area.

6.3 Stored resources

The combined stored groundwater resources in the valley-fill (154 GL) and CID (234 GL) aquifers for the Weelumurra area are estimated at 388 GL. Groundwater resources in the CID aquifer are much larger as it is mostly saturated throughout the area. The valley-fill aquifer, however, is unsaturated towards the headwaters and valley flanks. The largest resources are most likely to be towards the valley centre, where the saturated thickness is greater.

6.4 Resource development

There are good, fresh groundwater resources in the Weelumurra area – both in terms of storage and recharge. When compared with Weelumurra East, Weelumurra West should be better for developing groundwater resources with its greater saturated thickness, permeable aquifers, and a lack of other users.

The best place for a water supply borefield is in Weelumurra West along the aquifer system between FMG's Serenity deposit in the south and the confluence of the two creeks in the north. Despite there being a substantial aquifer system, the potential development area may be constrained by the possibility of future mine development by FMG.

The western tributary of Weelumurra Creek has excellent potential as a water supply option. The potential yield is estimated at about 7.8 GL/yr, being limited by the frequency and amount of recharge from flow events. Potential increases in aquifer infiltration capacity may be achieved through lowering the watertable near the creek line. Individual bore yields of up to 1000 kL/day are achievable at a bore spacing of about 1.5 km.

The Weelumurra catchment (both East and West) is within the source protection area for Millstream and also potentially mining areas for FMG (Solomon "queens valley" and Serenity). Any pumping from here would need to be assessed to ensure no effects on Weelumurra Creek and to the available supply (quality and quantity) at Millstream.

Further work is required to establish the sustainable yield of the groundwater system and assess the consequences of water supply development. A sustainable yield can only be established once the economic, social and environmental values of the area are well understood.

7 Caliwingina

7.1 Overview

The Caliwingina area is prospective for water resource development with its thick, permeable valley-fill and CID aquifer system that is recharged by Caliwingina Creek's surface water catchment. The development of FMG's Solomon mine, about 40 km south-east of Caliwingina, in a similar buried CID has highlighted its potential as a regionally extensive and high-yielding aquifer.

The Caliwingina area, within the Hamersley Range and south of the Fortescue River valley is 100 km north-north-west of Tom Price and 55 km south-east of the Millstream National Park. It is located at the western edge of the Central Hamersley Range CID province with a number of prospective mineral resources to the east including Flinders Mines' Blacksmith deposits; and FMG's Serenity, Mt Shelia, Firetail and Solomon deposits.

Since the late 1970s, various mining companies have explored the Weelumurra area. BHP (1978a) and CRA Exploration (1992 & 1993) completed drilling for CID in the northern part of Caliwingina Creek and beneath the large alluvial fan that merges into the Fortescue River valley. This was later followed up by Hamersley Iron Exploration (1999) with drilling along a number of tributaries associated with Caliwingina Creek.

There is a lack of publicly available information for Caliwingina owing to RTIO's interest in future mine development. Dalstra et al. (2009) presented a summary of RTIO's drilling programs with a detailed interpretation of the channel-iron deposits within Caliwingina Creek. This publication provided information on CID extent, with cross-sections indicating a sequence of valley-fill and CID up to 100 m thick.

The CID and overlying valley-fill aquifers are potentially good water supplies. There is a continuous CID aquifer buried under a thick sequence of permeable valley-fill deposits. The groundwater is fresh and potable with potentially large bore yields.

7.2 Renewable resources

Barnett and Commander (1986) suggested that the Caliwingina catchment is a major source of recharge. They estimated groundwater recharge to the Millstream aquifer from Caliwingina Creek at 7.7 GL/yr, using a chloride-ion balance approach. This showed the proportion of rainfall contributing to groundwater recharge as a ratio of chloride ion in rainfall to that in groundwater, assuming that no chloride-ion is lost.

The hydrographic approach estimated groundwater recharge in terms of potential infiltration related to streamflow events, based on a flooded creek width of 200 m; creek length (overlying aquifer) of 20 km; flow event duration of 14 days; and number of flow events per year being an average of 1.5 events per year (0.5 events for 25% percentile and two events for 75% percentile). The average potential groundwater recharge was estimated at 7.8 GL/yr with a range between 2.6 and 10.5 GL/yr.

The estimations are considered a maximum or total recharge potential, as the aquifer beneath the creek is now effectively full and recharge can only happen where the aquifer has receiving capacity. The shallow watertable and riverine pools suggest a large percentage of streamflow, or potential groundwater recharge, may be rejected by the aquifer.

Using Darcy's equation, groundwater throughflow is estimated at 0.8 ML/day or about 300 ML/yr. This is based on an aquifer area of 500 m by 80 m multiplied with a hydraulic gradient of 0.004 and hydraulic conductivity of 5 m/day.

7.3 Stored resources

The stored groundwater resources in the valley-fill (35 GL) and CID (71 GL) aquifers for the Caliwingina area are estimated at 106 GL. Groundwater resources in the CID aquifer are larger as it is mostly saturated throughout the area, with the valley-fill aquifer unsaturated towards the valley flanks. The largest resources will be towards the valley centre where there is increased saturated thickness.

7.4 Resource development

The Caliwingina area has groundwater resources, both in terms of storage and recharge, because of its saturated thickness, presence of permeable aquifers and a lack of other groundwater users.

There is about 20 km of aquifer for potential water supply borefields. The sustainable yield of the aquifer is limited by the frequency and volume of recharge from flow events, with the potential yield of the aquifer about 7.8 GL/yr. The aquifer has a lot of groundwater storage and is actively recharged by streamflow events. Potentially, the aquifer infiltration capacity can be increased by lowering the watertable near the creek line.

Bore yields are difficult to estimate without hydraulic testing, though individual bore yields of up to 1000 kL/day are achievable. Bores should be spaced about 1.5 km apart to minimise drawdown impacts and interference.

The development of the Caliwingina aquifer as a potable water supply for the West Pilbara Water Supply Scheme is affected by potential competition with RTIO's desire to dewater and mine the CID mineralised orebody. In addition, Caliwingina Creek is within the Priority 2 Groundwater Protection Area for the Millstream aquifer, as the creek is considered to be an important recharge area for aquifers in the Fortescue River valley.

8 Kumina Creek Confluence

8.1 Overview

The Kumina Creek Confluence is prospective because of Kumina Creek's large surface water catchment of about 570 km^2, its saturated thickness, presence of permeable aquifers and proximity to existing infrastructure. Previous groundwater investigations by Barnett and Commander (1986) suggested the buried CIDs contain fresh groundwater resources. The nearby Millstream infrastructure provided additional incentive for a more thorough assessment.

The Kumina Creek Confluence is located 55 km east-south-east of Pannawonica and 35 km south-west of the Millstream National Park. It is positioned at the base of the north-western Hamersley Range within the Fortescue River Valley.

The calcrete aquifer at Millstream was extensively explored from 1968 to 1982 by the Public Works Department (Davidson 1969) and the Geological Survey of Western Australia (Barnett & Commander 1986). The Kumina Creek Confluence is in the western part of the exploration area and a number of drill holes revealed variable sequences of valley-fill and CIDs to depths of about 60 to 80 m (Barnett & Commander 1986). More recently, Australian Premium Iron (API) has renewed interest in the economic potential of the CID at Kumina Creek (now referred to as the Yalleen CID).

The CID and overlying valley-fill aquifers at the mouth of Kumina Creek in the Fortescue Valley may contain good water supplies. The CID along the middle to upper reaches of the creek is localised and lacks the same potential for water supply. Barnett and Commander's (1986) investigation provides the only available groundwater data in Kumina Creek, as mineral exploration drilling generates no water data and the more recent studies by API have not been released.

8.2 Renewable resources

Between January and June 1984, 344 mm of rainfall caused significant runoff and streamflow in Kumina Creek, as well as a noticeable rise in groundwater levels. Groundwater storage, or effective recharge, increased by about 5 GL. This equates to an average rate of recharge of 45 ML per flow day, or 3.5 ML per km of aquifer per flow day. This volumetric recharge assessment compares well with the hydrographic approach, which suggests groundwater recharge tends to be an average of 5.1 GL/yr, ranging between 1.3 and 7.6 GL/yr.

Despite this, the recharge intake area may be a limiting factor for the Kumina Creek Confluence. There is a need to study whether streamflow can be slowed using barriers or diverted into infiltration areas to increase recharge, as the deep water levels suggest that there is ample groundwater storage capacity.

Groundwater throughflow for the Kumina Creek Confluence is estimated at 0.7 ML/day or about 260 ML/yr, based on an aquifer area of 500 000 m^2 multiplied

with a hydraulic gradient of 0.0014 and hydraulic conductivity of 1 m/day. This estimate compares closely with that by Barnett and Commander (1986) who suggested groundwater throughflow to the Robe River is about 400 ML/yr. Most groundwater throughflow is believed to be lost as evapotranspiration from the large areas of vegetation along the creek and with a minor component of groundwater flow within the shallow alluvium.

8.3 Stored resources

The stored groundwater resources in the valley-fill (53 GL) and CID (91 GL) aquifers associated with the Kumina Creek Confluence are estimated at 144 GL. The largest resources lie towards the centre of the Fortescue River Valley where there is increased saturated thickness. The groundwater resources in the valley-fill aquifer are best accessed indirectly via leakage into the CID aquifer. The discontinuous nature of the CID aquifer would require careful consideration in the development of a water supply borefield.

8.4 Resource development

A potential water supply borefield near the Kumina Creek could be developed before progressively moving eastward over time. The yield of the aquifer is limited by the frequency and volume of recharge from flow events, as well as the length of creek overlying the permeable valley-fill aquifer. The potential yield of the aquifer is estimated at about 5.1 GL/yr, but consideration should be given to retarding the streamflow to capture additional recharge as the aquifer has a large storage capacity.

The development of the Kumina Creek Confluence as a potable water supply for the West Pilbara Water Supply Scheme is affected by potential competition with API's desire to dewater and mine the CID mineralised orebody. The Kumina Creek Confluence is currently within the Priority 2 Groundwater Protection Area for the Millstream aquifer. The presence of a groundwater divide between Kumina Creek and Millstream suggests that groundwater flow may be towards the north-west and does not influence the water regime at Millstream.

9 Yanks Bore

9.1 Overview

In the western part of the north-west Hamersley Range, the CIDs have been topographically inverted resulting in mesa-like outcrops. Similar CIDs have been explored and are currently being mined by RTIO at Mesa J, about 40 km north of the Yanks Bore area. These mining operations are licensed to dewater up to 32GL, meaning there is a lot of groundwater associated with these mesa-like CIDs.

The Yanks Bore area is located about 55 km south-west of Pannawonica and 100 km east-south-east of Onslow. It is positioned at the western edge of the Hamersley Range within the Red Hill pastoral station. Red Hill Creek flows to the north-west through the area before discharging into the Robe River.

South of the Robe River, a number of westerly-trending CIDs have been of interest for mineral exploration and mine development for the past couple of decades. In recent years, there has been increased focus on the Ken's Bore, Cochrane and Jewel CID orebodies by API and so there is little publicly available information and data.

The Yanks Bore area is prospective and has a thick, permeable valley-fill aquifer associated with the CID aquifer. The CID aquifer has variable saturation because it is elevated. However, the adjacent valley-fill aquifer is likely to be saturated and readily recharged.

It is difficult to know how much groundwater is available due to the lack of adequate data. However, the CID and valley-fill aquifers have stored groundwater resources that are frequently recharged by streamflow and sheet flow. An estimation of groundwater resources was attempted to support the prioritisation and selection of water supply options.

9.2 Renewable resources

The hydrographic approach provided an estimate of groundwater recharge, based on a flooded creek width of 100 m; creek overlying aquifer length of 22 km; flow event duration of 14 days; and number of flow events per year being an average of 1.7 events per year (0.5 events at 25% percentile and three events at 75% percentile). The potential groundwater recharge is estimated at 4.7 GL/yr, with a range between 1.4 and 8.2 GL/yr.

9.3 Stored resources

The groundwater storage was estimated based on a limited understanding of aquifer distribution. A combined, single aquifer that considered stored groundwater resources for both the CID and valley-fill aquifers was assumed. The groundwater

storage in the Yanks Bore area is estimated at 67 GL, based on an aquifer area of 67 km^2, an average saturated thickness of 20 m and specific yield of 0.05.

9.4 Resource potential

There is groundwater resource potential for water supply in the Yanks Bore area but not enough data to confirm how much. The groundwater resources are likely to be fresh and there may be significant saturated thicknesses of valley-fill aquifer. A yield of 4–5 GL/yr could be possible. This is smaller than other supply options in terms of stored and renewable groundwater resources.

A water supply borefield could be developed but there are potential issues associated with the mining of CID orebodies within the catchment. Further work would also be required to assess the cumulative impacts of groundwater abstraction on the resource and associated ecosystems.

10 Urandy Creek

10.1 Overview

The Urandy Creek water supply area is located about 95 km south-west of Pannawonica and 130 km east-south-east of Onslow, at the western edge of the Hamersley Range. The Cane River flows from east to west to the north while Urandy Creek is in the middle and discharges into the Ashburton River to the south-west and eventually reaches the coast.

A number of west to south-west trending CIDs have been the interest of mineral exploration and mine development companies for the past couple of decades. In the Urandy Creek area, there has been recent focus by API in the Cardo Bore and Catho Well CID orebodies. As with Yanks Bore, there is little available information and data owing to the 'live' tenement status relating to the proposed mining operations.

Urandy Creek is prospective for groundwater resource development with its thick, permeable valley-fill aquifer that is associated with the adjacent CID aquifer. The CID aquifer is similar to those along the Robe River suggesting connectivity and recharge potential associated with streamflow. The CID aquifer has different saturations at the Cardo Bore and Catho Well. The CID is believed to thicken to the south-west and is buried beneath the valley-fill aquifer which is readily recharged by streamflow and sheet flow. As the CID to be mined in the north and east is largely unsaturated the focus of future water supply exploration should be in western areas.

It is difficult to know how much groundwater is available in the Urandy Creek area with the lack of adequate data. The CID and valley-fill aquifers could have plentiful stored groundwater resources that are frequently recharged. So, to support the prioritisation and selection of water supply options, a groundwater resource estimation was attempted.

10.2 Renewable resources

The hydrographic approach was used to estimate groundwater recharge. The main assumptions were a flooded creek width of 100 m; creek overlying aquifer length of 22 km; flow event duration of 14 days; and number of flow events per year being an average of 1.7 events per year (0.5 events at 25% percentile and three events at 75% percentile). The potential groundwater recharge was estimated at 3.4 GL/yr with a range between 1.4 and 5.8 GL/yr.

10.3 Stored resources

Groundwater storage, based on the limited understanding of aquifer distribution, was estimated. A combined, single aquifer that considers stored groundwater resources for both the CID and valley-fill aquifers was assumed. The groundwater storage in the Urandy Creek area is estimated at 92 GL, based on an aquifer area of 92 km^2, an average saturated thickness of 20 m and specific yield of 0.05.

10.4 Resource potential

There is groundwater resource potential for water supply in the Urandy Creek area but not enough data to properly evaluate and confirm how much. The groundwater resources are fresh and there may be significant saturated thicknesses of valley-fill, and possibly a buried CID aquifer. This aquifer could yield 3–4 GL/yr but, compared with other options, the Urandy Creek area is smaller in terms of stored and renewable groundwater resources and the least understood.

The south-western portion of the Urandy Creek area is considered the most prospective supply option. Despite the limited data, there is confidence that there are thick sequences of valley-fill and CID aquifer that should be fully evaluated for water supply. Further work is required to better understand the water resource potential, most importantly in terms of aquifer extent and recharge contribution.

There are no major development constraints related to the Urandy Creek water supply option. Despite API having environmental approval from the Environmental Protection Agency for mining of the Catho Well orebody (EPA 2011), it is understood that this orebody is largely above the watertable and dewatering impacts would be minimal and highly localised.

11 Buckland

The Buckland water supply option is located about 50 km south of Pannawonica. The RTIO Bungaroo Creek deposit and Mesa J iron-ore mines are 17 km and 40 km downstream respectively. It is located within the upper reaches of Bungaroo Creek that flows northward into the Robe River and has incised into the north-western Hamersley Range.

In the upper reaches of Bungaroo Creek are two tributaries with variable thicknesses of CID. There are important differences in the tributaries relating to their nature, continuity and availability of information. It was decided to focus on the southern tributary, as the northern tributary has deeply-incised, discontinuous CID with limited aquifer potential. In addition, there is little hydrogeological data on the northern tributary, while there has been mineral exploration in the southern tributary by API and Iron Ore Holdings (IOH).

The CID aquifer at Buckland has limited potential for water supply development because of its low groundwater storage and groundwater recharge. More importantly, the major limitation for resource development is the possibility of mining more than half of the CID orebody and aquifer.

12 Conclusions

The Pilbara region has seen tremendous growth and expansion over the past decade resulting in increased water consumption and demand. Current water supply schemes can meet the short-term water requirements although there is potential demand for low salinity, fit-for-purpose industrial water at and along the coast related to new mining projects and supporting project expansion.

The Department of Water's Regional Water Supply Strategy (Department of Water 2013) suggested a possible option is the development of groundwater resources in CID and valley-fill aquifers in the north-west Hamersley Range. This study provides the necessary groundwater information to help select future water supply options.

Seven prospective targets were identified for water supply development and individual resource assessments. The groundwater storage and potential recharge estimates for each option are summarised in Table 3. Storage estimates only relate to the most prospective parts of the groundwater resource and likely development area rather than the entire aquifer system. The minimum and maximum recharge estimates are indicative and aim to highlight the variability in groundwater recharge between years. The average recharge values may be considered an estimate of potential yield for planning purposes.

Table 3 Ranked groundwater supply options

Water supply option	Storage (GL)	Minimum recharge (GL/yr)	Maximum recharge (GL/yr)	Average recharge (GL/yr)
Upper Bungaroo	108	3.3	13.1	9.8
Weelumurra West	95	2.0	11.8	7.8
Caliwingina	94	2.6	10.5	7.8
Kumina Confluence	72	1.3	7.6	5.1
Yanks Bore	67	1.4	8.2	4.7
Urandy Creek	75	1.4	5.8	3.4
Buckland	23	1.2	7.1	3.1

The most prospective options for groundwater resource development are the Upper Bungaroo, Weelumurra West and Caliwingina. The Kumina Confluence has moderate potential because it is close to existing infrastructure and additional recharge may be captured via stream diversion. The western options of Yanks Bore and Urandy Creek need more investigation to resolve their potential; however, they may be strategically important for supplying Onslow and other sites en route.

The Buckland option is too small for consideration.

All water supply options require additional investigations to demonstrate their development potential and assess the impacts of groundwater abstraction on

ecosystems and other users. The size/extent of investigations is dependent on whether the mining companies will provide/release the data and information they hold. Further investigations will be required to resolve water supply potential prior to borefield development.

Development constraints mainly relate to the mining industry. All of the prospective CID aquifers have various mineral exploration and mining tenures and, in some cases, there are active mining proposals underway or approved for commencement. As a CID is both an iron-ore resource and an aquifer, all of the prospective water supply options are also considered potential mining areas.

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