
CENTRAL PILBABA GROUNDWATER STUDY

by

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Executive summary

The Central Pilbara Groundwater Study (CPGS) provides a regional review of the groundwater resources and assesses the potential impact of mining. The study provides essential groundwater information that will assist industry and Government agencies in the assessment of environmental impacts for proposed mining developments.

In order to achieve the study objectives, all hydrogeological reports held by the Water and Rivers Commission (WRC) and industry were reviewed and evaluated. In addition, several visits were made to current and proposed mining areas, and to sites of environmental importance. There are a number of different datasets created and stored on the CD, including topographic contours, borefield layouts and wetland sites.

The Central Pilbara generates approximately 87% of Western Australia's iron ore production and is dominated by Rio Tinto (operating as Hamersley Iron – HI) and BHP. The development of the iron ore industry has relied heavily on the exploitation of the premium (high grade and low phosphorus) Brockman deposits, but dwindling reserves has resulted in the development of the pisolite deposits (channel iron deposits - CID) and more recently the Marra Mamba deposits. The development of the new iron ore mines requires an improved regional understanding of the demand for water, ecological water requirements (EWR), available groundwater resources and the impact of proposed developments on groundwater systems.

The climate is semi-arid to arid with two distinct seasons: a hot summer extending from October to April, and a mild winter from May to September. The climate is one of extremes, with severe droughts and major floods often occurring at close intervals. The evaporation rate (about 3000 mm/yr) greatly exceeds annual rainfall (300 mm) keeping the landscape typically semi-arid, except along the drainage systems and areas that obtain moisture from groundwater sources.

Hydrogeology

The review and interpretation of the hydrogeological reports assisted in the identification of three major

aquifer groups in the Central Pilbara. These include unconsolidated sedimentary aquifers (valleyfill comprising alluvium and colluvium), chemically-deposited aquifers (calcrete and pisolitic limonite) and fractured-rock aquifers (dolomite and banded iron-formation).

Valleyfill deposits, up to 200 m thick, comprise interbedded sequences of clay, sand and gravel derived from alluviated drainages, outwash fans and scree slopes. These deposits form the major unconfined aquifer and are often in hydraulic connection with underlying calcrete and basement rocks. The groundwater salinity is variable, ranging from fresh to hypersaline beneath the Fortescue Marsh.

Calcrete and pisolitic limonite aquifers were chemically-deposited within Tertiary drainages or palaeodrainages. The calcrete is characterised by secondary porosity with karstic features developed through the partial dissolution of calcrete via percolating surface water and groundwater movement. The calcrete aquifer is capable of large bore yields, up to 5000 kL/day at Millstream.

The pisolitic limonitic aquifer is utilised at the Robe River and Yandicoogina mining operations. The origin of this CID aquifer is not clear; however, it is highly porous, vuggy and heterogeneous showing similar behaviour to that of a fractured-rock aquifer. Bore yields from the CID are commonly in excess of 1500 kL/day, and groundwater salinity is typically fresh to brackish.

Dolomitic formations (such as the Wittenoom Dolomite) are important fractured-rock aquifers, with the largest yields (greater than 5000 kL/day) occurring where the dolomite is overlain by a thick sequence of valleyfill. The Brockman and Marra Mamba Iron formations contain localised aquifers associated with deformation, fracturing and mineralised ore bodies.

There is potential for locating groundwater supplies in the Hardey Sandstone, although it is poorly explored in the area.

Consumptive use

The iron ore industry is the major groundwater user in the Central Pilbara. In 1999, annual groundwater abstraction was about 31 GL. Mining operations abstract groundwater for mine dewatering, dust suppression, mineral processing and ore beneficiation. The dewatering discharge is often used in mineral processing or released at controlled points into riverine drainages downstream of each operation.

There are currently 19 borefields established and operated by BHP and HI throughout the Central Pilbara. The production and monitoring data for each borefield have been reviewed and summarised to provide an understanding of borefield abstraction, aquifer performance and potential groundwater allocation issues. The borefield summaries and location plans are provided in Appendix 1.

Ecological water requirements

The study area surrounds the Karijini National Park and contains several major creek and river systems that support numerous well-known river pools and wetlands, including Weeli Wolli Spring. The significance of maintaining ecological water requirements is highlighted by the fact that the spring and river pool ecosystems of the Pilbara are dependant on groundwater.

Apart from a small number of tourist attractions, very few sites of environmental importance or ‘wetlands’ in the Central Pilbara are well known. The Water and Rivers Commission, being the Government agency responsible for managing the hydrological and conservation values of the State’s wetlands, identified the need for more detailed information on the distribution and characteristics of wetland sites, to increase the effectiveness of environmental planning and management.

A database, including environmental data from Hamersley Iron, has been compiled to identify and provide an inventory of wetlands including watercourses, sites of cultural significance and key monitoring sites. Many wetlands have been identified,

although further research is needed to determine how much water is required by each ecosystem.

The occurrence of stygofauna, a groundwater-dwelling fauna, has become an issue in the Central Pilbara. Stygofaunal communities have been found at most mine sites. The general lack of data and understanding about stygofauna in a regional context has made assessing the environmental impacts of proposed mining developments difficult.

Effects of mining

In the Central Pilbara, water issues at mining operations range from insufficient groundwater resource availability for mineral processing to disposal of surplus mine dewatering. Key areas for water management in the mining industry are water supply, disposal of excess dewatering discharge and potential contamination of local water resources. In the past five years, acid rock drainage and the long-term impact of mine voids have raised concerns within the mining industry and Government agencies.

The problem of acid rock drainage (ARD), a major mine-management issue around the world, was not originally considered a serious concern in the Central Pilbara owing to the low rainfall and high evaporation rates. In 1995, following heavy rains associated with Cyclone Bobby, acidic runoff was detected at Mount Whaleback resulting from the oxidation of highly reactive black pyritic shale (Mount McRae Shale). Spontaneous pyrite oxidation and subsequent generation of H_2SO_4 is a problem and any pit closure strategy must involve covering these surfaces with either inert backfill material or water. Operationally, in most mining operations, all overburden is now mapped and characterised to allow increased precision in the selective mining and placement of net acid generating material.

Opencut mining in the Central Pilbara has resulted in massive mine voids that commonly extend below the watertable. The largest final mine void will be at Mount Whaleback, with dimensions of 5.5 km by 2.2 km and a depth of 0.5 km. After the cessation of dewatering, groundwater levels will eventually recover, with the mine void showing a surface expression of the watertable. The exposure of the watertable will create an artificial lake, which will initiate geochemical and hydrological processes that will evolve over time.

A major long-term concern is the potential for most pit lakes in the Pilbara to become point sources of hypersaline water. The low annual rainfall and high evaporation results in a rainfall deficit, which over time will lead to the development of hypersaline water bodies. This is confirmed in limited monitoring data suggesting that final mine voids, such as Mount Goldsworthy mine, are groundwater sinks and have become progressively saline.

Five case studies in the Central Pilbara were conducted to understand the role and issues related to mine voids. The case studies, provided in Appendix 2, detail the hydrogeology and the potential impacts of the mine voids at Mount Goldsworthy, Orebody 18, Orebody 23, Hope Downs and Yandicoogina.

There are two broad hydrogeological environments for mine voids: groundwater sink (evaporation exceeds groundwater inflow) and groundwater throughflow (groundwater inflow exceeds evaporation). Mine voids that act as a 'groundwater sink' and only intersect local aquifers have limited contamination potential for neighbouring aquifers, such as at most Brockman mines. Mine voids that exhibit throughflow characteristics are a major environmental concern in the Central Pilbara, hence, these voids have more stringent environmental constraints imposed by Government regulators. The best examples are the channel iron deposits (Yandicoogina and Robe River) and the banded iron-formation deposits that are in hydraulic connection with significant aquifers (Orebody 23 and Hope Downs).

Water resource management

Water management is critical to the profitable development and sustainable operation of a successful mine. Over the past three decades, the iron ore industry has responsibly managed the local groundwater resources in the vicinity of their mining operations. The discovery and development of new iron ore deposits throughout the Central Pilbara has resulted in the need to gain a regional perspective of the water resource management issues.

Based on the spatial distribution of the current and proposed mining operations, seven key regional localities were identified: Ophthalmia / Fortescue River; Turee Creek / Seven Mile Creek; East Turee Creek; Weeli Wolli Creek; Marillana Creek; Southern Fortescue / Hardey River; and Caves Creek / Duck Creek areas. There is a brief description for each regional area detailing geology, groundwater resources and wetland sites, as well as highlighting the various water resource issues. Below is a summary of the main water-related issues for each regional area:

- Ophthalmia / Fortescue River — development of Orebody 23 (dewatering impacts on the Ethel Gorge Borefield; vegetation monitoring and stygofauna);
 - Turee Creek / Seven Mile Creek — potential impacts on Turee Creek (Ecological water requirement for Nanjilgardy Pool and Neramba Spring; borefield extensions to the east of Mount Channar; vegetation monitoring; and tailings dam at Paraburdoo Gold);
 - East Turee Creek — development of West Angelas (borefield isolation; aquifer sustainability and westerly borefield extensions may impact on wetlands);
 - Weeli Wolli Creek — development of BHP Mining Area C and Hope Downs (Ecological water requirement in the upper Weeli Wolli Creek catchment; agreement between Government and the proponent relating to mine closure issues);
 - Marillana Creek — impacts of CID mining at Yandi Downs (Ecological water requirement of Fortescue Marshes maintained by surface water; 'throughflow cell' mine closure; Weeli Wolli CID is a potential aquifer for ecological water requirement);
 - Southern Fortescue / Hardey River — long-term impacts (presence of sinkholes; ecological water requirement for Mindthi Spring); and
 - Caves Creek / Duck Creek — impacts on Caves Creek (dewatering drawdown; vegetation monitoring; disposal of excess dewatering discharge; water shortages and backfilling of pits).
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1 Introduction

The Central Pilbara Iron Ore Province is located in the north-west of Western Australia and is one of the world's major sources of iron ore. The Pilbara was first recognised to be rich in iron ore in the 1800s, but it was only in the late 1960s that the first mines opened. Initial growth was based on Archaean banded-iron formation (BIF) at Mount Goldsworthy and the premium Brockman deposits at Tom Price and Mount Whaleback. New iron ore mines have more recently been developed within Marra Mamba and pisolitic ores. The scale, project longevity and diverse ownership of the iron ore projects in a relatively confined area necessitates careful planning to ensure sustainable use of the region's vast natural resources.

Water is both a key infrastructure requirement and environmental need. The study area surrounds Karijini National Park and contains several major creek and river systems that support numerous well-known river pools/wetlands, including Weeli Wolli Springs. The significance of maintaining ecological water requirements is highlighted by the fact that spring and river pool ecosystems of the Pilbara are highly dependent on groundwater.

Development of the new iron ore mines in the Central Pilbara requires an improved regional understanding of the demand for water, ecological water requirements, available groundwater resources and the impact of proposed developments on groundwater systems. Information from this study will also support the draft groundwater allocation plan and the setting of ecological water provisions for the Pilbara region.

1.1 Scope and purpose of the study

The objective of the Central Pilbara Groundwater Study (CPGS) was to undertake a regional review of the groundwater resources and assess the possible impact of mining. The study provides essential groundwater information that will assist industry and Government agencies in the assessment of environmental impacts for proposed mining developments.

The study involved the review and evaluation of all existing hydrogeological reports held by both the Water and Rivers Commission (WRC) and industry. Specialist

consultants were employed where additional information was required to infill knowledge gaps, such as:

- Groundwater modelling and water balance studies in the Marillana / Weeli Wolli Creek area (Aquaterra, 2001);
- Identification of wetland sites, or sites of environmental importance (Worley Astron, 2000); and
- An assessment of current status of knowledge with regard to stygofauna (Humphreys, 2000).

A number of field visits were undertaken to current and proposed mining developments. Borefield reviews were produced for all existing borefields (Appendix 1). Case studies were also completed for five specific mine voids that are considered representative of the region (Appendix 2).

1.2 The study area

1.2.1 Location

The study area covers the Central Pilbara Iron Ore Province and extends from Jimblebar in the east to Robe River/Pannawonica in the west (Fig. 1.1). The area covers the Hamersley Range, located between the Fortescue River to the north and the Ashburton River to the south, which includes most of the iron ore bearing rocks of the Hamersley Group.

1.2.2 Climate

The Central Pilbara has a semi-arid to arid climate with two distinct seasons: a hot summer extending from October to April, and a mild winter from May to September. The climate is one of extremes with severe droughts and major floods often occurring at close intervals. The average annual rainfall ranges from 230 to 350 mm, but can vary dramatically due to the influence of tropical cyclones during the late summer months. In 1975, Cyclone Joan produced up to 600 mm of rainfall during its passage over the region. In recent years, some parts have experienced above average rainfall with Newman having four times its average annual rainfall over a period of four and half months

during 1999/2000. Rainfall can be erratic and very localised due to thunderstorm activity, hence, rainfall from a single site is not representative of the entire catchment (Table 1.1).

Table 1.1. Average annual rainfall at selected sites in the Central Pilbara

<i>Location</i>	<i>Annual average rainfall (mm)</i>
Pannawonica	380
Wittenoom	416
Tom Price	346
Paraburdoo	275
Juna Downs Station	357
Newman	303

Annual evaporation is extremely high with the mean exceeding 3000 mm. The evaporation rate greatly exceeds mean annual rainfall keeping the landscape typically arid, except for areas along the alluviated river systems.

1.2.3 Physiography

The Central Pilbara covers the entire Hamersley Plateau physiographic unit (Beard, 1975) and is drained by the Ashburton and Fortescue Rivers, which flow northwest towards the Indian Ocean (Fig. 1.2). Fronting onto the Fortescue valley, the Hamersley Range rises from 450 to 700 m with hills rising to about 900 m with local peaks to 1250 m (Mount Meharry). In places, the plateau has been incised by modern drainages producing spectacular gorges. Differential erosion within the plateau has produced an environment of extreme relief with hills, ranges, crests, ridges, spurs and gorges. Colluvial and alluvial material have formed extensive valley floors between the hills and ranges. The plateau has a complex drainage pattern characterised by seasonally intermittent flow and occasional widespread flooding, depending on the occurrence of high rainfall events.

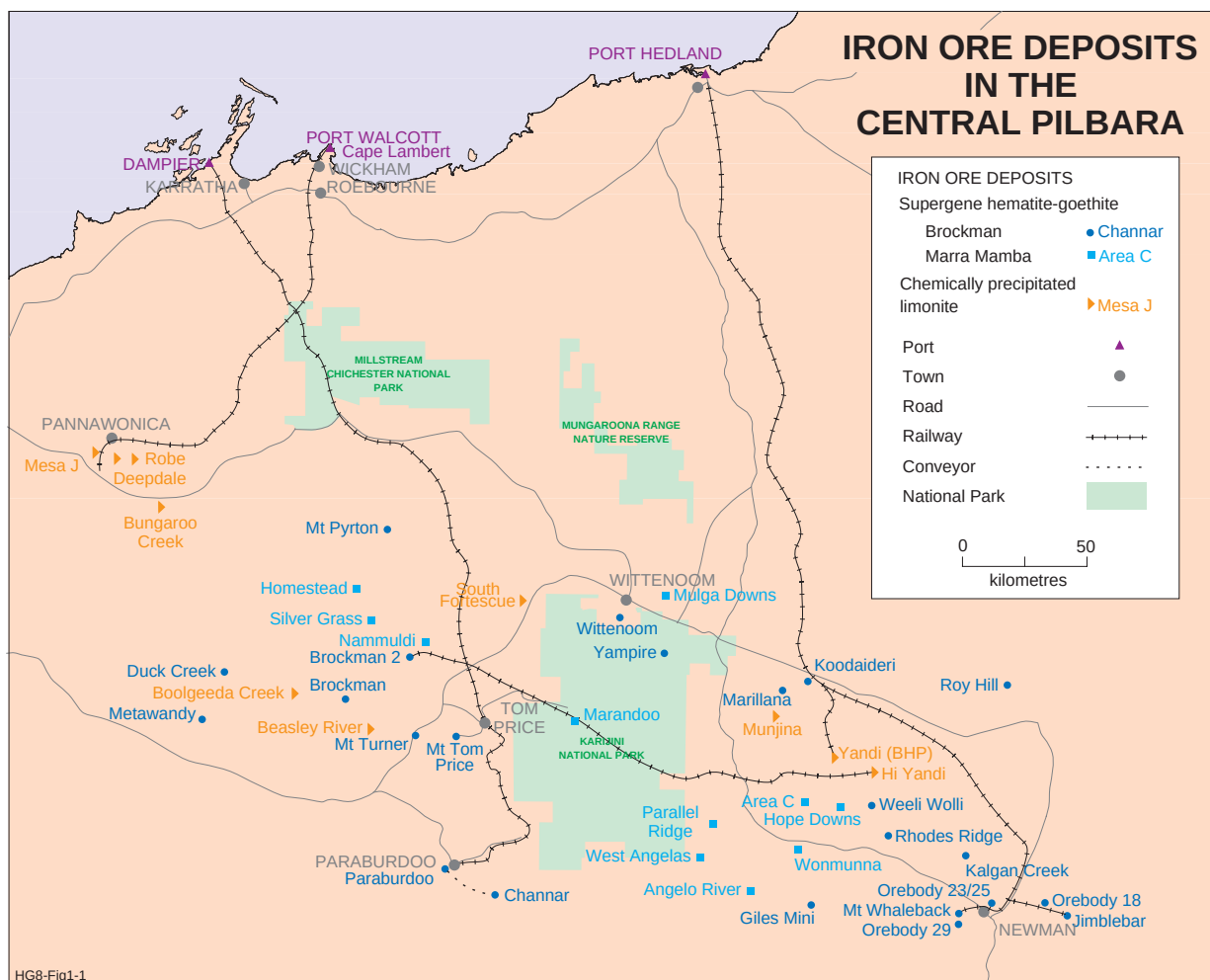


Figure 1.1 Location of major iron ore deposits in the Central Pilbara

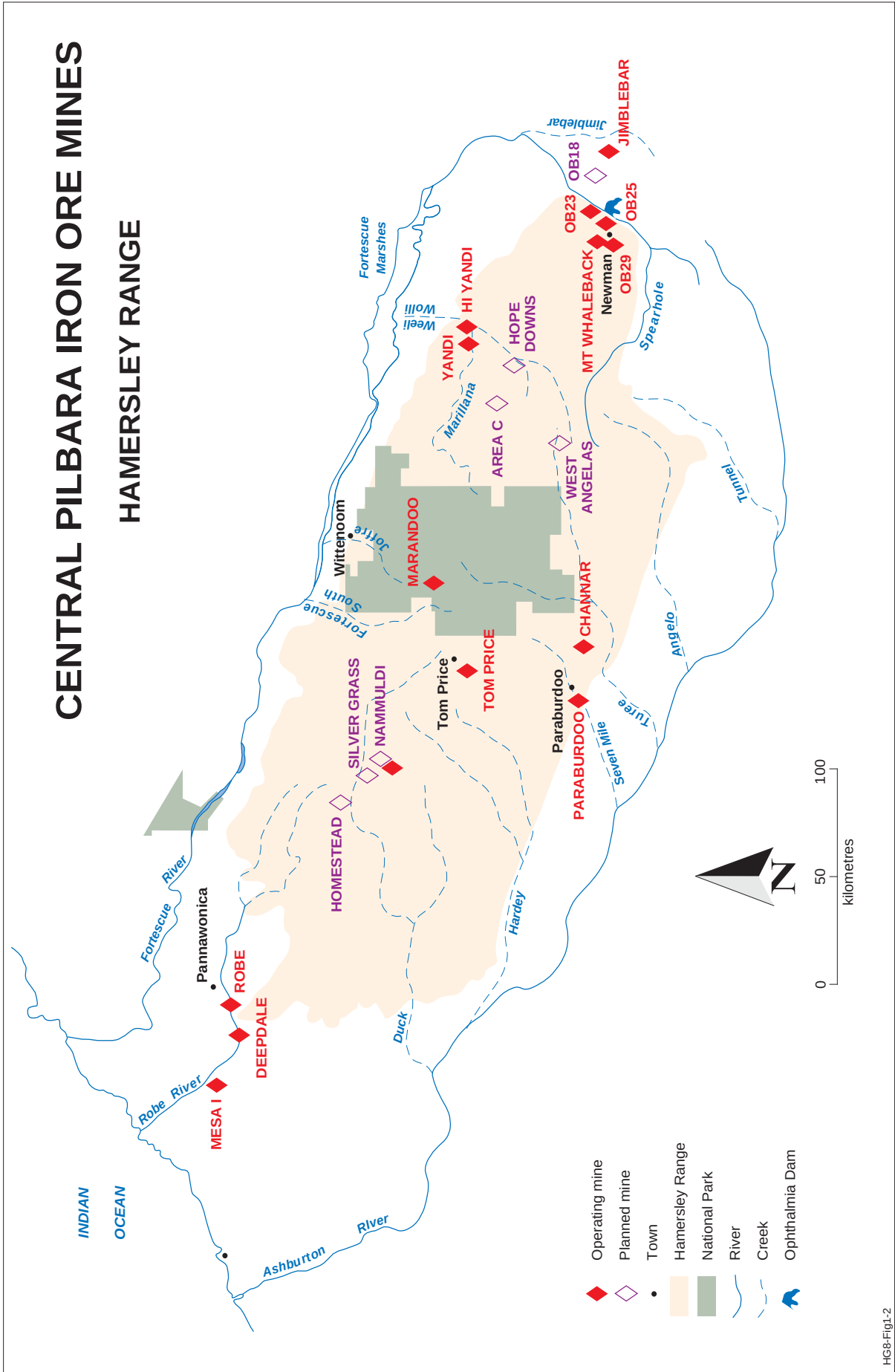


Figure 1.2 Distribution of existing and proposed iron ore operations

The vegetation changes across the landscape, with spinifex hummock grasslands on the shallow stony mountain slopes, spinifex on the erosional slopes, and a mixture of mulga shrublands and grasslands on the depositional plains. The alluvial plains with loamy and clay soils support mulga and snakewood woodlands with an undergrowth of spinifex, low shrubs and tussock grass. Tall river gums and cadjebuts line the major creeks and rivers.

1.2.4 Geology

The geology of the Central Pilbara comprises a depositional basin of Archaean to Lower Proterozoic sedimentary rocks (Hamersley Basin) overlying older Archaean granite and greenstone basement rocks (Trendall, 1990). The sedimentary rocks of the Hamersley Basin are divided into three major components (Table 1.2). The Fortescue Group, which

rests unconformably upon the granite and greenstone basement, comprises an interlayered sequence of sedimentary and basaltic rocks that have been intruded by dolerite sills and dykes. The Hamersley Group lies conformably over the Fortescue Group and consists of various metasedimentary rocks including banded iron-formations, interbedded with minor felsic volcanic rock and intruded by doleritic dykes. The Turee Creek Group, comprising shale and quartzite, is poorly exposed in the small areas in the south.

Less-resistant formations, such as the Wittenoom Formation, have been eroded and weathered resulting in considerable bedrock relief. During the Tertiary, a variety of sediments accumulated in the drainages including calcrete and Robe Pisolite (channel iron deposit – CID). There is also variable thickness of valleyfill deposits, comprising alluvium and colluvium, within the drainage systems.

Table 1.2. Stratigraphic summary of the Central Pilbara

<i>Age</i>	<i>Group</i>	<i>Formation</i>	<i>Member</i>	<i>Dominant lithology</i>
Quaternary				Alluvium, colluvium
Tertiary		Oakover Fm Robe Pisolite *		Calcrete Pisolitic limonite
Early Proterozoic- Archaean	Turee Creek Group	Kungarra Fm		Shale, dolerite, quartzite
Early Proterozoic- Archaean	Hamersley Group	Boolgeeda Iron Fm		BIF, shale
		Woongarra Volcanics		Felsic volcanics, tuff, minor BIF
		Weeli Wolli Fm		BIF, dolerite, shale
		Brockman Iron Fm *	Yandicoogina Shale Joffre Member Whaleback Shale Dales Gorge Member	Shale, chert BIF, minor shale Shale, chert BIF, minor shale
		Mount McRae Shale	Colonial Chert	BIF, shale, pyritic shale, dolomite
		Mount Sylvia Fm		Shale, chert, dolomite, BIF
		Wittenoom Fm *	Bee Gorge Member Paraburdoo Member West Angela Member	Shale, tuff Dolomite, chert, shale Dolomite, shale
		Marra Mamba Iron Fm *	Mt Newman Member MacLeod Member Nammuldi Member	BIF, minor shale BIF, shale BIF, chert, shale
Archaean	Fortescue Group	Jeerinah Fm	Roy Hill Shale	Shale, chert, sandstone, basalt
		Bunjinah Fm		Basalt, sandstone, minor chert
		Pyradie Fm		Basalt
		Boongal Fm		Basalt, pelite, minor chert
		Hardey Fm	Hardey Sandstone	Sandstone, conglomerate

* Units that are of greatest interest to this study

The Brockman and Marra Mamba Iron Formations of the Hamersley Group contain commercial quantities of iron ore. The dominant rock type is BIF, which is a sedimentary rock composed of iron and silica minerals in characteristic bands. Most BIF has little commercial value because of the low iron content. In places, however, it does have commercial value where it is enriched by the natural process of supergene enrichment to over 60% iron, and is low in impurities like phosphorus and silica.

Two other types of iron ore deposit found in the region are pisolites and detritals. Flat-lying deposits of pisolitic limonite within the Robe Pisolite (MacLeod, 1966) are found preserved as mesas and benches along former watercourses that drained the Hamersley Group. The pisolitic limonite possibly formed when humic, iron-rich solutions (leached from the iron ore formations) interacted with alluvium in low-energy, vegetation-rich river systems. These deposits have subsequently been exposed through weathering to form the ‘channel iron deposits’ and are currently mined along Robe River and Marillana Creek. The detrital deposits comprise iron ore detritus derived from erosion and weathering of the Brockman and Marra Mamba Iron Formations, as well as reworking of channel iron deposits.

1.2.5 Landuse

The economy of the Central Pilbara is dominated by the iron ore mining industry (\$3 billion per annum), with tourism the only other significant economic activity (\$75 million per annum). The pastoral industry has never been significant owing to the general lack of good grazing land.

The Central Pilbara generates approximately 87% of Western Australia’s iron ore production and is now dominated by Rio Tinto (operating as Hamersley Iron – HI) and BHP. Table 1.3 and Figure 1.3 show the location of existing mines and prospective deposits. The development of the iron ore industry has relied heavily on the exploitation of the premium (high grade and low phosphorus) Brockman deposits, but dwindling reserves has seen the development of the pisolite deposits (CID) and more recently the Marra Mamba deposits.

The towns of Tom Price, Pannawonica and Newman, and later Paraburdoo were initially built and serviced as company-owned towns. Although, the combined population in the three towns was 10 600 in 1996, it has been reduced markedly in the past five years owing to increased mining productivity and the trend towards ‘fly-in/fly-out’ operations (Dames and Moore, 2000).

Table 1.3 Major mining operations in the Central Pilbara

<i>Company</i>	<i>Operation</i>	<i>Ore type</i>	<i>Status</i>
BHP Iron Ore	Mount Whaleback	HG Brockman	Active
	Orebody 29, 30 & 35	Marra Mamba	Active
	Orebody 25	HG Brockman	Active
	Orebody 23	HG Brockman	Stalled
	Jimblebar	HG Brockman	Active
	Yandi (Marillana Creek)	CID (Pisolitic)	Active
	Mining Area C (MAC)	Marra Mamba	Proposed 2002
Hamersley Iron – Rio Tinto	Tom Price	HG Brockman	Active
	Paraburdoo	L-M Phos Brockman	Active
	Channar	L-M Phos Brockman	Active
	Marandoo	Marra Mamba	Active
	Brockman N°2	Brockman detritals	Active
	Nammuldi, Silvergrass & Homestead	Marra Mamba	Proposed 2003
	Yandicoogina (HI Yandi)	CID (Pisolitic)	Active
Rio Tinto Iron Ore	Robe River	CID (Pisolitic)	Active
	West Angelas	Marra Mamba	Construction 2001
Hope Downs (ISCOR)	Hope 1	Marra Mamba	Proposed 2003

Note: HG represents high grade, L-M represents low to medium grade, Phos represents phosphorus

Although this area is the traditional country of four Aboriginal language groups, it has only been since the late 1970s that Aboriginal people have returned to the Central Pilbara. Currently there are four aboriginal settlements in the region with a total population of some 240 (Dames and Moore, 2000).

1.3 Information on the CD

Numerous data themes generated, as part of the Central Pilbara Groundwater Study, have been collated for inclusion on the CD. The themes include wetlands (sites of ecological importance), stygofauna occurrence,

simplified geology; borefields; rivers; surface water gauging network; mining operations, towns, roads, National Park boundaries and general climatic data. A public domain version of ArcExplorer is included on the CD enabling the viewing of different themes on any computer system with CD-ROM access.

The report has been provided in *pdf* format (Adobe Acrobat Reader) for best presentation of the information and easier printing of selected sections. There are two versions: one containing the whole document and another separated into individual files or chapters for optimal running.

2 Hydrogeology

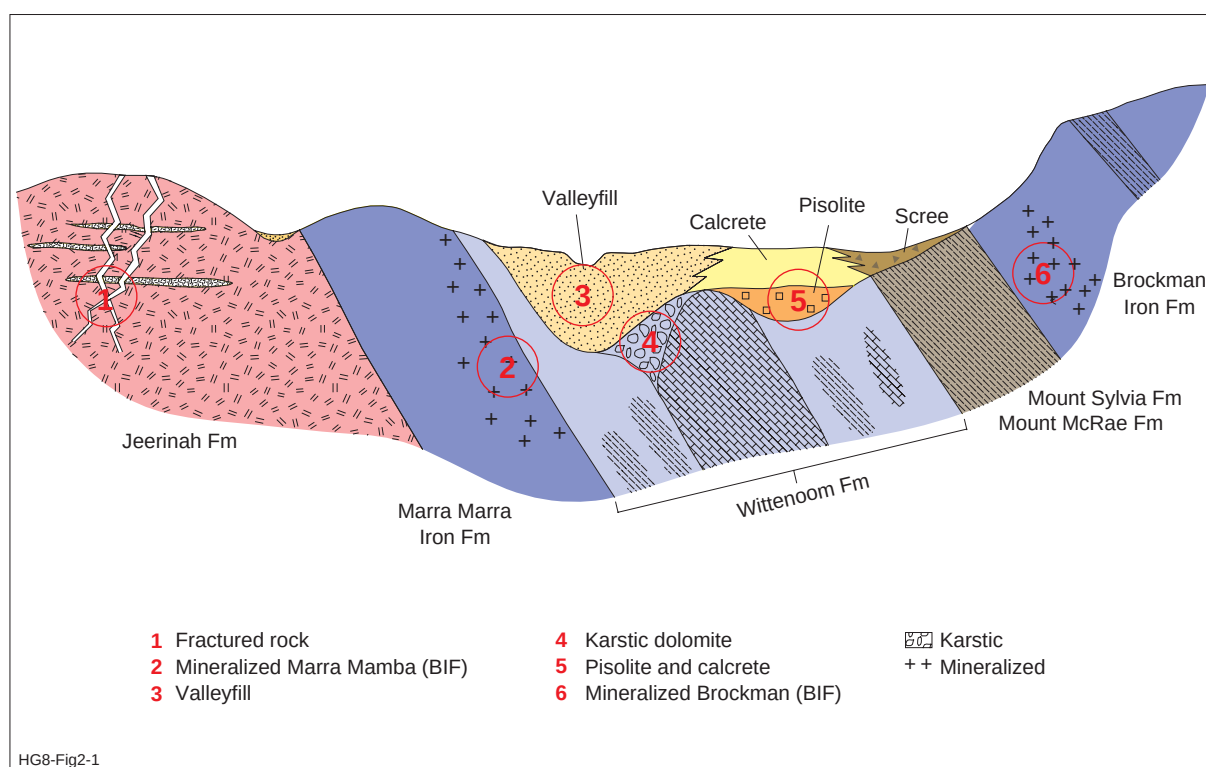
Groundwater occurs throughout the Central Pilbara in the Archaean/Proterozoic basement rocks and the Cainozoic deposits. It originates from direct rainfall recharge into basement rock outcrops and indirect recharge through runoff. The quantity and quality of the groundwater held in the different aquifers vary considerably. The most prospective aquifers have been grouped into three types, as illustrated in Table 2.1 and Figure 2.1.

2.1 Unconsolidated sedimentary aquifers

The valleyfill aquifer comprises alluvium and colluvium. The sedimentary sequence is often complex, reflecting various modes of deposition. The alluvium is often clayey with interbedded sand and gravel lenses, whereas the colluvium comprises cobble-sized detritals within a clay matrix. In places, there is a basal sand

Table 2.1 Summary of most prospective aquifers in the Central Pilbara

<i>Aquifer type</i>	<i>Aquifer</i>	<i>Geological unit</i>	<i>Saturated thickness (m)</i>	<i>Bore yield (kL/day)</i>	<i>Aquifer potential</i>
Unconsolidated sedimentary aquifer	Valleyfill	Alluvium	15	<1000	Major
		Colluvium	30	<1500	Major
Chemically deposited aquifer	Calcrete	Calcrete	15	5000	Major
	Pisolitic limonite	Robe Pisolite	10	1500	Major
Fractured-rock aquifer	Fractured sedimentary BIF	Hamersley Basin			
		Brockman Iron Fm	20	<500	Local
	Dolomitic Sandstone	Marra Mamba Iron Fm			
		Wittenoom Dolomite	25	2 000	Major
		Hardey Sandstone	30	<250	Local



unit, probably derived from weathering of granitoid rocks in the Sylvania Dome, such as in Ethel Gorge borefield. The thickness of valleyfill is highly variable, ranging from 20 m at Ethel Gorge (AGC Woodward-Clyde, 1997a) to about 150 m in the Fortescue River valley near Homestead HI operations (Sinclair Knight Merz, 1997).

The valleyfill forms the major unconfined or watertable aquifer, although the aquifer may be confined or semi-confined locally by sediments of low permeability. Groundwater is contained in the primary porosity of the clastic sediments. It is in hydraulic connection with the underlying pisolitic limonite and fractured-rock aquifers, particularly where the basement is weathered and fractured (AGC Woodward-Clyde, 1995a).

Recharge occurs mostly by leakage from streambeds during surface runoff, and to a lesser extent by direct infiltration of rainfall over the surface. Estimates of quantities of recharge in the valleyfill aquifers range from 90 to 17 000 ML/year/km length of valley and depend very much on frequency, flow volume and duration of surface flows, as well as on the permeability of the aquifer (Skidmore, 1996). Groundwater flow is away from the recharge areas, along the valley sides or centres, and then moves downgradient 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.

Bore yields in the valleyfill aquifer are variable ranging from 50 to 2500 kL/day and reflecting the interfingering relationship between the alluvium and colluvium. Groundwater is mostly fresh to marginal ranging between 200 and 1000 mg/L total dissolved solids (TDS); however, hypersaline groundwater (up to 60 000 mg/L TDS) has been recorded in the vicinity of Fortescue Marshes (AGC Woodward Clyde, 1994).

2.2 Chemically-deposited aquifers

The calcrete and pisolitic limonite aquifers were chemically-deposited within Tertiary drainages or palaeodrainages. Both aquifers are characterised by secondary permeability and large bore yields (in excess of 1500 kL/day).

2.2.1 Calcrete

Calcrete occurs within drainages as localised exposed mounds near discharge zones, such as river pools or springs. Many calcrete bodies are remnants of larger areas that have been dissected by recent drainages. The calcrete is up to 46 m thick at Millstream (Barnett and 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 calcrete via percolating surface water and groundwater movement. Groundwater recharge takes place mostly by leakage from streambeds during surface runoff, and to a lesser extent by direct infiltration of rainfall.

Bore yields from the calcrete are generally between 50 and 100 kL/day, although yields of up to 5000 kL/day have been encountered at Millstream (Water Corporation, 1997). Groundwater salinity is mostly fresh to marginal, but may be brackish during prolonged dry periods and where groundwater from basement rocks discharges into the aquifers. On the flanks of the Fortescue Marsh, the groundwater is hypersaline due to concentration via evaporation (AGC Woodward-Clyde, 1994).

2.2.2 Pisolitic limonite aquifer

The pisolitic limonite aquifer (often referred to as the CID aquifer) is utilised for groundwater supplies at the Robe River and Yandicoogina mining operations. The pisolite aquifer is up to 90 m thick within the BHP Yandi operations at Marillana Creek (Hall and Kneeshaw, 1990). The pisolitic limonite does not outcrop extensively and only constitutes an aquifer where it occupies channels incised into basement rocks by earlier drainages. The pisolite is often unsaturated where it outcrops outside the drainages, but forms large local aquifers where it occurs below the drainages.

The aquifer is highly porous, vuggy and heterogeneous showing behaviour similar to that of a fractured-rock aquifer (A.J. Peck and Associates, 1995). Bore yields from the pisolite are often in excess of 1500 kL/day. Most production bores show a delayed yield response suggesting groundwater can become perched due to poor interconnection between pores (AGC Woodward-Clyde, 1994) or clay layers (PPK, 1998). Groundwater salinity is typically fresh to brackish.

2.3 Fractured-rock aquifers

Fractured-rock aquifers exist within a host of different rock formations, which constitute the basement rocks. Groundwater occurs where secondary porosity has developed in fractured and weathered zones or along bedding plane partings or joints. The basement rocks are tight outside the zones of secondary porosity and contain little or no groundwater.

Groundwater recharge is episodic and affected by direct infiltration of rainfall over areas where the rocks are fractured, jointed and weathered. Recharge will also occur by leakage from surface flows directly into the basement rocks or indirectly through superficial sediments where they overlie the basement rocks. Groundwater flow is largely controlled by local geological structures and weathering.

2.3.1 Banded iron-formation

Banded iron-formation 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. The permeability in the BIF is typically associated with fractures and ore mineralisation. In most cases, the ore body is the major aquifer, such as Orebody 23 (BHP, 1997a) and Mining Area C (BHP, 1997b). Weathered and fractured chert within the BIF can also form local aquifers, such as at Turee Creek (AGC Woodward-Clyde, 1997b).

The BIF aquifers are not considered regional aquifers, although they do have potential as local aquifers. Groundwater levels are variable depending on the topography, ranging from 15 to 50 m bgl at Nammuldi–Sivergrass (PPK, 1999) and Brockman No. 2 (AGC Woodward-Clyde, 1991). Bores intersecting fracture zones within BIF are capable of yields up to 2000 kL/day. Groundwater quality is fresh to marginal ranging between 200 and 1400 mg/L TDS. Areas where drainages have carved channels through strike ridges may indicate zones of weakness in the aquifer and represent favourable exploration sites.

2.3.2 Dolomite

The dolomitic aquifers in the Wittenoom Formation are considered the primary groundwater supply target for both town and mining water supplies. Karstic features are often developed because of the susceptibility of the dolomite to chemical dissolution via percolating surface water and groundwater movement (Balleau, 1972).

Drilling indicates that fractured or cavernous zones may extend to a depth of 100 m.

Bore yields from the dolomitic aquifers are variable, up to 1600 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 unfractured. Groundwater is fresh to marginal ranging from 150 to 1500 mg/L (Skidmore, 1996).

2.3.3 Sandstone

The Hardey Sandstone comprises sandstone and conglomerate, with some shale, mudstone, siltstone, tuff and basalt. The weathered zone in the Hardey Sandstone aquifer extends down to 30 m depth, and partings between lithological beds extend as deep as 150 m. Groundwater levels are dependent largely on topography. Bore yields often reach 200 kL/day, although localised yields in excess of 1000 kL/day have been recorded near Paraburdoo. Groundwater salinity is fresh to marginal ranging between 350 and 1200 mg/L TDS. The groundwater potential of the Hardey Sandstone has not been properly evaluated, although the best prospects are within drainages where recharge from streamflow is available and sustainable bore yields are supported by utilising storage in the alluvium.

2.4 Resource potential

The most prospective groundwater areas within the Central Pilbara are those localities where valleyfill aquifers, comprising alluvium, scree-slope deposits and outwash fans, can be exploited in conjunction with pisolitic limonite, calcrete and fractured-rock aquifers.

The dolomitic formations, represent significant local aquifers, are the primary groundwater target in the Pilbara. The high-yielding nature of the dolomite is related to its well-developed secondary porosity and high permeability.

The pisolitic limonite aquifer is an important source of groundwater for the mining industry. In places, such as Robe River and Marillana Creek, the pisolitic limonite aquifer is currently being dewatered and mined. In order to rehabilitate the aquifer, the mined-out area is backfilled with waste ore. This process may well re-establish the groundwater flow path, although it remains to be seen how effectively the infilled channel acts as a conduit for regional groundwater flow.

3 Groundwater development

3.1 Current use

Consumptive water use in the Central Pilbara is totally dependent on the development and utilisation of groundwater resources. Groundwater usage falls into three main categories:

- Mine water supply — used for two purposes: mining related activities (mineral processing and dust suppression), and dewatering activities. An additional water supply need arises during construction of road and rail infrastructure.
- Town water supply — the major town water supplies have been established and developed by the mining companies. The distribution of the water is contracted to the Water Corporation.
- Pastoral requirements — pastoral stations, many of which are operated by mining companies, require water for livestock watering. The water is obtained from bores and creek lines, including permanent pools along ephemeral watercourses. The volume of water used for stock watering is insignificant compared with that abstracted for mining and town water supplies.

The iron ore industry is the major groundwater user in the Central Pilbara (Fig. 3.1). In 1999, annual groundwater abstraction was about 31 GL. Mining operations abstract groundwater for mine dewatering, dust suppression, mineral processing and ore beneficiation. The dewatering discharge is often used in mineral processing or released at controlled points into riverine drainages downstream of each operation.

Most borefields are established to provide potable and mining-process water, with bores abstracting groundwater at the ‘safe-yield’ to ensure long-term sustainability. Mine dewatering borefields are designed to lower the watertable in advance of mining to facilitate safe mining conditions. In order to achieve dewatering, pumping rates must exceed the groundwater throughflow, resulting in localised storage depletion. The pumped groundwater is used largely for mineral processing or potable water supply. If dewatering discharge exceeds the mine water demand, the excess should be responsibly disposed of into local creeks,

such as at Marillana Creek. On completion of mining and cessation of dewatering, groundwater levels should recover to near pre-pumping levels. All groundwater licensing and allocation is the responsibility of the Water and Rivers Commission.

3.2 Summary of borefields

There are currently 19 borefields established and operated by BHP and Hamersley Iron throughout the Central Pilbara (Fig. 3.2). This section provides an overview of each borefield, based on monitoring information provided by BHP Iron Ore (BHP, 1998a,b, 2000a,b,c,d) and Hamersley Iron (Aquaterra, 1999, 2000) as part of their licensing agreement with the Water and Rivers Commission.

Hamersley Iron operates twelve separate borefields in the Pilbara under eleven separate Water and Rivers Commission Groundwater Well Licences (GWLs). Four of the borefields are used for dewatering (with the water being used for mining activities), while the remaining eight are used for water supplies and processing water for mining activities.

BHP currently operates four borefields, covered by separate GWLs. Two borefields are related to dewatering and two are used to supply water for mining activities and for water supply for the town of Newman.

The individual borefields are discussed in detail in Appendix 1. Table 3.1 provides a summary of borefield details including owner, GWL number, annual allocation, recorded abstraction for 1999, bore yields and number of bores. Table 3.2 summarises aquifer type, water quality and aquifer performance.

3.3 Future demand

Future water requirements for the region are directly linked to mining development in the iron ore industry. There are no plans for development of any further towns in the area and new mines are expected to be ‘fly-in/fly-out’ operations. Existing water resources are considered adequate for proposed extensions of current mining operations. Mining companies are also now recognising the value of water in their operations and

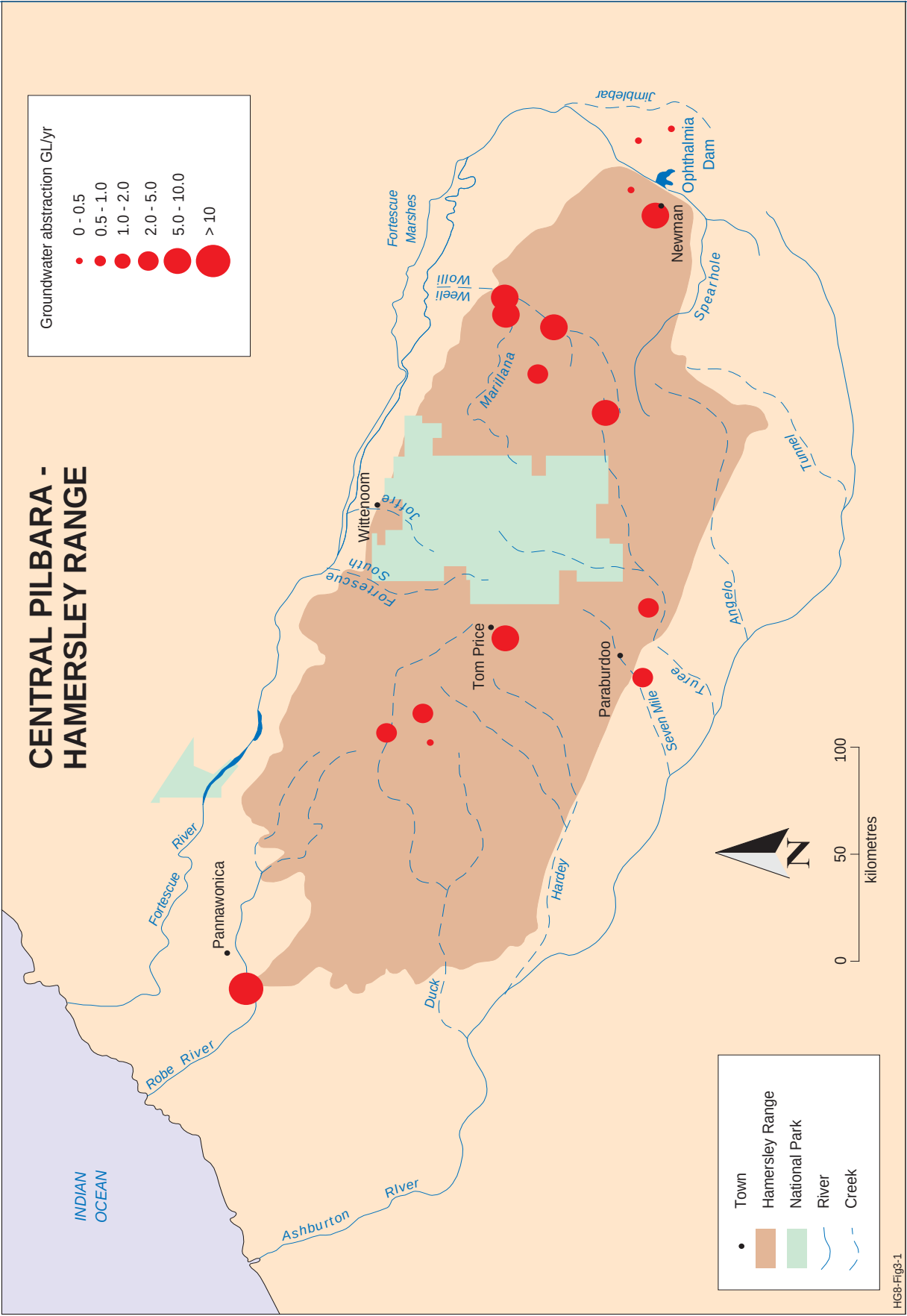


Figure 3.1 Groundwater abstraction by mining industry in 1999

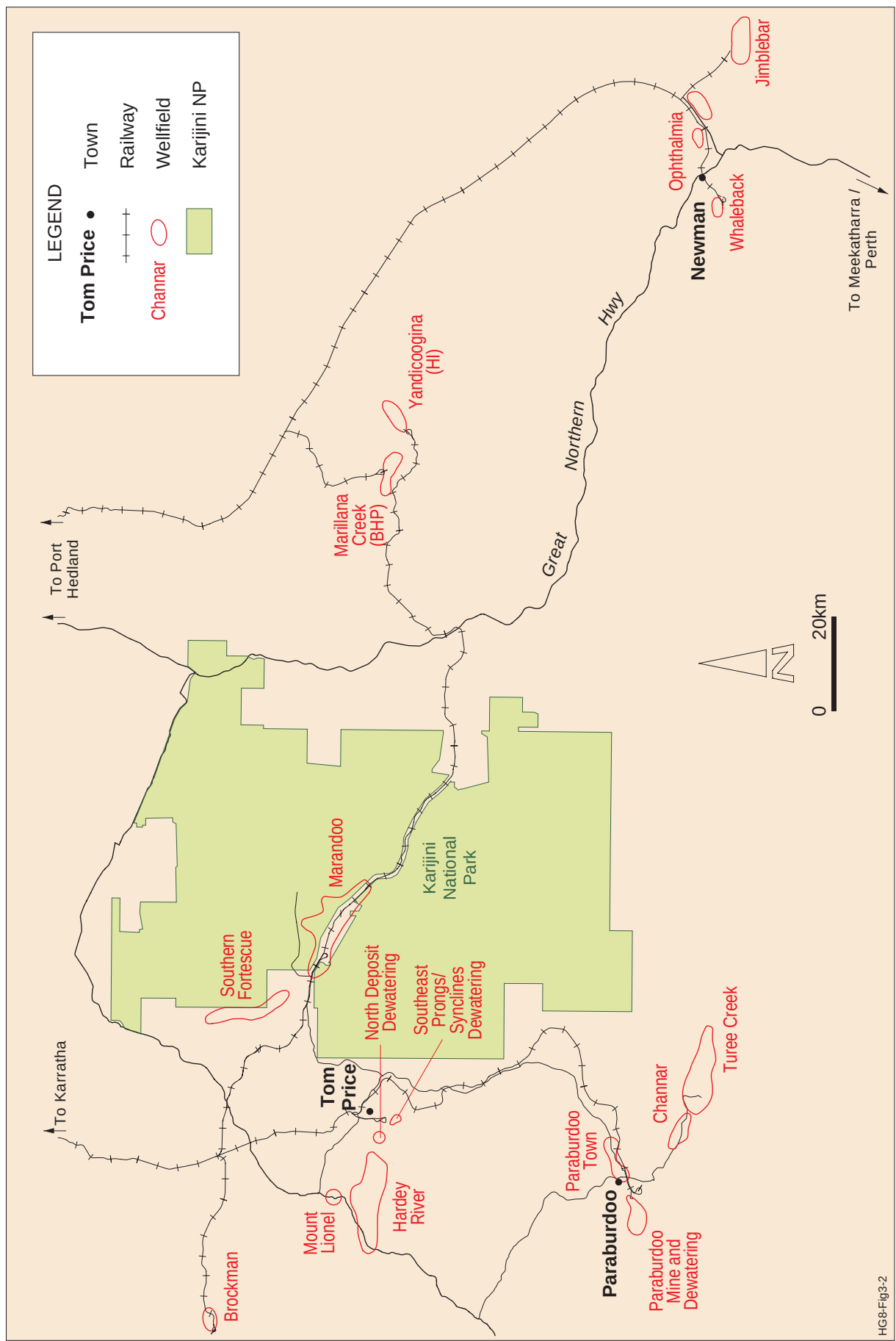


Figure 3.2 Location of mine water supply and dewatering borefields

the need to conserve and manage the available resources in a sustainable way. The development of mine-site water balances is enabling companies to set targets for improving water efficiency and encouraging greater use of recycled water.

Provision has been made for the water supply requirements of the new generation of Marra Mamba iron ore mines and satellite ore bodies soon to be developed in the Central Pilbara. It is very difficult to predict exactly what the demand will be as the level of operation is largely dependent on the market.

An indication of future water requirements and groundwater sources is provided in Table 3.3. Based on current information, there are three new mining areas that may experience water-supply problems.

- There is considerable uncertainty as to whether the

East Turee Creek borefield could be extended beyond a 10 ML/d capacity should the West Angelas mining operations ever require more water.

- Current groundwater modelling predictions indicate that dewatering operations at the proposed Hope North pit (Hope Downs) will lower groundwater levels in the proposed Mining Area C (MAC) water supply borefield by 140 m. The mine-water requirements at MAC can be provided from the Hope North dewatering discharge; however, the water source for MAC is uncertain on the cessation of dewatering at Hope Downs.
- Local aquifers will have to be developed to meet mining-water requirements in the proposed Homestead mining area.

Table 3.1 Borefield details of the Central Pilbara

<i>Borefield</i>	<i>Owner</i>	<i>GWL number</i>	<i>Allocation (kL/year)</i>	<i>Abstraction (kL in 1999)</i>	<i>No. of operating production bores in 1999</i>	<i>Individual bore yield (kL /day)</i>	<i>No. of monitor bores</i>
Paraburdoo							
• Mine Borefield				994 518	4	600 – 2400	10
• Town Borefield	HI	67260	6 500 000	1 742 109	12	40 – 1600	22
• 4 West Mine Dewatering				824 312	2	1 300 – 3000	19
Turee Creek (Paraburdoo)	HI	65718	3 230 000	2 032 110	6	600 – 1900	31
Channar	HI	65719	1 000 000	639 029	5	200 – 1200	12
Hardey River (Tom Price)	HI	65716	2 240 000	1 000 000	10	100 – 1100	21
Southern Fortescue (Tom Price)	HI	65715	4 680 000	2 873 144	10	300 – 1900	13
Mount Lionel (Tom Price)	HI	65714	1 000 000	650 000	1	1600 – 2600	5
North Deposit Dewatering (Tom Price)	HI	65712	1 000 000	512 270	1	900 – 1900	3
Southeast Prongs (Tom Price)	HI						
• Southeast Prongs Dewatering		65713	1 000 000	0	1	900	3
• Synclines Dewatering				146 460	3	100 – 800	3
Marandoo	HI	65711	2 000 000	554 543	5	200 – 1100	26
Brockman	HI	65717	600 000	202 439	5	100 – 300	6
Yandicoogina	HI	63158	10 000 000	5 095 490	10	1300 – 4900	8
Marillana Creek	BHP	89501	14 500 000	6 981 000 ¹	10	100 – 4100	29
Jimblebar	BHP	94546	340 000	232 737	5	2 – 100	5
Mount Whaleback	BHP	65148	6 000 000	4 186 000 ²	15	300 – 2100	62
Ophthalmia	BHP	65219	10 000 000	2 948 000 ²	14	300 – 2300	137

Notes

¹ covers the period July 1998 to June 1999² covers the period July 1999 to June 2000

Table 3.2 Borefield monitoring and aquifer performance of the Central Pilbara

<i>Borefield</i>	<i>Aquifer type</i>	<i>Water quality 1999 TDS (mg/L)</i>	<i>Aquifer performance</i>
Paraburdoo			
• Mine Borefield	Alluvium and underlying fractured basement	830 – 1300	Recent waterlevel rises due to high recharge. Long-term water trend is stable indicating no net changes in aquifer storage.
• Town Borefield	Alluvium and fractured basement	640 – 1350	
• 4 West Mine Dewatering	Mineralised Joffre (orebody)	850 – 1200	Recent waterlevel rises due to decreased pumping and high recharge. Long-term waterlevels expected to decline with continued dewatering pumping. Higher pumping rates will be required to achieve full dewatering if mining continues to full design pit depth.
Turee Creek (Paraburdoo)	Alluvium and fractured basement	400 – 1300	Upper (shallow) aquifer shows no change in waterlevels. The lower aquifer(s) show declining waterlevels in response to abstraction.
Channar	Alluvium and fractured basement	280 – 1200	Local waterlevel fluctuations in response to pumping (from both Channar and Turee Creek borefields) and to recharge. Overall waterlevels indicate no net change in aquifer storage.
Southern Fortescue (Tom Price)	Alluvium and weathered/ fissured Wittenoom Formation	490 – 740	Waterlevels show minor increases in aquifer storage due to decreased pumping and higher recharge.
Hardey River (Tom Price)	Alluvium and weathered/ fractured bedrock	260 – 680	Mostly stable waterlevel data indicate no net change in aquifer storage.
Mount Lionel (Tom Price)	Alluvium and Wittenoom Formation	1200	Waterlevel declines observed in previous years have stabilised reflecting a decrease in pumping rates.
North Deposit Dewatering (Tom Price)	Mineralised Dales Gorge (orebody)	1590 – 5400	Waterlevels continue to decline in response to dewatering. Higher pumping rates will be required to achieve final pit dewatering of mining schedules to full design depth.
Southeast Prongs (Tom Price)			
• Southeast Prongs Dewatering	Mineralised Dales Gorge (orebody)	430*	Waterlevels have recovered due to suspended pumping. Waterlevels will again decline once dewatering resumes.
• Synclines Dewatering	Mineralised Dales Gorge (orebody)	**	Waterlevels continued to decline in response to dewatering until the bores were decommissioned.
Marandoo	Calcrete and underlying weathered and fractured Wittenoom Dolomite	500 – 550	Waterlevels have risen slightly, compared to recent years due to decreased pumping rates and recent aquifer recharge.
Brockman	Fractured bedrock	470 – 840	Recent waterlevel rises in remote bores indicate a slight increase in aquifer storage.
Yandicoogina (Hamersley)	Channel Iron Deposit (orebody)	380 – 440	Recent levels in 1999 were steady in the mine area. However, with the recent commissioning of the new sacrificial line, pumping induced drawdowns will extend up-gradient of the new mine area. Waterlevels are expected to again stabilise once dewatering targets have been achieved.

continued

Table 3.2 Borefield monitoring and aquifer performance of the Central Pilbara (cont.)

<i>Borefield</i>	<i>Aquifer type</i>	<i>Water quality 1999 TDS (mg/L)</i>	<i>Aquifer performance</i>
BHPIO Yandi	Channel Iron Deposit (orebody)	350 – 750	Waterlevels have declined in response to dewatering and are now relatively stable. Drawdowns are limited to within a 5 – 10 km distance from the mine.
Jimblebar	Weathered Wittenoom, Marra Mamba and Jeerinah	680 – 1215	Stable waterlevels indicate no net decrease in storage.
Mount Whaleback	Mineralised Joffre and Dales Gorge (orebodies) and fractured bedrock	420 – 2800	Waterlevels have decreased in response to dewatering since 1984 and will continue to do so until groundwater levels are below final mining depth. Waterlevels outside the mine area are largely unaffected by dewatering.
Ophthalmia	Alluvium and calcrete	700 – 2200	Waterlevels respond to seasonal recharge related to dam leakage and have risen slightly in recent years. Overall, however, there has been no significant change in aquifer storage in recent years.

* measured in 1998

** no data available

Table 3.3 Additional mine water requirements

<i>Mine</i>		<i>Water requirement (ML/day)</i>	<i>Usage</i>	<i>Water source</i>
Orebody 18	BHP	1.4	Mine process	Local borefield
Orebody 30 & 35	BHP	n/a	n/a	Existing Mount Whaleback & Ophthalmia borefields
Mining Area C (MAC)	BHP	6 0.6	Mine process Village	Local borefield & Hope North dewatering Local bore
Hope Downs (Hope 1)	ISCOR	30 – 110 5.7 14	Dewatering Mine process EWR	Hope North dewatering Hope North dewatering Hope North dewatering
West Angelas	Rio Tinto	2 4 8.5	Construction Standby Mine process	Mine dewatering & Jeerinah borefield Jeerinah borefield East Turee Creek borefield
Nammuldi	HI	18 1	Dewatering Mine process	Dewatering borefield & Brockman borefield Dewatering borefield
Silvergrass	HI	18 1 – 5	Dewatering Mine process	Dewatering borefield Dewatering borefield
Homestead	HI	n/a	n/a	Unknown
Giles-Mini	HI	n/a	n/a	Unknown

4 Ecological water requirements

4.1 Overview

In order to adhere strictly to the principles of ecologically sustainable development, groundwater resources must be managed in ways that are consistent with the principles of conservation of biological diversity. It is therefore necessary that the water allocation process considers the environmental needs of each dependent ecosystem. Where appropriate, the process must ensure that water is provided to meet the needs of key ecological functions in groundwater-dependent ecosystems.

The Water and Rivers Commission statewide policy on environmental water provisions for Western Australia (WRC, 2000) defines Ecological Water Requirements (EWR) and Environmental Water Provisions (EWP) as follows:

Ecological Water Requirements are the water regimes needed to maintain ecological values of water dependent ecosystems at a low level of risk.

Environmental Water Provisions are the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts. They may meet in part or in full the ecological water requirements.

The dependency of ecosystems on groundwater is based on one or more of four basic groundwater attributes:

- flow or flux — the rate and volume of supply of groundwater;
- level — for unconfined aquifers, the depth below surface of the watertable;
- pressure — for confined aquifers, the potentiometric head of the aquifer and its expression in groundwater discharge areas;
- quality — the chemical quality of groundwater expressed in terms of pH, salinity and/or other potential constituents, including nutrients and contaminants.

The response of ecosystems to change in these attributes is variable. There may be a threshold response in some

cases, whereby an ecosystem collapses completely if a certain attribute value is exceeded.

The direct impacts of mining on groundwater-dependent ecosystems will vary with the type of mining, intensity of groundwater pumping and the proximity to groundwater-dependent ecosystems (Evans, 2000). Mining-related industrial activities (such as on-site processing) and mine residential development may also affect groundwater-dependent ecosystems. Mining may affect each of the key groundwater attributes in the following ways:

- *Flux* — mine dewatering also has the potential to reduce discharge flux and volumes of water available for habitat for aquatic ecosystems in wetlands and baseflow streams.
- *Level or pressure* — mine dewatering will lower the watertable or aquifer pressure. The magnitude and rapidity of change will be relatively great for large opencut mines, or where the mine intersects highly transmissive aquifers. Mine construction activities, such as diversion and/or canalisation of streams, may also contribute to changes in riverine aquifer levels. Impacts on groundwater-dependent ecosystems in proximity to the mine could be substantial. Lowering of watertable could reduce, or even eliminate, cave or aquifer ecosystems that used the groundwater as habitat and were close to the mine. Mine dewatering is unlikely to have a major impact on baseflow-dependent systems unless the mine is located close to a spring that is the main source of flow, or there is a cluster of mining operations that have produced a regional change in groundwater levels. Wetlands and groundwater-dependent terrestrial or riparian ecosystems may be threatened by changes in groundwater level or pressure.
- *Quality* — mining poses several hazards to groundwater quality. Where groundwater is stratified, or changes in quality with depth (such as salinity, pH, chemical composition), dewatering may alter the environment experienced by cave or aquifer ecosystems. Ecosystems sensitive to those changes may be simplified or even eliminated by such changes.

4.2 Determining ecological water requirements of groundwater-dependent systems

The ecological water requirement of a groundwater-dependent ecosystem is the amount of water or water regime needed to sustain its ecological values. The EWR of any ecosystem must be understood if the management of groundwater resources is to be consistent with the principles of ecologically sustainable development. Ecological water requirements may be derived from an understanding of four key factors:

- nature of ecosystem dependency on groundwater;
- water requirements of the ecosystem;
- groundwater regime that will satisfy the water requirements of the ecosystem; and
- impacts of change in groundwater regime on ecological processes.

A conceptual framework for data collection and determination of the ecological water requirements of groundwater-dependent ecosystems is given in Figure 4.1. Literature review, expert opinion and direct investigation all assist in the determining of ecological water requirements. Table 4.1 provides an outline of the process for EWR assessment that might be used for three levels of resourcing or complexity.

4.3 Inventory of wetlands

The Central Pilbara has numerous groundwater-dependent ecosystems. Groundwater-dependent ecosystems are defined as those parts of the environment, the species composition, and natural ecological processes that are dependent on the permanent or temporary presence or influence of groundwater (Evans, 2000).

In order to ensure simplicity and avoid confusion, the term 'wetland' was used to describe the many rockholes, claypans, inundated areas, springs, river pools and watercourses of various sizes. Some are permanent, while others are ephemeral. Some, such as parts of the Fortescue Marsh, have high conservation value. Others, such as Weeli Wolli Springs, have high recreation/tourism and heritage values. The many documented Aboriginal archaeological or ethnographic sites are other important sites of heritage value.

The Water and Rivers Commission is the Government agency responsible for managing the hydrological and conservation values of the State's wetlands. The Commission is however not in a position to undertake large regional field assessments and have thus concentrated on developing the broad guidelines for establishing EWR and EWP (WRC, 2000). The Commission is conducting a specialist study to describe the wetland systems in the Pilbara Region, that also forms part of a statewide study concentrating on the broad consanguineous suites and their significance.

It is important that the Commission has an understanding of the location of wetlands and all available information on their values, significance and their function. Each new development proposal submitted through the Environmental Protection Authority (EPA) includes a considerable amount of site-specific work and large amounts of research conducted by the different mining companies. The Commission, in conjunction with Pilbara Iron-ore Environmental Committee (PIEC), coordinated a one-day workshop to examine currently procedures in the management of groundwater-dependent vegetation in the central Pilbara. A select group of experts presented papers on their work in the region, with the mining industry provided comments on their needs and management strategies with respect to EWR (Ergo, 2000).

Apart from a small number of tourist attractions, very few wetlands in the Central Pilbara are well known. In 1997, Hamersley Iron identified the need for more detailed information on the distribution and characteristics of wetlands in order to increase the effectiveness of environmental planning and management. Environmental Management and Research Consultants were commissioned to prepare an inventory of wetlands of the Pilbara.

Waters and Rivers Commission recognised the usefulness of this inventory, but required that it be expanded and updated. Worley Astron (2000) were commissioned to carry out this work, which involved:

- Extending the wetland mapping onto the ROBERTSON 1:250 000 sheet, in an area bounded by 120° 15'E, 22° 54'S and 23° 30'S (east to Jimblebar Creek and north to its confluence with the Fortescue River).
- A complete set of 1:250 000 maps showing all wetlands in the area covered by the Hamersley Iron dataset and the above extension.

Table 4.1 Guide to level of input for ecological water requirement assessment (after Evans, 2000)

<i>Step in Ecological Water Requirements determination process</i>	<i>Low resource &/or information availability Simple groundwater dependency¹</i>	<i>Moderate resource availability Moderately complex groundwater dependency²</i>	<i>High resource availability Complex groundwater dependency³</i>
Identification of groundwater dependency	Direct observation, checklist	Direct observation, checklist, land assessment impact study	Checklist, land assessment impact study, plant water relations, hydrograph interpretation
Dependency analysis			
• Groundwater-dependent elements of ecosystem	Literature review, expert opinion	Literature review, expert opinion, land assessment impact study	Literature review, expert opinion, land assessment impact study, limited physiological or isotope analysis, root depth sampling
• Key groundwater attributes	Literature review, expert opinion	Literature review, expert opinion	Literature review, expert opinion
• Type of groundwater dependency	Literature review, expert opinion	Literature review, expert opinion	Literature review, expert opinion
Assessment of water regime			
• Nature of water requirement	Literature review, expert opinion	Literature review, expert opinion	Literature review, expert opinion
• Source of water	Literature review, expert opinion	Literature review, expert opinion	Literature review, expert opinion
• Pattern of water use	Literature review, benchmarking against similar ecosystems	Literature review, hydrograph interpretation, base-flow analysis	Literature review, hydrograph interpretation, water use measurements, water balance studies, isotope analysis, base flow analysis
Water requirement determination			
• Ecosystem response to change	Expert opinion	Response function derived from existing information – historical information, monitoring, other studies	Response function derived from existing information – historical information, monitoring, other studies
• Ecological water requirement	Current or interpreted natural water regime	Water regime interpreted as sustaining all key ecological processes	Water regime expected to sustain all key ecological processes
Confidence level	Very low-moderate	Low-moderate	Moderate-high

Notes:

1. Suggested approach to EWR determination for groundwater-dependent ecosystems where there is currently little information available about the water regime and/or nature of dependency and where there are few resources available to gather new information. May also apply to ecosystems where the groundwater–ecosystem interactions are readily understood and do not require detailed experimentation to elicit the nature of these interactions.
2. Suggested approach to EWR determination for groundwater-dependent ecosystems where there is existing information that can be assessed to draw inferences about groundwater–ecosystem interactions. Applies also to circumstances where there are resources for limited new investigations of groundwater–ecosystem interactions.
3. Suggested approach where groundwater–ecosystem interactions are complex and where resources are available for detailed investigation of those interactions (or where the results of such investigations are already available).

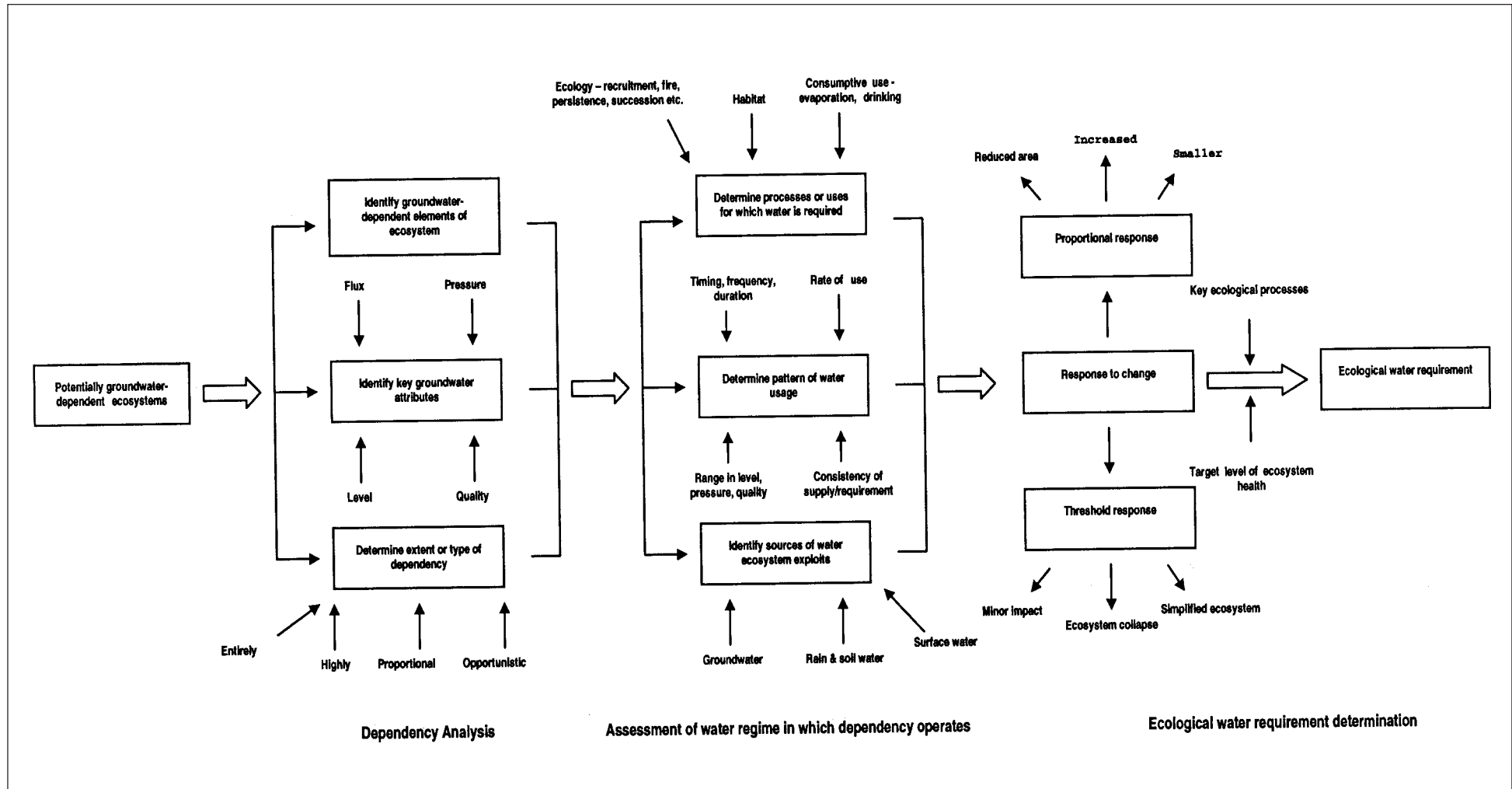


Figure 4.1: Conceptual framework for determination of ecological water requirements of groundwater-dependent ecosystems (after Evans, 2000)

- A summary report outlining how the data were captured, what they include (including limitations) and how they can be used.
- Identifying and mapping at the 1:250 000 scale wetlands in the study area that are outside Karijini National Park. Updating relevant environmental information and briefly summarising the wetland data in the following areas:
- The Fortescue River between Ophthalmia Dam and the confluence with Jimblebar Creek (Ethel Gorge area).
- Weeli Wolli Creek in the area between Weeli Wolli Springs and the confluence with Marillana Creek.
- Duck Creek, particularly the stretch between Hamersley and Duck Creek Homesteads.
- Turee Creek from West Angelas Mining Area (the Turee Creek East Branch gorge at the south eastern corner of Karijini National Park to Rocky Pool).

4.4 Sources of information

The sources of information consulted when preparing the Hamersley Iron wetland inventory are described, plus the additional sources that were consulted by Worley Astron (2000).

4.4.1 Masini EPA bulletins

Masini (1988, 1989) produced two EPA bulletins entitled *Inland Waters of the Pilbara*, Parts 1 and 2. The vegetation data collected were related to site characteristics and hydrology. For selected wetlands, a variety of data on water quality, water birds and aquatic fauna was obtained.

A physical classification system was also developed, with wetlands being divided into nine categories. These categories proved useful for wetland classification, although two identifiable wetland types (rockholes and inundated areas) were not described. It is assumed that Masini (1988, 1989) included rockholes under springs; however, this is not appropriate in all cases. Springs are assumed to have connections with groundwater, whereas rockholes located in gorges may have no groundwater connection and may simply accumulate rainfall. Inundated areas include several important floodplains of the Fortescue and other river systems.

4.4.2 AUSRIVAS scheme

In 1994, CALM funded by the Commonwealth Government set up a bio-monitoring program for rivers and streams throughout the State, as part of the Australian River Assessment Scheme (AUSRIVAS). The program used macroinvertebrates to monitor environmental conditions. As well as collecting macroinvertebrates, extensive data on water chemical and physical parameters, disturbance, vegetation and other aspects were obtained. As a result, considerable information is available for the sites studied. Unfortunately, few of the sites were located within the present study area.

4.4.3 Waters and Rivers Commission monitoring sites

Surface water sampling sites listed in the WRC Catalogue of Water Resources Information 1996 (Water and Rivers Commission, 1996) including monitoring sites. The list includes, but is not limited to wetlands linked to, watercourses with possible water-supply potential. Unfortunately, the amount of information available is small. Nevertheless, for a number of sites the dataset provides information not available elsewhere.

4.4.4 An inventory of important wetlands of Australia

The Australian Nature Conservation Agency produced a list of wetlands of national importance. The only wetland listed in that part of the Pilbara covered by the present study is the Fortescue Marshes. The listing includes information on the area's hydrology and its importance as a waterbird-breeding site when inundated.

4.4.5 A review of water-based recreation in Western Australia

This review was commissioned by the WA Water Resources Council and the Ministry of Sport and Recreation, and prepared by Martinick and Associates (1995). It was designed to examine the needs and opportunities for water-based recreation in Western Australia. The study reviewed available data on waterbody resources and usage distribution throughout the State. Unfortunately, the study found that little information was available on use patterns in the study area. Over the whole Pilbara, 114 waterbodies were recorded.

4.4.6 Aerial photography

Aerial photographs were consulted to determine whether they could be used in mapping wetlands. Unfortunately, the region is so large that high-resolution photographs are available only for a small portion. The date of photography is also relevant. Many important wetlands are ephemeral, and for most of the year are not apparent in photographs. It was therefore decided that little useful information could be obtained from aerial photographs.

4.4.7 Satellite images

Composite satellite photographs were consulted, but proved to be unsuitable because of insufficient resolution. As with aerial photography, timing in relation to rainfall was an issue which limited the usefulness of most images.

4.4.8 Maps

Maps at the 1:50 000 and 1:250 000 scales are available for the whole area. They show a range of wetland types such as watercourses, waterholes, claypans, inundated areas, waterfalls, river pools and springs. They include well-known wetlands such as Weeli Wolli Springs, and wetlands for which no documented information is available.

The main limitation posed by using maps is that for many wetlands, very little information apart from their location and wetland type (as defined in the mapping legend) is available. There is usually no indication of permanence, surrounding vegetation type, degree of disturbance or significance. The complete 1:50 000 and 1:250 000-scale map series were all searched with wetlands documented onto an EXCEL spreadsheet.

4.5 Wetland dataset

Records of wetlands from other sources including the documents listed above were also included. Hamersley Iron and BHP staff, as well as others with detailed knowledge of the area, were consulted to add wetlands not previously included and provide information on the characteristics and significance of wetlands. Three datasets were produced as a result of investigation:

- HIWET is an overall inventory of all wetlands, excluding watercourses;

- KEYWET includes wetlands considered to have significance, or those which are key monitoring sites. The wetlands included in KEYWET are also listed in HIWET;

- HISTREAM includes all named watercourses.

The datasets are described in sections 4.6.1 to 4.6.3 explaining how the inventory should be used when conducting an environmental assessment of a particular area. A complete list of wetland records, held by the Water and Rivers Commission, is provided on the CD accompanying this report.

4.5.1 HIWET

The HIWET dataset includes all:

- named pools on waterways;
- unnamed pools on unnamed waterways;
- waterholes*;
- rockholes*;
- claypans*;
- waterfalls*; and
- inundated areas.

Wetlands denoted with an asterisk (*) commonly include several sites in close proximity to each other. In such cases, only the easting and northing of one point are recorded with a description stating how many are present; e.g. 'four mainly dry lakes'.

The HIWET dataset was established initially by listing the map sheet and number, wetland reference number, easting, northing, wetland type and name (if available) of all wetlands on an EXCEL spreadsheet, prior to loading into MAPINFO. The accuracy of all records was then checked, and if necessary improved in MAPINFO. Key wetlands included in the HIWET dataset are denoted with a K to indicate that they are listed in KEYWET, where more information is available.

Since the only information available for most wetlands is that obtained from the maps, the dataset should be used as an awareness-raising tool. In most cases, when a wetland is present within an area of interest, more information will be needed before the environmental or heritage significance of that wetland is known.

4.5.2 KEYWET

The KEYWET dataset includes:

- All wetlands listed by Masini (1988, 1989) and the Inventory of Important Wetlands of Australia.
- All wetlands monitored by the Waters and Rivers Commission and AUSRIVAS scheme.
- Wetlands identified as having important recreation potential by the Newman and Tom Price Tourist Bureau and staff of Hamersley Iron and BHP Iron Ore.
- Wetlands with documented Aboriginal Heritage significance, or which contain known Aboriginal sites.

4.5.3 HISTREAM

Watercourses cannot be designated as a single point. For this reason, a different approach was used to store records of watercourses. The HISTREAM dataset used 1:50 000-scale maps and lists all named watercourses. In many cases, sections of watercourses are shown but not named; hence, it may be necessary to consult an adjoining map to determine the watercourse name. For each named watercourse, the dataset lists the types of wetland (*after* Masini, 1988) occurring along its course within the particular map sheet described.

4.5.4 Summary

The very large area and the paucity of existing information limit the dataset. However, with refinement it should provide a workable method of detecting wetlands and locating any information relating to them. It should be noted that the three datasets are only to be used as an awareness-raising tool. Figure 4.2 shows the distribution of wetland areas that have been collected during the study and stored on the CD. It is recommended that a designated person within the Waters and Rivers Commission have the responsibility for managing and updating the datasets, as new work is undertaken both by Government agencies and industry.

4.6 Stygofauna

The occurrence of stygofauna, a groundwater-dwelling fauna, has become a major issue in the Central Pilbara. Stygofaunal communities have been identified in the vicinity of most mines (Figure 4.2). The general lack of data and understanding about stygofauna in a regional context has made assessing the environmental impacts of proposed mining developments difficult.

Eberhard and Humphreys (1999) noted that stygofauna are significant for a number of reasons, primarily because the rare and relict taxonomy constitutes a significant component of biodiversity. The biodiversity may be of considerable value to studies in zoogeography, evolution of the Australian biota and landscape. The stygofauna may also play an important role in maintaining water quality through bioturbation.

At the request of the Water and Rivers Commission, the Western Australian Museum of Natural Science completed an initial situation assessment of the stygofaunal communities in the Pilbara (Humphreys, 2000). The report concluded that the region has been sparsely sampled for stygofauna with most samples collected from groundwater calcrete aquifers that lie in the palaeodrainages. The fauna has not been formally described, but it is rich by world standards and distinct from those in the surrounding regions (Carnarvon Basin, Yilgarn and Kimberley). The fauna in each calcrete is distinct.

Humphreys (2000) suggested that infilling of the sampling distribution is required, in conjunction with additional taxonomic work using both morphometric and molecular methods. This will improve substantially the understanding of the regional variation in the fauna, as well as of the implications of direct and indirect anthropogenic impacts. The complete lack of information on the functioning of the groundwater calcrete ecosystems needs to be addressed, if informed management of these systems is to be implemented.



5 Effects of mining

5.1 The mining process

Large-scale opencut mining in the Pilbara will result in massive voids, such as the pit void at Mount Whaleback with final dimensions of 5.5 km by 2.2 km and a depth of 0.5 km. The mining and processing of iron ore is a simple process. Segments of high-grade ore and waste material are identified within the pit. The pit floor is drilled and blasted with ore selected for transport to the plant and waste rock transported to waste dumps.

The ore undergoes several stages of crushing and screening to produce the final product, usually lump ore (6 – 30 mm) and fines (<6 mm). Some mines undertake all stages of the crushing at the individual mine sites, whereas others only undertake primary crushing. Some operations beneficiate lower grade ore by heavy-media separation to remove impurities from the ore producing both coarse and fine tailings. The coarse tailings are dumped and the inert, fine tailings are sent as a slurry to a tailings dam.

5.2 Overview of mining impacts on water resources

Mining operations face a variety of water management issues. Water and its management is critical to the profitable development and operation of a successful mine. In the Pilbara, water issues range from insufficient resource availability for processing to excessive mine dewatering. The issues also change as a mine operation proceeds through its development. Post-closure water issues are often quite different from operational issues.

Operating mines have to contend with three main water issues: water supply, wastewater disposal, and contamination of local water resources. Water demand for a major mine may exceed 2 GL/yr for a period of 30 to 50 years. Regulatory authorities allocate water resources according to expected economic returns and environmental requirements to ensure sustainable development. Increasing consideration is given to factors such as beneficial use, ecological water requirements, and water use efficiency.

Wastewater disposal becomes an issue particularly where it has been generated during the mineral extraction process (water held within slurries, fines and other waste products) and mine dewatering. Mines that extend below the watertable require dewatering, which results in the disposal of large volumes of water. Lowering the local watertable to below the base of the excavation via mine dewatering will permit dry-floor mining practice. Wastewater is generally used for dust suppression and mineral processing, disposed to evaporation ponds, or discharged back into the environment.

Groundwater abstraction related to mining operations (water supply and dewatering) lowers the local watertable. However, on the completion of mining, the groundwater usually recovers to the original level over time. An exception is the complete removal of an orebody, which is also the main aquifer, resulting in the permanent depletion of a local groundwater resource.

Mining has the potential to contaminate regional water resources, with the major water quality issues including:

- Acid rock drainage management;
- Dewatering;
- Mine voids;
- Stormwater management;
- Tailings storage facility management; and
- Workshop and process plant (liquid and solid) waste management.

A major concern is the mining impact on the environment after mining has ceased. Elsewhere in the world, many mine closures have left a legacy of substantial environmental damage. Mine closure, if not planned and carried out effectively, can leave a significant financial and environmental liability. The State must protect future generations from these liabilities, especially as considerable savings in final rehabilitation can be achieved when mine closure is planned and incorporated into continuing operational plans.

The mining industry is constantly improving rehabilitation techniques, with current closure procedures endeavouring to return the mining area to its original condition. The best examples of mine rehabilitation in the northern Pilbara are the Mount Goldsworthy mine and the mining villages of Goldsworthy and Shay Gap.

On the completion of mining, all remaining waste material is a potential source of pollution. Some leakage should be expected from tailings storage facilities, evaporation ponds and heap-leach facilities. These storage facilities are designed to leak during the life of the mine, with leakage diminishing when mining ceases. Current management strategies are therefore aimed at minimising the leakage problem to the immediate area of influence.

5.3 Acid rock drainage

The problem of acid rock drainage (ARD), a major mine-management issue around the world, was not originally considered a serious concern in the Pilbara owing to the low rainfall and high evaporation rates. Acidic runoff was detected in 1995 from an overburden storage area at Mount Whaleback following heavy rains associated with Cyclone Bobby. The ARD at Mount Whaleback originates from oxidation of highly reactive pyritic shale (Mount McRae Shale), which has the potential to form acid upon exposure to air, water and bacteria over a period of time.

ARD is a significant issue and how it is managed will be essential to the long-term success of many Pilbara iron ore mines. Many lessons concerning the management of ARD have been learnt at Mount Whaleback. Operationally, all overburden to be mined should be mapped and characterised to allow increased precision in the selective mining and placement of net acid-generating material. Spontaneous pyrite oxidation and subsequent generation of H_2SO_4 is a problem, and any mine-closure strategy must therefore involve covering these surfaces with either inert backfill material or water.

5.4 Mine voids

Opencut mining has resulted in massive mine voids that extend below the watertable. After the cessation of dewatering, groundwater levels recover over time and the mine void shows a surface expression of the

watertable. The exposure of the watertable has the effect of creating an artificial lake, initiating geochemical and hydrological processes that evolve with time. The infilling of the void with water may potentially take centuries, with chemical evolution via evaporation continuing much longer.

It is often difficult to understand void-water evolution and determine the potential impact that a final void lake may have on the surrounding groundwater environment. This presents a significant challenge to the authorities responsible for protecting the State's water resources, who have to act on modelling predictions that often may not have been verified. The extent of these voids means that any remediation of the water quality in the void would prove very expensive and unrealistic.

The final water quality in the pit lake is dependent on a host of factors including the oxygen status of the lake, pH, hydrogeological flow system, composition of wall rock, concentration through evaporation (evapo-concentration), biological activity and hydrothermal inputs (Fig. 5.1). The circulation patterns of pit lakes are important because of the central role of oxygen in the chemical reactions affecting water quality, particularly iron and arsenic. During mining, the rocks in the pit wall and floor are exposed to the atmosphere. Flushing of the rocks with water during lake development can release constituents dissolved from the rocks into the lake water, thus becoming biologically available. On the exposure of surrounding rock to air, reduced surfaces can be oxidised and generate soluble metal-bearing salts.

In a semi-arid climate, the concentration of all constituents in a pit lake increases significantly due to evapo-concentration. In situations where net evaporation greatly exceeds precipitation, it can result in dramatic increases in total dissolved solids content producing saline to brine water bodies, particularly where surface inflow to the pit is limited to direct precipitation. The generation of relatively dense, saline water at depth and periodic addition of fresh rainwater to the surface layers can result in a stratified water body.

The prediction of final water quality and quantity in mine voids is a relatively new challenge in mine-site rehabilitation. Existing modelling techniques, such as stochastic water-balance modelling, are capable of providing accurate predictions of water levels in the final pit lake. The length of time needed for the lake to

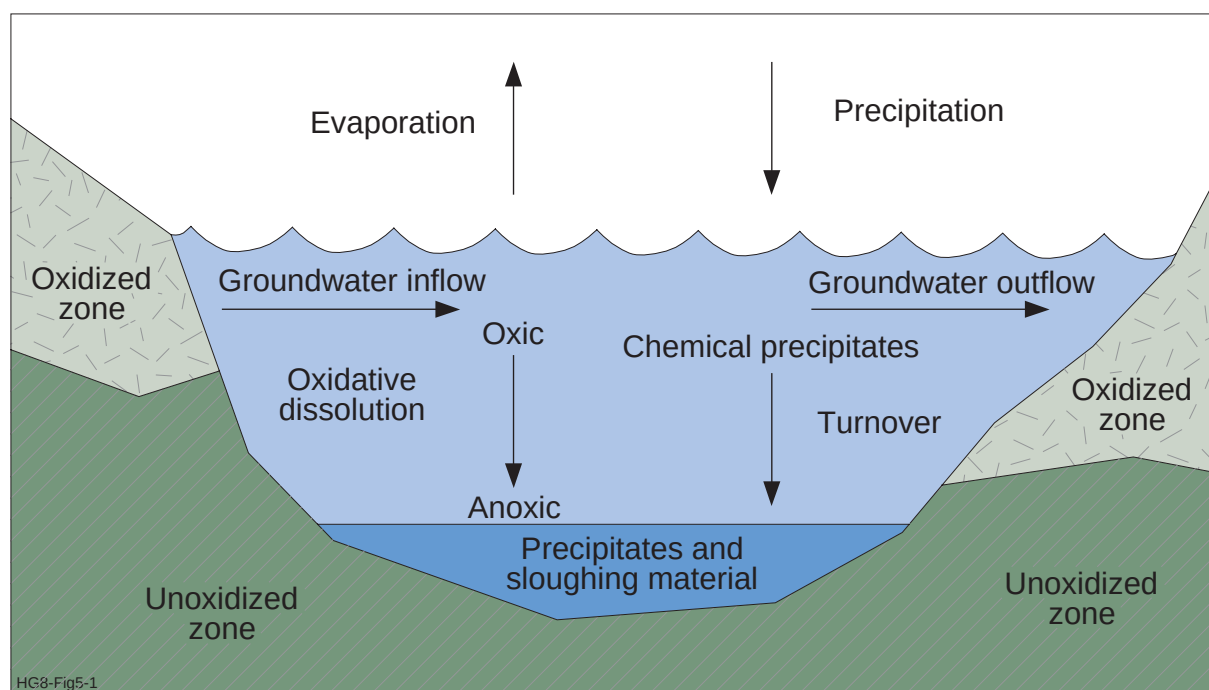


Figure 5.1 Chemical and physical processes in pit lakes (after Miller *et al.*, 1996)

reach final depth is dependent on several factors, including the area and depth of the pit, the rate of groundwater infiltration, direction of groundwater flow, rate of evaporation and the amount of rainfall.

There are difficulties in long-term predictions of water quality. The prediction of water-quality evolution in mine voids requires an understanding of the hydrogeological, limnological and biological/biochemical processes that control solute fate and transport quality. Jones (1997) observed that present models do not adequately account for all of these processes. As most mine pit lakes are relatively young, there are insufficient data available to support the testing and validation of available computer models.

5.4.1 Salinisation of mine-void water

A major long-term concern is the potential for most pit lakes in the Pilbara to become point sources of hypersaline water. The low annual rainfall and high evaporation experienced over much of the region result in a rainfall deficit, which may result in the development of hypersaline water bodies. Limited monitoring data suggest that final mine voids act as groundwater sinks and are becoming progressively saline. This is the case at the Mount Goldsworthy pit (northern Pilbara), where the salinity of the pit lake has gone from 1400 mg/L to

5500 mg/L TDS over a 14 year period (Waterhouse and Davidge, 1999).

5.4.2 Types of mine voids

Few, if any, mine voids are hydrogeologically isolated from the surrounding area, and the potential exists for contamination of local groundwater resources. The extent of impact on the surrounding groundwater environment is largely dependent on the local hydrogeology. Commander *et al.* (1994) defined three broad hydrogeological environments for mine voids.

Groundwater sink: Evaporation exceeding the rate of groundwater inflow; hence, the void acts as a groundwater sink. Groundwater levels recover slowly to a level lower than that of the pre-mining watertable. Continued evaporation with no outflow leads to progressive salinity increase resulting in brine formation, either to salt crystallisation in the pit, or reflux brine discharge driven by its density against the apparent hydraulic gradient. Most hard rock mines in the State form groundwater sinks.

Groundwater throughflow: Groundwater inflow exceeds evaporation with the void acting as a throughflow cell. The post-mining groundwater level will recover relatively slowly (decades) and probably

stabilise at a level lower than pre-mining. The salinity increases slowly in the pit lake with the development of a brackish to saline plume. The migration of the plume from the pit results in increased groundwater salinity down-gradient of the void. The salt concentration and resultant impact on the surrounding aquifer depends largely on the rate of throughflow. This type is primarily associated with voids in high-permeability ore bodies hosted in lower permeability country rocks.

Groundwater recharge: Inflow to the pit greatly exceeds evaporation from the pit-lake surface and groundwater levels may recover rapidly (years) to pre-mining levels. This is most likely to occur in areas of high rainfall, or where surface water is diverted into the void once mining has ceased. The void acts as a recharge area for the local aquifer and may overflow during periods of excessive rainfall. The monsoonal zone in Northern Australia, for example, commonly experiences tropical rain depressions that result in deluges of rain during the wet season. The pit-lake water may increase slightly in salinity during the dry season,

but will have minimal impact on the surrounding aquifer as the diluted ‘plume’ moves along the groundwater flow path.

As a rule, most mine voids in the Central Pilbara fall into the first two categories as depicted in Figure 5.2. Mine voids that exhibit throughflow characteristics are an environmental concern in the Central Pilbara. However, mine voids that act as a groundwater sink and intersect local aquifers (the orebody constituting the aquifer) have limited contamination potential of neighbouring aquifers, as is the case with most Brockman deposit mines (Fig. 5.3).

The loss of the local orebody aquifer is generally acceptable and there is limited justification with respect to impacts on future groundwater resources for requiring the pit to be backfilled, as aquitards separate the final pit lake from any other aquifers that may constitute potential water supplies. However, the infilling of pits during mining operations is obviously encouraged wherever possible as it overcomes residual uncertainties in modelling and is beneficial for a number of other reasons.

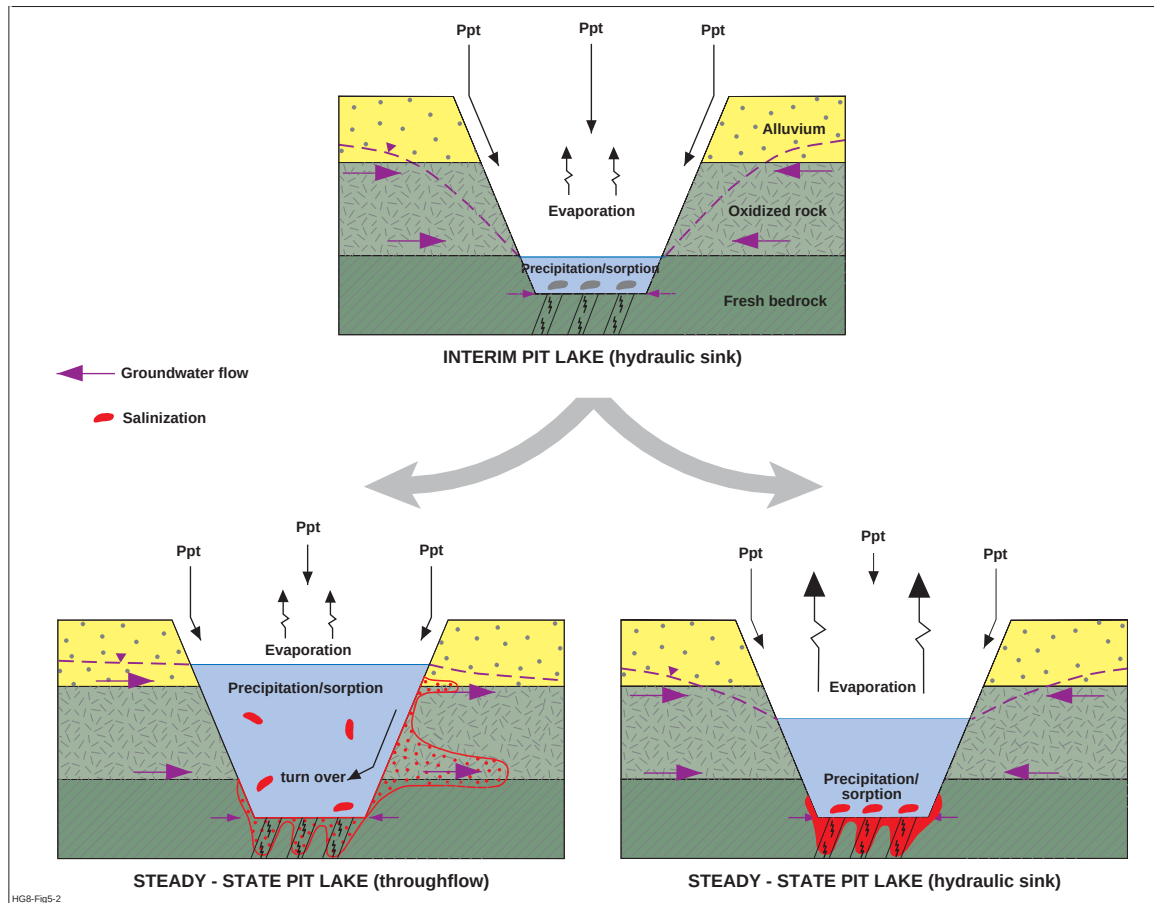


Figure 5.2 Most common hydrogeological processes occurring in Western Australian metalliferous mine voids

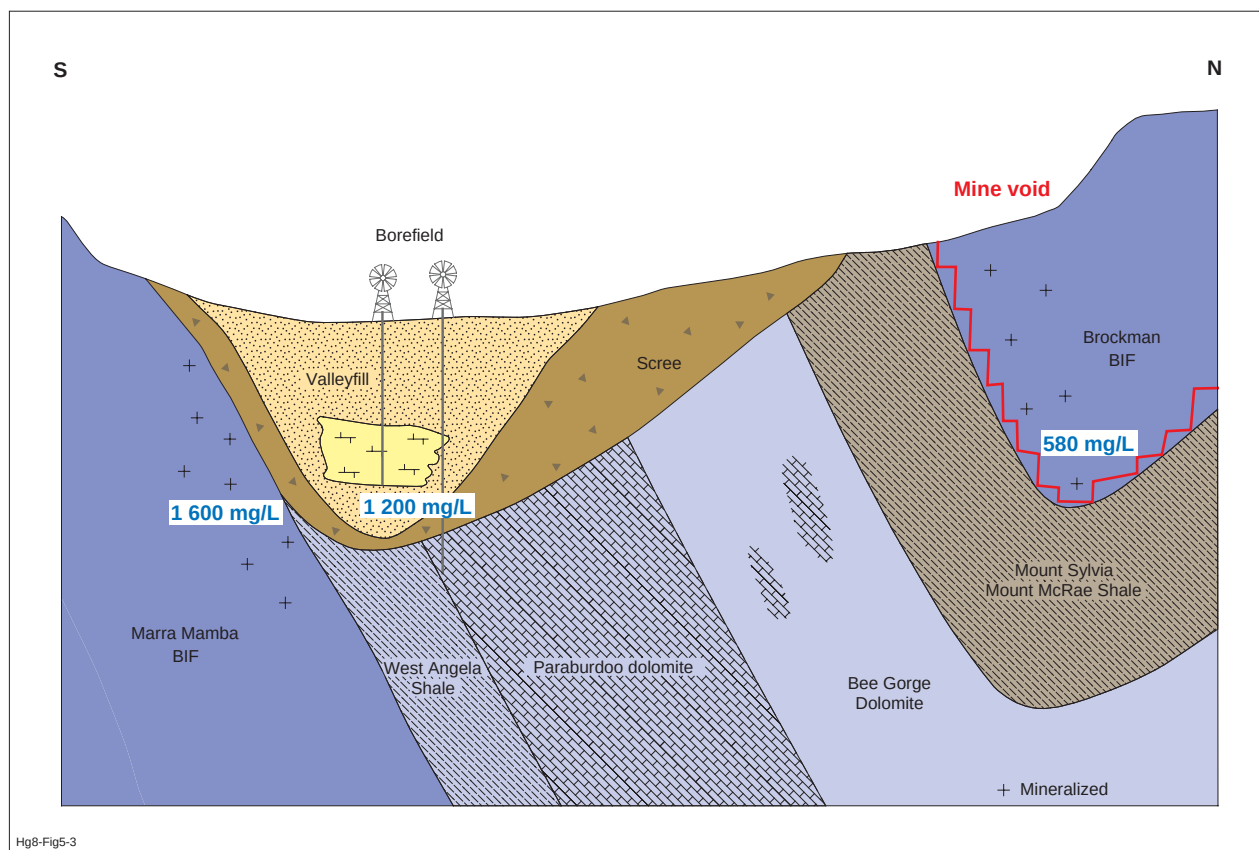


Figure 5.3 Orebody 18 – 'groundwater sink' mine-void scenario

Mine voids that exhibit throughflow characteristics are more stringently reviewed and have environmental constraints. The best examples in the Central Pilbara are the channel iron deposits (Yandi, Marillana Creek and Robe River) and the BIF deposits hydrogeologically linked to other important aquifers (Orebody 23 and Hope North).

Figure 5.4 is a schematic visualisation of the proposed Hope North mine, showing the throughflow scenario. It also highlights the potential impact on the adjacent aquifer, which supplies fresh water and supports a highly-sensitive spring system of heritage value. The adjacent aquifer is fully allocated to ecological water requirements for maintaining Weeli Wolli Spring, hence the State needs to ensure that any mining development will not have a significantly deleterious impact on the aquifer. The proposed mine void at Hope Downs will have to be backfilled to avoid the development of a pit lake after closure.

In channel iron deposits, the limonitic pisolite often represents a significant aquifer. As a result of mining the pisolite iron-ore deposit, the aquifer, is removed, and mine closure must involve a strategy for recreating the system as a throughflow cell. Fortunately, this can

be largely achieved by backfilling during mining operations. The option of creek diversion should be investigated in those localities where some form of void remains.

5.4.3 Closure strategy for mine voids

In determining what closure strategy to adopt, the mining company must:

- Provide some prediction of pit-lake water quality over time (Jones, 1999).
- Determine if the area has any significant groundwater resources and the beneficial use (including EWR) of the aquifer.
- Identify what the hydrogeological linkage is between the void and adjacent aquifers.
- Determine what potential impact the selected void-management strategy could have on the surrounding groundwater system (worst case scenario).
- Develop and implement a monitoring program to confirm the predicted trends, so that the State is able to sign off on the closure plan.

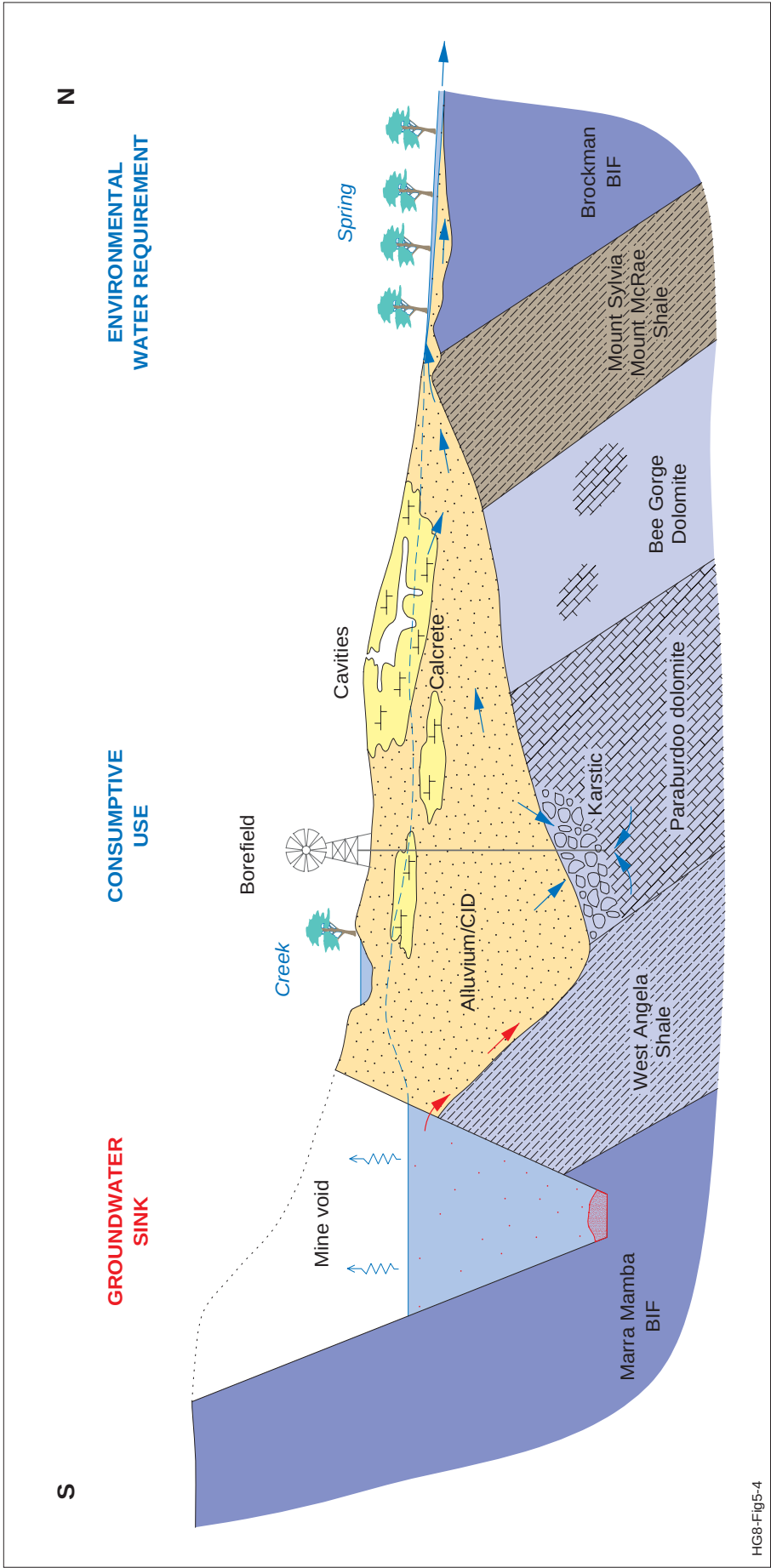


Figure 5.4 Hope Downs / Weeli Wolli Springs area – ‘throughflow’ mine-void scenario

6 Water resource issues

Groundwater demand and use in the Central Pilbara is concentrated around a number of mining centres with supplies from borefields and dewatering. Water management is critical to the profitable development and operation of a successful mine. Over the past three decades, the iron ore industry has successfully managed the local groundwater resources in the vicinity of their mining operations. The discovery and development of new iron ore deposits throughout the Central Pilbara has resulted in the need to gain a regional perspective of the water resource issues.

Based on the spatial distribution of the current and proposed mining operations, seven key regional localities were identified: Ophthalmia; Turee Creek; East Turee Creek; Weeli Wolli Creek; Marillana Creek; Tom Price / Southern Fortescue; and Caves Creek/Duck Creek areas (Fig. 6.1). This section will briefly discuss the geology, groundwater resources and wetlands in the area, prior to highlighting the water resource issues. Schematic sections have been compiled to show the relationship between aquifers and, where possible, typical bore yields and groundwater salinity.

6.1 Ophthalmia/Fortescue River area

The Ophthalmia/Fortescue River aquifer system supplies groundwater to the town of Newman and BHP Newman mining operations. The first borefield was commissioned in the early 1970s. In 1981, Ophthalmia Dam was constructed to artificially recharge the alluvial aquifer when pumping was exceeding the sustainable yield of the aquifer. Today, the Ophthalmia Dam–Newman Water Supply Scheme has one of the most comprehensive monitoring datasets in the Pilbara.

The Fortescue River and its main tributaries (Shovelanna, Whaleback, Homestead and Warrawanda) join before cutting through the Ophthalmia Range via the 400 m-wide Ethel Gorge. The alluvium-filled palaeovalleys of these creek systems, up to 90 m thick, have been eroded into basement rocks of the Wittenoom Dolomite, Brockman Iron Formation, Mount Sylvia Shale and Mount McRae Shale (Fig. 6.2). Groundwater flows north through Ethel Gorge to the Fortescue Marshes.

Aquifers exist in the calcrete and underlying sand and gravel units that are generally separated by a sequence of clays that act as confining layers (Fig. 6.3). Local perched aquifers may develop for short periods when the shallow alluvium in the modern streambeds is saturated during flow events. Basement rocks form localised aquifers as a result of the mineralisation and structurally induced development of secondary permeability, as well as karst development in the Wittenoom Dolomite. Groundwater quality is generally fresh to brackish, with salinity ranging from 540 to 2700 mg/L TDS.

The borefield along Homestead Creek supplies potable water to the town, while Ethel Gorge borefield provides about 14 ML/day of raw water to the mining operations. Storage in the Ethel Gorge aquifer is mainly replenished from recharge (seepage) from Ophthalmia Dam, which is estimated at about 24 ML/day with evapotranspiration accounting for 10 ML/day. Current groundwater abstraction appears to have reduced throughflow at Ethel Gorge from 1–2 ML/day to 500–700 kL/day. The effective natural seepage from Ophthalmia Dam itself has meant that the artificial recharge basins constructed in the calcrete areas below the dam have not been used. There are a number of wetlands in the Ophthalmia/Fortescue River area. Most of the wetlands sites are associated with pools and falls in the creek and riverine system of the Fortescue River (Fig. 6.4).

The Water and Rivers Commission suggests that the following water-related issues in the Ophthalmia/Fortescue River area are considered as part of any current or proposed mining development.

- Future mining at Orebody 23 will necessitate dewatering, which will produce significant drawdowns in the Ethel Gorge Borefield. Groundwater outflow at Ethel Gorge will be greatly reduced except immediately after heavy rainfall events. It is anticipated that the groundwater system will fully recover within three years of dewatering cessation.

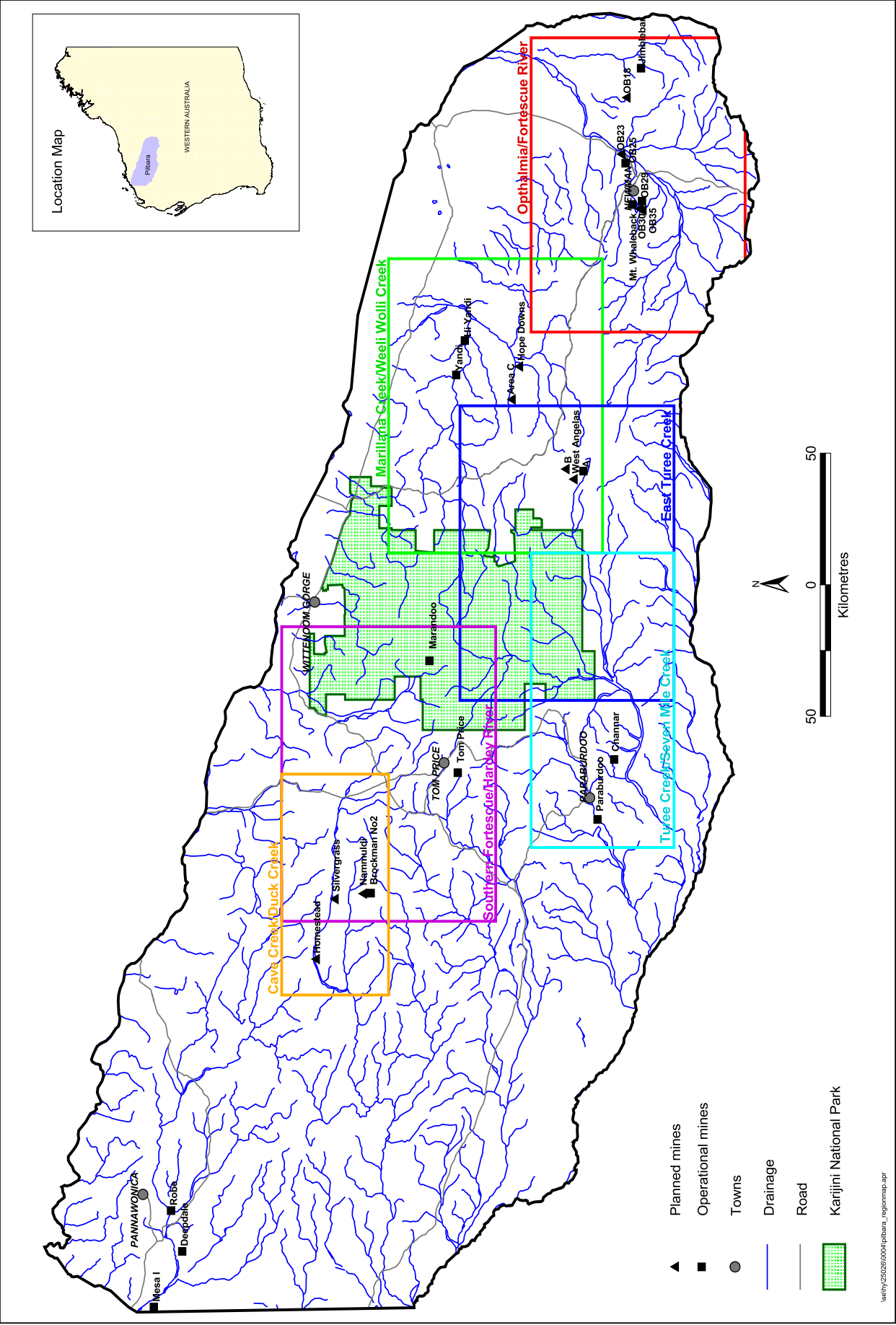
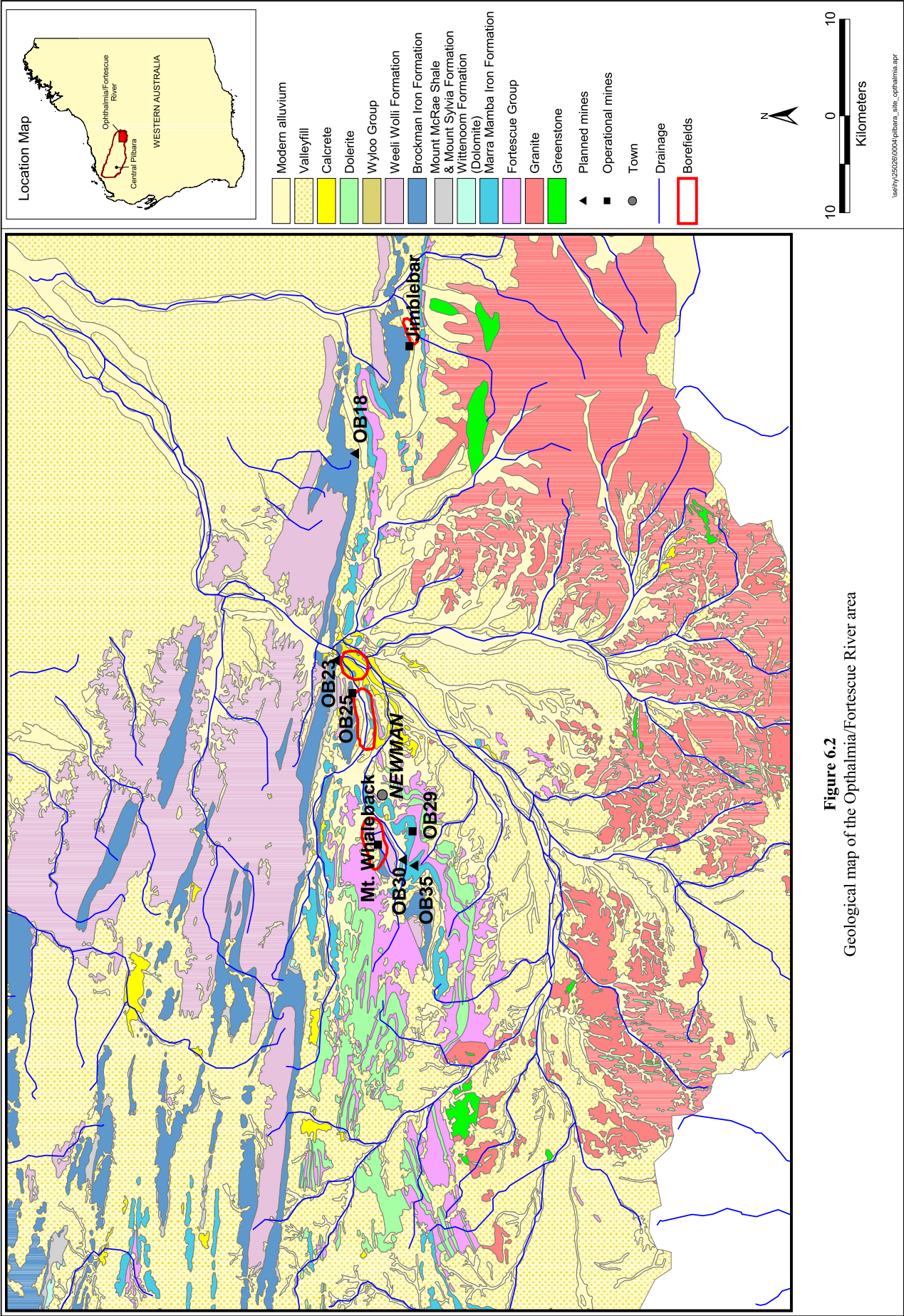


Figure 6.1 Regional areas used to highlight water management issues



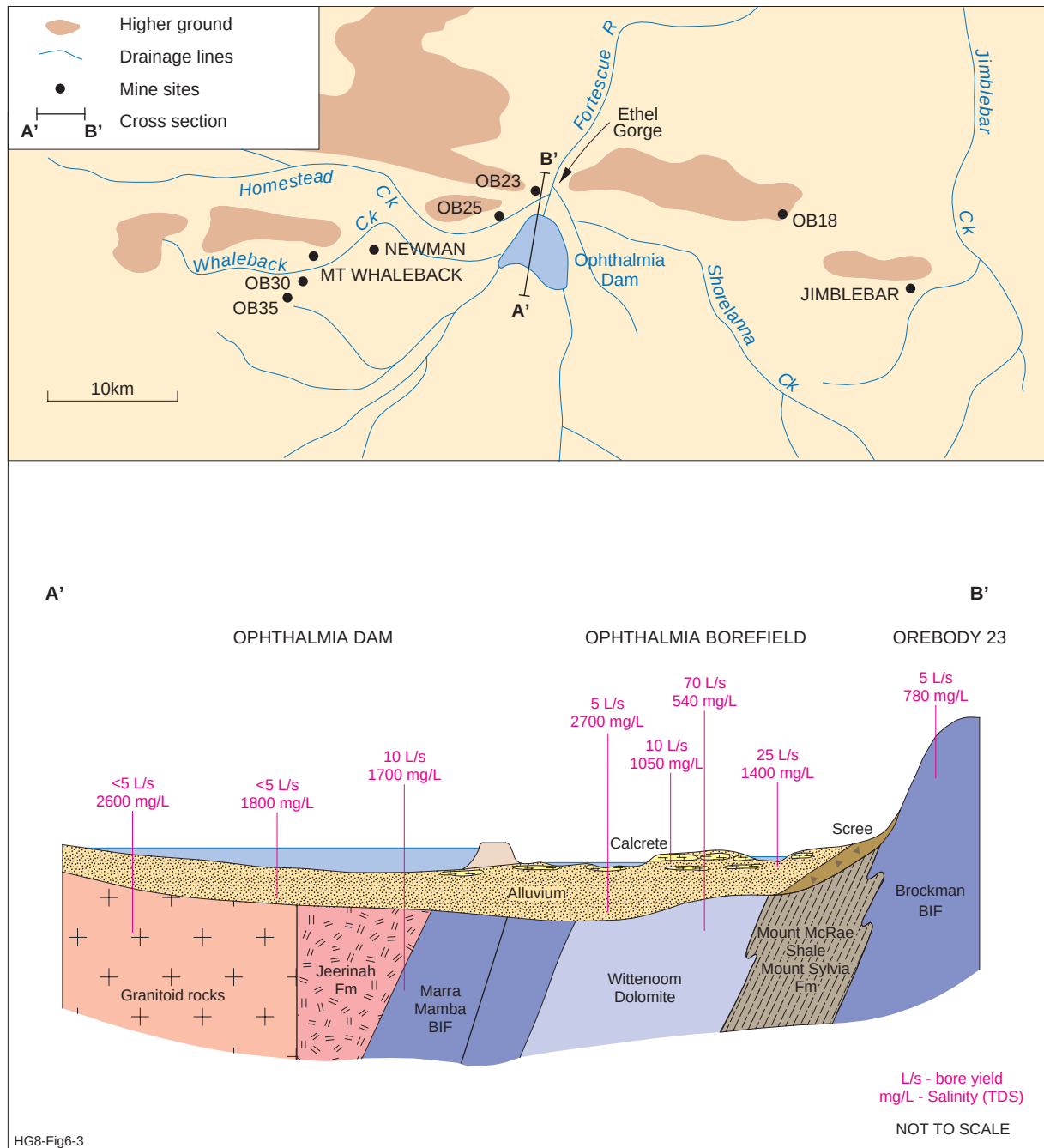


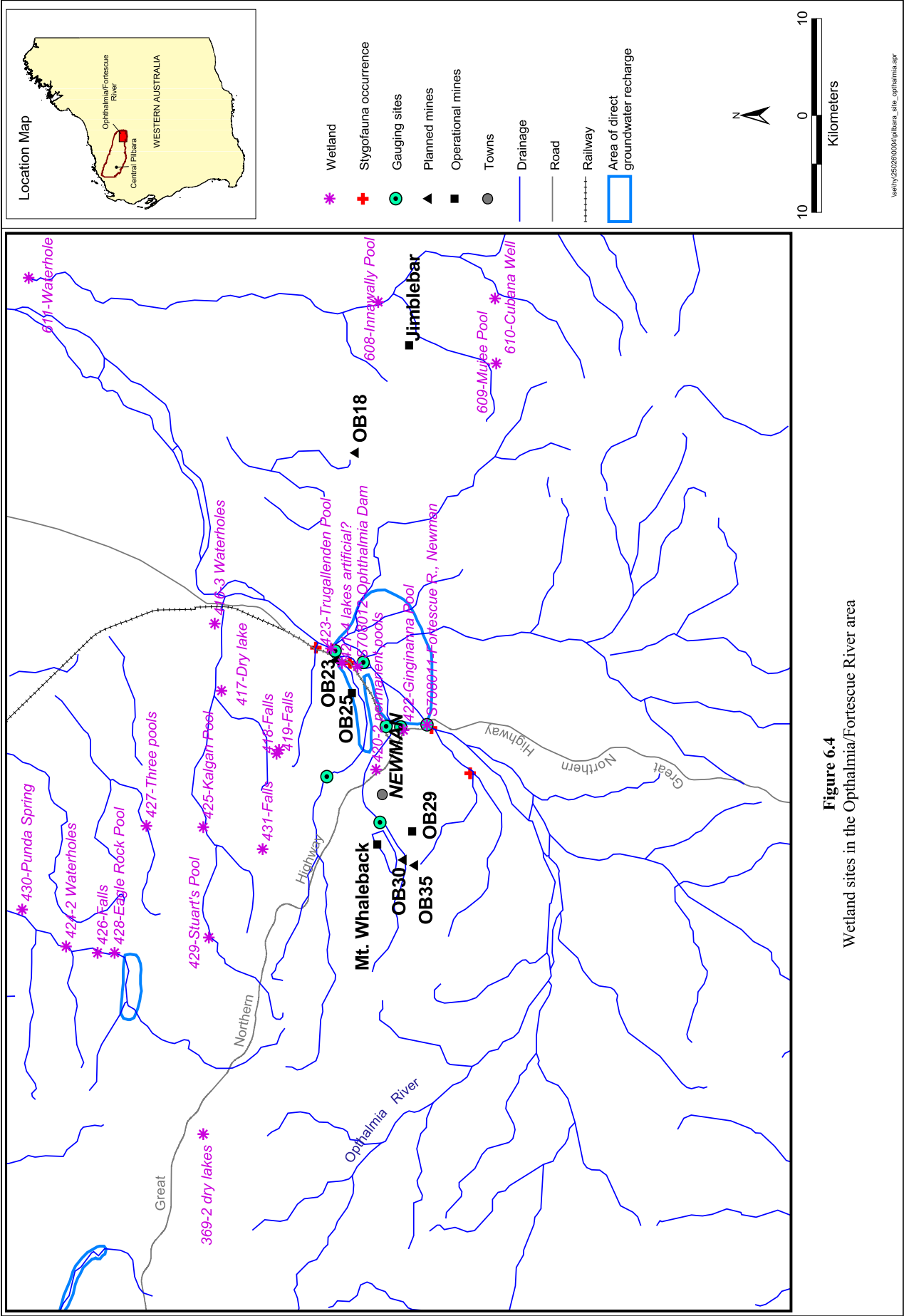
Figure 6.3 Location plan for mine sites around Newman and schematic section showing aquifer relationships

- BHP has initiated a tree-monitoring program and installed an irrigation system that can be implemented should mining impact on creek-line vegetation.
- The lowering of groundwater levels may affect stygofauna within the calcrete and alluvial aquifers. Further research is required to ascertain whether the stygofauna are able to survive gradual changes within an aquifer.
- The water supply borefields and important aquifers are isolated from the mining activity at Mount

Whaleback. If required, controlled releases of water from the dam could be utilised to rapidly recharge the aquifer in the Ethel Gorge area.

6.2 Turee Creek/Seven Mile Creek area

Southeast of Paraburdoo, Turee Creek flows west along a broad (4 km wide) valley before turning sharply south to exit the Hamersley Range (Fig. 6.5). The catchment supports three mine-water supply borefields: Turee Creek, Channar and Mount Olympus borefields.



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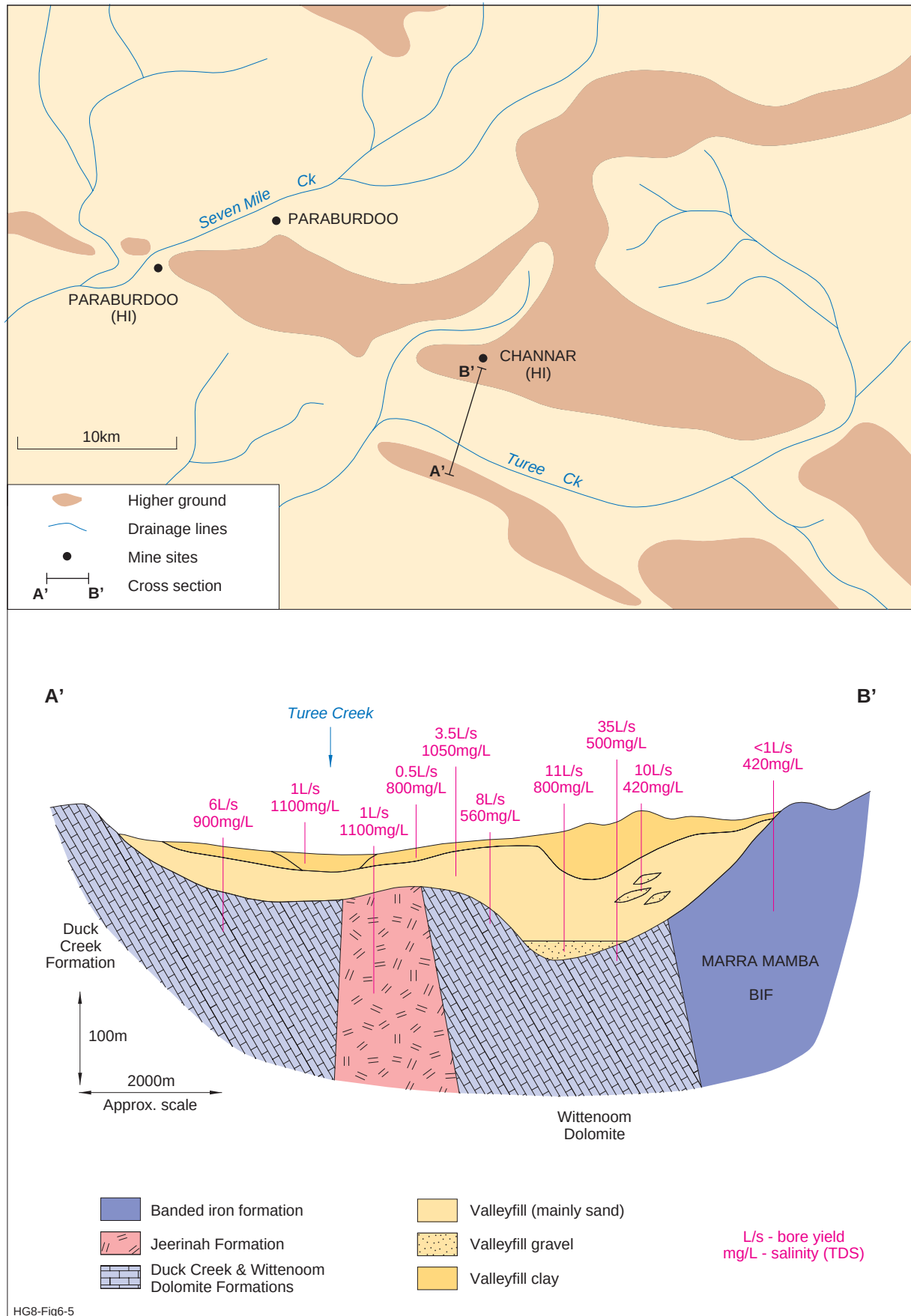


Figure 6.5 Location and schematic section through Turee Creek showing aquifer relationships, bore yields and salinity

The Turee Creek / Seven Mile Creek area contains two distinct aquifer systems (Fig. 6.5); a shallow unconfined alluvial system associated with the current creek drainage, and a deep confined system associated with palaeodrainage gravels and interconnected dolomitic units. A thick succession of low-permeability valleyfill clay separates the two systems. Waterlevels in the shallow alluvial system respond to creek-flow recharge. Water-supply potential is restricted by a combination of limited storage and sensitivity to prolonged periods of drought. Water quality is generally fresh.

The Hamersley Iron Turee Creek and Channar borefields abstract groundwater from the shallow alluvial aquifer and deeper fractured basement rocks. While upstream, the Paraburdoo Gold Mount Olympus borefield targets the shallow alluvial aquifer and fracture zones within the Duck Creek Dolomite and Wittenoom Dolomite Formations (Fig. 6.6).

The Water and Rivers Commission suggests that the following water-related issues in the Turee Creek/Seven Mile Creek area are considered as part of any current or proposed mining development.

- The protection of nearby wetland sites. Down-gradient of the Turee Creek Borefield, the shallow groundwater system supports both the Nanjilgardy Pool and Neeramba Spring and pools. Monitoring indicates that current groundwater abstraction is not affecting on these systems (Fig. 6.7).
- Upstream of the Mount Olympus and Channar borefields, a number of river pools depend upon groundwater baseflow during the dry season. It is possible that any borefield extension to the east of Mount Channar may have a significant impact on these wetlands.
- Hamersley Iron has an ongoing vegetation-monitoring program along Turee Creek, and the borefields are managed to avoid any detrimental environmental impacts. The vegetation within the creek is well adapted to the prolonged droughts that frequently occur in the area.
- The position of the tailings dam at Paraburdoo Gold Mount Olympus within the Turee Creek drainage system. In order to avoid potential contamination of the Turee Creek aquifers, it will be important that the tailings dam is structurally sound upon cessation of mining.

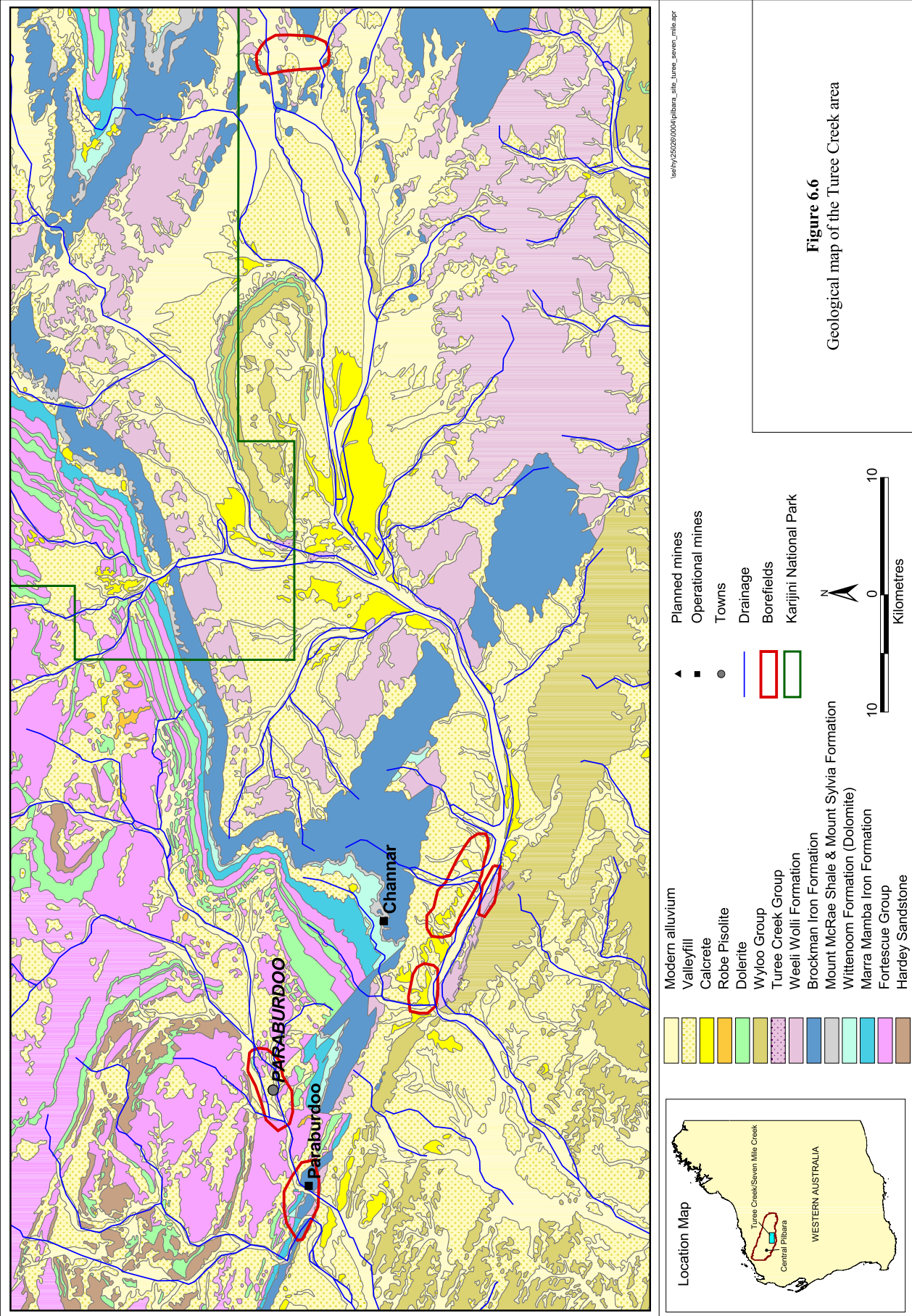
6.3 East Turee Creek area

The East Turee Creek catchment contains the proposed West Angelas mine. Structurally, the mine is positioned within a low-lying plateau of Jeerinah Formation flanked by Marra Mamba Iron Formation. Aquifers in the Jeerinah Formation are limited to zones of local, fractured-induced permeability. Creek valleys on the flanks of the plateau are subcropped by the Marra Mamba and Wittenoom Formations (Fig. 6.8).

Mining will continue for 30 years, with a water requirement of about 8 ML/day. The Turee B borefield within the East Turee Creek catchment, 40 km west of the mine, should meet process-water requirements. The Turee B borefield is located on a large (15 km wide) alluvial plain that is bounded by high hills of Brockman Formation in the east and a lower range of Boolgeeda Iron Formation in the west (Fig. 6.9). The Turee Creek East drainage is fed by a number of smaller creeks originating in the hills to the west. The creek system is ephemeral and does not support any permanent surface-water feature. Vegetation along the creek is variable with eucalypts, spinifex and acacia.

The local fractured-rock aquifers in the Jeerinah Formation will supply construction water (2 ML/day), and serve as a standby water supply on the commencement of mining. The standby borefield will be able to provide 3.5 ML/day for a month or 3 ML/day for five months resulting in localised dewatering with any recovery of the aquifers being extremely slow.

The main aquifer in the area, particularly near Turee B borefield, is the vuggy pisolite (Robe Pisolite) which overlies fractured basement rocks of the Woongarra volcanics and Boolgeeda Iron Formations (Fig. 6.9). The pisolitic aquifer lies within Tertiary palaeochannels that are aligned with two major faults on either side of a regional anticlinal fold (Fig. 6.10). The aquifer zone varies between 50 and 80 m in thickness and has an estimated permeability of 40–80 m/day. Groundwater throughflow is estimated at 400 KL/day. The pre-mining groundwater level is about 30 m bgl. The aquifer is overlain by a sequence of alluvial clays containing significant groundwater storage that can be utilised via downward leakage. Groundwater quality is potable and may be used for process and potable supply.



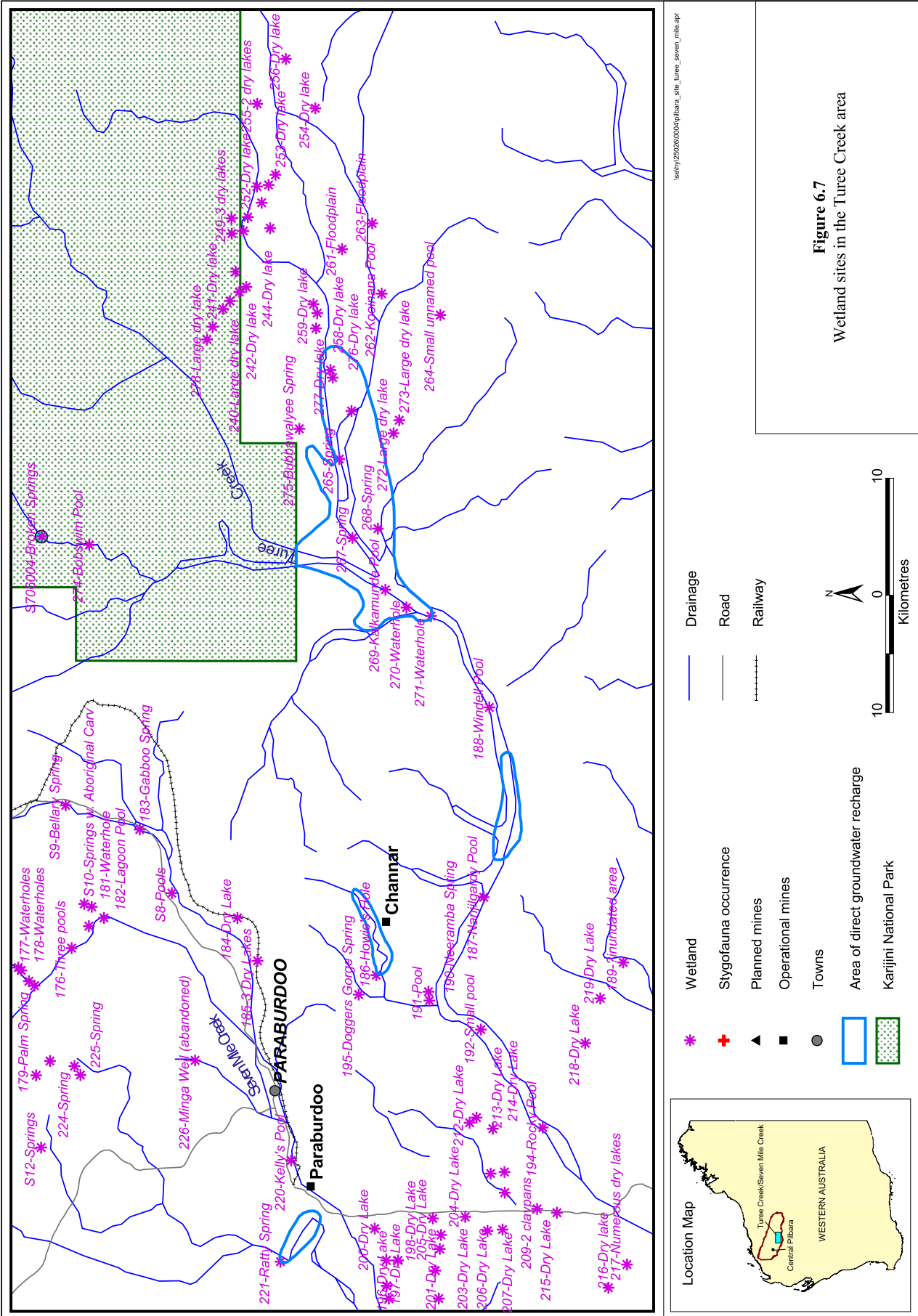


Figure 6.7
Wetland sites in the Turee Creek area

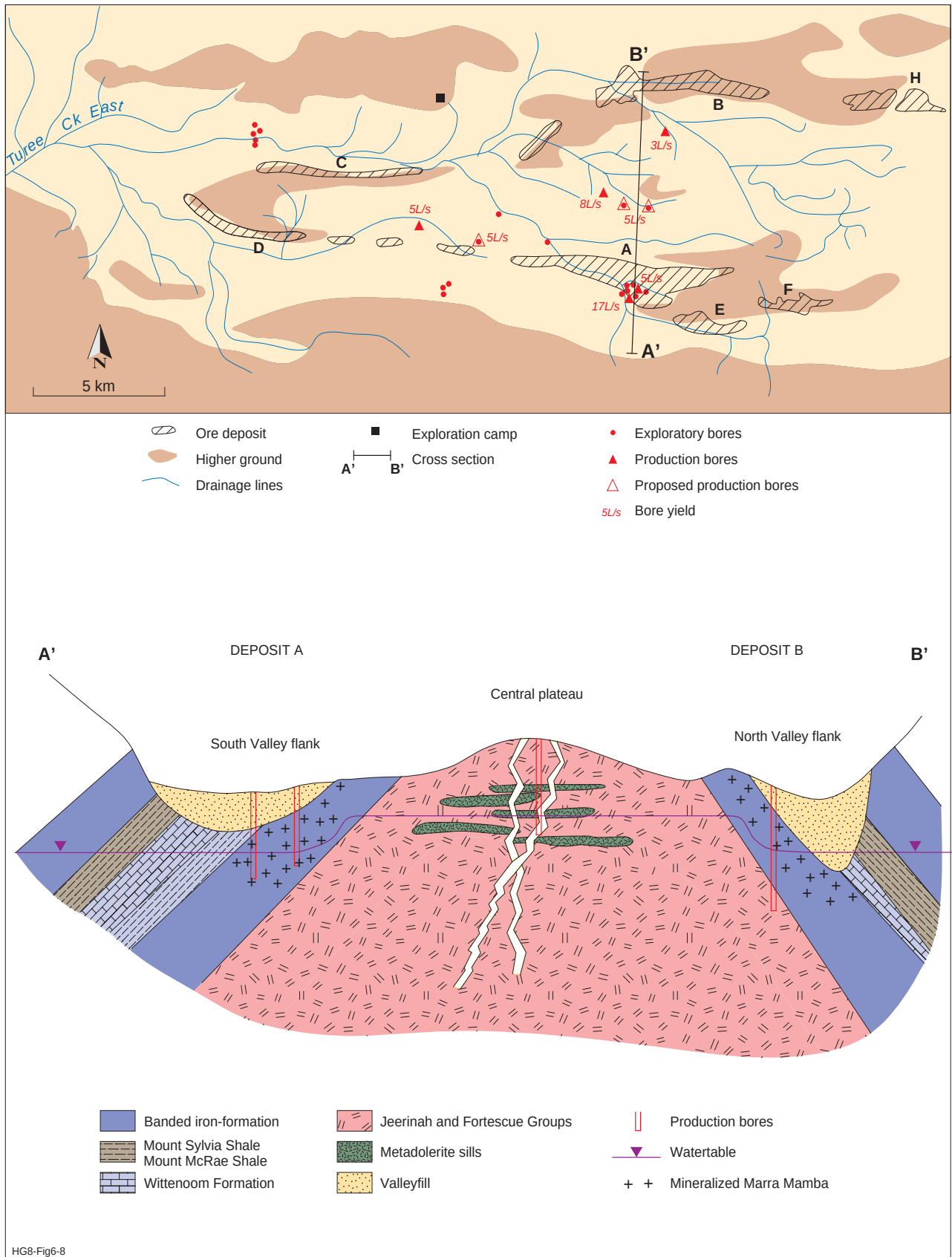


Figure 6.8 Location of West Angelas mine site and conceptual hydrogeology

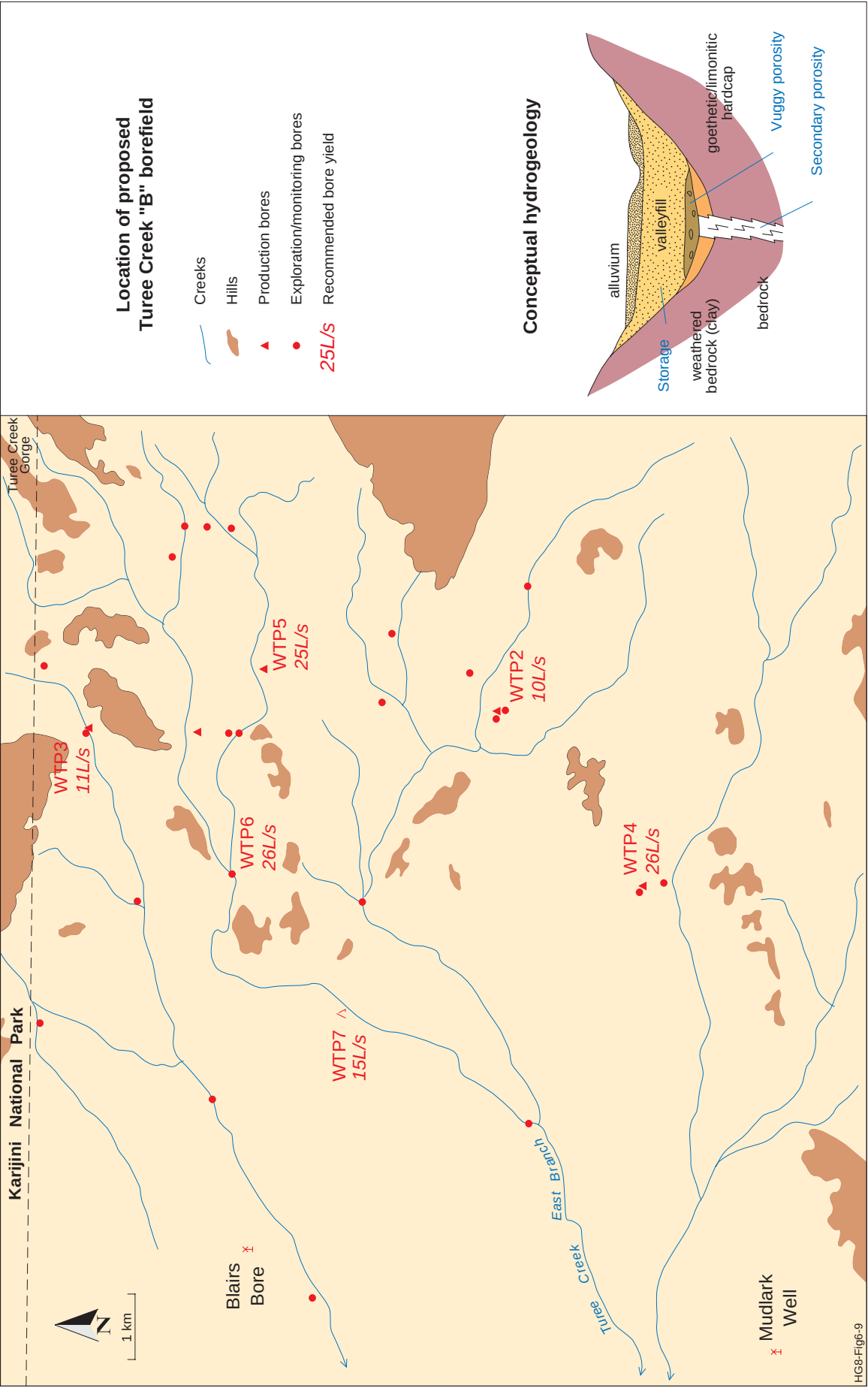
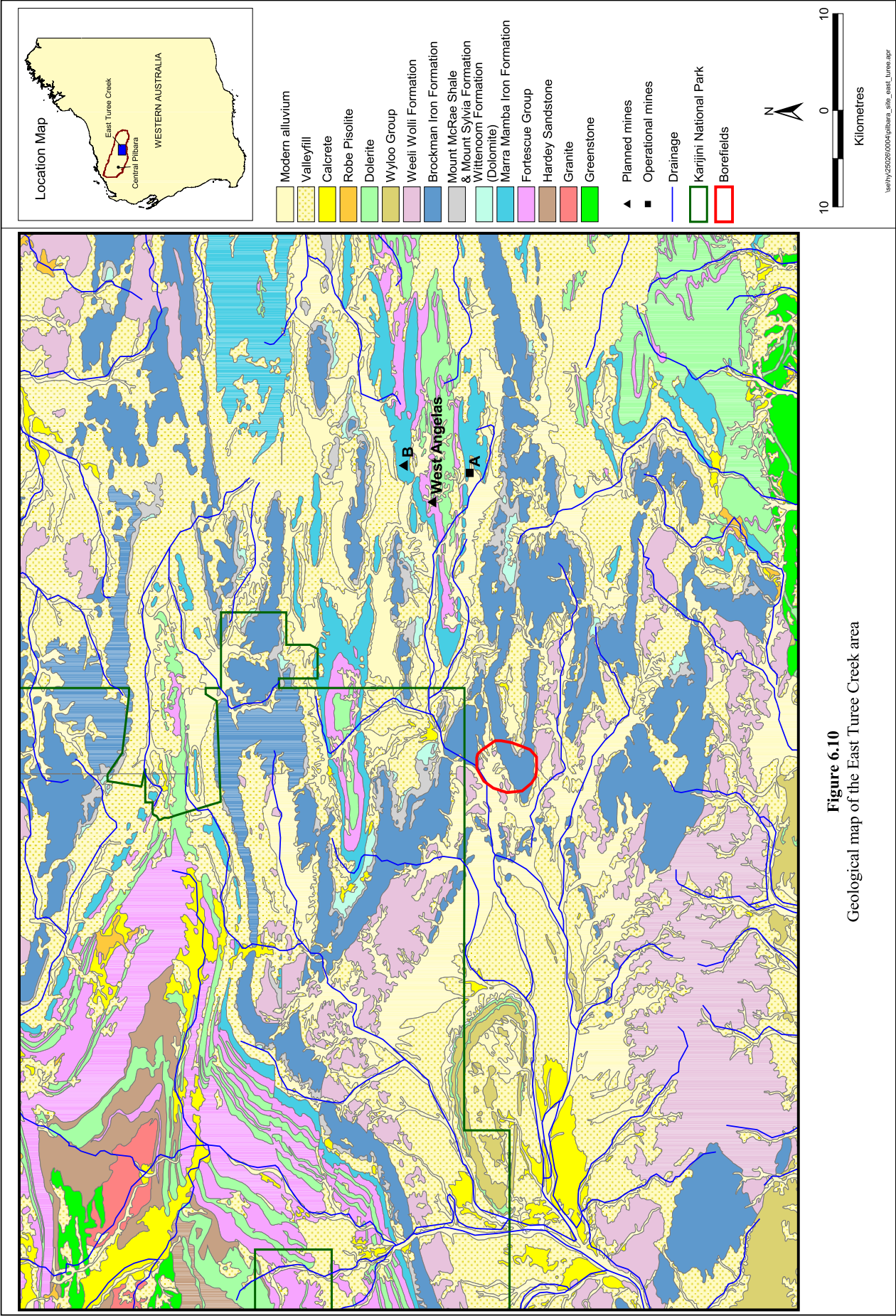


Figure 6.9 Location and schematic hydrogeology at Turee B borefield



The Water and Rivers Commission suggests that the following water-related issues in the East Turee Creek area are considered as part of any current or proposed mining development.

- Based on the groundwater resource investigation, it is questionable whether the aquifer could sustain an annual abstraction of greater than 10 ML/day;
- Any future borefield expansion in a westerly direction would encounter a number of wetlands as shown in Figure 6.11.

6.4 Weeli Wolli Creek area

The Weeli Wolli Creek catchment, including Marillana Creek and Yandicoogina Creek, represents a significant surface water flow (10%) into the Fortescue Marshes (Aquaterra, 2001). Weeli Wolli Creek can be divided into three zones: an upper catchment (above Weeli Wolli Springs), a lower catchment (trunk drainage between the Weeli Wolli Springs and the Hamersley Ranges escarpment), and broad outwash on the Fortescue Plain. The focus is the upper catchment and the areas to be impacted by BHP Mining Area C and Hope Downs (Hope 1) operations (Fig. 6.12).

The upper catchment comprises a number of tributaries that flow between east–west trending ranges before flowing through a narrow gorge in the Packsaddle Range at Weeli Wolli Springs. The gorge forms the surface and groundwater outlet from the southern half of the Weeli Wolli catchment (Fig. 6.12). The spring is a permanent water feature that is supported by groundwater discharge. Surface water flow disappears about 2 km downstream of the spring, as a result of seepage and evaporation. The area often experiences periodic heavy rainfall during summer because of both monsoonal effects and cyclones. Although the average surface flow is 2.8 GL/year, it has been as high as 22 GL during an exceptional flood year.

The upper catchment contains rocks of the Hamersley Group including the Brockman Iron and Marra Mamba Iron Formations (Figure 6.13). The ore deposits are in the Marra Mamba Iron Formation with

most mineralisation confined to the Mount Newman Member and the base of the West Angelas Member (Fig. 6.14). The Hope Downs mining area comprises two deposits that are positioned on a major northeast–southwest structural lineament dictating the lower Weeli

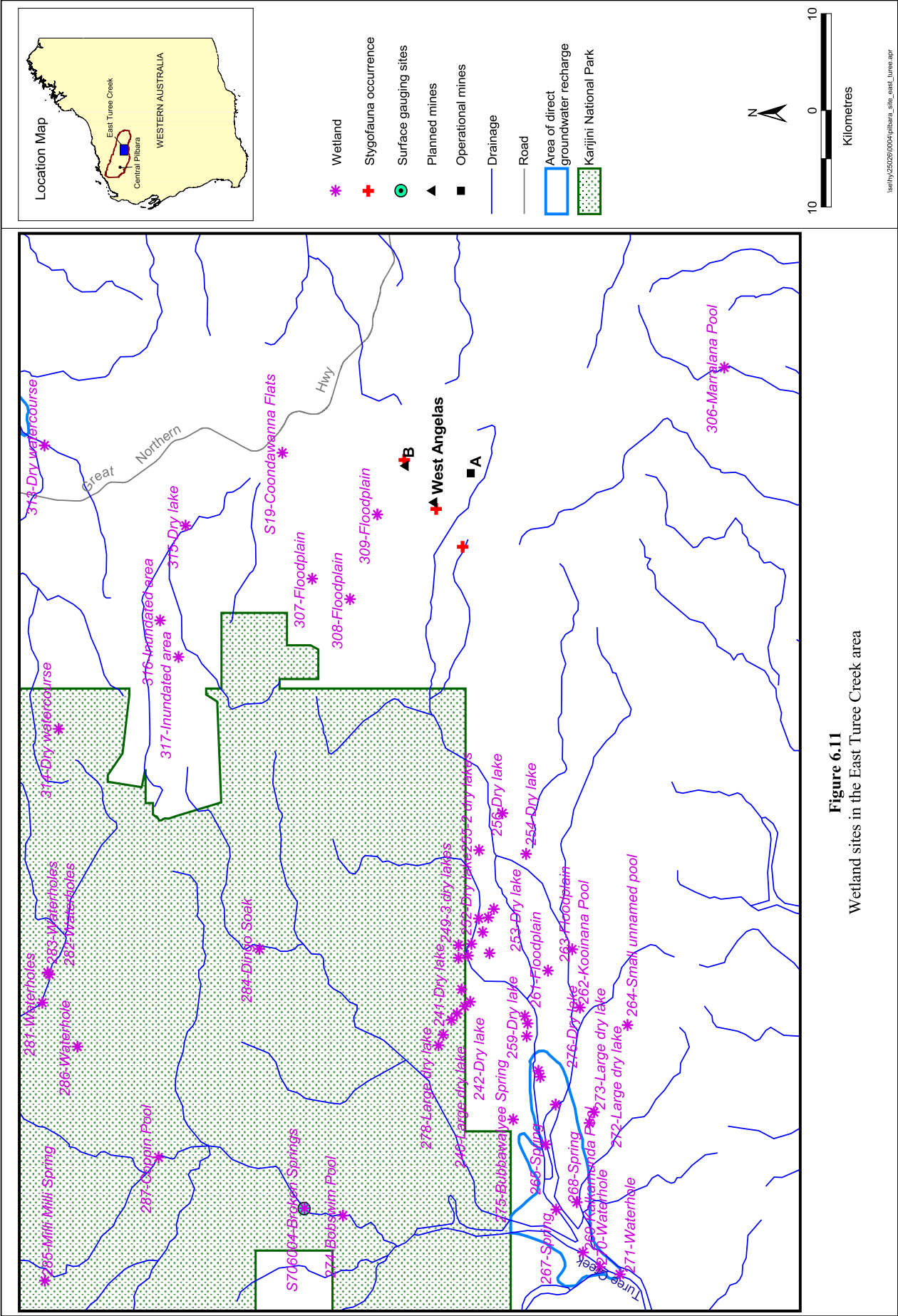
Wolli Creek drainage pattern. The lineament may have also formed the gorge in the Brockman BIF, where Weeli Wolli Spring is located. Mining Area C, located along the Western Tributary, comprises Brockman Formation detrital deposits at the foot of the Packsaddle Range.

The karstic dolomite within the Paraburdoo Member of the Wittenoom Formation is an important aquifer (Fig. 6.14 and 6.15). Other bedrock aquifers occur within the West Angela Member (where manganiferous) and in fractured Marra Mamba Iron Formation with the enhancement of permeability related to structural features. Many of the high-permeability zones underlie the Tertiary valleyfill sequence. The pisolite and calcrete, where present below the watertable, constitute a significant aquifer. The aquifer is recharged via direct rainfall infiltration and creek-line infiltration. Groundwater contours show steep hydraulic gradients in the upper reaches of the subcatchments, with gradients decreasing downstream towards the proposed mines and Weeli Wolli Spring.

Weeli Wolli Spring has formed by the concentration of flow through a relatively narrow gap in the Brockman Formation outcrop and changes in topographic gradient. This ‘damming effect’ of groundwater flow results in an apparent “underground reservoir” that discharges over the shallow basement forming the spring. A linear zone of high permeability is inferred in the bedrock between the proposed mines and the spring.

Groundwater is fresh and slightly alkaline, although there is increasing groundwater salinity towards the spring (up to 600 mg/L TDS). This is a result of increased evapotranspiration near the gorge, as the shallow watertable supports extensive stands of phreatophytic vegetation.

The two Hope Downs orebodies are significant local aquifers with relatively high permeability. Low-permeability Marra Mamba Iron Formation binds the Hope North orebody on the southern side. However, it is in hydraulic connection with the various dolomite–pisolite–calcrete aquifers to the north. At Hope South, the small orebody pods are below the watertable within low-permeability BIF. Dewatering will be required to maintain dry mining conditions, as both deposits lie at the edge of the valleyfill aquifer. In order to lower the watertable by 180 m at Hope North, it is anticipated that groundwater abstraction rates of between 30 and



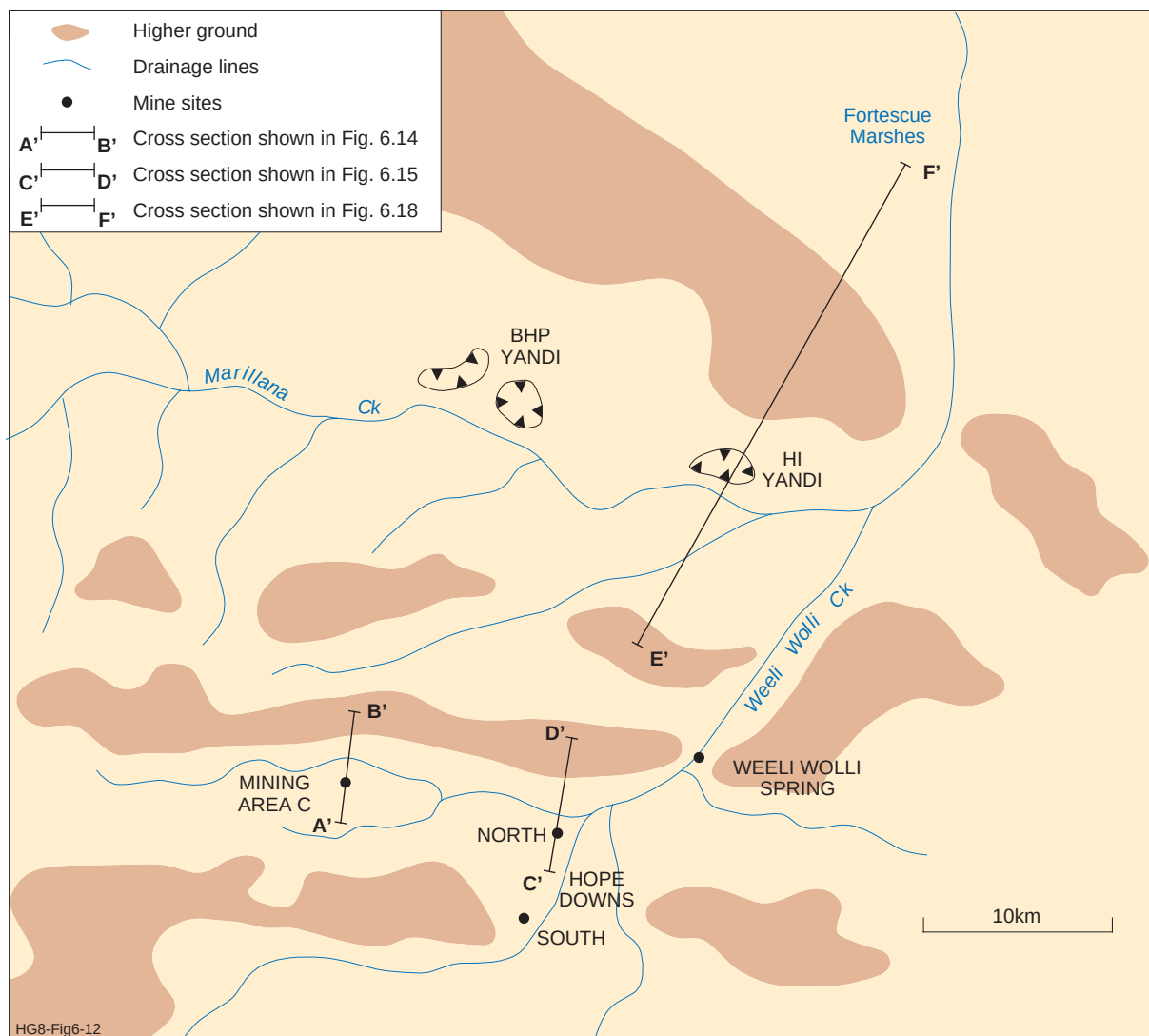


Figure 6.12 Location of important features in the Weeli Wolli Creek area

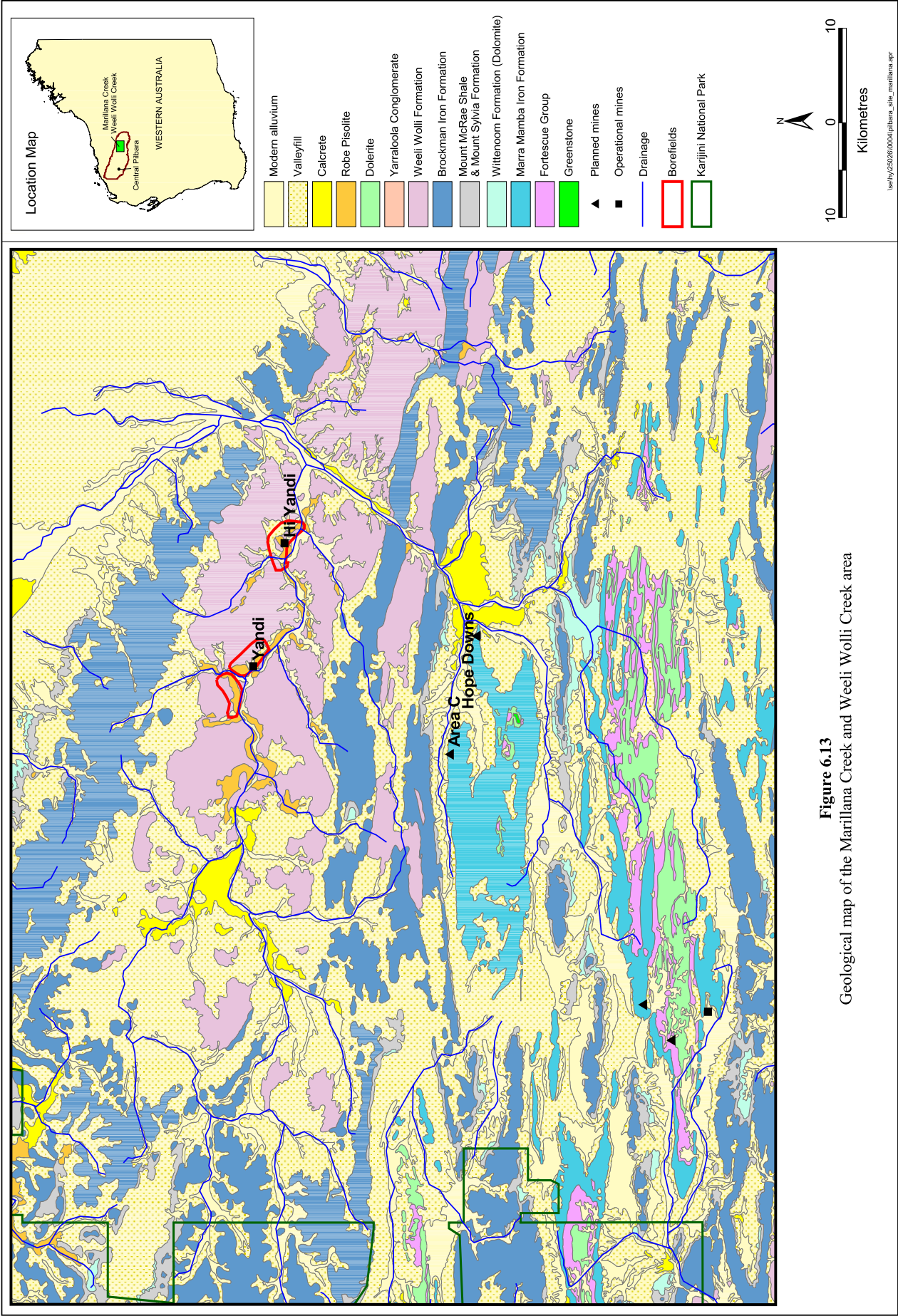
110 ML/day will be required over a period of 22 years. This would lead to a drawdown of about 50 m at Weeli Wolli Spring, with shallow groundwater contribution to the spring ceasing in the first two years (Fig. 6.16).

In addition, dewatering at Hope Downs will also dewater the proposed water-supply borefield for BHP Mining Area C. This is not a major problem as the mine-water balance at Hope Downs indicates a surplus of 90 ML/day of excess dewatering, after the ecological and mine-water requirements have been met.

The groundwater–spring interaction at the head of the gorge is a critical hydrological factor with regards to the proposed mining at Hope North (as shown in Fig. 5.4). Weeli Wolli Spring is supported entirely by groundwater baseflow for most of the year and this ecological water requirement is the major beneficial use of the aquifer. The environmental and cultural importance of the spring is of such importance that

groundwater abstraction would not be permitted to allow the spring to dry up. The spring would have to be artificially maintained if groundwater abstraction in the catchment resulted in significant flow reduction. In fact, because of the very high hydraulic sensitivity of the spring, groundwater abstraction would not be allowed for any consumptive use close to the spring.

The large number of important environmental sites (Fig. 6.17) and highly sensitive water balance in the catchment implies that the groundwater resource has to be fully allocated to ecological water requirements. Any modification to the groundwater system will necessitate some form of spring supplementation. During mining, it is possible to use surplus dewatering discharge to artificially maintain spring flow via either artificial recharge into the calcrete (upgradient of the spring) or direct surface supplementation. However, the major concern is spring supplementation on the cessation of mining.



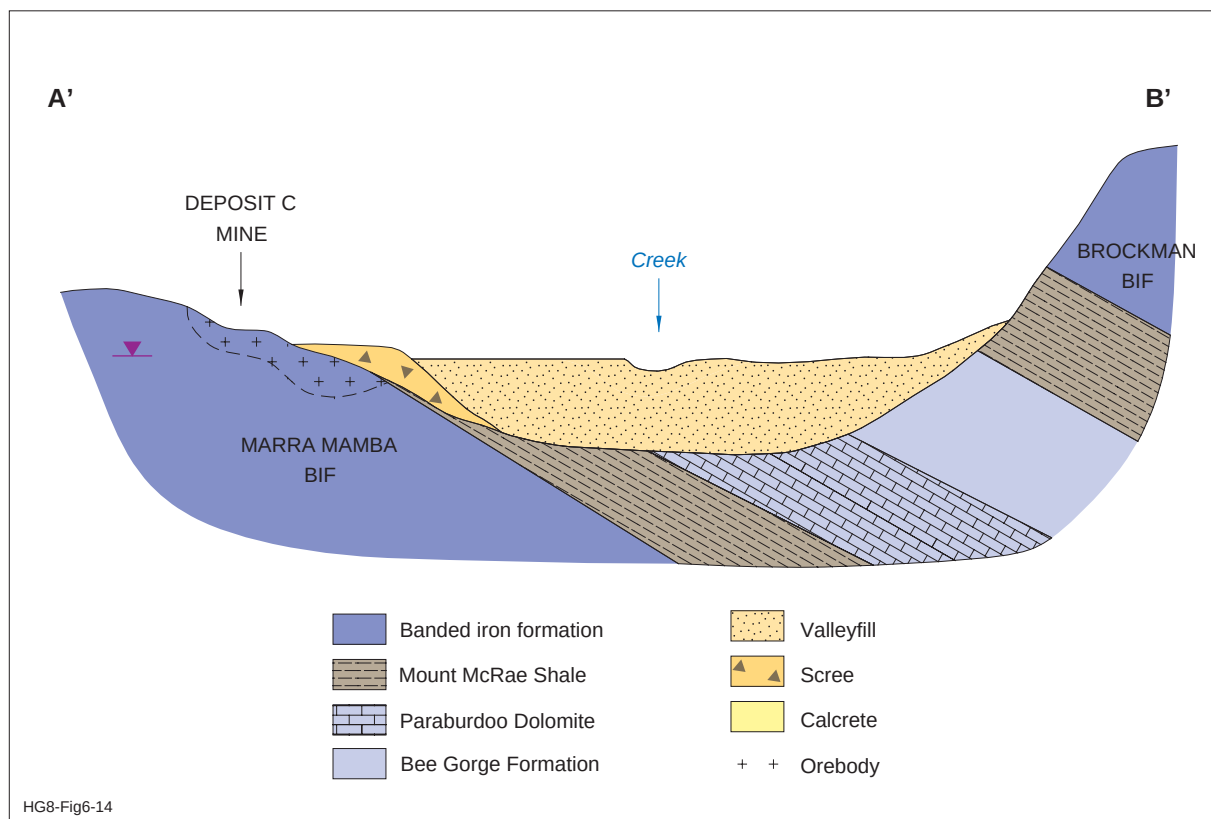


Figure 6.14 Schematic section through the Weeli Wolli tributary at Mining Area C (refer to Fig. 6.12)

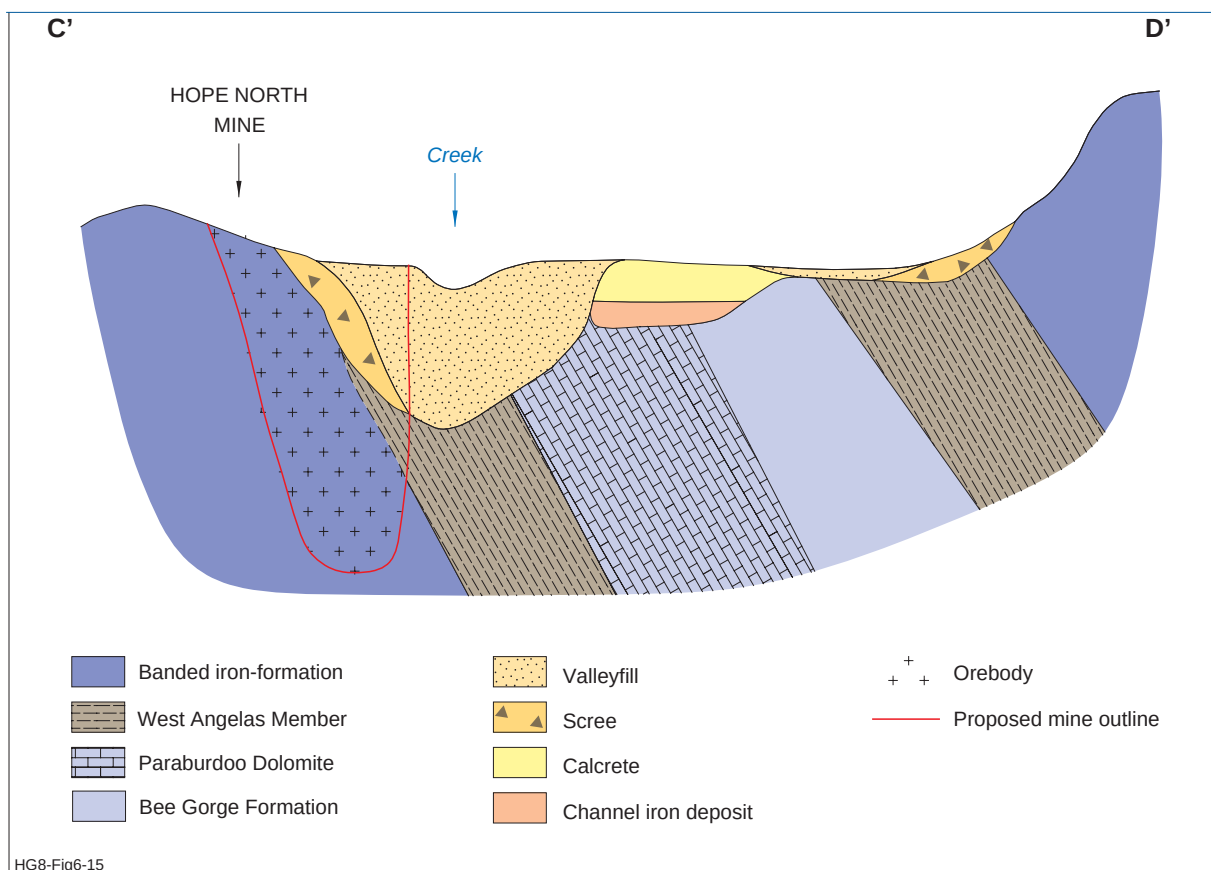


Figure 6.15 Schematic section through the Weeli Wolli tributary at Hope Downs (refer to Fig. 6.12)

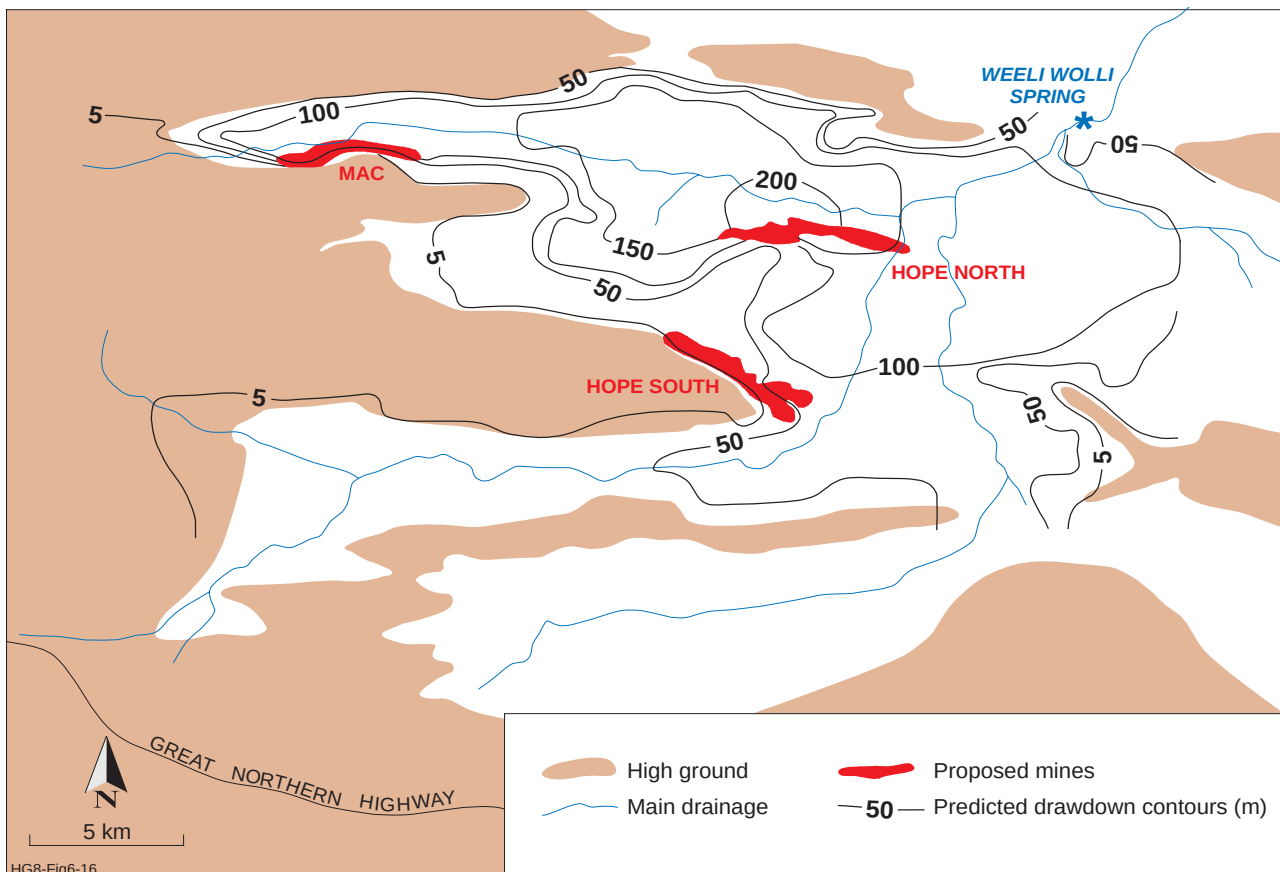


Figure 6.16 Predicted drawdowns resulting from dewatering at Hope Downs

Groundwater modelling has indicated that it may take 60 years for the groundwater levels at the Hope North Pit to recover to pre-mining levels and resumption of natural spring flow. The importation of water from outside the catchment and mining lease is dependent on negotiations with other mining companies. The proponent must also make a commitment to artificially maintain the system for possibly twenty years after mining ceases. Any mining of the Hope Downs deposit will therefore require agreement between Government and the proponent on an approach to ensure satisfactory environmental performance including addressing mine void closure issues

The Water and Rivers Commission suggests that the following water-related issues are considered as part of any current or proposed mining development.

- Ecological water requirements are of paramount concern in the upper Weeli Wolli Creek catchment.
- The need for long-term supplementation of the spring requires agreement between Government and the proponent relating to mine closure issues.

6.5 Marillana Creek area

The Marillana Creek catchment covers 2050 km², with the creek flowing in an easterly direction between ranges of Brockman Iron Formation (Fig. 6.12). The upper catchment comprises a broad alluvial plain with several large areas of calcrete. In the lower catchment, the drainage is well-defined with the creek merging with Yandicoogina Creek and Weeli Wolli Creek prior to entering the Fortescue Marshes. The creek is ephemeral and only flows between 30 and 60 days per year. Marillana Creek contributes approximately 50% of the flow into the Fortescue Marshes from the Weeli Wolli Creek system (Aquaterra, 2001).

Marillana Creek comprises a gravel and calcrete aquifer that subparallels and meanders across the CID palaeodrainage at several locations. The CID or pisolitic limonite aquifer is aligned with the eroded keel of the Yandicoogina Syncline and is underlain by the Weeli Wolli Formation (Fig. 6.13). The Marillana Creek CID forms a strip aquifer with a total length of 70 km, width of 800 m and saturated thickness of 60 m. The aquifer is unconfined with transmissivity between 200 and 2000 m²/day. Groundwater throughflow has

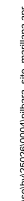


Figure 6.17
Wetland sites in the Marillana Creek and Weeli Wolli Creek area

been estimated at between 1300 and 3000 kL/day. The Marillana Creek CID aquifer merges with the Weeli Wolli Creek CID aquifer, which together contribute groundwater flow northward into the Fortescue Valley (Fig. 6.18). Groundwater inflow from the Marillana Creek CID appears to reduce salinity within the Weeli Wolli Creek CID. Groundwater quality is fresh (less than 500 mg/L TDS).

The Fortescue Valley comprises calcrete and valleyfill aquifers overlying localised basement aquifers in the Wittenoom Dolomite and Marra Mamba Iron Formation (Fig. 6.18). The main palaeodrainage of the Fortescue River lies along the southern section of the Fortescue Valley, contrasting with the present drainage, which is aligned on the northern side under the marsh. Groundwater quality in the aquifers varies from 5000 to 70 000 mg/L between the southern edge of the valley and the under the marsh area. Brackish water exists as a result of recharge from the creek alluvium and direct seepage from surface flows.

Groundwater flow in the CID is estimated at 2.5 GL/yr, which is equivalent to the smallest monthly surface flow from Weeli Wolli Creek and 10 to 20 times lower than most flood flows. Groundwater modelling by Aquaterra (2001) indicates that groundwater flow along the Weeli Wolli Creek system contributes less than 1% of the combined (surface and groundwater) flow into the Fortescue Marsh.

The CID forms a single, continuous high-grade pisolitic ore body that is currently mined by BHP and Hamersley Iron. At present, mining operations are focusing only on the sections of the CID that do not underlie the modern creek system. Dewatering will result in significant drawdowns producing large volumes of excess water. Currently, the BHP operations abstract 7 GL/yr from 24 bores and HI abstracts 5 GL/year from 11 bores. The mining process is largely removing the aquifer, with the final voids forming local groundwater sinks. There will be some regional impact on the groundwater quality, even with the partial infilling of the voids. On the cessation of mining, the salinity of the groundwater leaving the Marillana Creek CID will be about 2500 mg/L TDS with significant dilution through mixing upon entry into the Weeli Wolli Creek CID aquifer.

The excess dewatering discharge is returned to Marillana Creek. The discharge infiltrates the alluvial aquifer and subsequently recharges the underlying CID, thus maintaining throughflow in the Marillana Creek CID and Weeli Wolli Creek CID aquifers. Recent groundwater modelling by Aquaterra (2001), as part of this study, has indicated that most dewatering discharge is lost to the system with very little contribution to the Fortescue Valley water balance. The discharge volume accounts for only 10–15% of the

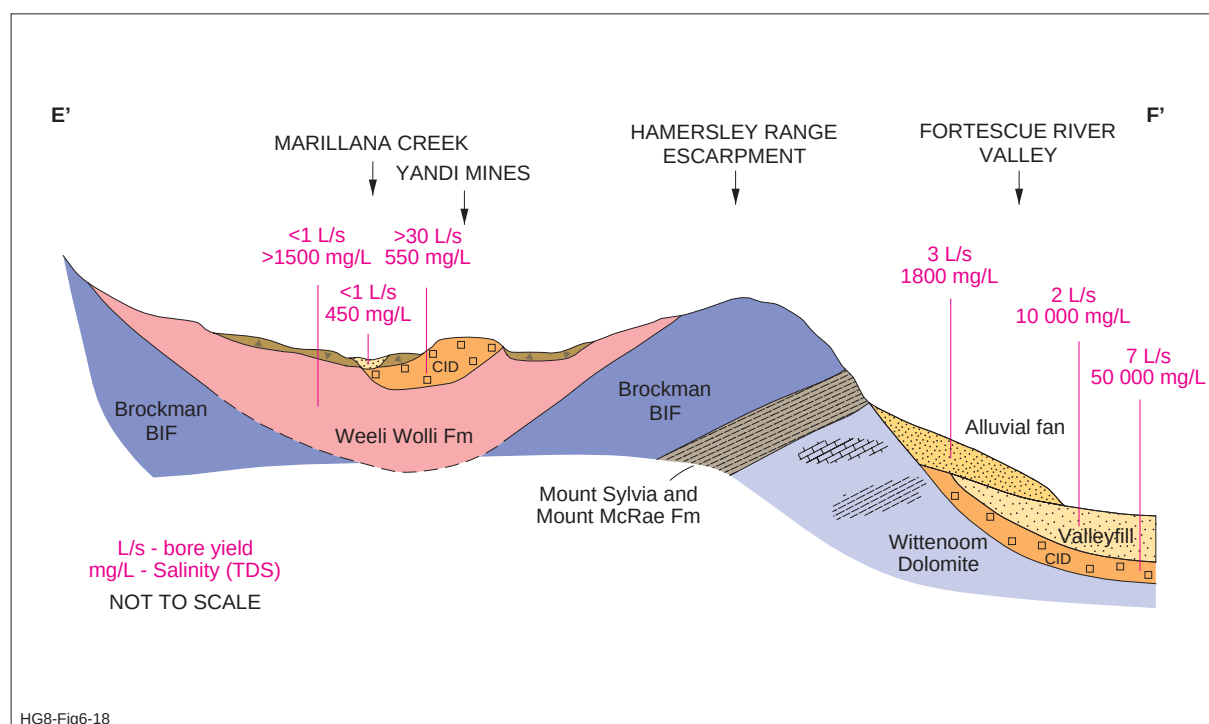


Figure 6.18 Schematic section through Marillana Creek and Fortescue Valley area (refer to Fig. 6.12)

annual groundwater balance, hence excess discharge may be available for consumptive use. In addition, the Weeli Wolli Creek CID aquifer may be exploited for consumptive use.

The Water and Rivers Commission suggests that the following water-related issues are considered as part of any current or proposed mining development.

- Groundwater modelling (Aquaterra, 2001) has shown that the ecological water requirements of the Fortescue Marshes are not affected by excess dewatering discharge in the CID.
- Surface-water flow within Marillana and Weeli Wolli Creeks maintains the Fortescue Valley alluvial-fan aquifer, and provides the ecological water requirements for the Fortescue Marshes.
- Mine closure along the Marillana Creek CID should maintain a 'throughflow cell' void type to ensure that groundwater recharged in the upper catchment enters the CID, thus enabling recharge to enter the Weeli Wolli Creek CID aquifer.

6.6 Southern Fortescue/Hardey River Area

Borefields in the upper Hardey and Southern Fortescue River catchments provide water to the town of Tom Price and the mining operations. The three major borefields are the Hardey River borefield (10 km west of Tom Price), the Mount Lionel borefield (5 km northwest of the Hardey River Borefield) and the Southern Fortescue borefield (30 km northeast of Tom Price). The potable water demand is provided by the Southern Fortescue borefield. The borefields exploit calcrete and valleyfill aquifers in conjunction with underlying fractured and weathered Wittenoom Dolomite aquifers (Fig. 6.19). The borefields have been pumping for over 25 years and in most cases have reached steady-state conditions. Monitoring indicates that the aquifer can sustain current abstraction rates, and possibly even slightly higher rates.

Since mining below the watertable commenced in the 1990s, dewatering at Tom Price has accounted for an annual total abstraction of 0.65 GL. At the nearby Marandoo mine, groundwater is abstracted from a calcrete aquifer in conjunction with underlying fissured and weathered Wittenoom Dolomite.

The Water and Rivers Commission suggests that the following water-related issues in the Southern Fortescue / Hardey River area are considered as part of any current or proposed mining development.

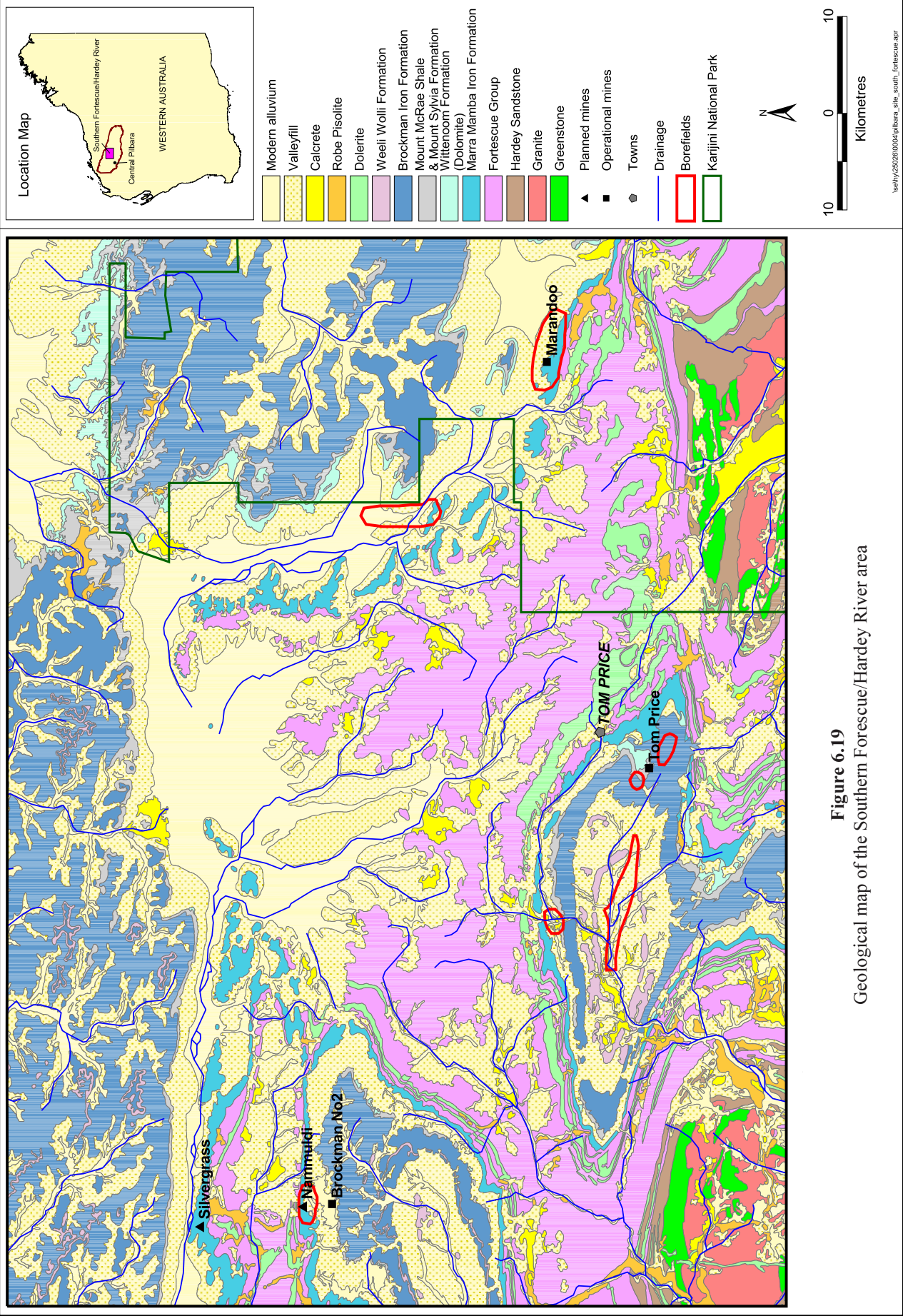
- The occurrence of sinkholes is a natural phenomenon in valleys underlain by Wittenoom Dolomite, although it would appear that their numbers have increased in the Southern Fortescue borefield. Groundwater abstraction has the effect of lowering the watertable, and this often destabilises the roof of existing caverns and accelerates the natural process of cavern collapse.
- The only important wetland site is Mindthi Spring, a small discharge spring that is located about 15 km southeast of Marandoo borefield in the upper reaches of Turee Creek (Fig. 6.20).

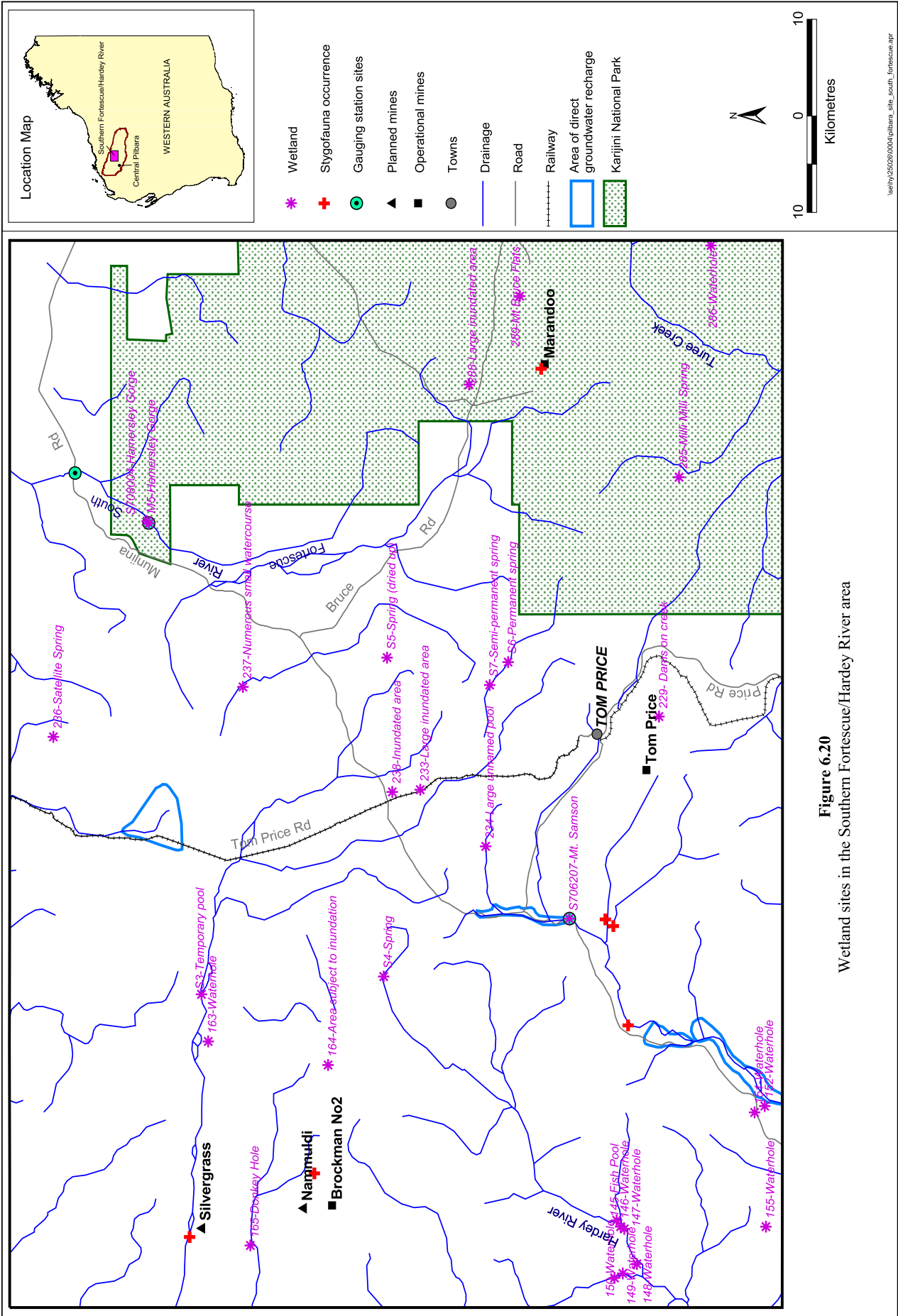
6.7 Caves Creek/Duck Creek area

The Caves Creek / Duck Creek area, which covers a broad plateau lying between two east–west trending ridges, is drained by Caves and Duck Creeks (Fig. 6.21). Hamersley Iron's Brockman No.2–Nammuldi and Silvergrass–Homestead deposits lie on opposing limbs of the broad Jeerinah Anticline. The Jeerinah Formation outcrops in the centre of the anticline flanked by ridges of Brockman Iron Formation. Valleyfill deposits comprising creek alluvium, clays, detritals, gravels and sands occur within two palaeodrainages at the foot of the Brockman Hills (Fig. 6.22).

There are no significant groundwater resources in the area. The most important aquifers are within the mineralised Marra Mamba Iron Formation, as well as the valleyfill and underlying weathered Wittenoom Dolomite (Fig. 6.23). The mineralised Marra Mamba aquifer is semi-confined owing to the lower permeability characteristics of the overlying West Angelas Shale and valleyfill clays. The largest bore yields are associated with the base of the mineralisation in the Marra Mamba Iron Formation.

Construction water requirements of 200 ML/yr are met from two borefields; the Brockman Mine borefield (3 bores) providing process water and the Camp borefield (2 bores) supplying potable water. The groundwater from both borefields is fresh. The proposed mining of Marra Mamba orebodies will necessitate dewatering





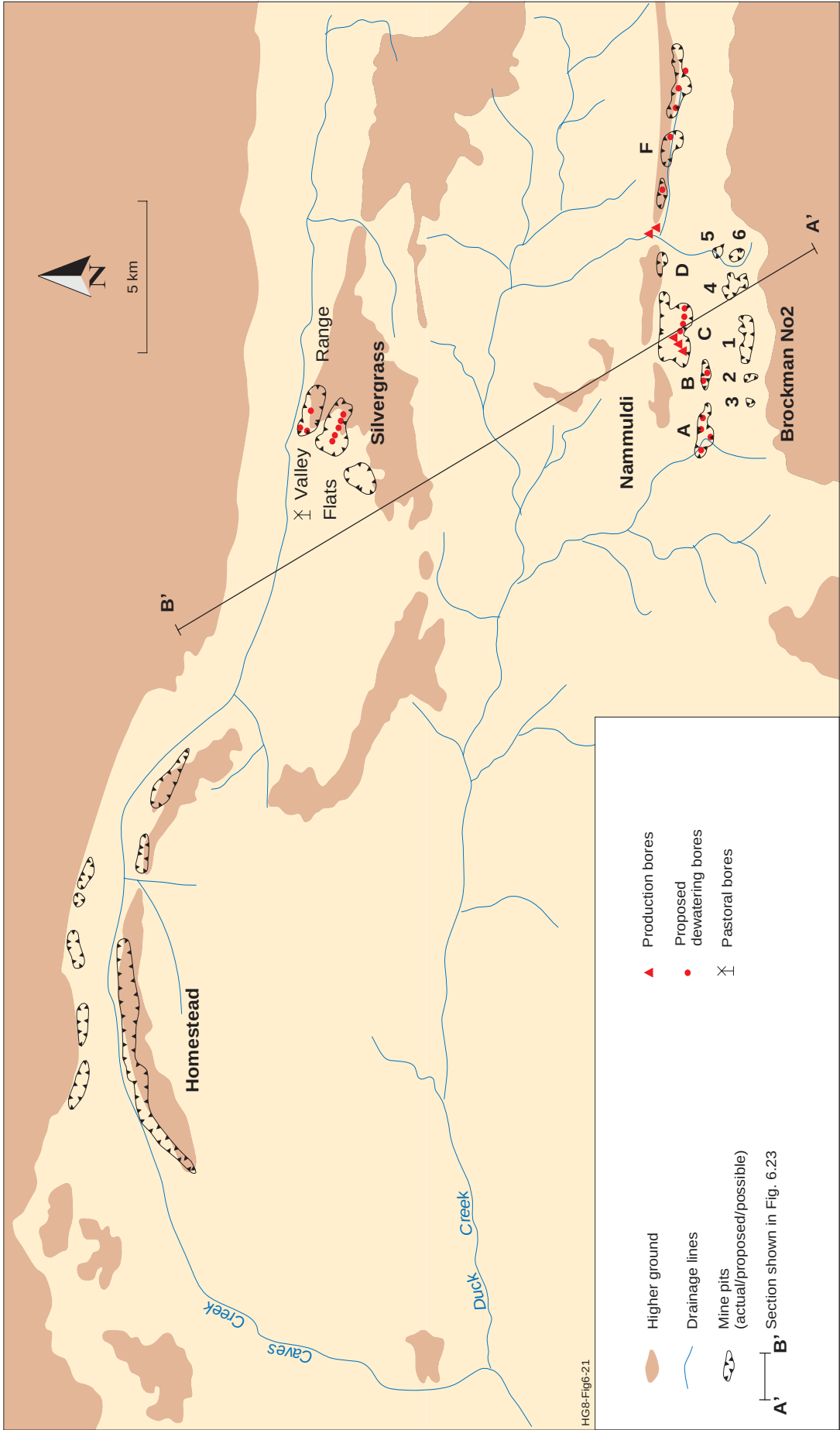
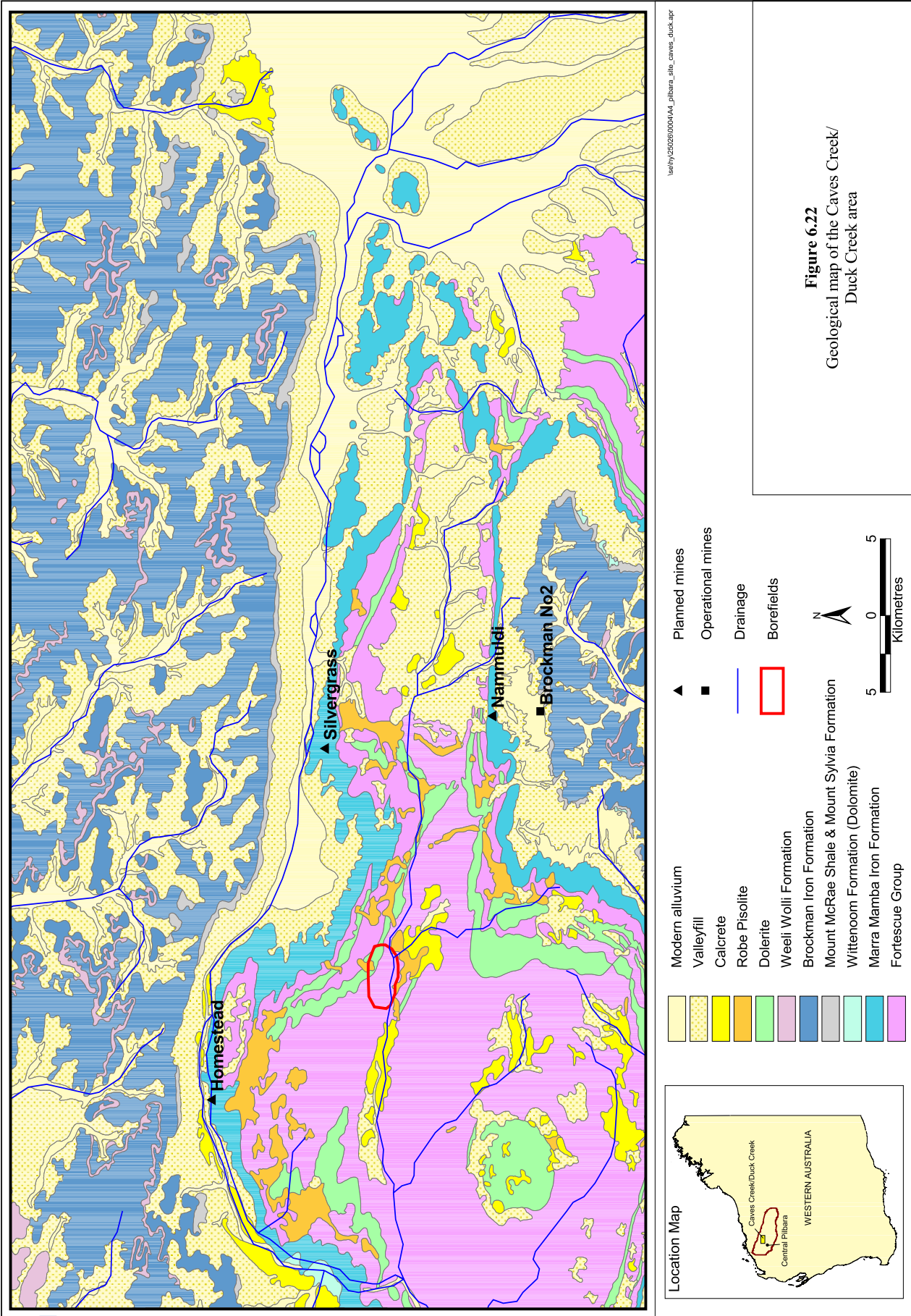


Figure 6.21 Location of mine sites and schematic section at Caves Creek



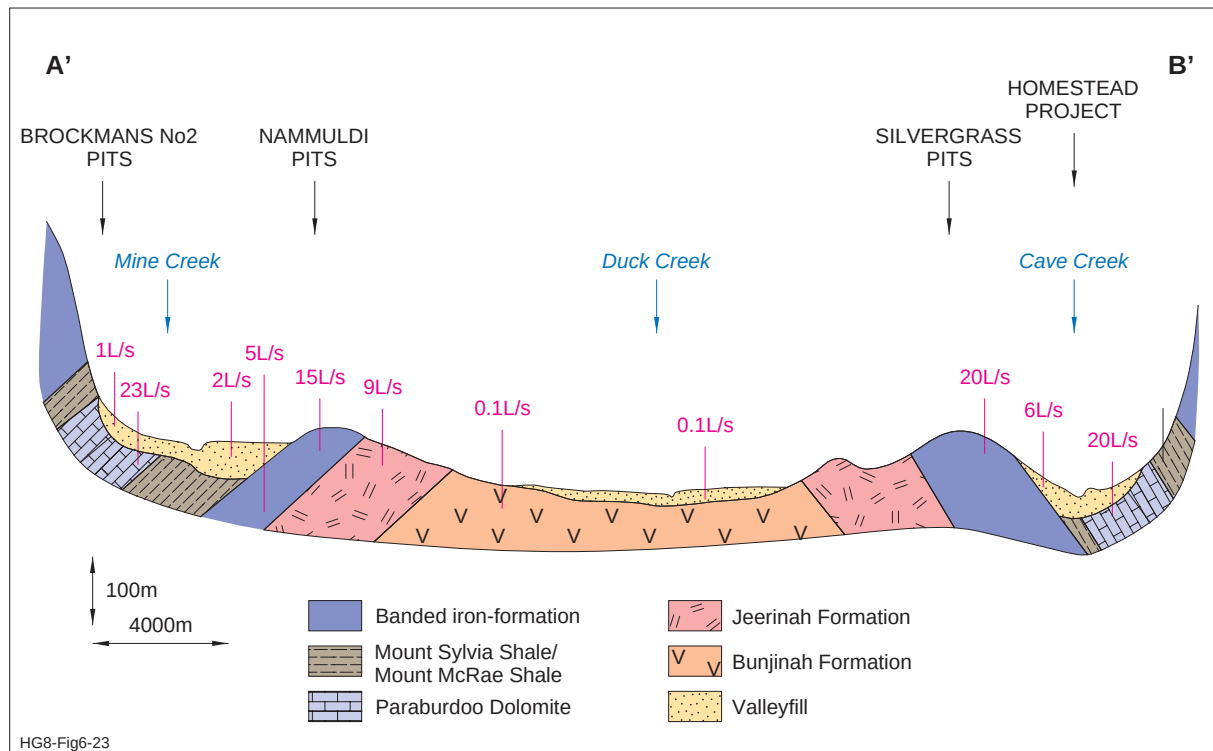


Figure 6.23 Schematic section through Caves Creek / Duck Creek area

operations at all the deposits. Numerical modelling has indicated that about 18 ML/day of dewatering is required at each site, hence total water abstraction will be about 30 GL over the life of the operations at Nammuldi and Silvergrass.

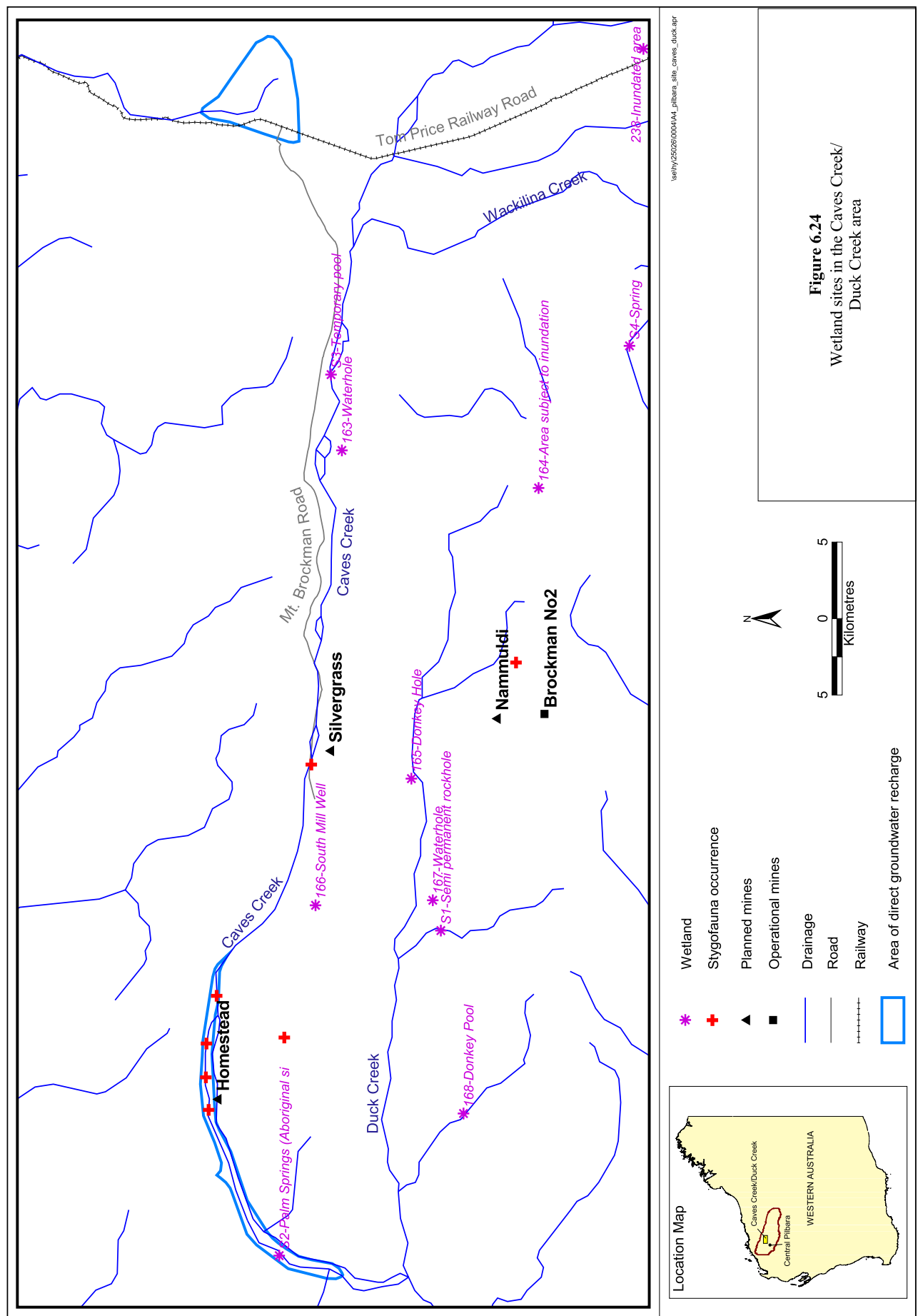
The lateral extent of dewatering drawdown is anticipated to be about 1000 m at Nammuldi, resulting in no significant environmental impacts. At Silvergrass, drawdown in the alluvial aquifer may extend about 3 km along the creek system and may have a noticeable temporary impact on creek line vegetation and stygofauna. Figure 6.23 illustrates the direct hydrogeological linkage between the proposed mine pits and the creek system.

The most significant environmental water sensitive area is Palm Springs, which is 10 km downstream of the Homestead deposits (Fig. 6.24). It is anticipated that the potential environmental impact will not only be significant during the proposed mining operations but also upon mine closure. Consequently, HI has committed to the infilling of mine voids to at least one metre above the pre-mining groundwater level. The company also proposes to plant phreatophytic vegetation within backfilled voids, which will help to keep groundwater levels depressed and reduce the potential of capillary rise to the surface.

The potential for aquifer recharge at the proposed Nammuldi mine site has also been investigated. Excess dewatering discharge during the earlier stages of mining may possibly be re-injected into the Marra Mamba aquifer. This strategy will avoid the issue of discharging large volumes of water into the creek systems and the creation of temporary (semi-permanent?) surface-water bodies. The company has committed to mine scheduling to match dewatering with process-water demand.

The Water and Rivers Commission suggests that the following water-related issues in the Caves Creek / Duck Creek area are considered as part of any current or proposed mining development.

- The impact of dewatering activity on the Caves Creek system. Although of a temporary nature, it may result in (a) possible stress to the phreatophytic vegetation within the drawdown area and (b) the creation of a surface-water body through the disposal of excess discharge into the creek system.
- Excess available water at the initial stages of mining and a possible water shortage during the later stages.
- The need to backfill/infill any mine voids that are hydrogeologically linked to the Caves Creek alluvial aquifer.



7 Conclusions and recommendations

The development of new iron ore mines in the Central Pilbara requires an improved regional understanding of the demand for water, ecological water requirements, available groundwater resources and the impact of proposed developments on groundwater systems. The Central Pilbara Groundwater Study (CPGS) provides a regional review of the groundwater resources and assesses the possible impact of mining. The study provides essential groundwater information that will assist industry and Government agencies in the assessment of environmental impacts for proposed mining developments.

Three major aquifer types in the Central Pilbara have been identified: unconsolidated sedimentary aquifers (valleyfill comprising alluvium and colluvium), chemically deposited aquifers (calcrete and pisolitic limonite), and fractured-rock aquifers (dolomite and banded iron-formation).

Valleyfill deposits form the major unconfined aquifer, which is often in hydraulic connection with underlying calcrete and basement rocks. The calcrete and pisolitic limonite aquifers, present within Tertiary drainages, are characterised by secondary porosity and large bore yields in excess of 1500 kL/day. Dolomitic formations (such as the Wittenoom Dolomite) are important fractured-rock aquifers, with the largest yields (greater than 5000 kL/day) occurring where the dolomite is overlain by a thick sequence of valleyfill. The Brockman and Marra Mamba Iron Formations contain localised aquifers associated with deformation, fracturing and mineralised ore bodies.

The iron ore industry is the major groundwater user in the Central Pilbara. In 1999, annual groundwater abstraction was about 31 GL. Mining operations abstract groundwater for mine dewatering, dust suppression, mineral processing and ore beneficiation. The dewatering discharge is often used in mineral processing or discharged at controlled points into riverine drainages downstream of each operation.

There are currently 19 borefields established and operated by BHP and HI throughout the Central Pilbara. The production and monitoring data for each borefield have been reviewed and summarised to provide an

understanding of borefield abstraction, aquifer performance and potential groundwater allocation issues.

The study area surrounds the Karijini National Park and contains several major creek and river systems that support numerous well-known river pools and wetlands, such as Weeli Wolli Spring. Apart from a small number of tourist attractions, very few wetland sites in the Central Pilbara are well known. The Water and Rivers Commission, being the Government agency responsible for managing the hydrological and conservation values of the State's wetlands, identified the need for more detailed information on the distribution and characteristics of wetland sites, in order to increase the effectiveness of environmental planning and management. A database has been compiled to provide an inventory of wetlands, including watercourses, areas of cultural significance and key monitoring sites. A large number of wetlands have been identified, although further research is still required to determine how much water is required by each ecosystem.

The occurrence of stygofauna, a groundwater-dwelling fauna, has become a major issue in the Central Pilbara. Stygofaunal communities have been found at most mine sites. The general lack of data and understanding about stygofauna in a regional context has made assessing the environmental impacts of proposed mining developments difficult. The functioning of groundwater calcrete ecosystems needs addressing by Government agencies, if informed management is to be implemented.

Water issues at mining operations in the Central Pilbara can range from insufficient groundwater resource availability for mineral processing to disposal of surplus mine dewatering. Key areas for water management within mining operations are water supply, wastewater disposal and potential contamination of local water resources. In the past five years, acid rock drainage and the long-term impact of mine voids have raised concerns with the mining industry and Government agencies.

The problem of acid rock drainage (ARD), a major mine management issue around the world, was not originally

considered a serious concern in the Central Pilbara because of the low rainfall and high evaporation rates. Spontaneous pyrite oxidation within the Mount McRae Shale and subsequent generation of H_2SO_4 is a problem, and any mine-closure strategy must involve covering these surfaces either with inert backfill material or water. Operationally, in most mining operations, all overburden is now mapped and characterised to allow increased precision in the selective mining and placement of net acid-generating material.

Opencut mining in the Central Pilbara has resulted in massive mine voids that commonly extend below the watertable. After the cessation of dewatering, groundwater levels will eventually recover and the mine void shows a surface expression of the watertable. The exposure of the watertable will create an artificial lake that will initiate geochemical and hydrological processes evolving over time. A major long-term concern is the potential for these pit lakes to become point sources of hypersaline water. The low annual rainfall and high evaporation result in a rainfall deficit which, over time, will lead to the development of hypersaline water bodies.

Five case studies in the Central Pilbara were conducted to understand the role and issues related to mine voids. The case studies detail the hydrogeology and the potential impacts of the mine voids at Mount Goldsworthy, Orebody 18, Orebody 23, Hope Downs and Yandicoogina. It has been determined that there are two broad hydrogeological environments for mine voids: groundwater sink (evaporation exceeds groundwater inflow) and groundwater throughflow (groundwater inflow exceeds evaporation).

Mine voids that act as a groundwater sink and only intersect local aquifers have limited contamination potential of neighbouring aquifers, such as at most Brockman mines. In contrast, mine voids that exhibit throughflow characteristics are a major environmental concern in the Central Pilbara, hence these voids have more stringent environmental constraints imposed by Government regulators. The best examples are the channel iron deposits (Yandicoogina and Robe River) and the banded iron-formation deposits (Orebody 23 and Hope Downs) that are in hydraulic connection to significant aquifers.

Water management is often critical to the profitable development and operation of a successful mine. Over the past three decades, the iron ore industry has successfully managed the local groundwater resources in the vicinity of their mining operations. The discovery and development of new iron ore deposits throughout the Central Pilbara has resulted in the need to gain a regional perspective of the water resource management issues.

The water resource issues in the Central Pilbara are related to dewatering impacts on the environment (vegetation along creeks, drawdown in borefields, EWR for wetland areas, stygofauna), competition for water resources, potential contamination risks (gold tailings), aquifer sustainability, mine closure, and disposal of excess dewatering discharge. Seven key regional localities were identified to highlight the spatial distribution of water-management issues with respect to current and proposed mining operations: Ophthalmia/Fortescue River; Turee Creek/Seven Mile Creek; East Turee Creek; Weeli Wolli Creek; Marillana Creek; Southern Fortescue/Harvey River; and Caves Creek/Duck Creek.

8 References

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9 Glossary

Alluvial	Unconsolidated sediments derived from stream and river activity.	Detritals	Material derived from the weathering of pre-existing rocks.
Anticline	An upward fold in the strata in the form of an arch.	Dewatering	Abstraction of groundwater via bores to assist in dry-floor mining.
Aquifer	A porous and permeable rock unit capable of supplying groundwater from bores and well.	Dolomite	Carbonate rock with more than 15% magnesium carbonate.
Archaean	Period containing the oldest rocks of the Earth's crust – older than 2.4 billion years.	Dyke	Tabular igneous rock intrusion cutting across other rock units.
ARD	Acid rock drainage.	EPA	Environmental Protection Authority.
Banded iron-formation	Tabular rock consisting of alternating bands of quartz and iron-rich minerals.	Evapo-concentration	Concentration of salts via evaporation.
Basement	Competent rock formations underneath sediments.	EWP	Environmental water provision.
Beneficiation	Value adding to a product.	EWR	Ecological water requirement.
BHP	Broken Hill Proprietary Co. Ltd.	Formation	A geological term for the primary unit of lithostratigraphic classification.
BIF	Banded iron-formation.	Gigalitre	A measure of water quantity – one gigalitre equals one billion litres or one million kilolitres.
Brockman	Stratigraphic name of a banded iron-formation in the Hamersley Group.	GL	Gigalitre.
Calcrete	Carbonate rock formed by the in-situ replacement of alluvium or colluvium by magnesium and calcium carbonate precipitating from percolating carbonate-rich groundwater.	Granite	Coarse-grained igneous crystalline rock with a high silica content.
CID	Channel iron deposits.	Greenstone	Consolidated sequence of sedimentary and volcanic rocks – Archaean in age.
Colluvial aquifer	Loose incoherent deposits at the base of a slope.	H₂SO₄	Sulphuric acid.
Confined	An aquifer that is overlain by a confining bed of relatively impermeable material.	Hematite	Iron oxide material (Fe ₂ O ₃).
		HI	Hamersley Iron (subsidiary of Rio Tinto plc).

Hydraulic	The slope of the watertable over distance, gradient	Proterozoic	Period containing the youngest rocks of the pre-Phanerozoic era.
Karstic	Weathering features such as sinkholes, caves and underground drainage formed by dissolution of calcium carbonate.	Recharge	The process of ‘topping up’ groundwater by infiltration from rainfall or rivers - synonymous with ‘renewable resource’.
kL/day	A measure of water quantity – equivalent to 1000L/day.	Safe yield	The amount of naturally occurring groundwater that can be economically and legally withdrawn from an aquifer on a sustained basis without impairing the native groundwater quality or creating undesirable effects such as environmental damage. It is generally considered equivalent to the amount of recharge.
Limonite	Iron oxide material ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$).		
Lineament	Large-scale linear feature in the topography reflecting underlying structure.		
Lithologies	Rock types.	Shale	Sedimentary rocks formed by the consolidation of mud or silt.
Marra	Stratigraphic name of the oldest banded iron-formation in the Hamersley Group.	Stygofauna	Groundwater-dwelling fauna that are fully adapted to living in complete darkness in alluvial and calcrete aquifers.
Mamba			
mg/L	Milligrams per litre (equivalent to parts per million).	TDS	Total dissolved solids.
Mineralisation	In the sense of economic geology, the introduction of valuable elements into a rock unit.	Tertiary	Geological age representing time period from 66 – 18 million years ago.
Palaeodrainage	Ancient surface water drainage system.	Throughflow	The amount of water that passes through a given area.
Permeability	The ability of rock or soil to transmit water.	Unconfined aquifer	Also known as watertable aquifer. An aquifer where the watertable is in direct connection with the atmosphere through the unsaturated zone.
Phanerozoic	Period containing all later rocks in which evidence of life is abundant.	Valleyfill	Variety of unconsolidated sediments deposited in a valley environment.
PIEC	Pilbara Iron-ore Environmental Committee.	Watertable	The level to which water rises in a bore or well tapping an unconfined aquifer.
Pisoliths	Chemically precipitated spherical particles (about 3 to 6 mm in diameter).		
Porosity	The ratio of the volume of void spaces in a rock or sediment, to the total volume of the rock or sediment.		