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CENTRAL PILBARA
GROUNDWATER STUDY

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CENTRAL PILBABA GROUNDWATER STUDY

by

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Cover photograph: Kalamina Falls in Karijini National Park

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Groundwater consultants have completed hundreds of hydrogeological reports in the Pilbara relating to borefield development, groundwater exploration and dewatering activities. The staff of Aquaterra and Liquid Earth, who have provided valuable advice and data used in the completion of this report are acknowledged.

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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:

- Ophthalamia / 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).

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

Location	*Annual average rainfall (mm)*
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.

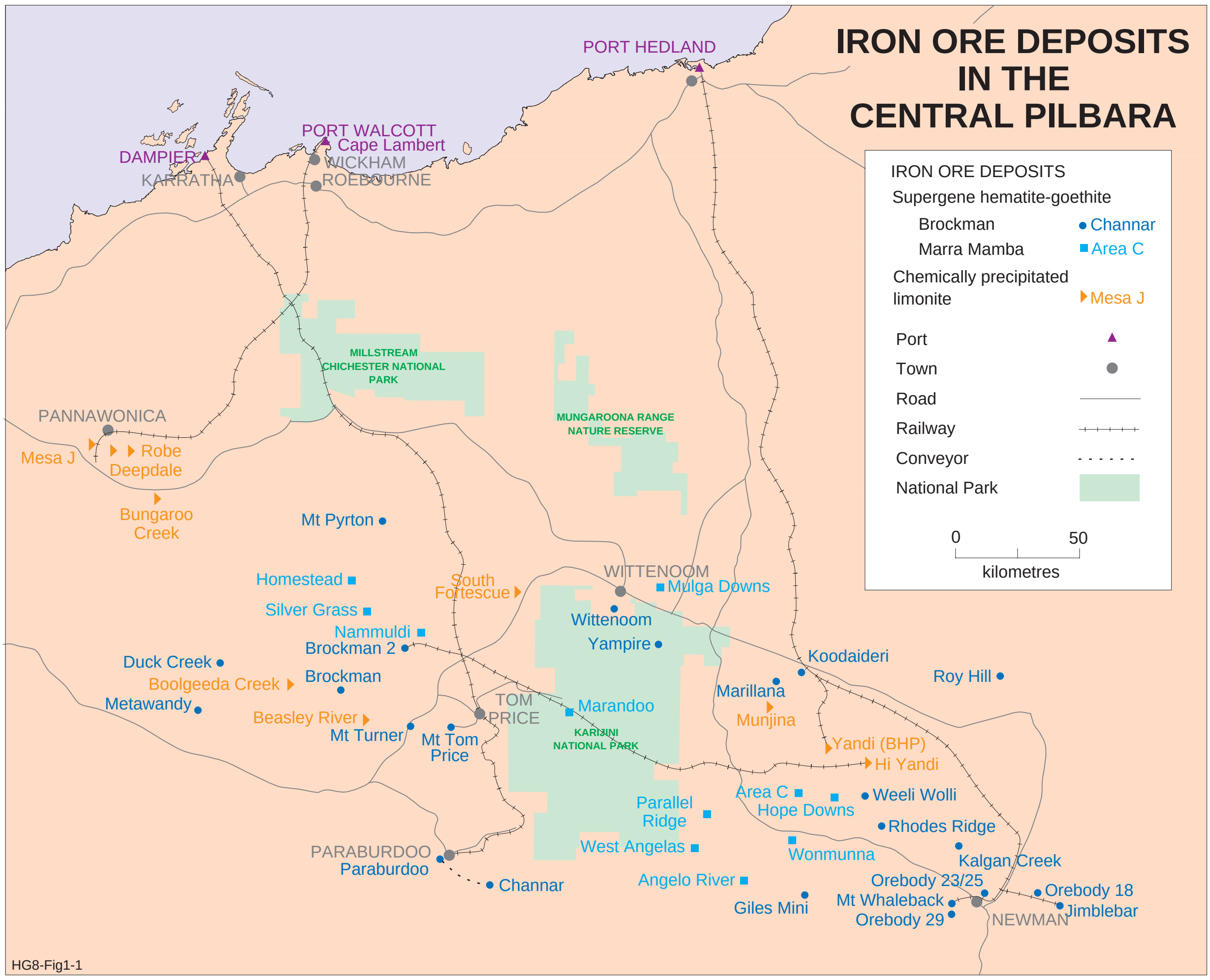


Figure 1.1 Location of major iron ore deposits in the Central Pilbara

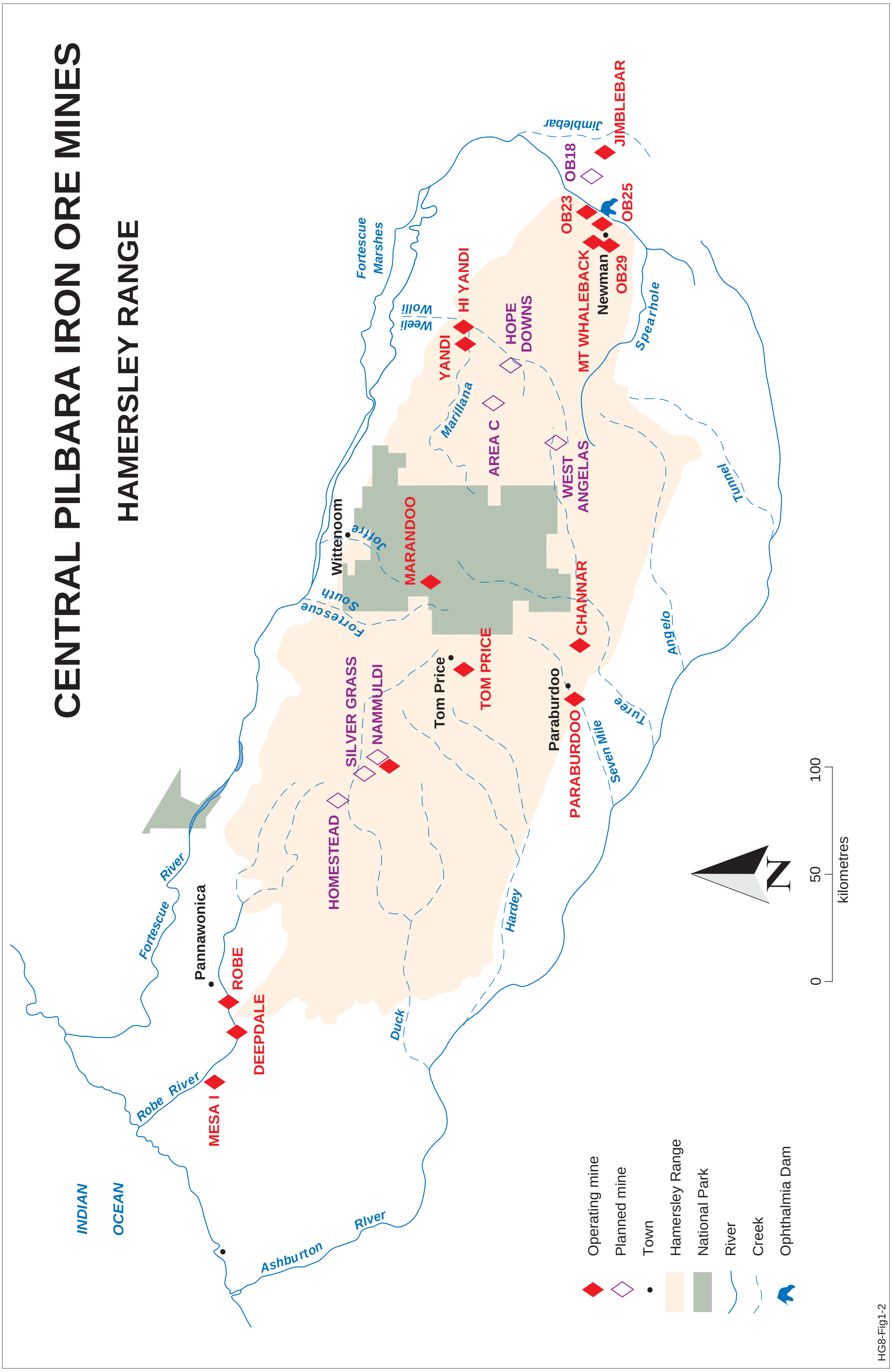


Figure 1.2 Distribution of existing and proposed iron ore operations

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

Age	*Group*	*Formation*	*Member*	*Dominant lithology*
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

Company	*Operation*	*Ore type*	*Status*
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 Nº2	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

Aquifer type	*Aquifer*	*Geological unit*	*Saturated thickness (m)*	*Bore yield (kL/day)*	*Aquifer potential*
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	Hamersley Basin			
	BIF	Brockman Iron Fm	20	<500	Local
		Marra Mamba Iron Fm			
	Dolomitic	Wittenoom Dolomite	25	2 000	Major
	Sandstone	Hardey Sandstone	30	<250	Local

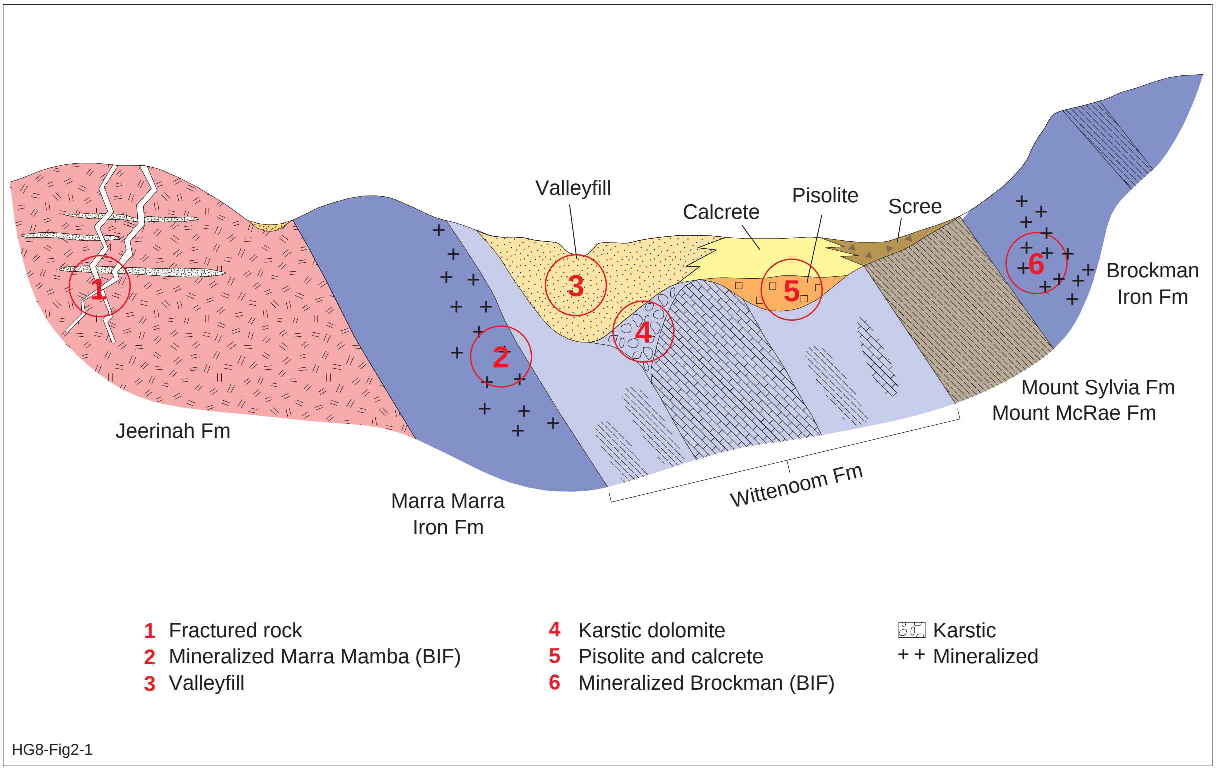


Figure 2.1 Most significant aquifers in the Hamersley Province

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 dominant 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

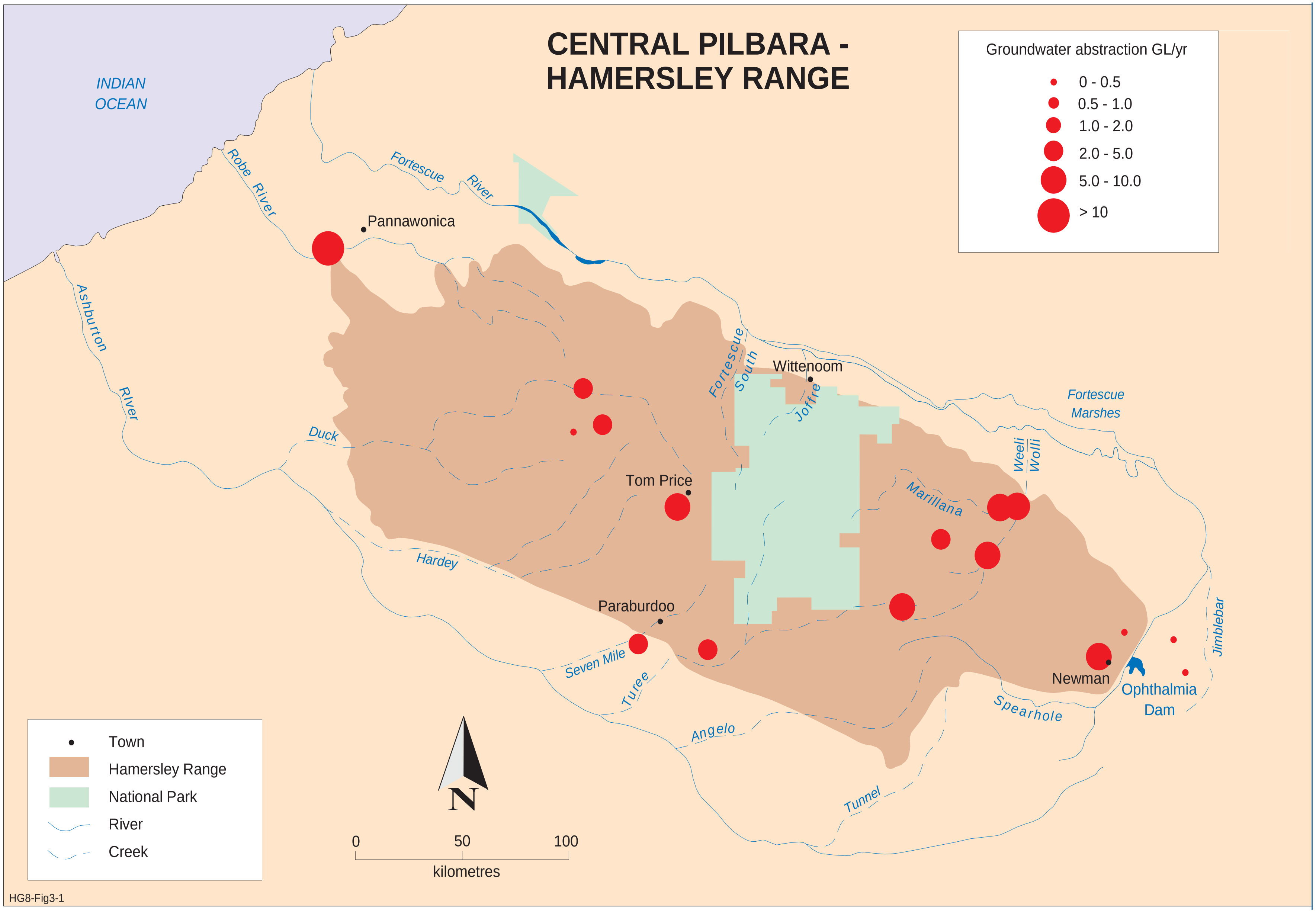


Figure 3.1 Groundwater abstraction by mining industry in 1999

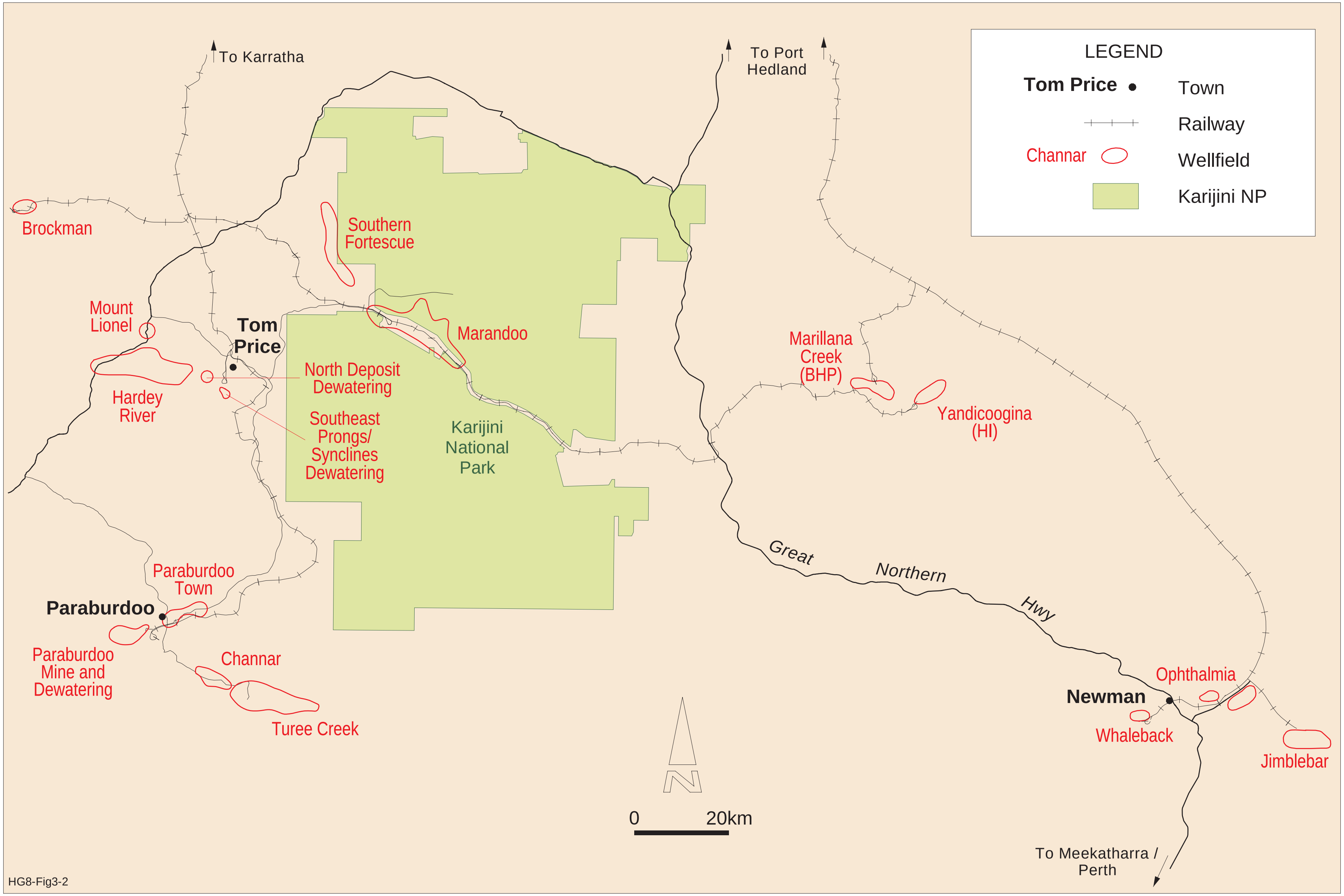


Figure 3.2 Location of mine water supply and dewatering borefields

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

Borefield	*Owner*	*GWL number*	*Allocation (kL/year)*	*Abstraction (kL in 1999)*	*No. of operating production bores in 1999*	*Individual bore yield (kL /day)*	*No. of monitor bores*
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 1999

[2] covers the period July 1999 to June 2000

Table 3.2 Borefield monitoring and aquifer performance of the Central Pilbara

Borefield	*Aquifer type*	*Water quality 1999 TDS (mg/L)*	*Aquifer performance*
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.)

Borefield	*Aquifer type*	*Water quality 1999 TDS (mg/L)*	*Aquifer performance*
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

Mine		*Water requirement (ML/day)*	*Usage*	*Water source*
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)

Step in Ecological Water Requirements determination process	*Low resource &/or information availability Simple groundwater dependency*[1]	*Moderate resource availability Moderately complex groundwater dependency*[2]	*High resource availability Complex groundwater dependency*[3]
Identification of groundwater depedency	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 drawn 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).

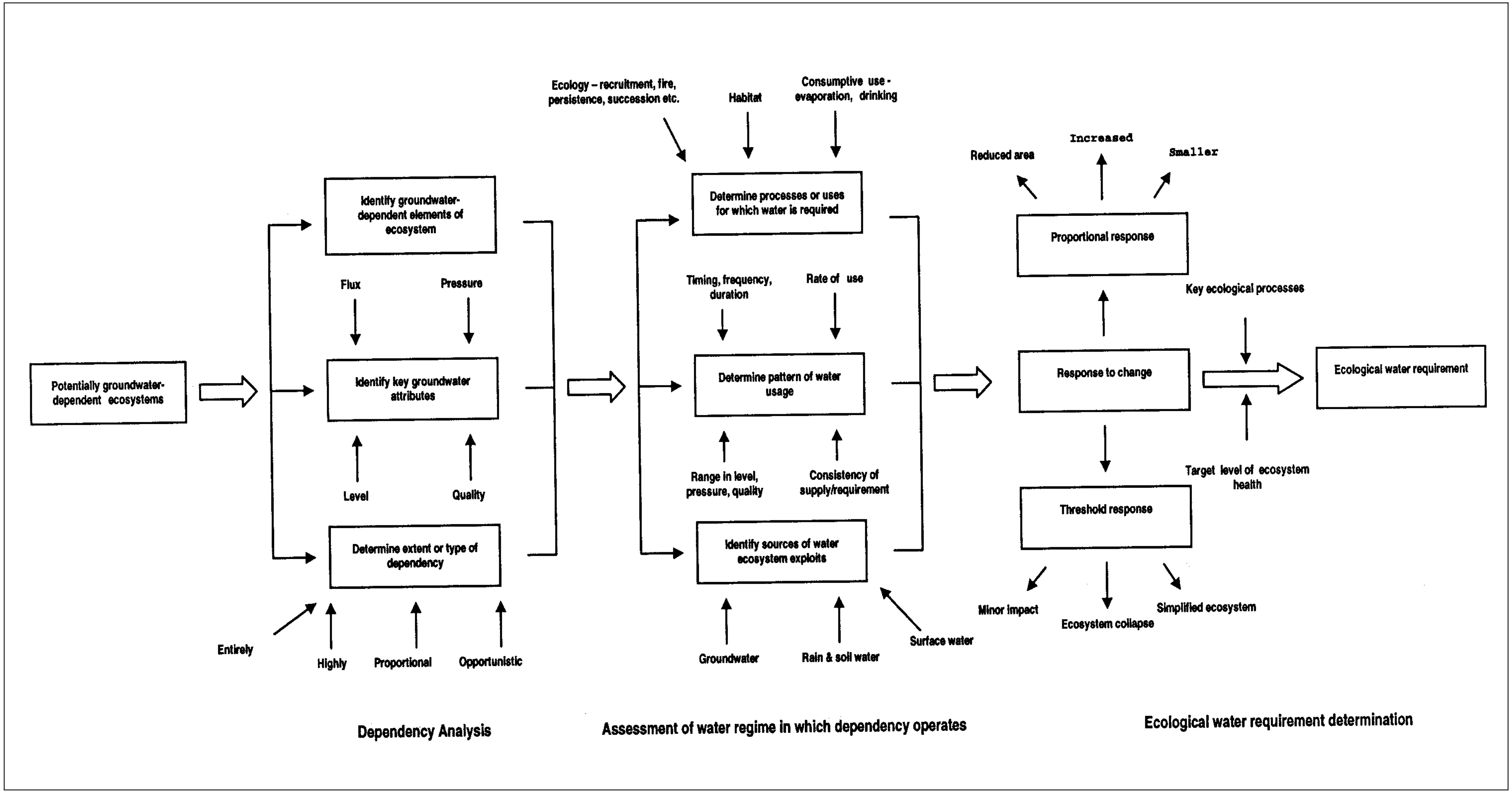


Figure 4.1: Conceptual framework for determination of ecological water requirements of groundwater-dependent ecosystems (*after* Evans, 2000)

- 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 asterix (*) 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.

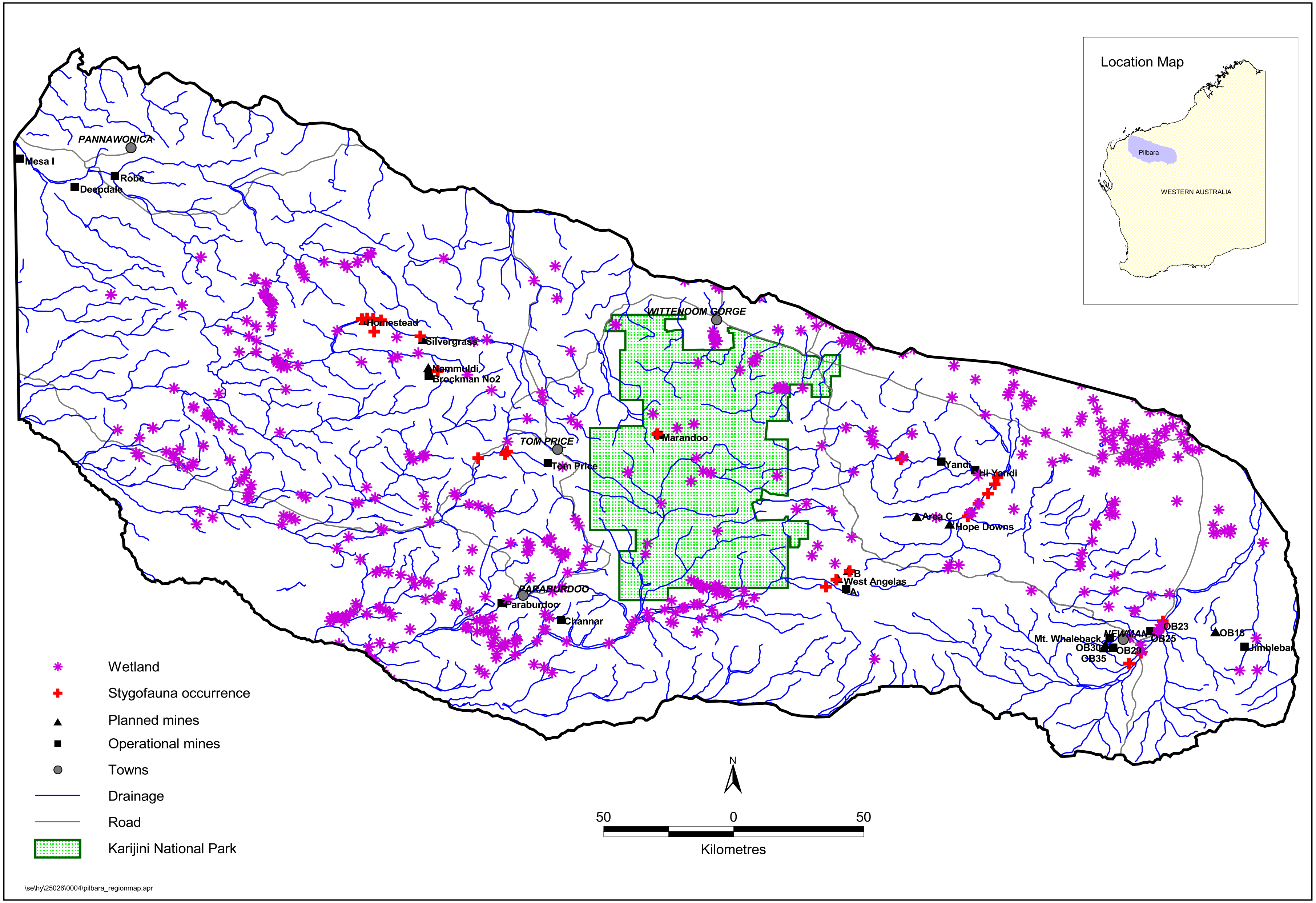


Figure 4.2 Wetland and stygofauna sites throughout the Central Pilbara

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

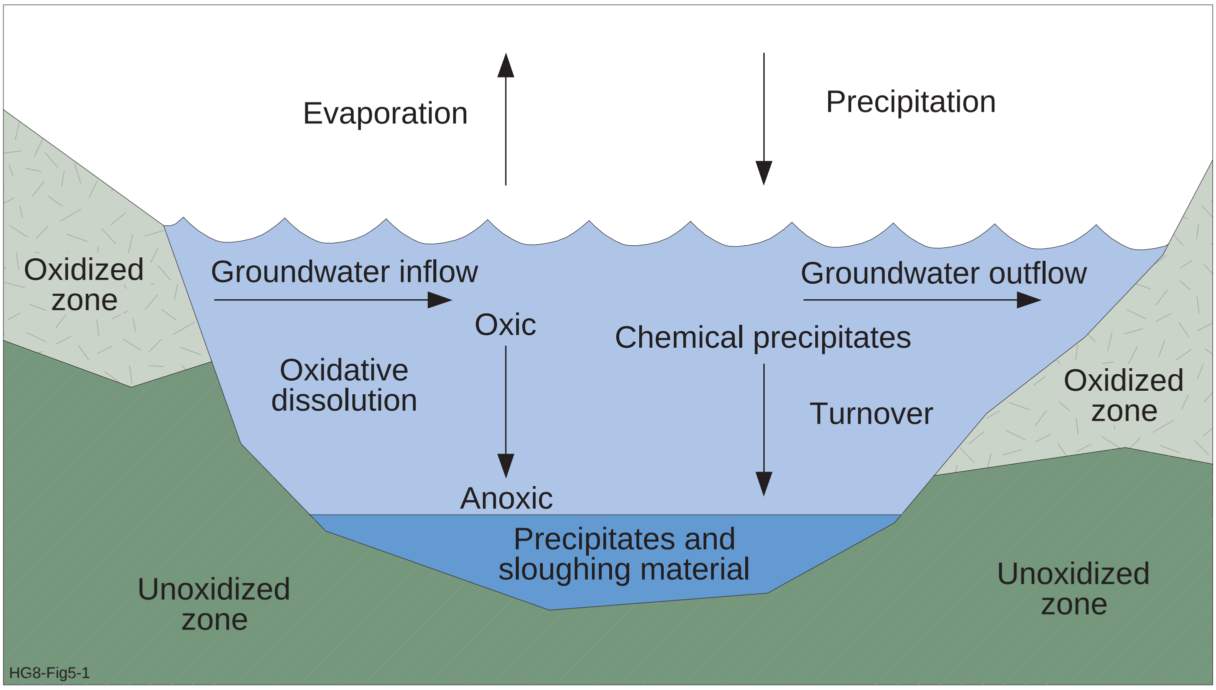


Figure 5.1 Chemical and physical processes in pit lakes (*after* Miller *et al*., 1996)

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.

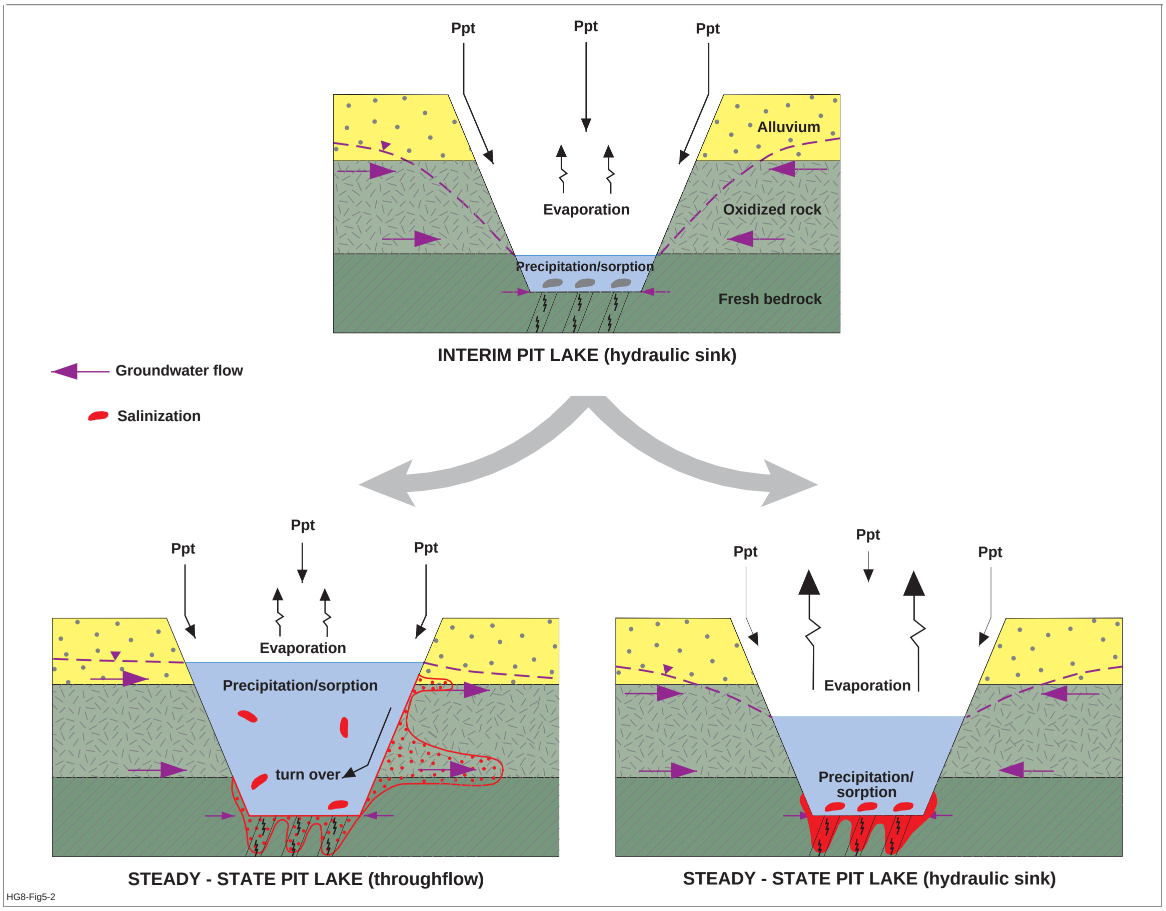


Figure 5.2 Most common hydrogeological processes occurring in Western Australian metalliferous mine voids

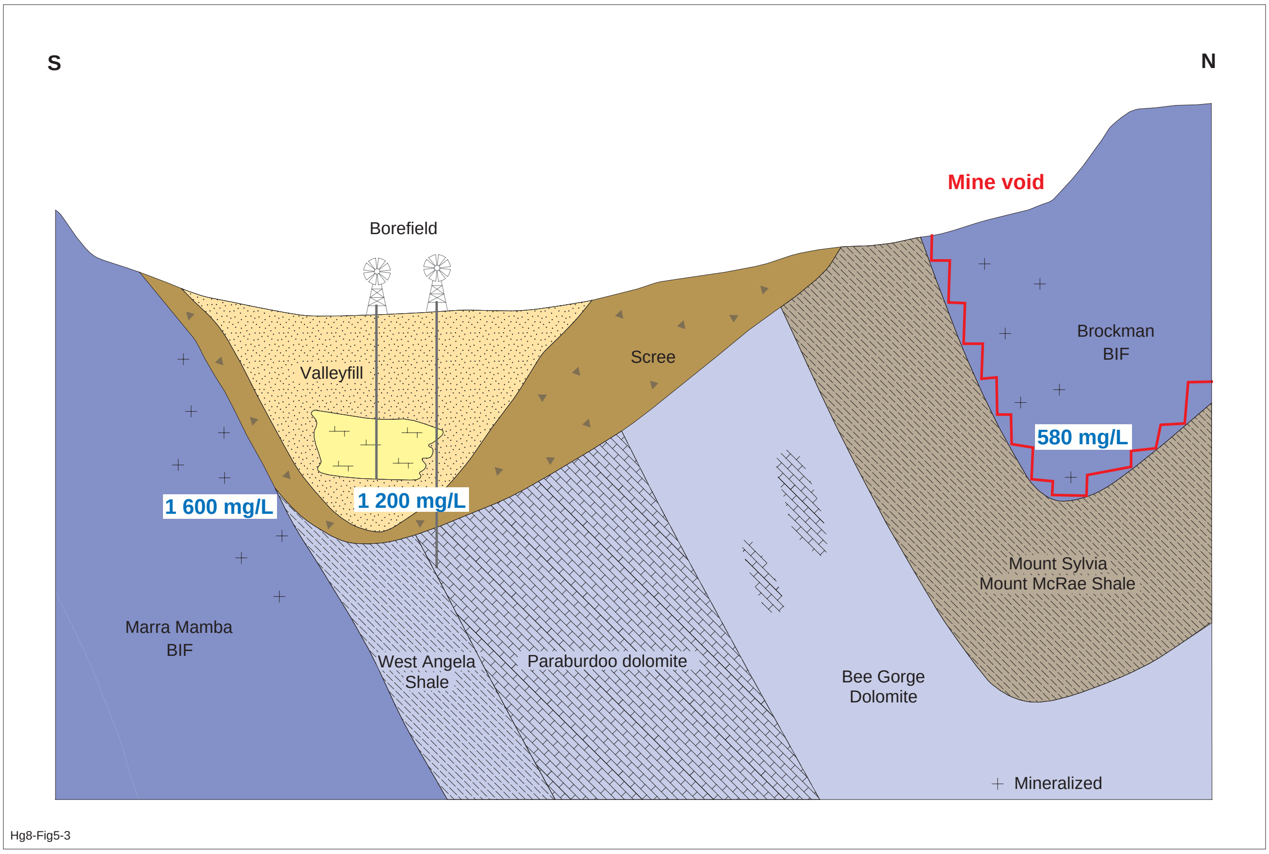


Figure 5.3 Orebody 18 – 'groundwater sink' mine-void scenario

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.

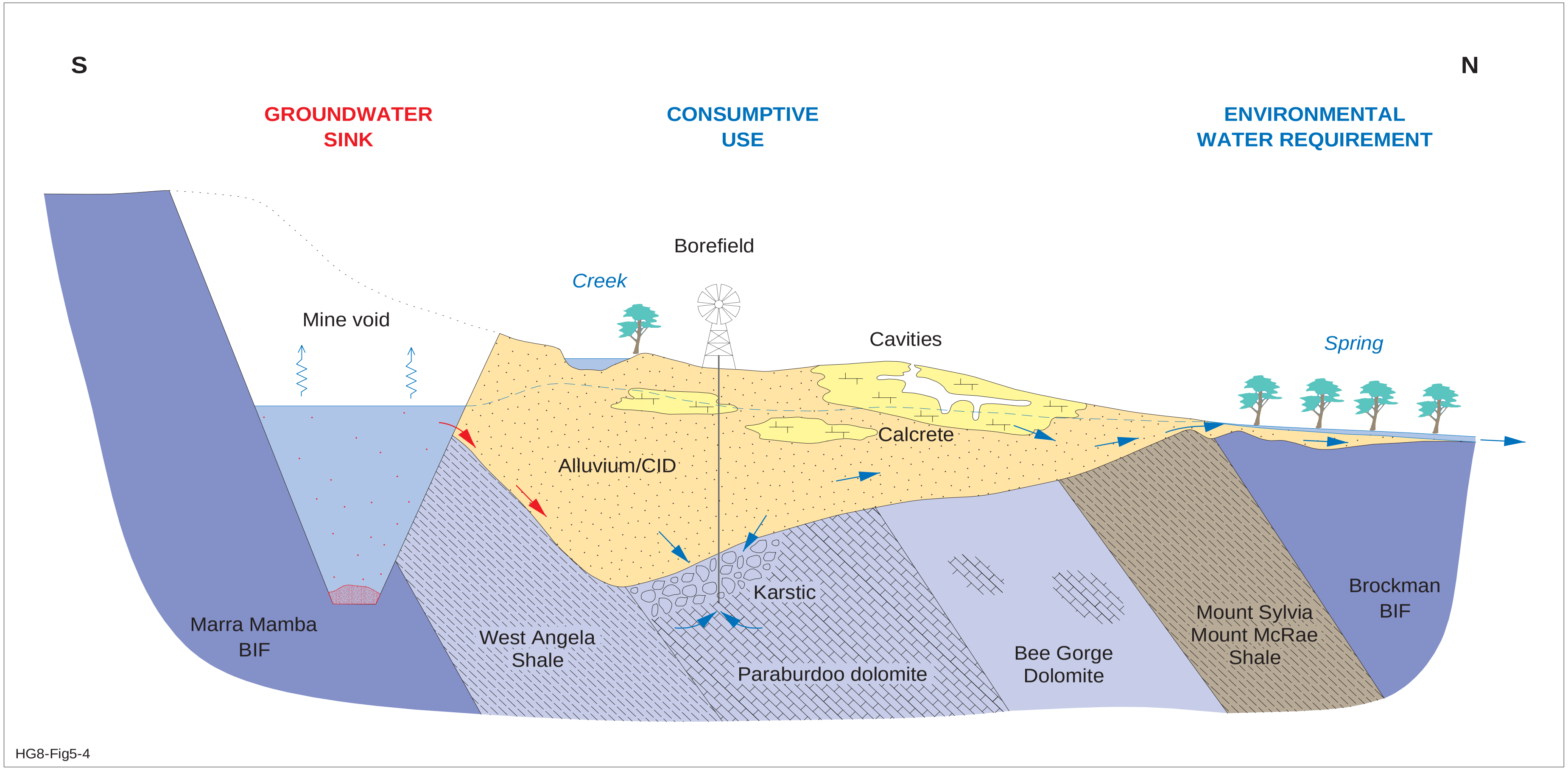


Figure 5.4 Hope Downs / Weeli Wolli Springs area – ‘throughflow’ mine-void scenario

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.

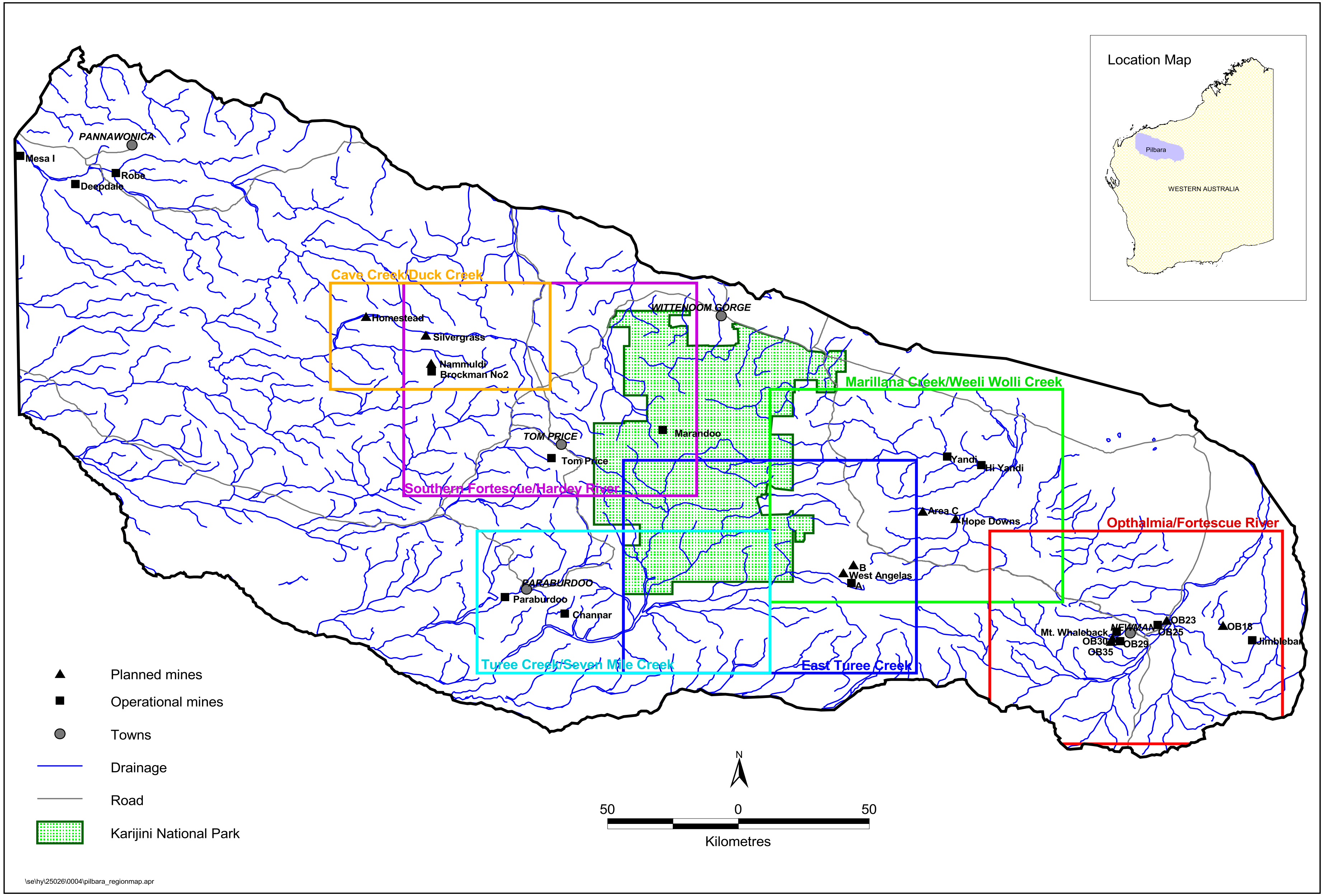


Figure 6.1 Regional areas used to highlight water management issues

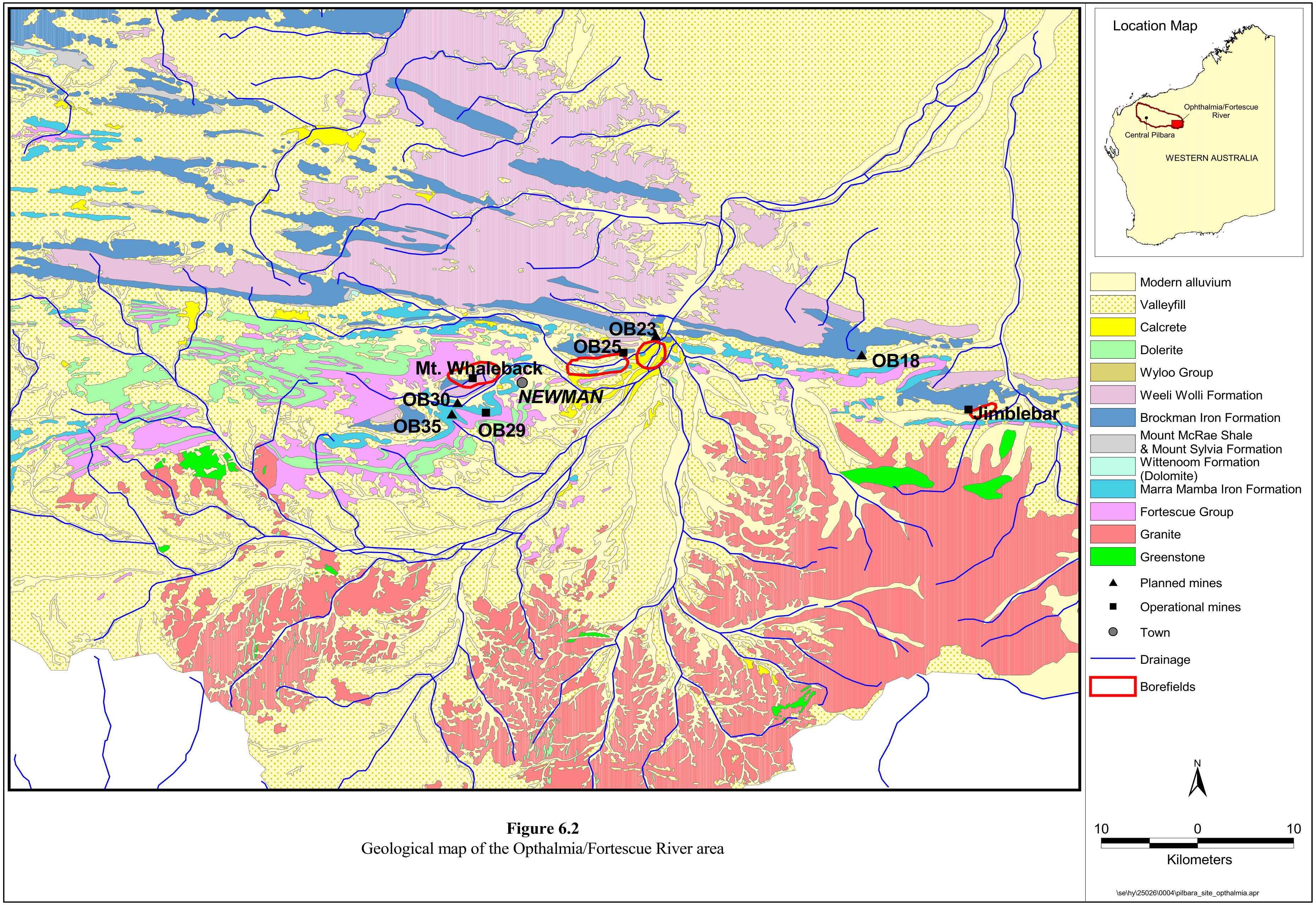


Figure 6.2
Geological map of the Opthalmia/Fortescue River area

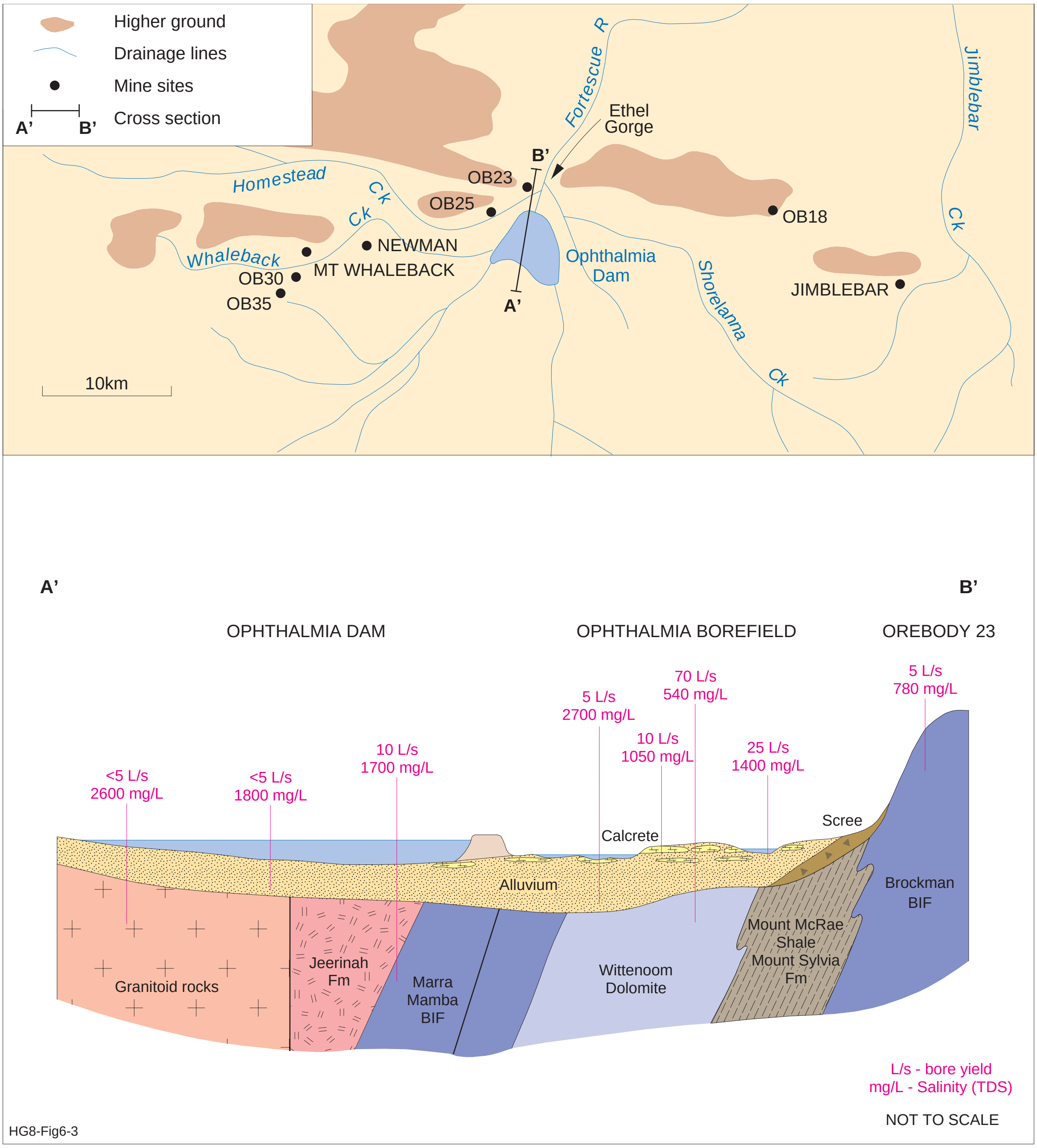


Figure 6.3 Location plan for mine sites around Newman and schematic section showing aquifer relationships

- 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.

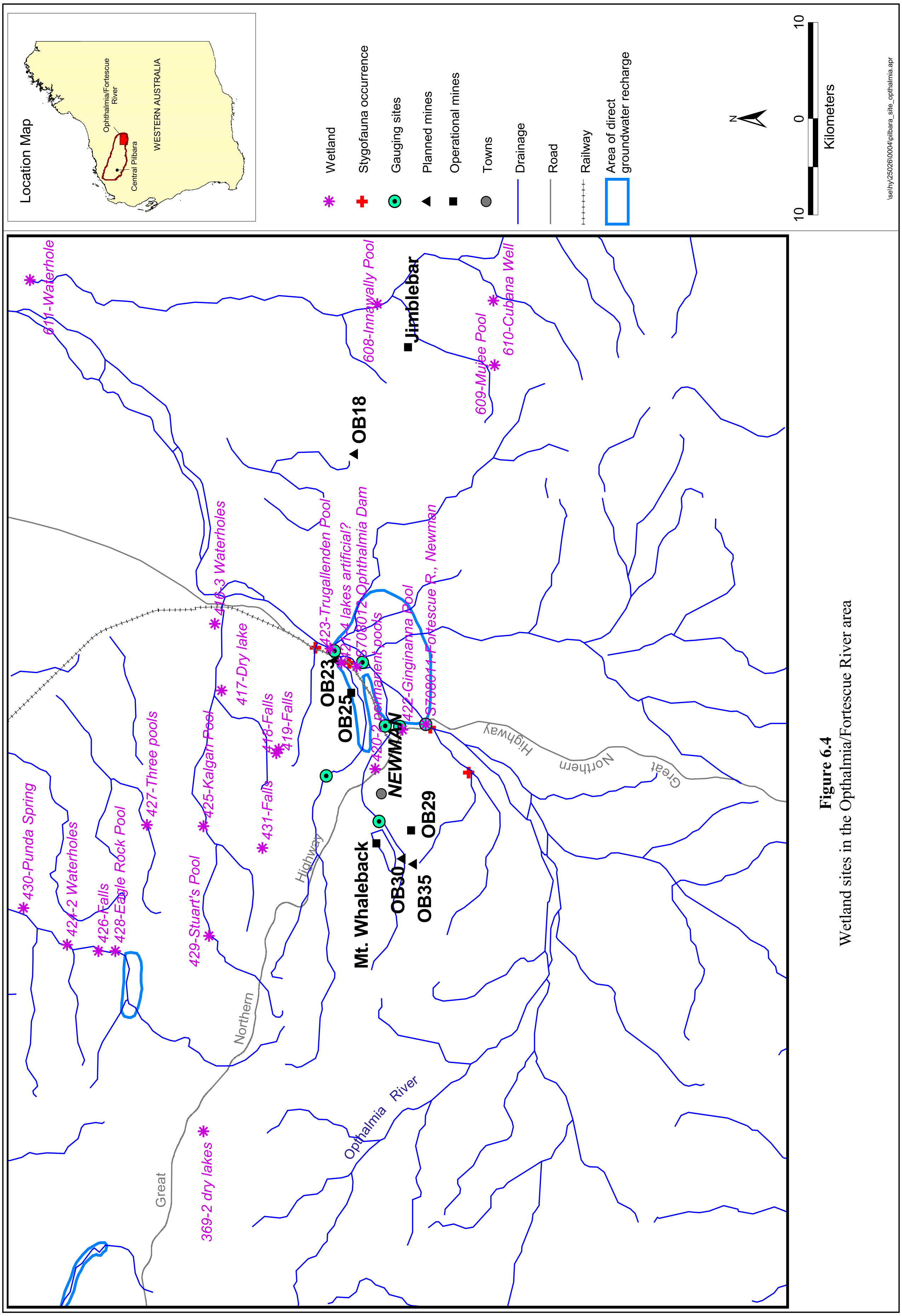


Figure 6.4
Wetland sites in the Opthalmia/Fortescue River area

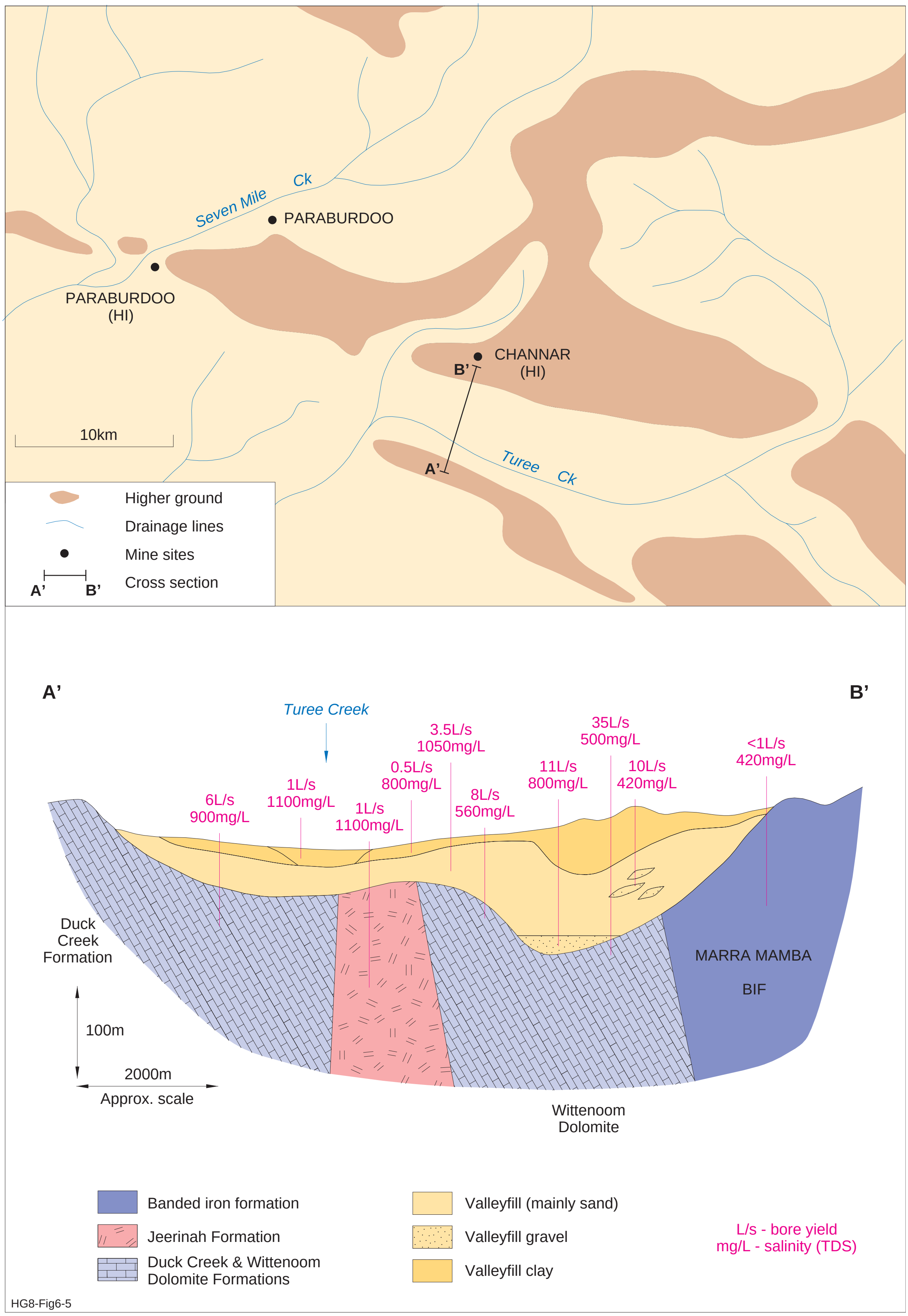


Figure 6.5 Location and schematic section through Turee Creek showing aquifer relationships, bore yields and salinity

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 Jerrinah 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.

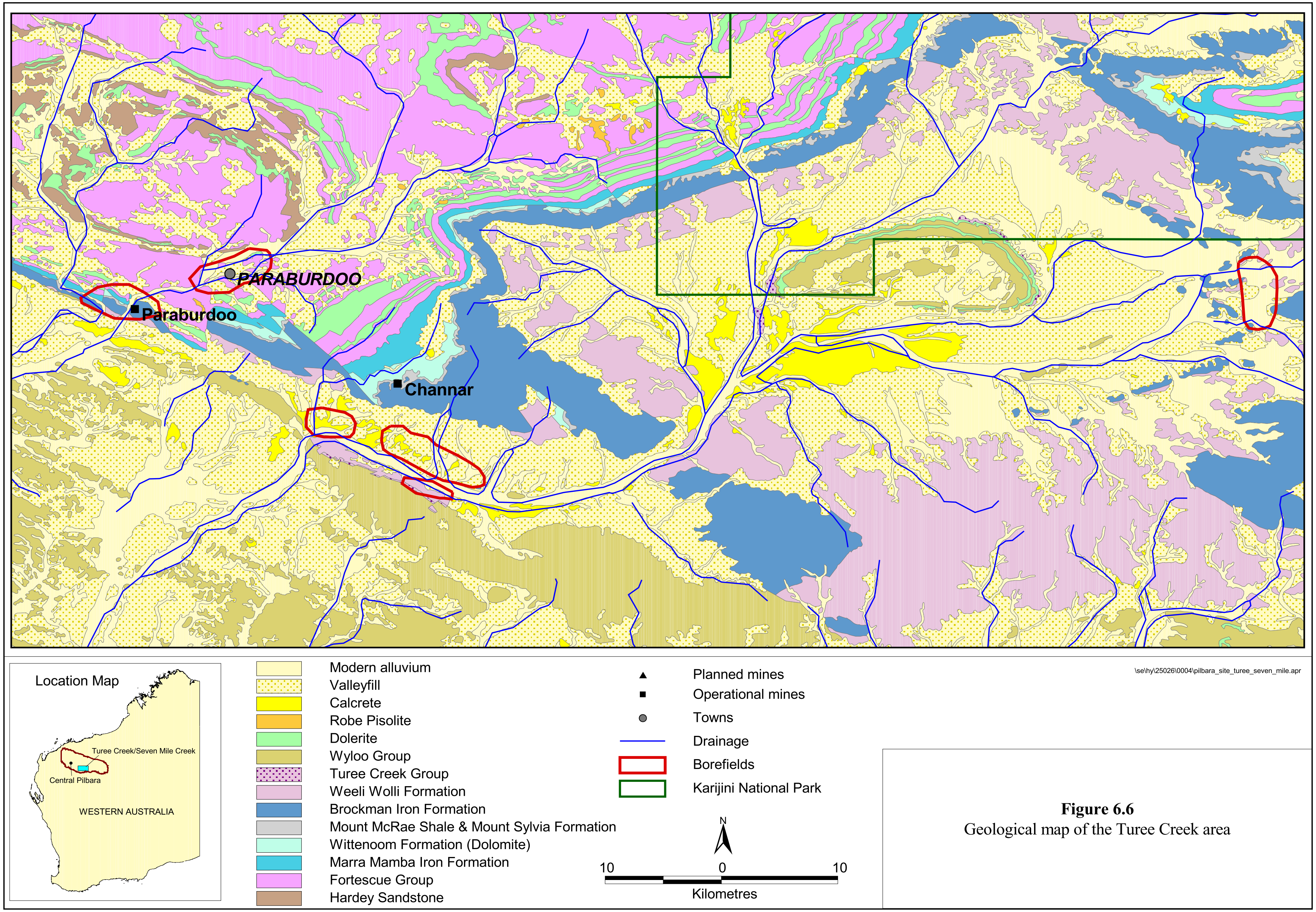


Figure 6.6
Geological map of the Turee Creek area

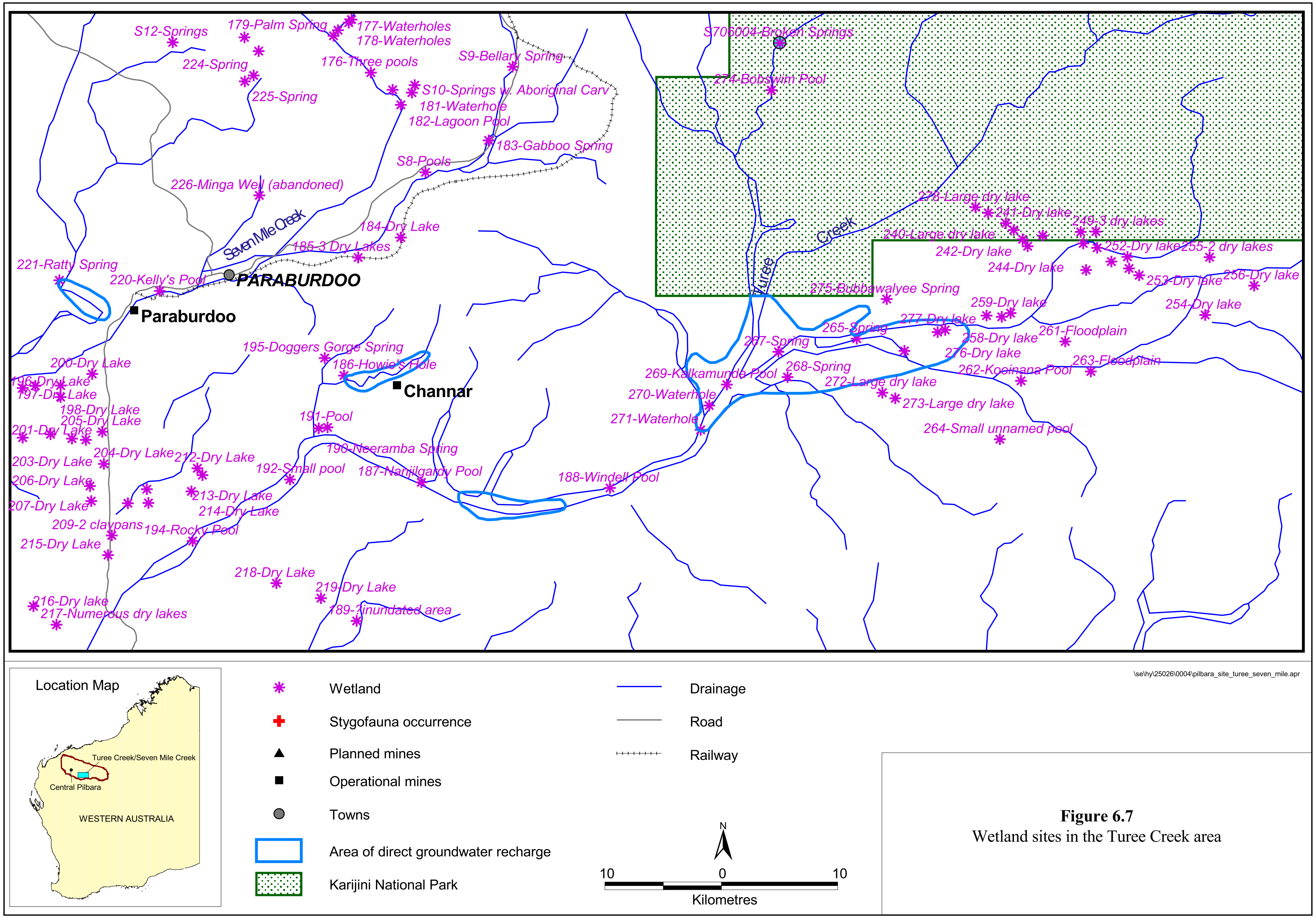


Figure 6.7
Wetland sites in the Turee Creek area

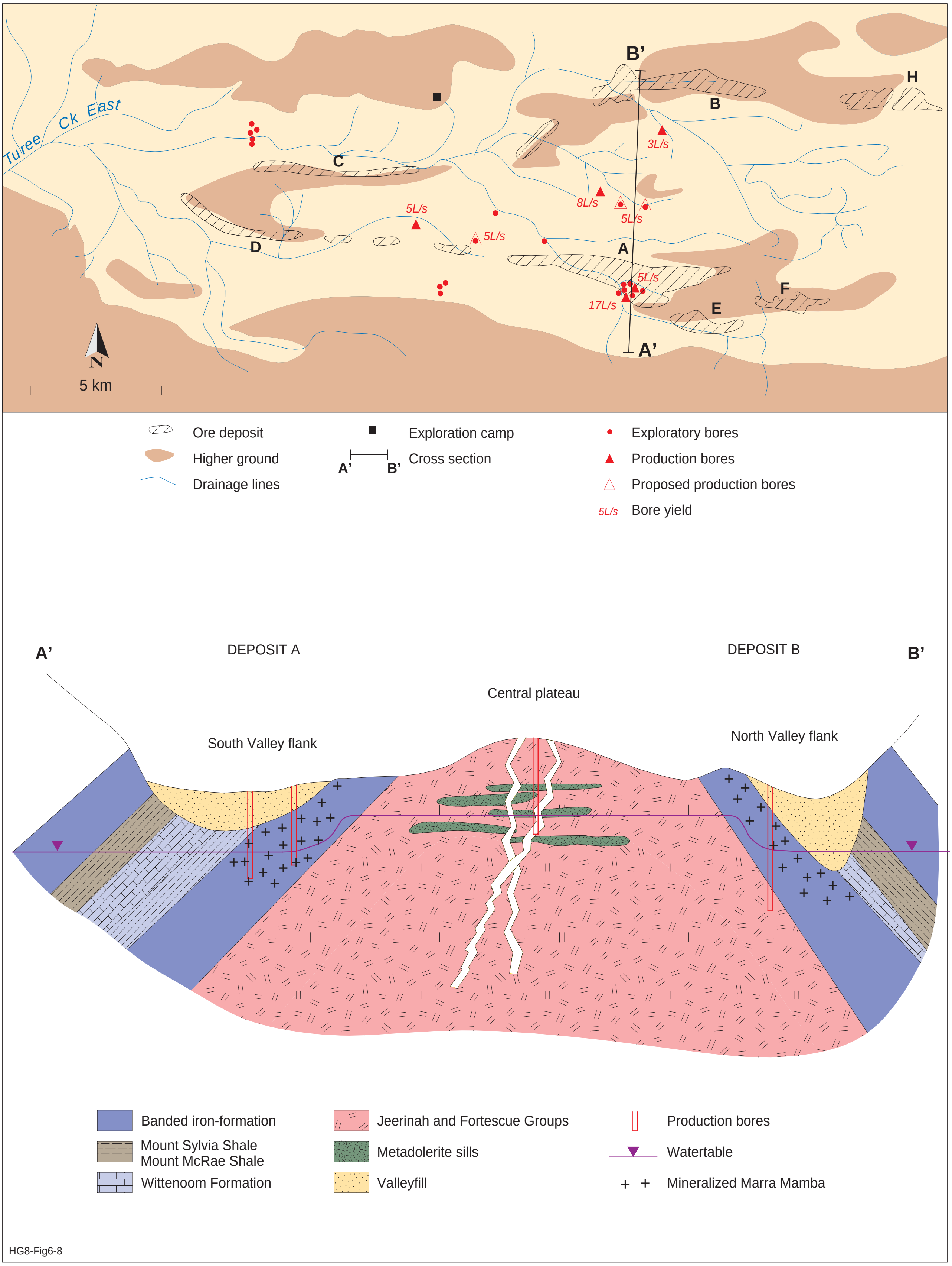


Figure 6.8 Location of West Angelas mine site and conceptual hydrogeology

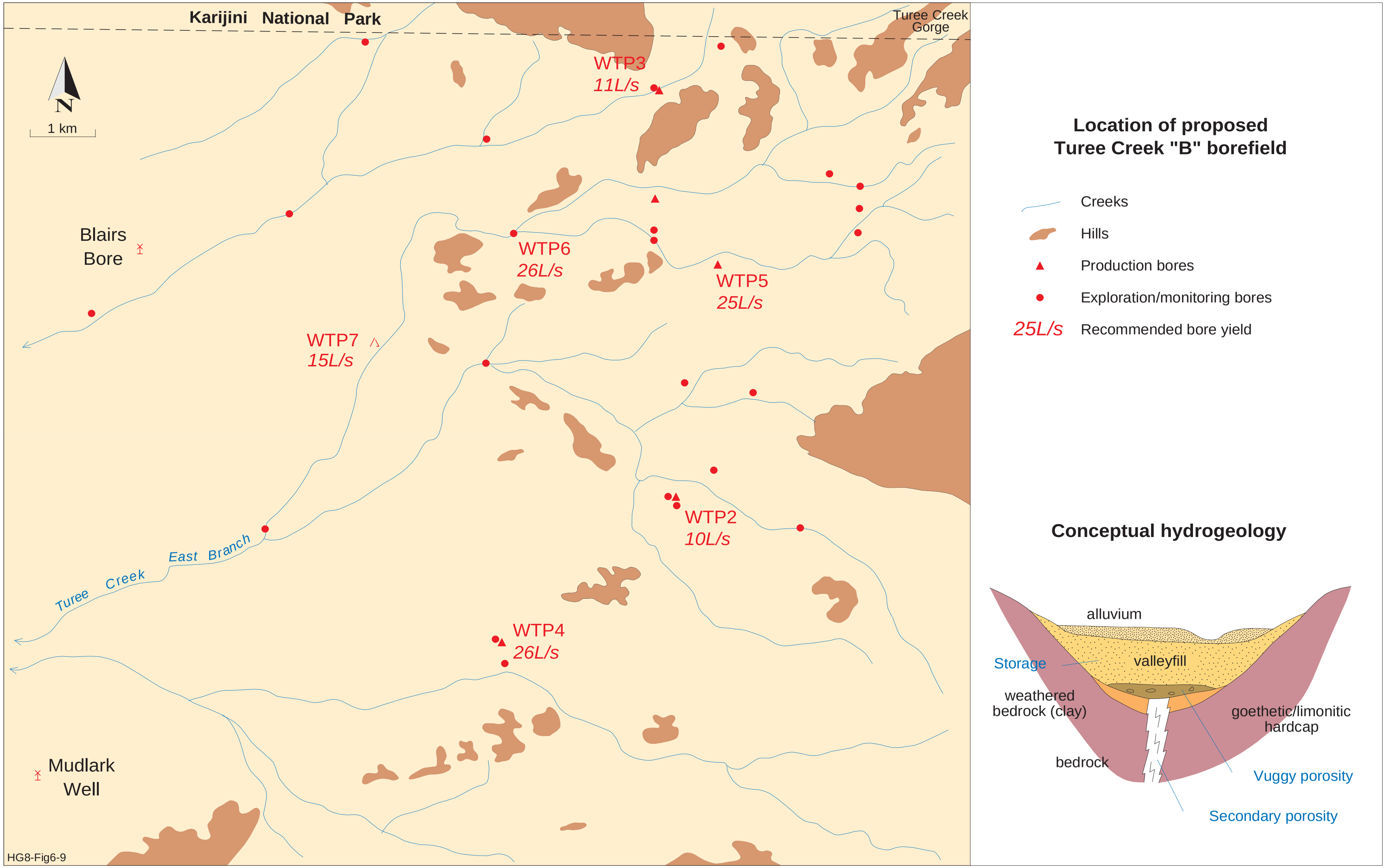


Figure 6.9 Location and schematic hydrogeology at Turee B borefield

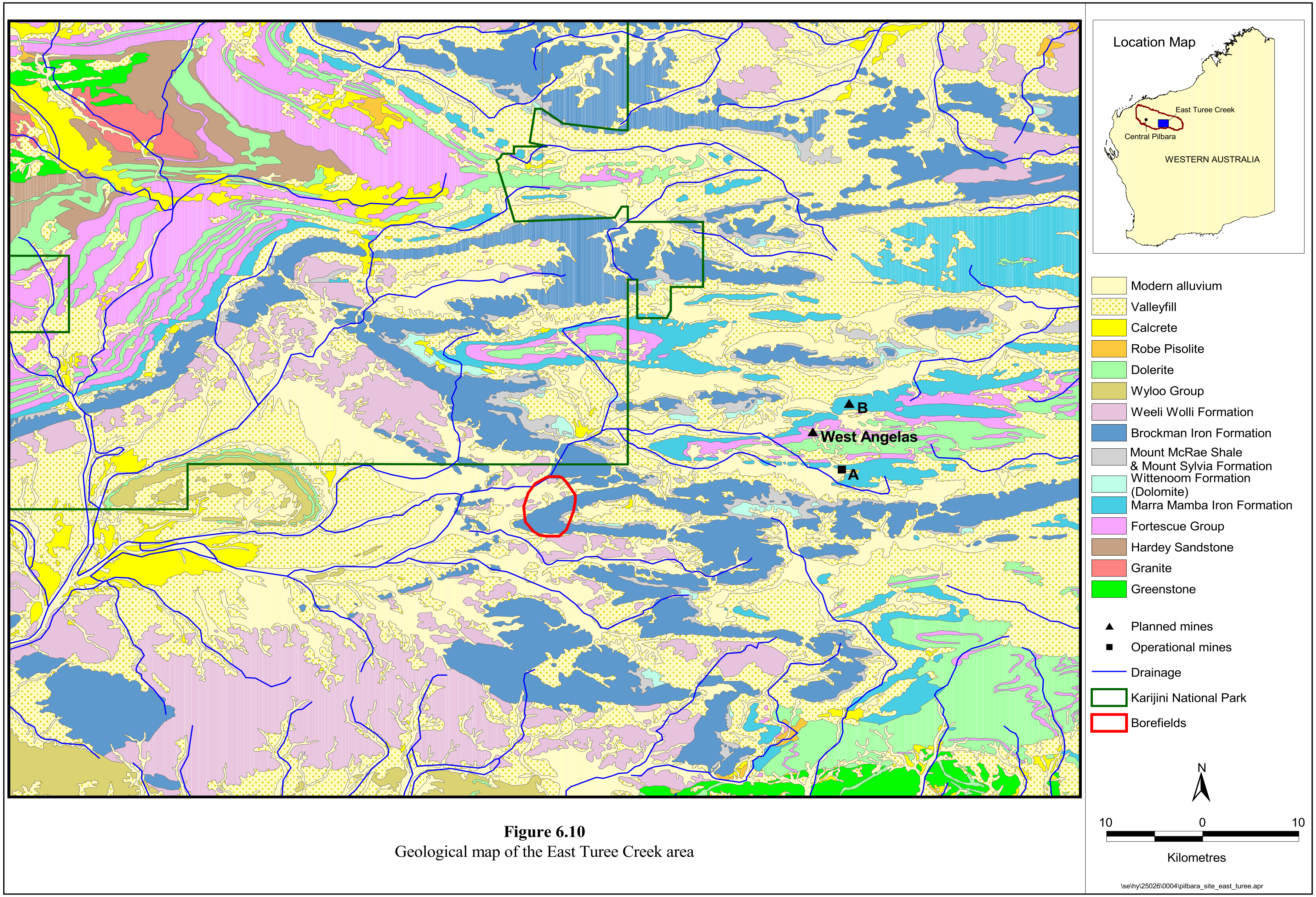


Figure 6.10
Geological map of the East Turee Creek area

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

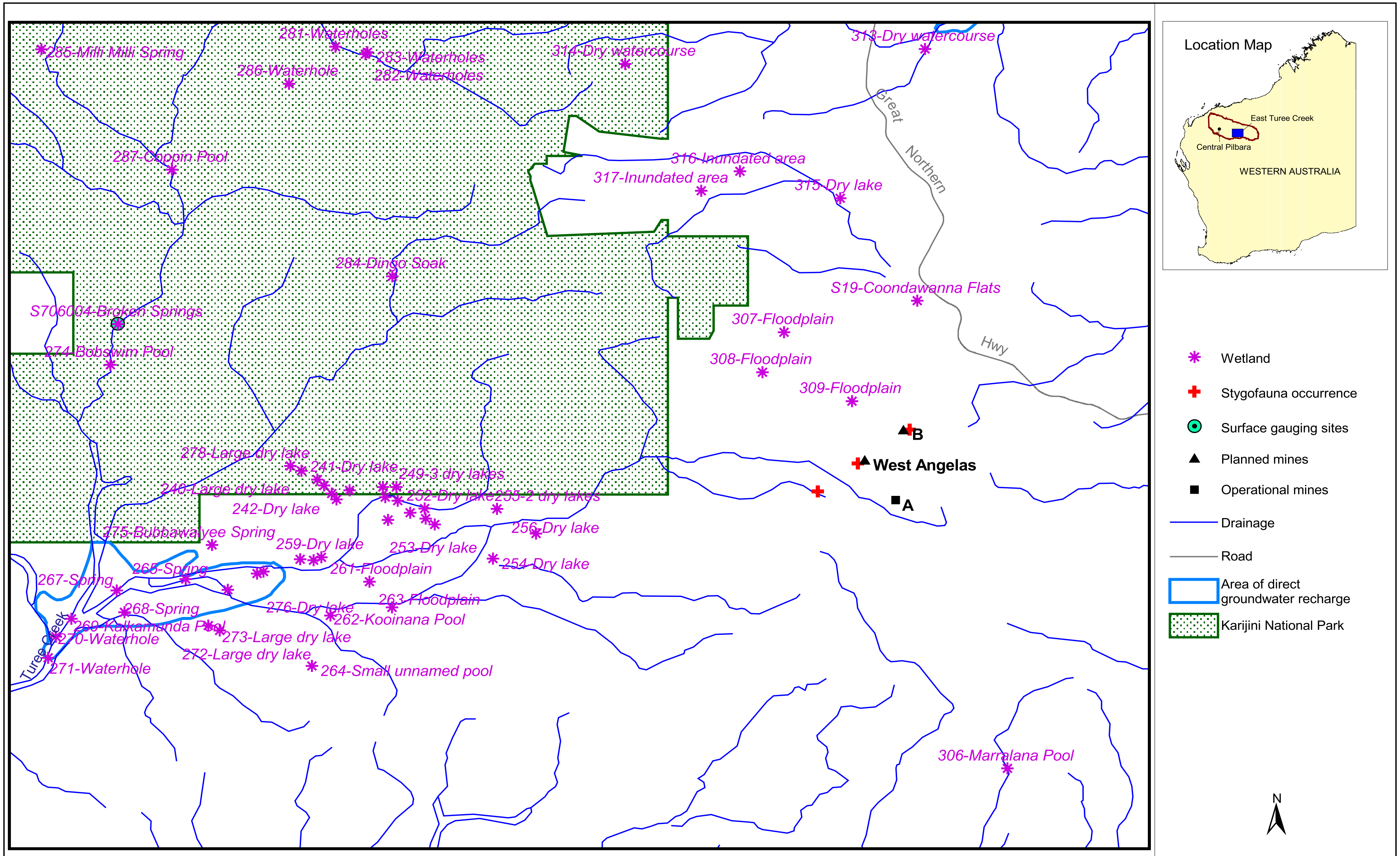


Figure 6.11
Wetland sites in the East Turee Creek area

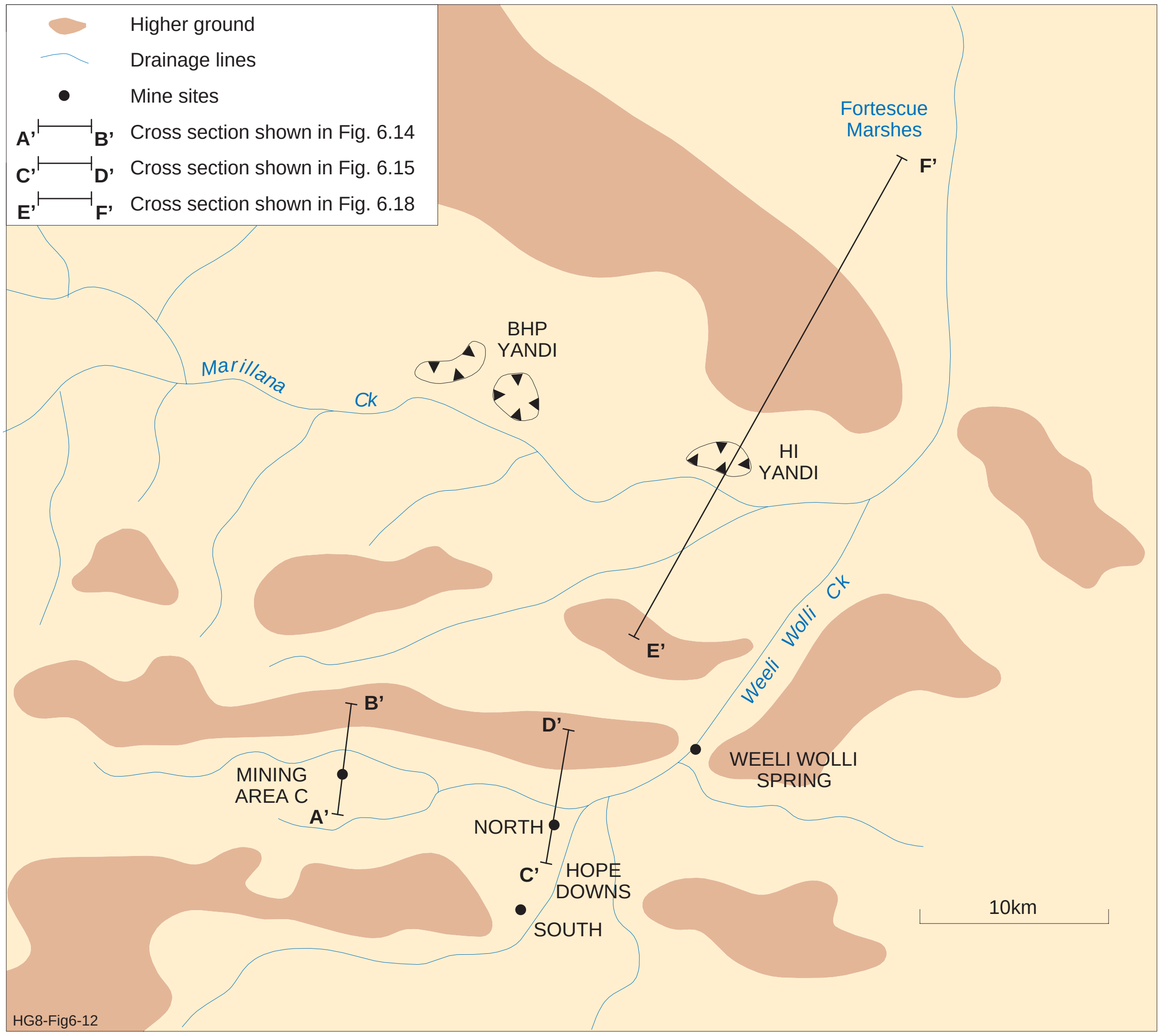


Figure 6.12 Location of important features in the Weeli Wolli Creek area

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.

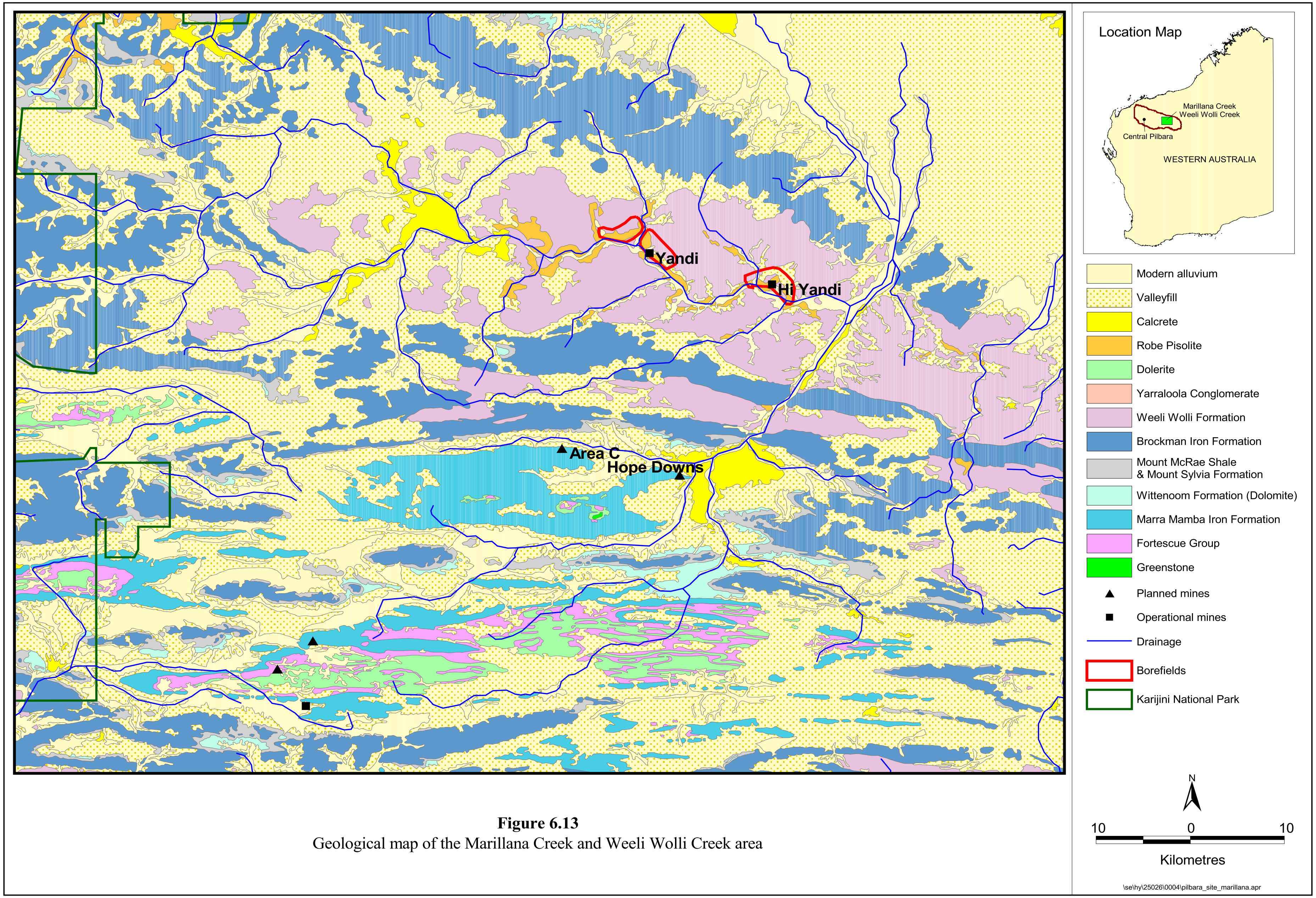


Figure 6.13
Geological map of the Marillana Creek and Weeli Wolli Creek area

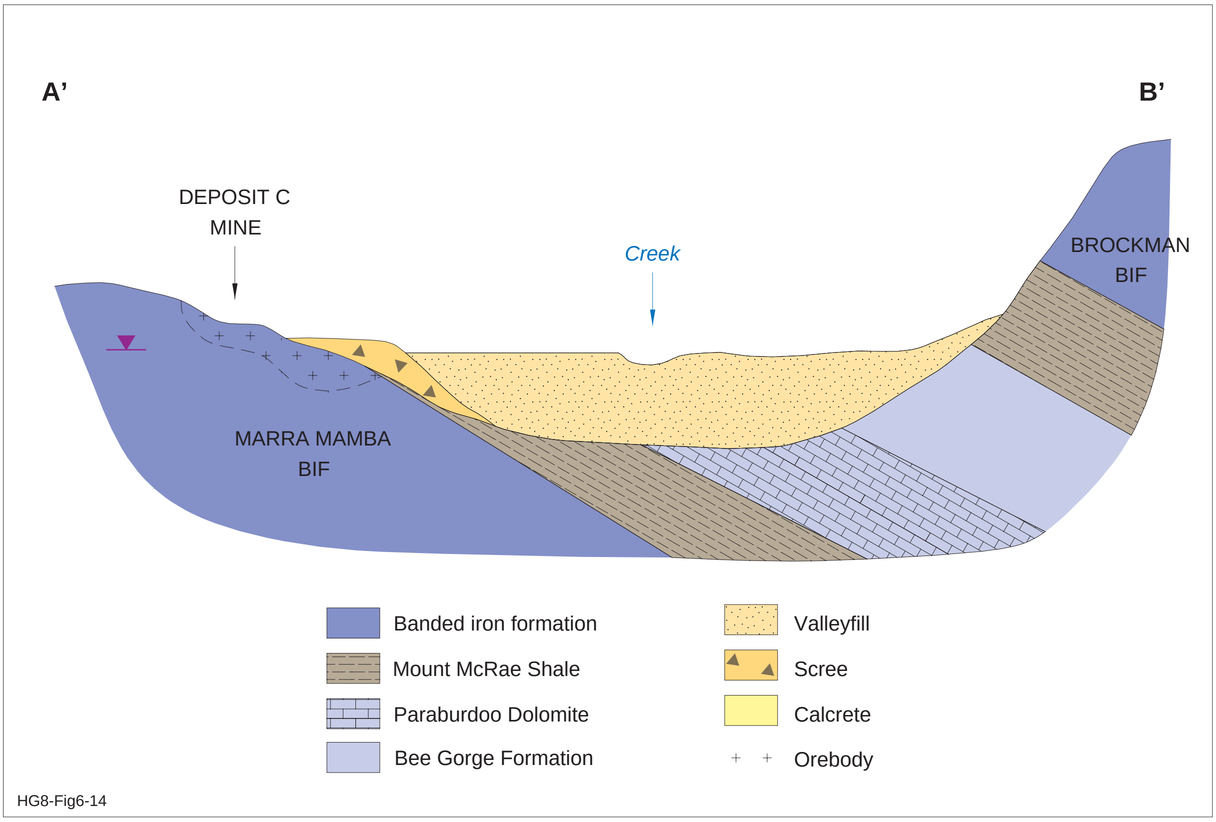


Figure 6.14 Schematic section through the Weeli Wolli tributary at Mining Area C (refer to Fig. 6.12)

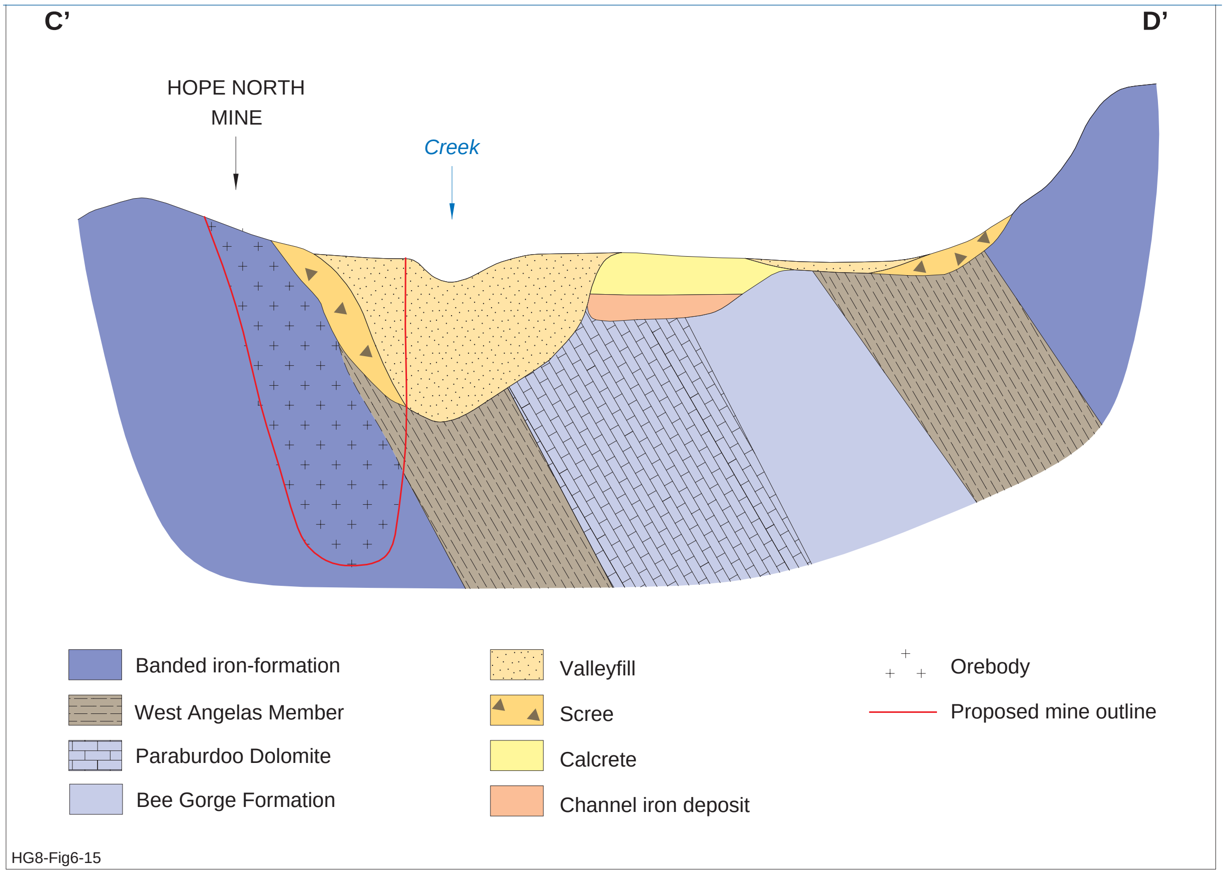


Figure 6.15 Schematic section through the Weeli Wolli tributary at Hope Downs (refer to Fig. 6.12)

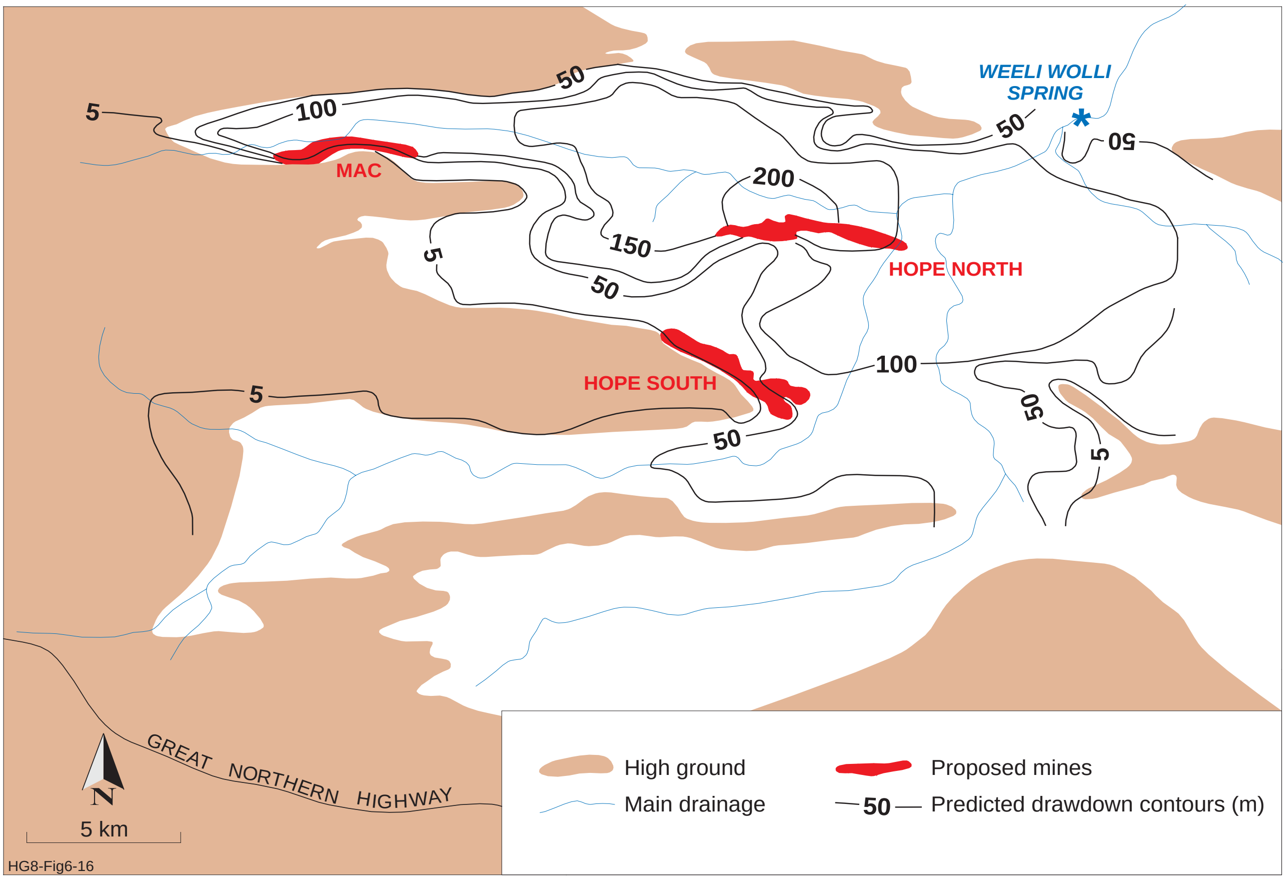


Figure 6.16 Predicted drawdowns resulting from dewatering at Hope Downs

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

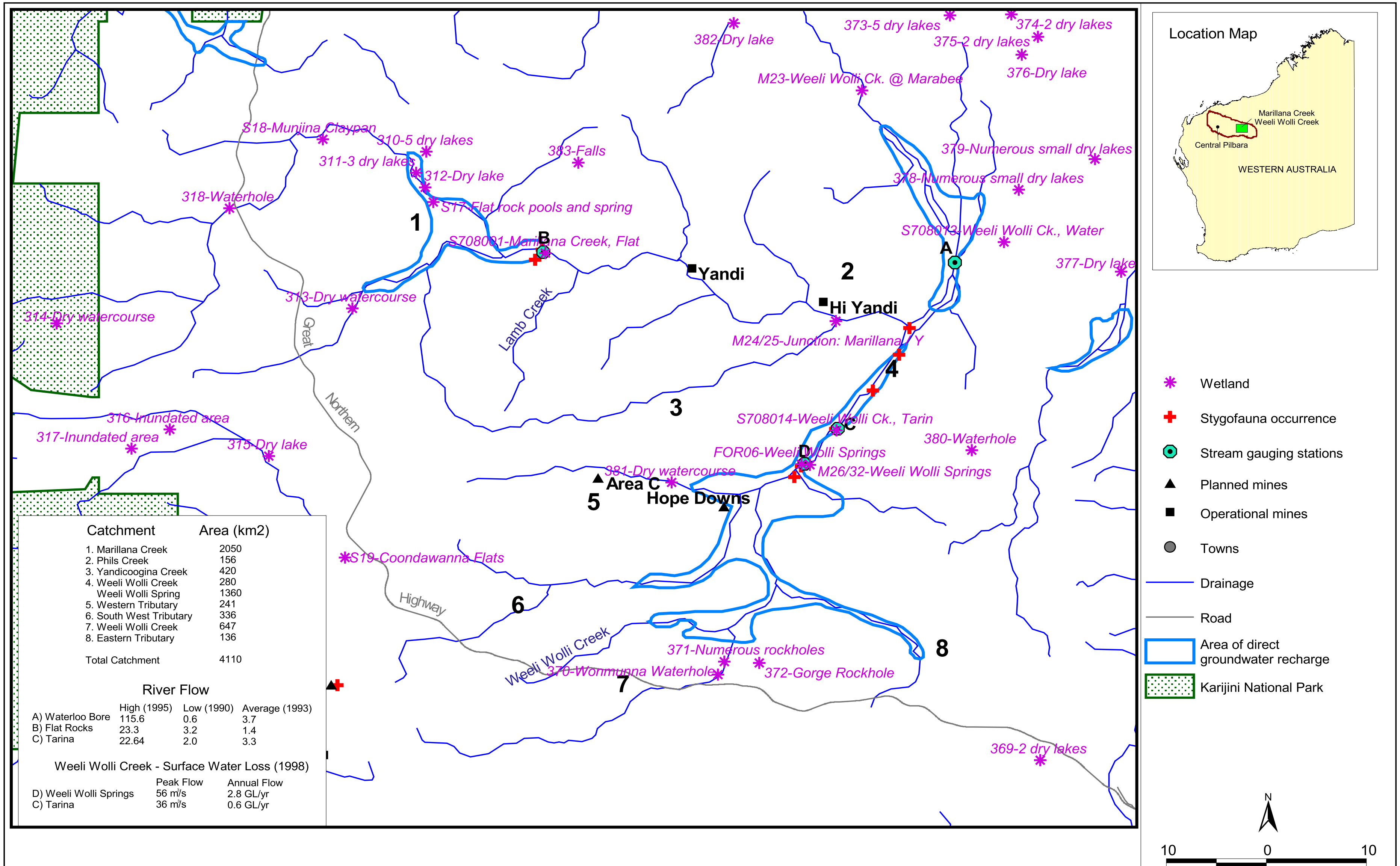
The Water and Rivers Commission suggests that the following water-related issues are considered as part of any current or proposed mining development.

- 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 km^2, 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 m^2/day. Groundwater throughflow has



Catchment	Area (km2)
1. Marillana Creek	2050
2. Phils Creek	156
3. Yandicoogina Creek	420
4. Weeli Wolli Creek	280
Weeli Wolli Spring	1360
5. Western Tributary	241
6. South West Tributary	336
7. Weeli Wolli Creek	647
8. Eastern Tributary	136
Total Catchment	4110

River Flow

	High (1995)	Low (1990)	Average (1993)
A) Waterloo Bore	115.6	0.6	3.7
B) Flat Rocks	23.3	3.2	1.4
C) Tarina	22.64	2.0	3.3

Weeli Wolli Creek - Surface Water Loss (1998)

	Peak Flow	Annual Flow
D) Weeli Wolli Springs	56 m/s	2.8 GL/yr
C) Tarina	36 m/s	0.6 GL/yr

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

\se\hy\25026\0004\pilbara_site_marillana.apr 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

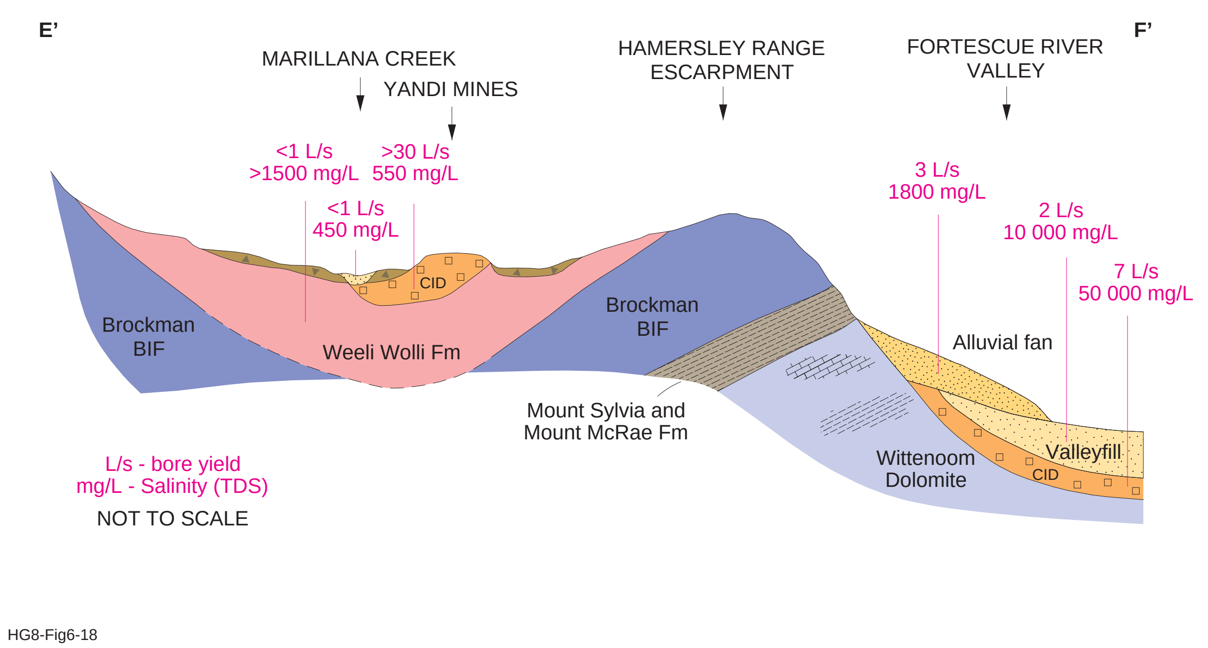


Figure 6.18 Schematic section through Marillana Creek and Fortescue Valley area (refer to Fig. 6.12)

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

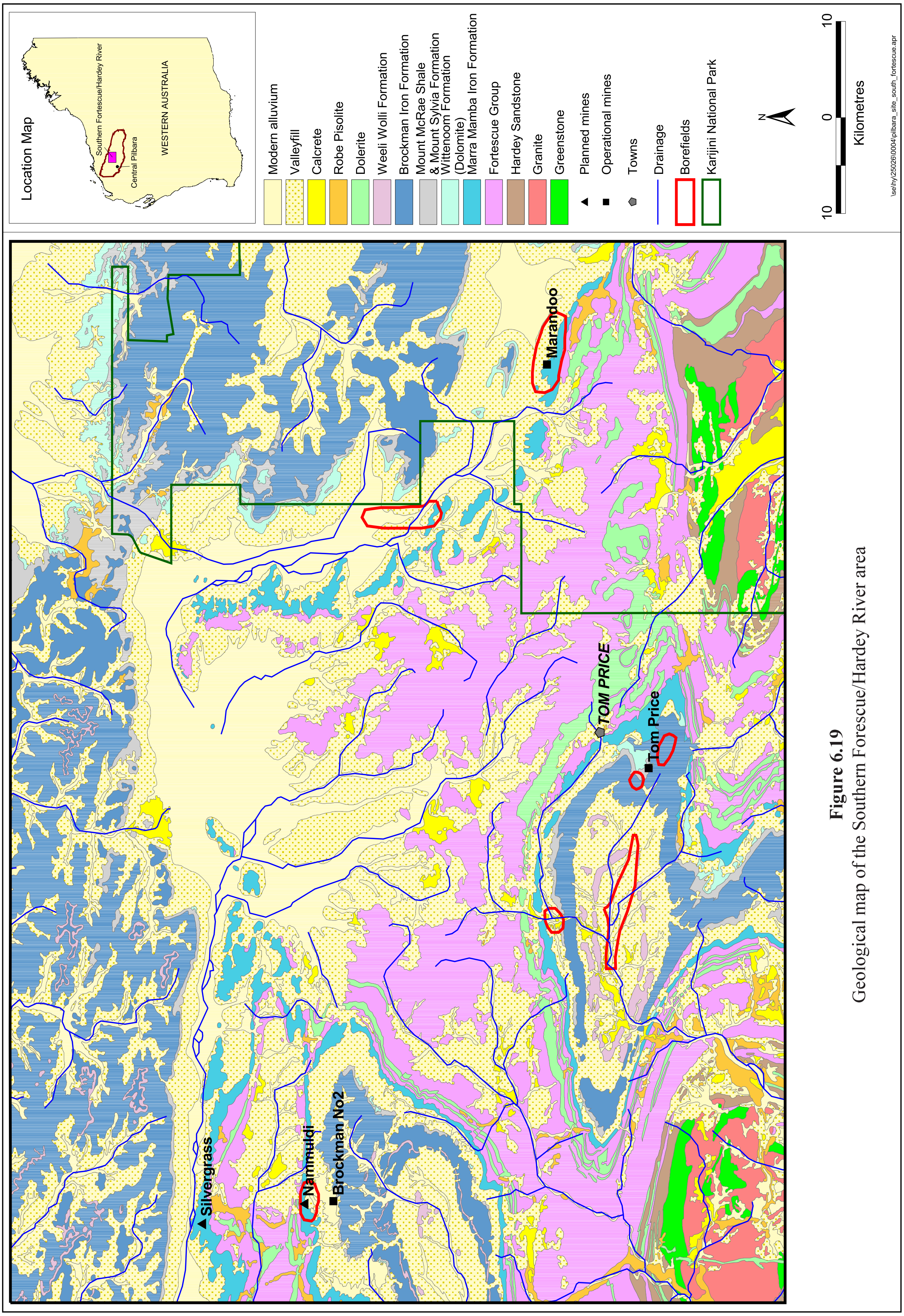


Figure 6.19
Geological map of the Southern Forescue/Hardey River area

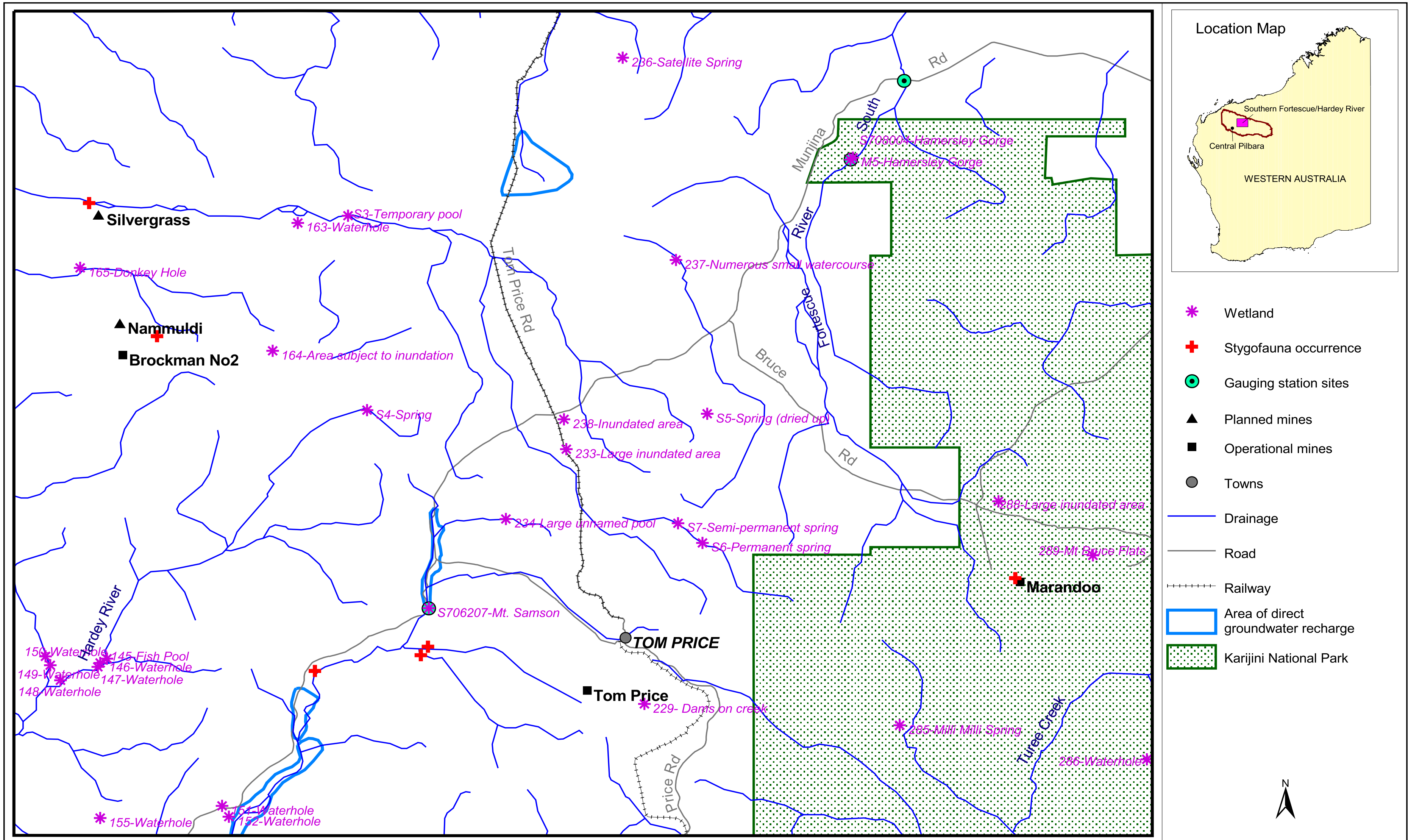


Figure 6.20

Wetland sites in the Southern Fortescue/Hardey River area

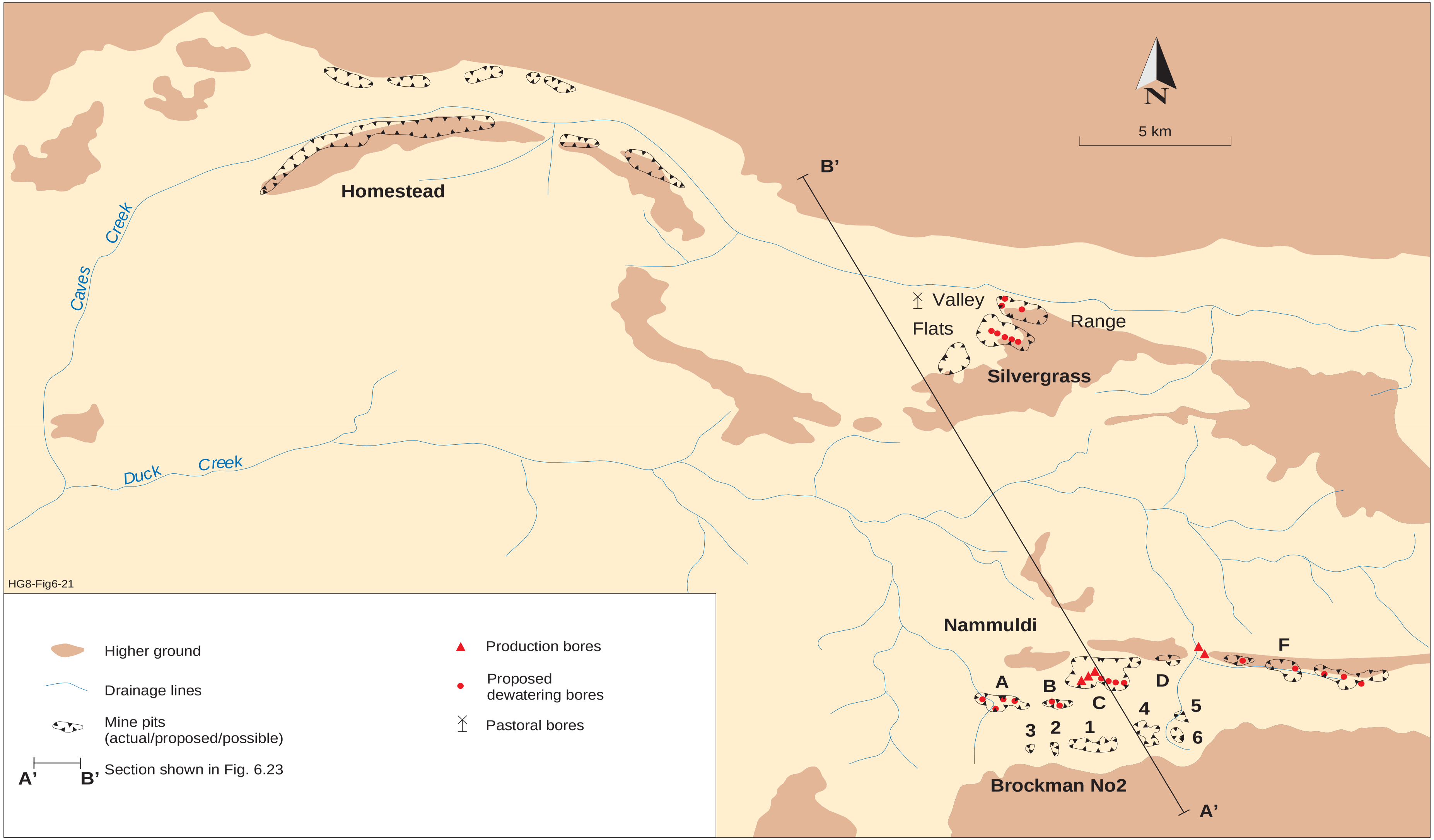


Figure 6.21 Location of mine sites and schematic section at Caves Creek

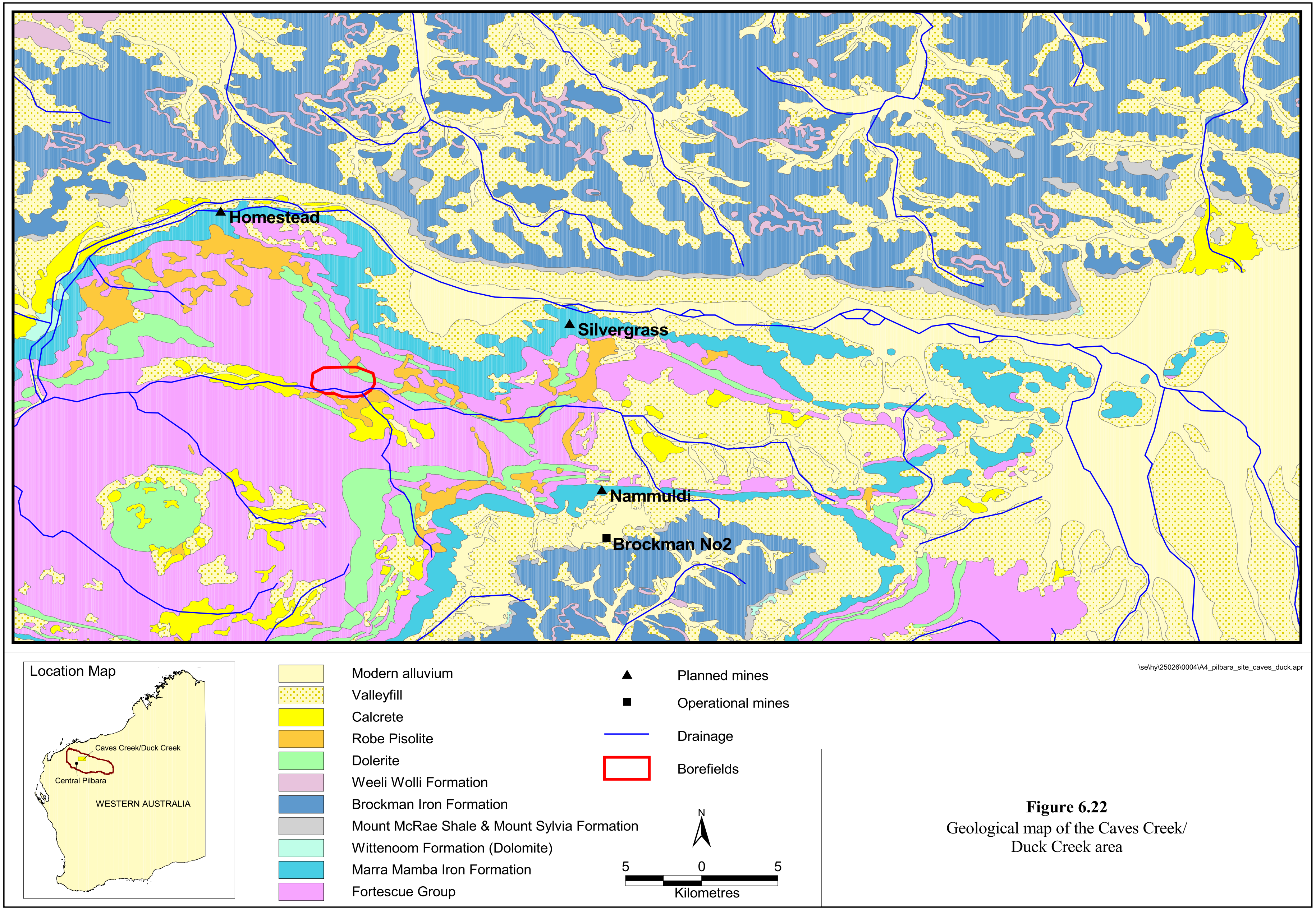


Figure 6.22
Geological map of the Caves Creek/ Duck Creek area

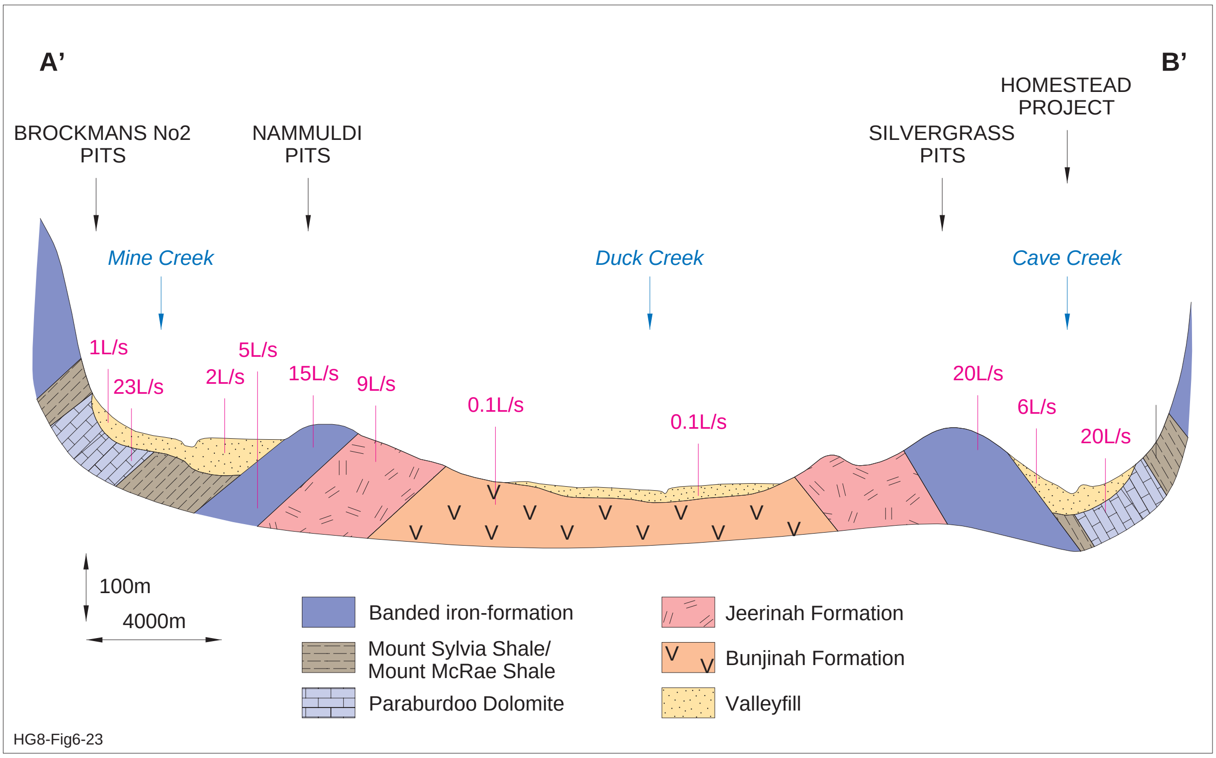


Figure 6.23 Schematic section through Caves Creek / Duck Creek area

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.

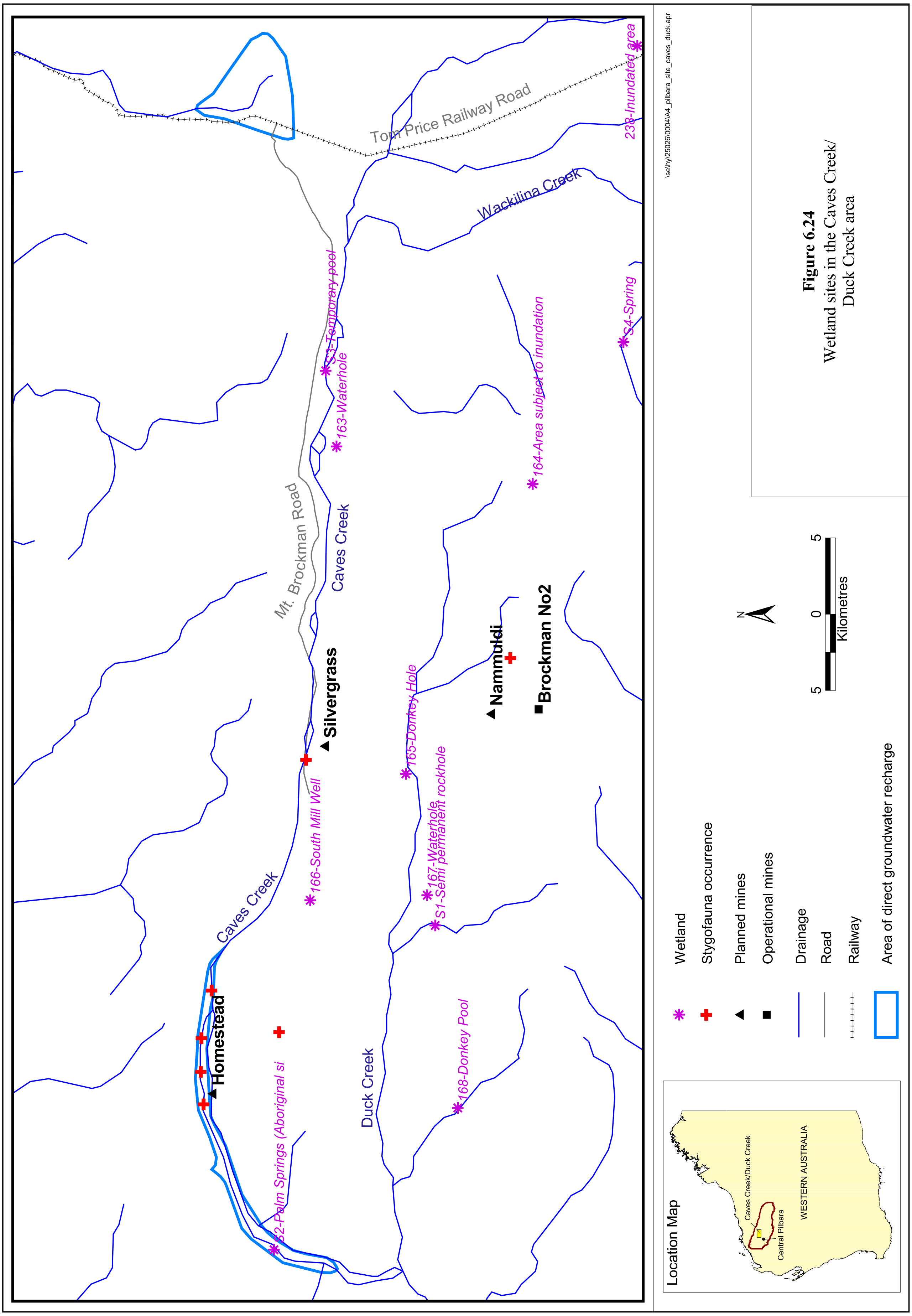


Figure 6.24
Wetland sites in the Caves Creek/
Duck Creek area

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/Hardey River; and Caves Creek/ Duck Creek.

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9 Glossary

Alluvial	Unconsolidated sediments derived from stream and river activity.
Anticline	An upward fold in the strata in the form of an arch.
Aquifer	A porous and permeable rock unit capable of supplying groundwater from bores and well.
Archaean	Period containing the oldest rocks of the Earth's crust – older than 2.4 billion years.
ARD	Acid rock drainage.
Banded iron-formation	Tabular rock consisting of alternating bands of quartz and iron-rich minerals.
Basement	Competent rock formations underneath sediments.
Beneficiation	Value adding to a product.
BHP	Broken Hill Proprietary Co. Ltd.
BIF	Banded iron-formation.
Brockman	Stratigraphic name of a banded iron-formation in the Hamersley Group.
Calcrete	Carbonate rock formed by the in-situ replacement of alluvium or colluvium by magnesium and calcium carbonate precipitating from percolating carbonate-rich groundwater.
CID	Channel iron deposits.
Colluvial aquifer	Loose incoherent deposits at the base of a slope.
Confined	An aquifer that is overlain by a confining bed of relatively impermeable material.
Detritals	Material derived from the weathering of pre-existing rocks.
Dewatering	Abstraction of groundwater via bores to assist in dry-floor mining.
Dolomite	Carbonate rock with more than 15% magnesium carbonate.
Dyke	Tabular igneous rock intrusion cutting across other rock units.
EPA	Environmental Protection Authority.
Evapo-concentration	Concentration of salts via evaporation.
EWP	Environmental water provision.
EWR	Ecological water requirement.
Formation	A geological term for the primary unit of lithostratigraphic classification.
Gigalitre	A measure of water quantity – one gigalitre equals one billion litres or one million kilolitres.
GL	Gigalitre.
Granite	Coarse-grained igneous crystalline rock with a high silica content.
Greenstone	Consolidated sequence of sedimentary and volcanic rocks – Archaean in age.
H_2SO_4	Sulphuric acid.
Hematite	Iron oxide material (Fe_2O_3).
HI	Hamersley Iron (subsidiary of Rio Tinto plc).

Hydraulic gradient	The slope of the watertable over distance.
Karstic	Weathering features such as sinkholes, caves and underground drainage formed by dissolution of calcium carbonate.
kL/day	A measure of water quantity – equivalent to 1000L/day.
Limonite	Iron oxide material ($2Fe_2O_3.3H_2O$).
Lineament	Large-scale linear feature in the topography reflecting underlying structure.
Lithologies	Rock types.
Marra Mamba	Stratigraphic name of the oldest banded iron-formation in the Hamersley Group.
mg/L	Milligrams per litre (equivalent to parts per million).
Mineralisation	In the sense of economic geology, the introduction of valuable elements into a rock unit.
Palaeodrainage	Ancient surface water drainage system.
Permeability	The ability of rock or soil to transmit water.
Phanerozoic	Period containing all later rocks in which evidence of life is abundant.
PIEC	Pilbara Iron-ore Environmental Committee.
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.
Proterozoic	Period containing the youngest rocks of the pre-Phanerozoic era.
Recharge	The process of ‘topping up’ groundwater by infiltration from rainfall or rivers - synonymous with ‘renewable resource.
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.
Shale	Sedimentary rocks formed by the consolidation of mud or silt.
Stygofauna	Groundwater-dwelling fauna that are fully adapted to living in complete darkness in alluvial and calcrete aquifers.
TDS	Total dissolved solids.
Tertiary	Geological age representing time period from 66 – 18 million years ago.
Throughflow	The amount of water that passes through a given area.
Unconfined aquifer	Also known as watertable aquifer. An aquifer where the watertable is in direct connection with the atmosphere through the unsaturated zone.
Valleyfill	Variety of unconsolidated sediments deposited in a valley environment.
Watertable	The level to which water rises in a bore or well tapping an unconfined aquifer.

Appendices

1 Summary of borefields

Paraburdoo – GWL No. 67260

Aquifer type and location

The Paraburdoo borefield comprises the Mine, Dewatering and Town borefields, which are located approximately 55 km south of Tom Price (Figs. A1.1 to A1.2). Bores in the Paraburdoo mine borefield abstract groundwater from the alluvial sediments of the Seven Mile Creek and Paraburdoo Creek drainages, as well as from the underlying fractured basement rocks. The Dewatering borefield abstracts groundwater from the mineralized Joffre Member units of the Brockman Iron Formation (4 West orebody). The Town borefield (including the Airport bore) abstracts groundwater from the alluvial sediments in the Seven Mile Creek and Bellary Creek drainages and from the underlying fractured basement rocks.

Borefield purpose

The Paraburdoo mine borefield, commissioned in 1970, supplies water for the mining operations. The Dewatering borefield, commissioned in 1997, is designed to enable mining to continue below the watertable in the 4 West mining area and supplement process water. The Town borefield, commissioned in the early 1970s, supplies potable water for Paraburdoo town domestic use (including the airport).

Borefield description

The Paraburdoo mine borefield comprises six production bores of which four were operational during 1999. Bore depths range from 100 to 150 m bgl and are constructed of 250 mm ND FRP casing and stainless steel screens. Ten bores within the Mine borefield are currently monitored (Fig. A1.1).

The Dewatering borefield, located in the 4 West mining area, comprises two operational production bores and three production bores which are yet to be commissioned. The two operational production bores, constructed of 200 m and 250 m ND slotted and blank steel casing, have depths of 150 m and 166 m. Eleven observation bores of the Dewatering borefield combined with a further eight observation bores (four in Paraburdoo Creek and four at Ratty Springs) are used to monitor waterlevels (Fig. A1.1).

The Town borefield comprises twelve operating production bores constructed of 150 to 400 mm ND FRP or steel casing with stainless steel screens. Bore depths range from 50 to 250 m. Twenty-two observation bores are currently used to monitor waterlevels in the Town borefield (Fig. A1.2).

Bore yield and quality (based on 1999 monitoring data)

Bores in the Mine borefield pumped up to 2360 kL/day each with combined monthly volumes ranging from 34 715 to 134 259 kL. Water quality ranged from 830 to 1300 mg/L TDS. The Dewatering borefield bores pumped up to 2680 kL/day (individual bores) with total monthly borefield production ranging from 53 208 to 94 289 kL. Water quality ranged from 850 to 1200 mg/L TDS. The Town borefield bores pumped up to 2460 kL/day (individual bores), while total monthly borefield production ranged from 67 556 to 235 509 kL. Water quality ranged from 640 to 1350 mg/L TDS.

Water from all three borefields is of similar quality, with fresh to marginal groundwater reported as weakly alkaline (pH 7.3 to 7.7) and hard.

Allocation and usage

The Groundwater Well Licence for Paraburdoo, GWL 67260, includes groundwater abstraction from the Town borefield, Mine borefield and Dewatering borefield. A total draw of 6 500 000 kL/year is permitted from 22 bores. During 1999, a total of 3 560 939 kL of groundwater was abstracted from the three borefields representing 55% of the licensed allocation. A total of 1 742 109 kL (26%) was abstracted from the Town borefield, 994 518 kL (15%) from five bores in the Mine borefield and 824 312 kL (13%) from two bores in the Dewatering borefield.

Aquifer performance and status

Most of the Town borefield observation bores are located adjacent, or very close to production bores.

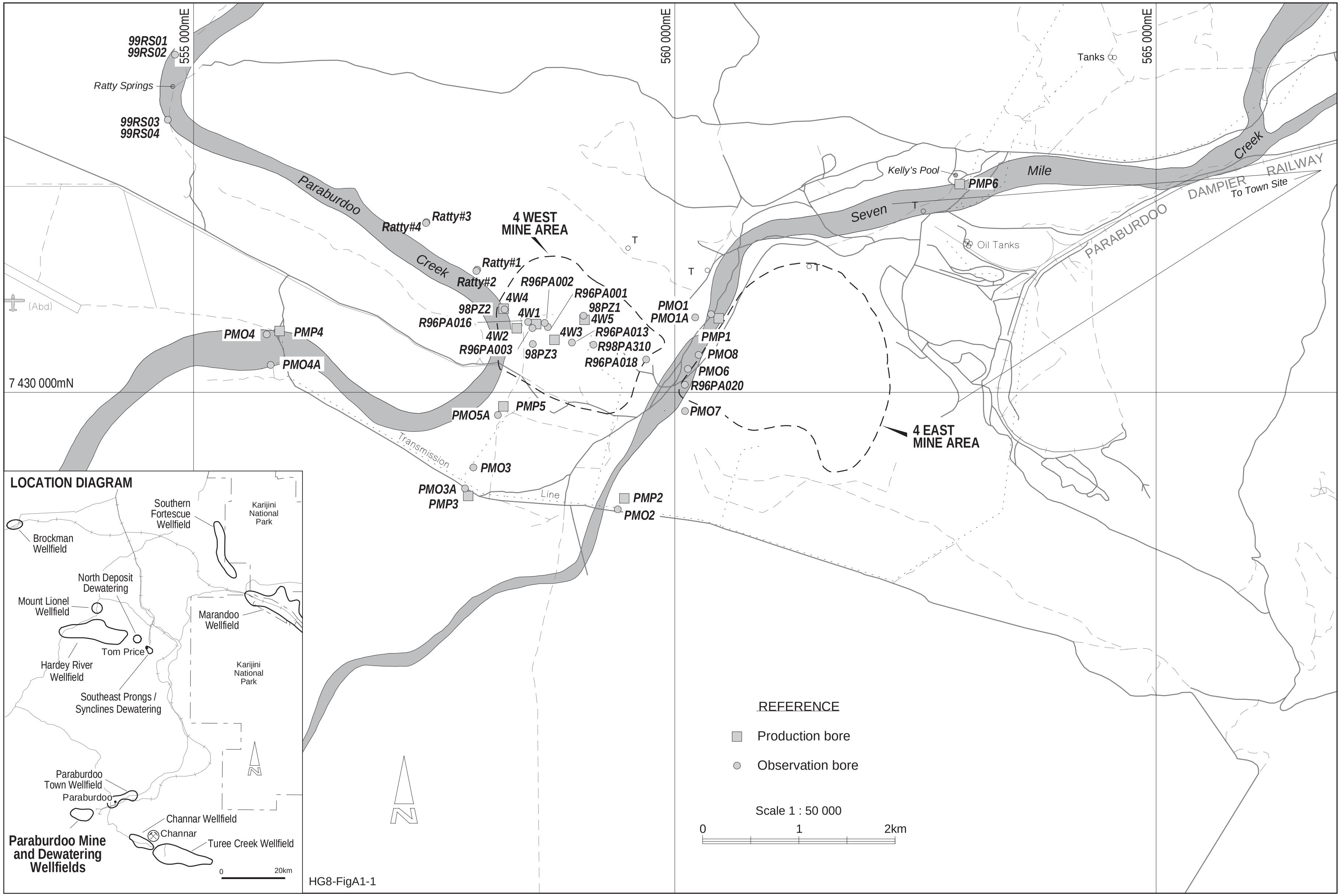


Figure A1.1 Paraburdoo mine borefield

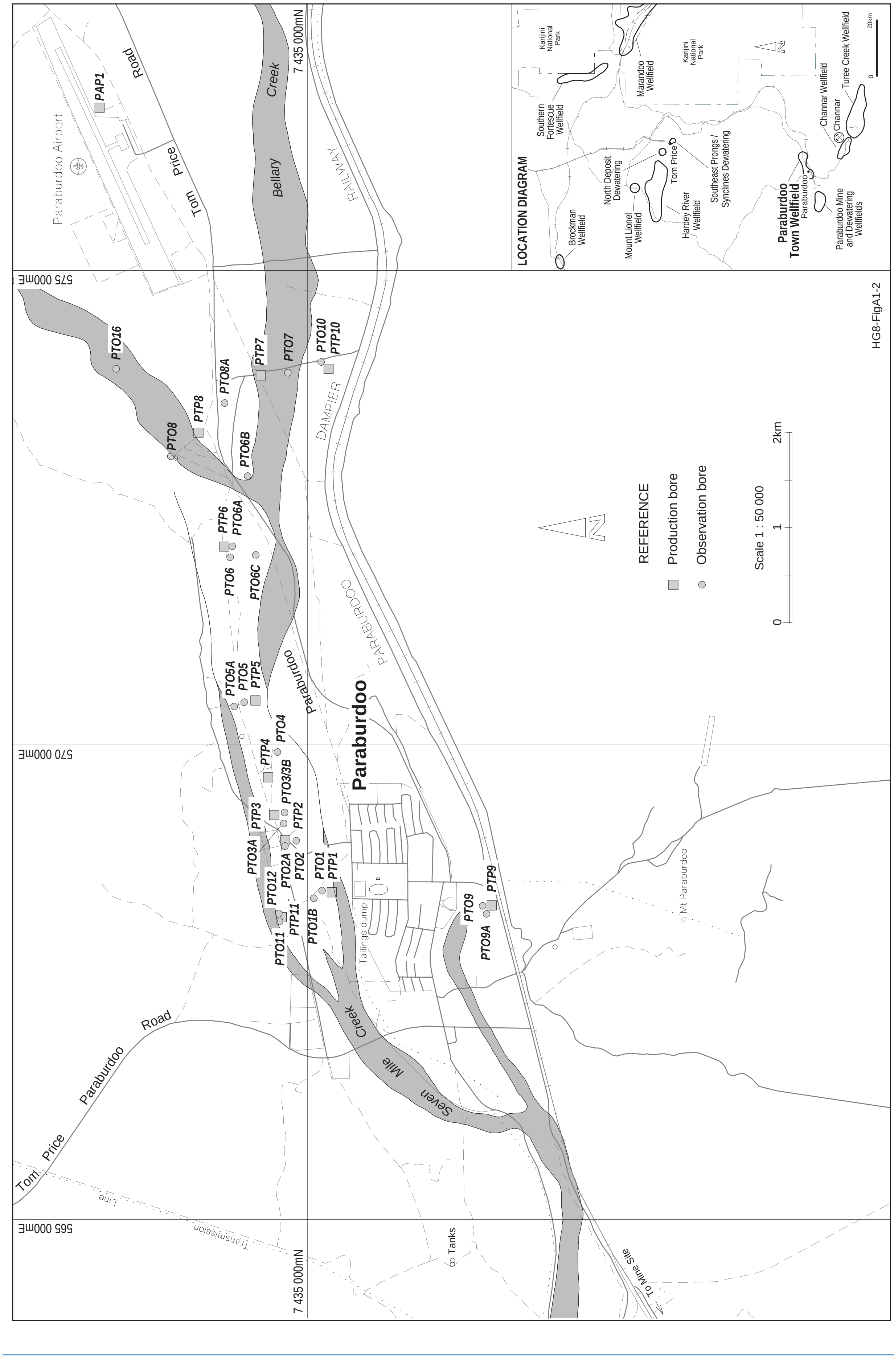


Figure A1.2 Paraburdoo town borefield

Observation bores more distant from pumping bores show the influence of recharge after significant rainfall. Owing to a balance of aquifer recharge and abstraction, there appears to have been no significant change in aquifer storage over the previous two years.

Some of the observation bores in the Mine borefield, adjacent to the production bores, are influenced both by variations in abstraction rates from the adjacent production bores and more regional aquifer effects (recharge and total borefield discharge). Waterlevels in bores located away from pumping bores show less fluctuation and are relatively stable.

During 1999, a reduction in overall pumping from the Dewatering borefield has produced 5 m of recovery in and around the 4 West pit area. Mining below the watertable at 4 West has been deferred and three extra production bores, installed in late 1998, are yet to be commissioned.

The aquifers supplying the Town and Paraburdoo Mine borefields continued to meet groundwater demand. Waterlevel data indicate no significant change in aquifer storage and both aquifers should continue to sustain the current abstraction rates.

Turee Creek – GWL No. 65718

Aquifer type and location

The borefield is located approximately 30 km southeast of Paraburdoo (Fig. A1.3). The aquifer comprises the alluvial sequences along the Turee Creek palaeovalley and the underlying fractured basement rocks associated with a series of northwest-trending shear zones.

Borefield purpose

The Turee Creek borefield, commissioned in 1996, supplies groundwater to the Paraburdoo fines processing plant.

Borefield description

The borefield currently comprises eight production bores of which six were operational in 1999 (Fig. A1.3). Bore depths range from 150 to 215 m bgl. The bores are constructed of 250mm ND FRP casing and stainless steel screens. Thirty-one observation bores are currently used to monitor waterlevels. The observation bores are multi-level bores, with up to three bore nests at each of 16 sites, each screened to a maximum depth of 90 m bgl.

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 1690 kL/day each with combined monthly volumes ranging between 108 172 and 250 533 kL. The groundwater is fresh, ranging from 400 to 1300 mg/L TDS, weakly alkaline (pH 7.4 to 7.6) and hard.

Allocation and usage

The Groundwater Well Licence for Turee Creek, GWL 65718, allows a total annual abstraction of 3 230 000 kL from eight bores. In 1999, the total abstraction was 2 032 110 kL from six bores, representing 63% of the licensed allocation.

Aquifer performance and status

During the three years of borefield operation, the waterlevels near Nanjilgardy Pool and elsewhere in the upper (shallow) aquifer have remained relatively constant. In the deeper parts of the aquifer, the waterlevels reflect variations in groundwater abstraction rates and also exhibit measurable drawdown due to overall borefield abstraction. The aquifer system should continue to sustain the current (and even higher) abstraction rates with little effect on the upper aquifer and associated pools.

Channar – GWL No. 65719

Aquifer type and location

The Channar Creek borefield is located approximately 20 km southeast of Paraburdoo (Fig. A1.4). The aquifer comprises thick valleyfill sediments in the Turee Creek drainage and underlying fractured basement. The aquifer system is essentially a westerly extension of the aquifer tapped by the Turee Creek borefield.

Borefield purpose

The borefield supplies potable and process water to the Channar mining operations.

Borefield description

The borefield comprises five operating production bores (Fig. A1.4). Bore depths range from 130 to 170 m bgl. Four bores are constructed of 250 mm ND FRP casing with inline stainless steel screens, and one bore is constructed of 100 mm ND PVC. Twelve observation bores are currently used to monitor waterlevels.

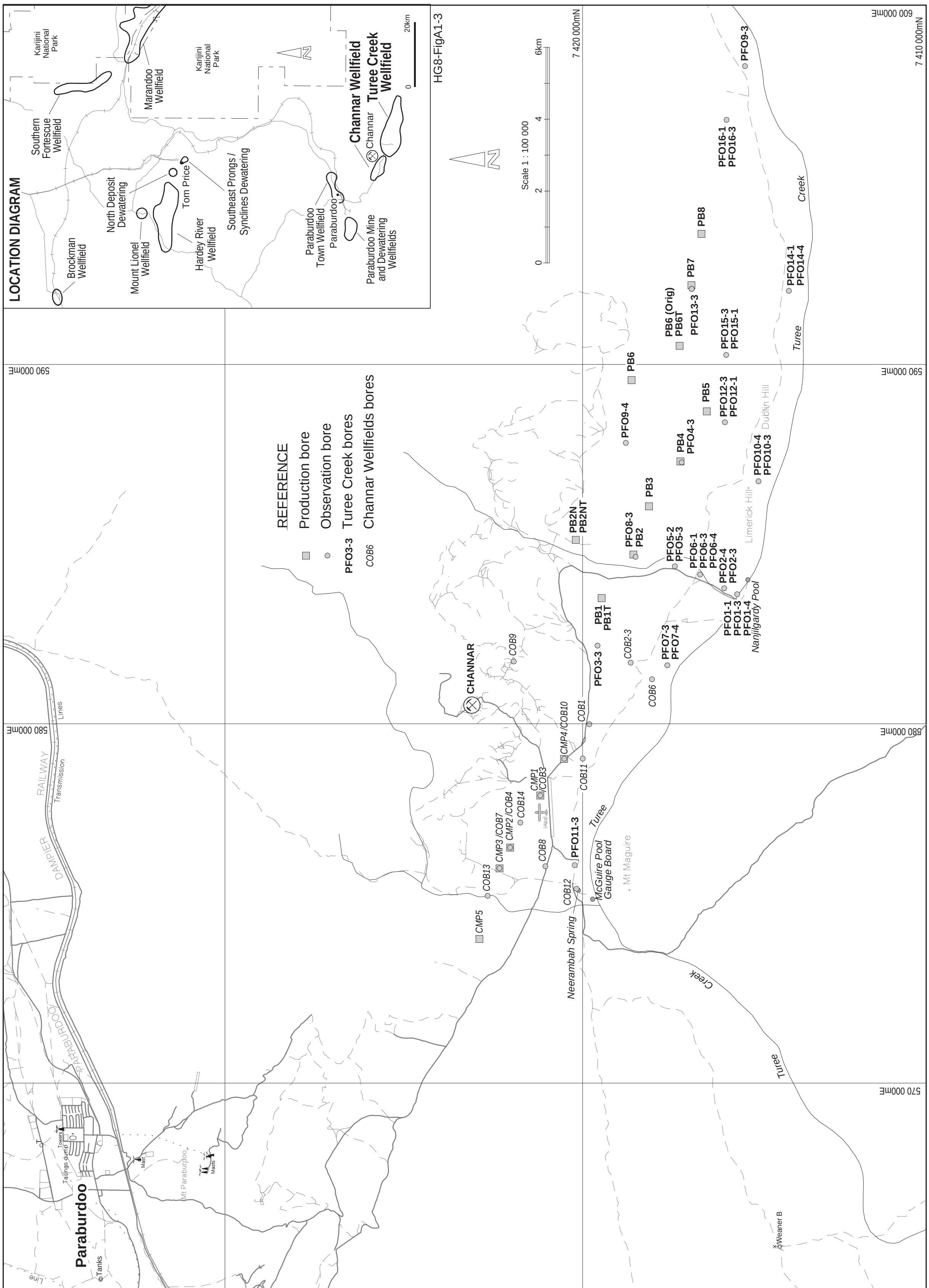


Figure A1.3 Turee Creek borefield

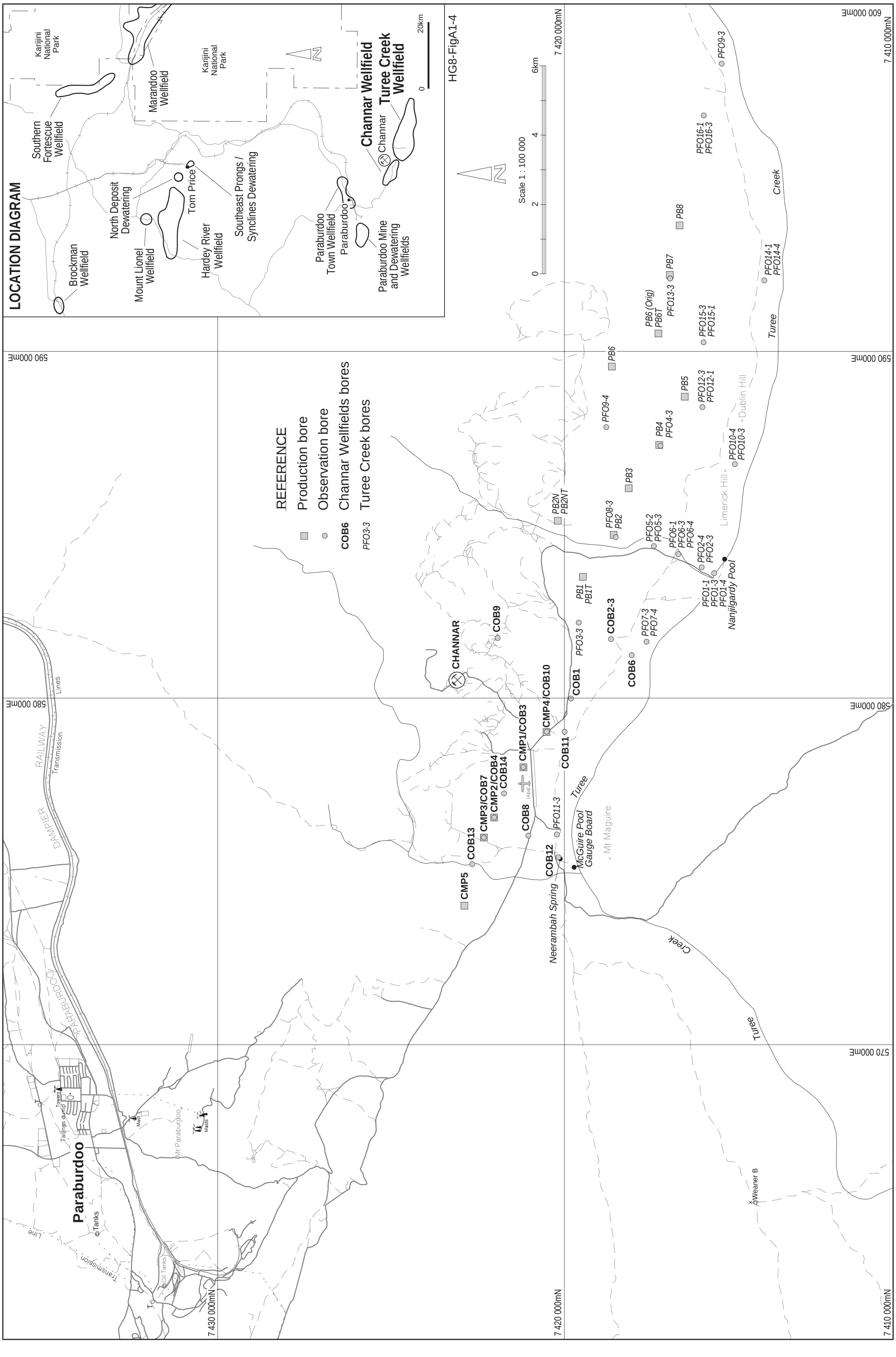


Figure A1.4 Channar borefield

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 1285 kL/day with combined monthly abstraction ranging between 26 441 and 78 651 kL. The groundwater is fresh, ranging from 280 to 1200 mg/L, weakly alkaline (pH 7.5 to 7.8) and hard.

Allocation and usage

The Groundwater Well Licence for Channar borefield, GWL 65718, allows a total annual abstraction of 1 000 000 kL from five bores. In 1999, the total abstraction was 639 029 kL, representing 64% of the licensed allocation.

Aquifer performance and status

Some of the waterlevels (1998 to 1999) show that observation bores, close to pumping bores, respond to variations in pumping rates. Waterlevels rise during periods of lower abstraction and decrease during periods of higher abstraction. Some observation bores reflect pumping in the adjacent Turee Creek borefield rather than the Channar borefield. Waterlevel data in 1999 indicate that groundwater storage in the aquifer system has remained relatively stable over the year. The aquifer system will continue to sustain current (and even higher) water demands.

Southern Fortescue (Tom Price) – GWL No. 65715

Aquifer type and location

The Southern Fortescue borefield is located approximately 30 km north east of Tom Price (Fig. A1.5). The borefield abstracts groundwater from alluvium and chemical sediments of a broad palaeovalley and the underlying weathered and vuggy Wittenoom Dolomite.

Borefield purpose

The borefield, commissioned in 1971–72, is one of five borefields that supplies potable and process water to the Tom Price mine site and town.

Borefield description

The borefield comprises ten production bores (Fig. A1.5). Bore depths range from 90 to 200 m bgl. Four bores are constructed of 150 mm ND steel casing with inline stainless steel screens, and five bores are completed with FRP casing and stainless steel screens. Thirteen observation bores are currently used to monitor waterlevels.

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 1920 kL/d (each) with combined monthly abstraction ranging between 223 921 and 272 787 kL. The groundwater is fresh, ranging from 490 to 740 mg/L TDS, weakly alkaline (pH 7.4 to 7.7) and hard.

Allocation and usage

The Groundwater Well Licence for Southern Fortescue borefield, GWL 65715, allows a total annual abstraction of 4 680 000 kL from 11 bores. In 1999, the total abstraction was 2 873 144 kL from ten bores, representing 61% of the licensed allocation.

Aquifer performance and status

The monitoring data for 1999 indicate a minor increase in aquifer storage. Aquifer recovery is most likely due to a decrease in pumping rates compared with those for 1998. The aquifer should continue to sustain current (and even higher) levels of abstraction.

Hardey River (Tom Price) – GWL No. 65716

Aquifer type and location

The Hardey River borefield is located approximately 10 km west of Tom Price (Fig. A1.6). The borefield abstracts groundwater from alluvium and chemical sediments of an elongated palaeovalley and from underlying fractured basement rocks.

Borefield purpose

The borefield is one of five supplying potable and process water to the Tom Price mine site and town. The borefield was established in 1966 as a sole water supply for the mine and town site. It was upgraded in 1978 with the establishment of the beneficiation plant at the mine. In the mid-1980s, many of the bores were replaced.

Borefield description

The borefield comprises ten production bores (Fig. A1.6). The bores are constructed of 200 mm ND and 250 mm ND FRP casing with inline stainless steel

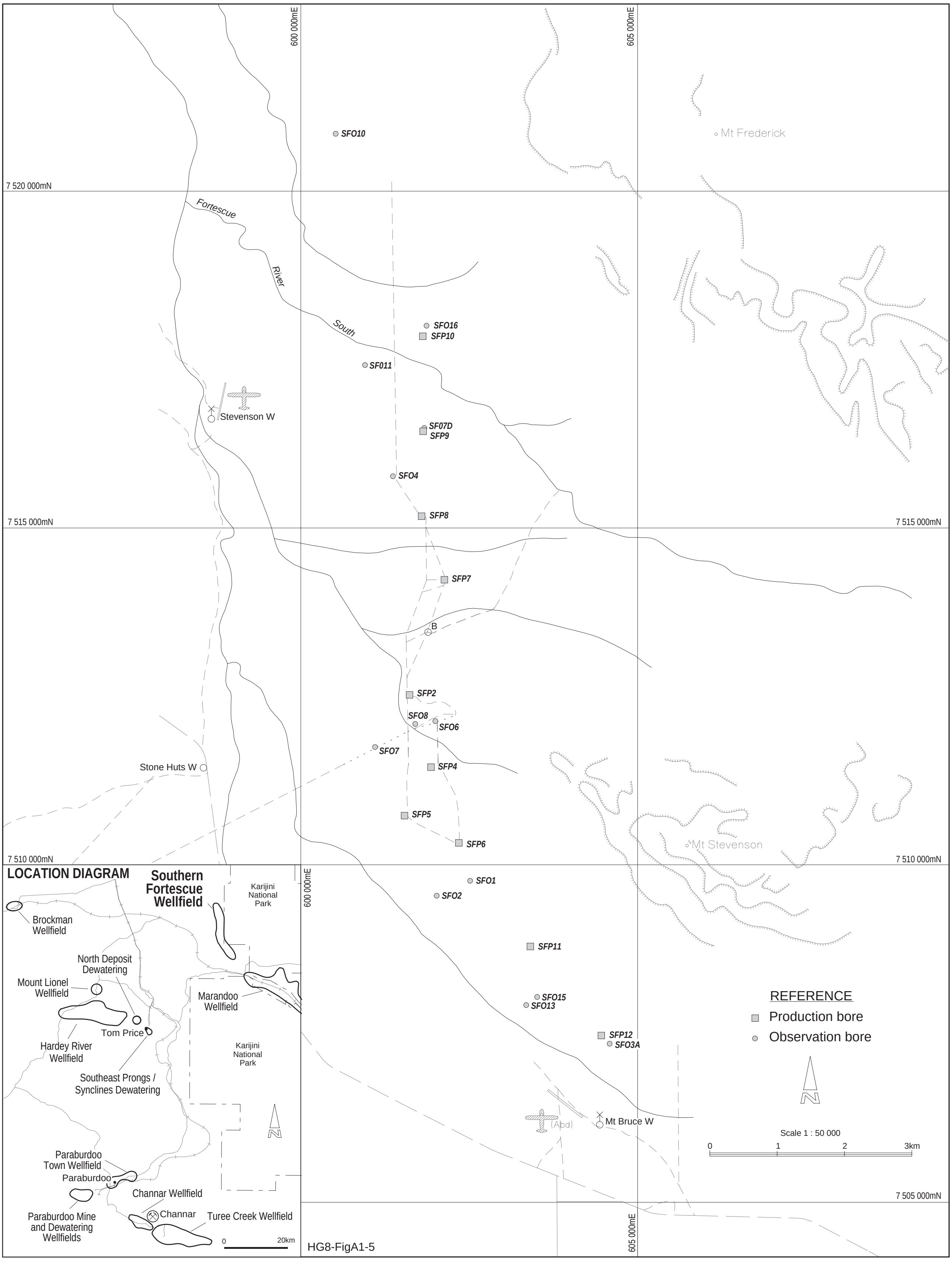


Figure A1.5 Southern Fortescue borefield (Tom Price)

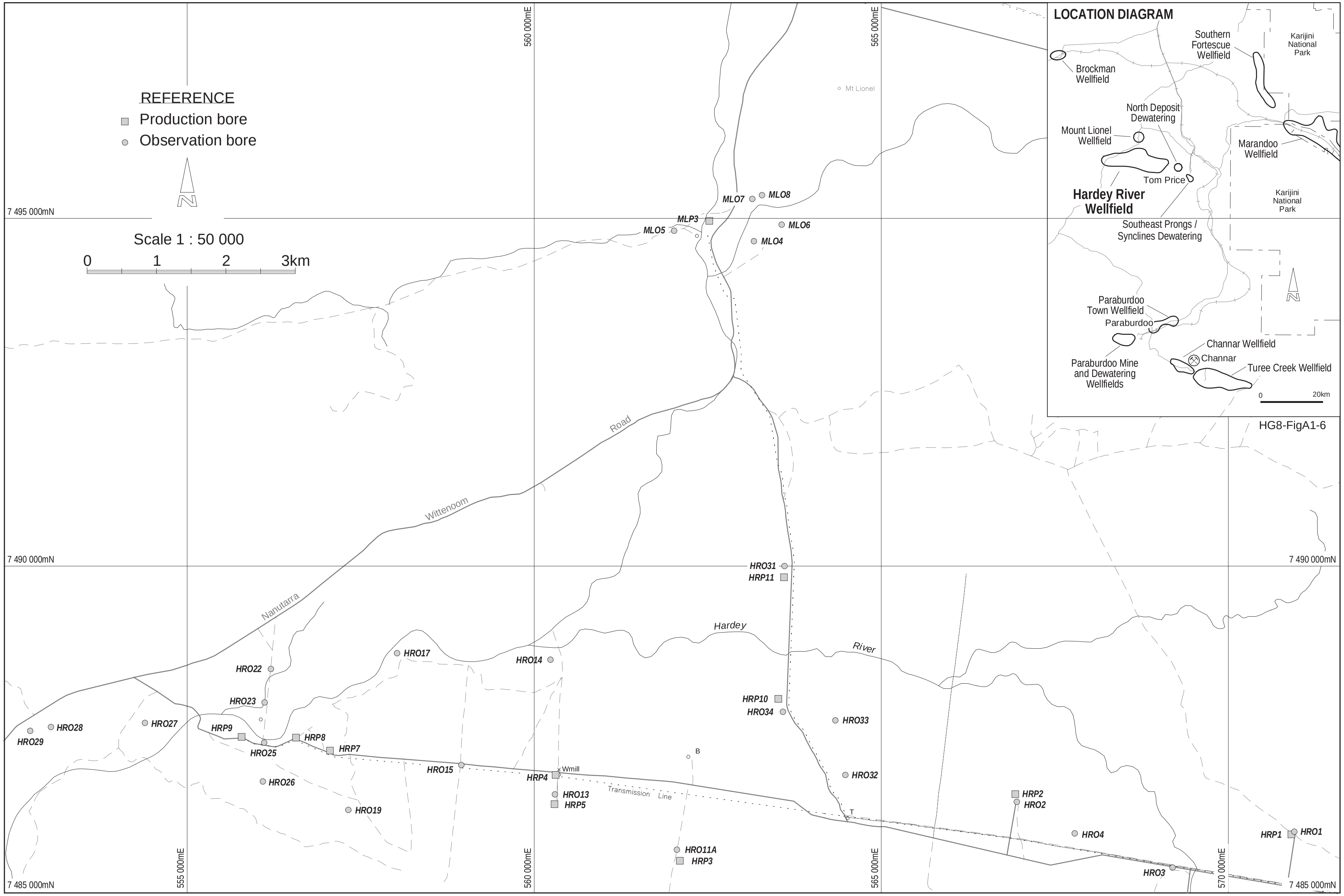


Figure A1.6 Hardey River and Mount Lionel borefields screens. Twenty-one observation bores are currently used to monitor waterlevels with screen depths ranging from 60 to 150 m bgl.

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 1070 kL/day, while combined monthly abstraction ranged between 50 792 and 58 132 kL. The groundwater is fresh, ranging from 260 to 680 mg/L, weakly alkaline (pH 7.4 to 7.7) and hard.

Allocation and usage

The Groundwater Well Licence for the Hardey River borefield, GWL 65716, allows a total annual abstraction of 2 240 000 kL from 11 bores. In 1999, the total abstraction was estimated at 1 000 000 kL from ten bores, representing 45% of the licensed allocation.

Aquifer performance and status

The monitoring data for 1999 show stable waterlevels indicating no significant change in aquifer storage. Some bores showed slight waterlevel recoveries due to reduced borefield pumping and to recharge. The aquifer should continue to sustain current (and even higher) levels of abstraction.

Mount Lionel (Tom Price) – GWL No. 65714

Aquifer type and location

The Mount Lionel borefield is located approximately 10 km west of Tom Price (Fig. A1.6). The aquifer comprises locally cavernous, steeply dipping Wittenoom Dolomite overlain by Tertiary calcrete and valleyfill sediments.

Borefield purpose

The borefield is one of five borefields supplying potable and process water to the Tom Price mine site and town. The borefield was installed between 1976 and 1978 to provide additional water to the Tom Price beneficiation plant.

Borefield description

The borefield currently comprises one production bore constructed of 250mm ND FRP casing with a stainless steel screen. Bore depth is 80 m bgl. Five observation bores are currently used to monitor waterlevels.

Bore yield and quality

The production bore in 1998 pumped up to around 2600 kL/day. In April 1999, the groundwater was fresh (1184 mg/L), weakly alkaline (pH 7.4) and hard.

Allocation and usage

The Groundwater Well Licence for the Mount Lionel borefield, GWL 65716, allows a total annual abstraction of 1 000 000 kL from one bore. In 1999, the total abstraction was estimated (due to a faulty flow meter and hours-run meter) at between 600 000 and 700 000 kL representing about 60 to 70% of the licensed allocation.

Aquifer performance and status

Since 1996, there has been a 2 m waterlevel decline, although it is currently stable. This may reflect a steady-state balance between pumping and aquifer waterlevel drawdown or possibly increased diffuse recharge from the relatively high rainfall wet seasons over the last two years. Observation-bore hydrographs show no response to increased rainfall, suggesting little direct aquifer recharge from surface runoff. The aquifer should continue to maintain current (and even higher) levels of abstraction.

North Deposit – GWL No. 65712

Aquifer type and location

The North Deposit Dewatering borefield is located approximately 4 km northwest of Tom Price (Fig. A1.7). The aquifer comprises mineralized and permeable units of the Dales Gorge Member of the Brockman Iron Formation.

Borefield purpose

Dewatering at the North Deposit abstracts groundwater to lower the watertable in advance of mining. The water is used for dust suppression and mine processing purposes.

Borefield description

The dewatering borefield comprises one production bore constructed of 250 mm ND steel casing and slotted over the entire 96 m depth. Three observation bores monitor waterlevels in the mine area and these are screened at depths of between 16 and 120 m bgl (Fig. A1.7).

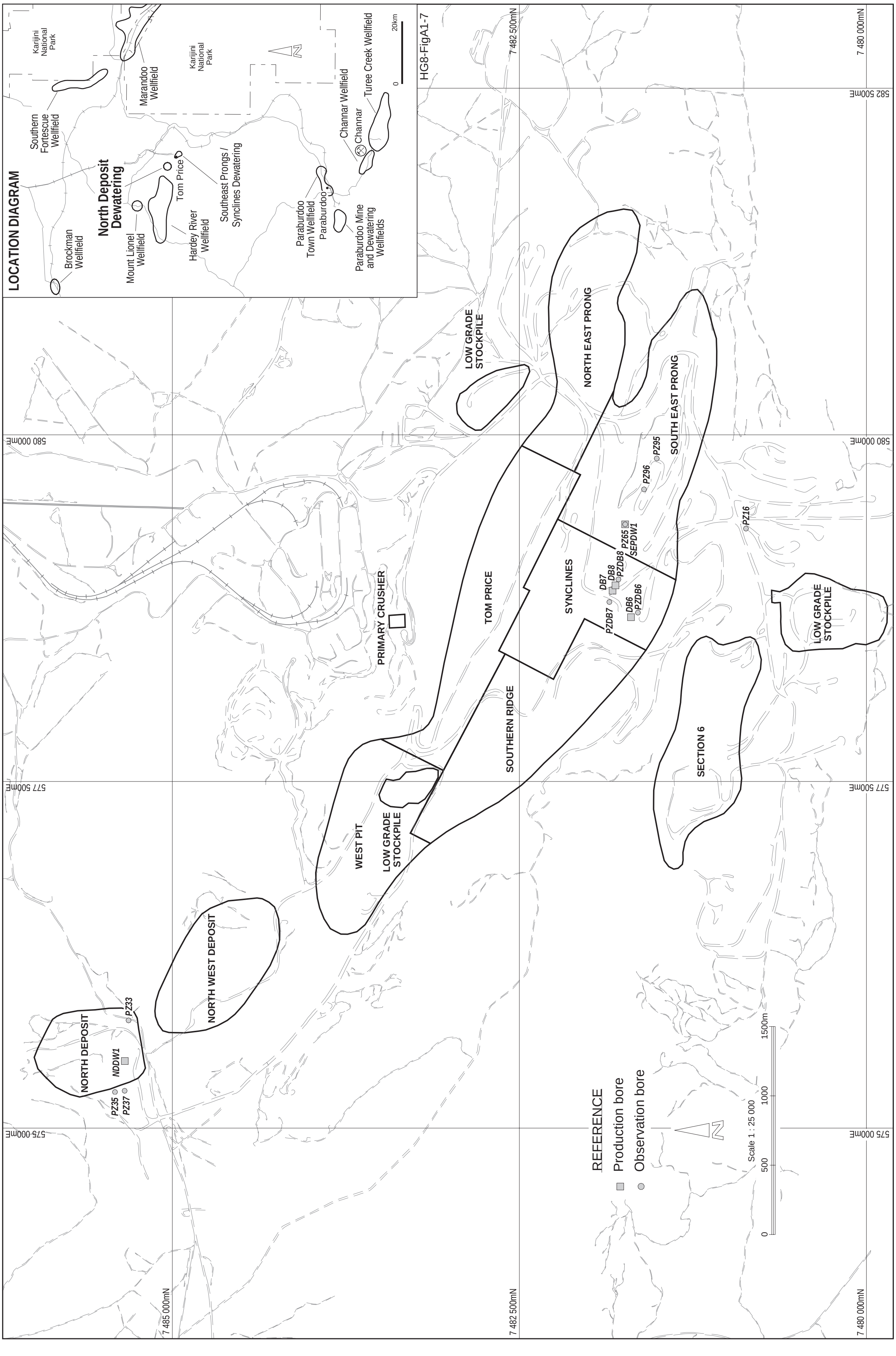


Figure A1.7 North Deposit and Southeast Prongs dewatering borefields

Bore yield and quality (based on 1999 monitoring data)

The production bore was pumped between 900 and 1900 kL/day with combined monthly abstraction ranging between 28 151 and 57 478 kL. The groundwater is brackish, ranging from 1440 to 1590 mg/L, weakly alkaline (pH 7.2) and hard.

Allocation and usage

The Groundwater Well Licence for North Deposit dewatering borefield, GWL 65712, allows a total annual abstraction of 1 000 000 kL from one bore. In 1999, total abstraction was 512 270 kL, representing 51% of the licensed allocation.

Aquifer Performance and Status

During 1999, waterlevels in the North Deposit area continued to decline in response to groundwater pumping. Assuming similar performance of the existing dewatering bore in the near future, a greater pumping rate will be required to draw waterlevels below the projected base of mining (maximum pit depth is expected to be reached in 2009).

Southeast Prongs – GWL No. 65713

Aquifer type and location

The Southeast Prongs (SEP) and Synclines dewatering borefields are located within the Tom Price mine area (Fig. A1.7). The SEP borefield intersects mineralised and permeable Dales Gorge Member units of the Brockman Iron Formation. In addition, the Synclines bores intersect pre-blasted areas of mineralised Dales Gorge Member.

Borefield purpose

The Southeast Prongs and Synclines dewatering bores are designed to lower the watertable to enable dry-floor mining to proceed. The water is used for mine processing.

Borefield description

The Southeast Prongs dewatering borefield comprises one bore, about 80 m deep, that is constructed of 238 mm ID ABS casing. Three observation bores, between 30 and 80 m deep, are used to measure waterlevels. The Synclines dewatering borefield consists of three bores, about 50 m deep, that are constructed of 219 mm ID steel casing. Waterlevels are measured in three piezometers.

Bore yield and quality (based on 1999 monitoring data)

The Synclines dewatering bores pumped up to 1570 kL/day with combined monthly abstraction up to 52 761 kL. There were no pumping and water quality data from the Southeast Prongs bore in 1999. In April 1998, the groundwater was fresh (429 mg/L TDS) and acidic (pH 5.88).

Allocation and usage

The Groundwater Well Licence for Southeast Prongs and Synclines dewatering, GWL 65713, allows a total annual abstraction of 1 000 000 kL from one bore. In 1999, total abstraction was 146 460 kL, representing 15% of the licensed allocation.

Aquifer performance and status

Waterlevels within the Southeast prongs pit area have recovered about 20 m, since the cessation of dewatering in 1998. The waterlevels will decline on the resumption of dewatering. Mining is almost complete at the Synclines Pit and dewatering pumping has now ceased.

Marandoo – GWL No. 65711

Aquifer type and location

The Marandoo borefield is located approximately 40 km northeast of Tom Price (Fig. A1.8). Groundwater is abstracted from calcrete and underlying fractured and weathered Wittenoom Dolomite. The bores were installed in the early 1990s, with the borefield having been commissioned in 1994.

Borefield purpose

The Marandoo borefield supplies potable and process water to the Marandoo mining operations.

Borefield description

The Marandoo borefield comprises five operating production bores (Fig. A1.8). The bores are constructed of 200 mm ND ABS casing (PB3 is constructed of PVC) with screen depths ranging from 50 to 100 m bgl. Twenty-six observation bores at twenty sites are currently used to monitor waterlevels in the mining area.

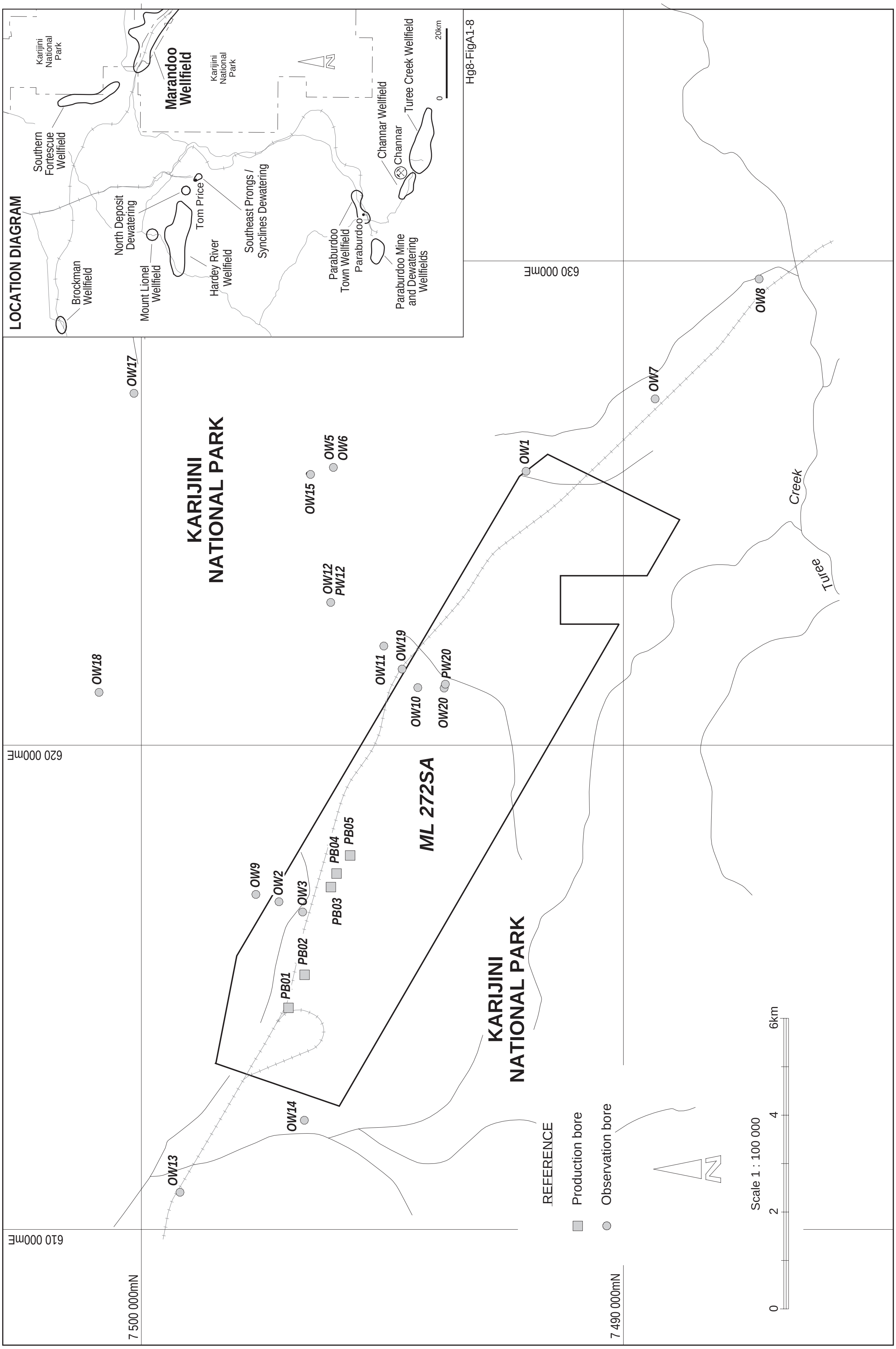


Figure A1.8 Marandoo borefield

Bore yield and quality (based on 1999 monitoring data)

The bores pumped up to 860 kL/day with combined monthly abstraction ranging between 32 921 kL and 67 361 kL. Groundwater from the Marandoo borefield is fresh, ranging between 500 and 550 mg/L, weakly alkaline (pH 7.3 to 7.5) and hard.

Allocation and usage

The Groundwater Well Licence for the Marandoo borefield, GWL 65711, allows an annual abstraction of 2 000 000 kL from seven bores. In 1999, total abstraction was 554 543 kL, representing 28% of the licensed allocation.

Aquifer performance and status

During 1999, waterlevels showed a slight increase of about 0.1 to 0.5 m. The waterlevels reflect the decrease in production volumes (7% decrease since 1998) and rainfall recharge. The aquifer should continue to sustain current (and even higher) production rates.

Brockman – GWL No. 65717

Aquifer type and location

The Brockman borefield is located approximately 55 km north west of Tom Price (Fig. A1.9). Mine processing water is sourced from alluvium, calcrete and underlying weathered Wittenoom Formation. Potable water is sourced from weathered and fractured Marra Mamba Iron Formation.

Borefield purpose

The Brockman borefield supplies process water to the Brockman mining operations and potable water to the Brockman mining camp.

Borefield description

The Brockman borefield comprises five production bores (Fig. A1.9). The three mining supply bores are constructed of 200 mm ND casing, and the two camp supply bores are constructed of 150 mm ND casing. The production bores range up to 90 m in depth. Six observation bores currently monitor waterlevels.

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 420 kL/day with combined monthly abstraction ranging between 6041 and 25 068 kL. The groundwater in the Brockman borefield is fresh, ranging from 470 to 840 mg/L, and weakly alkaline (pH 7.2 to 8).

Allocation and Usage

The Groundwater Well Licence for the Marrandoo borefield, GWL 65717, allows an annual abstraction of 600 000 kL from five bores. During 1999, total abstraction was 202 439 kL, representing 34% of the licensed allocation.

Aquifer Performance and Status

Observation bore waterlevels indicate no long-term decline in aquifer storage. Rising waterlevels in observation bores, located further away from the Mine borefield, suggest that aquifers are recovering due to the reduction in groundwater abstraction. The aquifer should continue to sustain current (or even higher) rates of abstraction.

Yandicoogina (HI) – GWL No. 63158

Aquifer type and location

The Yandicoogina borefield is located approximately 90 km northwest of Newman (Fig. A1.10). The borefield, commissioned in 1998, abstracts groundwater from the CID aquifer (the mined orebody).

Borefield purpose

The Yandicoogina borefield is designed to lower the watertable ahead of mining. Most of the water is discharged to the adjacent creek, with a small amount used for mine process water.

Borefield description

The initial Yandicoogina borefield comprised ten production bores screened against the lower section of the CID orebody (Fig. A1.10). Four permanent dewatering bores were located down-gradient of the mine and six sacrificial bores were located up-gradient of the mine. The six initial sacrificial bores have now been removed.

The bores are constructed of 300 mm ND blank and slotted steel casing. The slotted intervals range from 45 to 70 m bgl. Eight observation bores, five upstream (sacrificial bore line) and three downstream (permanent bore line) of the mining operation, were monitored for waterlevels in the mining area in 1999 and early 2000.

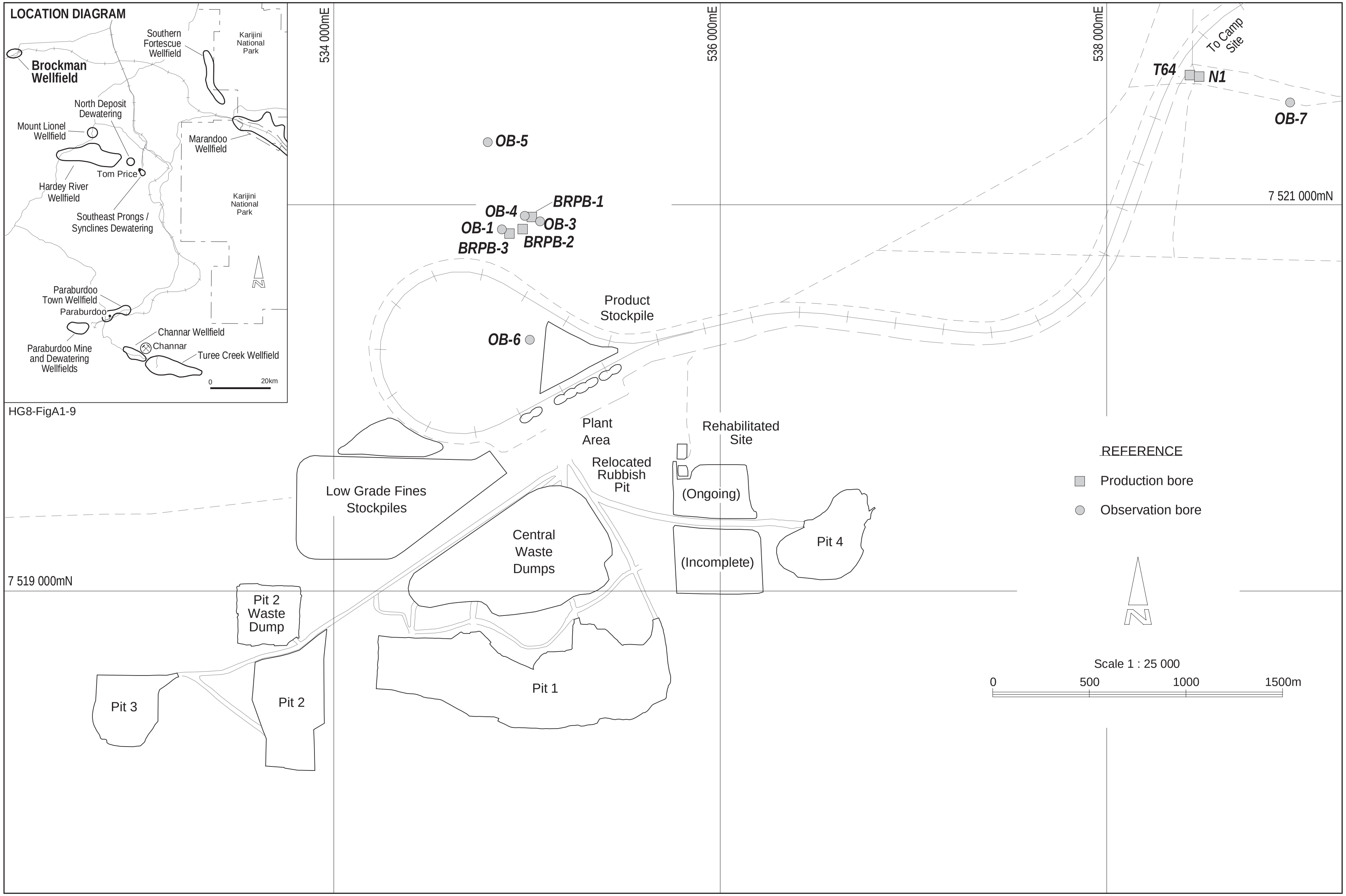


Figure A1.9 Brockman borefield

In addition, there are four production bores in the Yandicoogina mine area – two Batch Plant bores (YPP07 and YPP08) and two Rail Loop bores (YPP32 and YPP33). These bores are screened in the CID aquifer but, due to low abstraction volumes, there is no requirement for them to be licensed by the GWL that covers the other bores at the site (by agreement with the WRC).

Bore yield and quality (based on 1999 monitoring data)

The production bores pumped up to 3800 kL/day with combined monthly abstraction ranging between 304 323 and 634 155 kL; however, there was little or no production from SP05, SP06 and PP01. The groundwater is fresh, ranging from 390 to 490 mg/L TDS, and alkaline (pH 8.1 to 8.4).

Allocation and usage

The Groundwater Well Licence for the Yandicoogina borefield, GWL 63158, allows an annual abstraction of 10 000 000 kL from 11 bores. In 1999, a total abstraction of 5 095 490 kL was abstracted, representing 51% of the licensed allocation.

Aquifer performance and status

During 1999, waterlevels were stable, indicating that the aquifer is near steady-state. The initial drawdown from pre-mining waterlevels occurred in early 1998. A rise in waterlevels during the latter part of 1999 related to aquifer recharge following substantial rainfall and subsequent stream flow. The establishment of a new sacrificial line of bores further upstream suggests that pumping rates will increase for a few months, while waterlevels are drawn down to below mining levels, but stabilise once waterlevels again reach a steady-state balance.

Marillana Creek – GWL No. 89501

Aquifer type and location

The Marillana Creek borefield at BHPIO Yandicoogina operations is located approximately 90 km northwest of Newman. The bores abstract groundwater from the CID aquifer, which is also the mined orebody (Fig. A1.10).

Borefield purpose

Bores and sumps located near and in the two operational BHPIO pits, C1 and E2, abstract groundwater from the CID aquifer for dewatering purposes. Most of the water (approximately 97%) is discharged to the adjacent creek, with the remainder used for dust suppression and ore handling. The potable borefield also draws water from the CID aquifer to supply potable water for the mine and mining camp.

Borefield description

Dewatering at E2 commenced in May 1991 with a line of permanent dewatering bores installed at the downstream end of the E2 pit. A line of sacrificial bores was installed farther upstream with the purpose of being progressively relocated. A second set of sacrificial bores was installed in 1995, followed by a third set in September 1999, located immediately upstream of the final pit outline (Fig. A1.10). As dewatering continued to below final mining depth, a series of sumps was developed in the pit floor to dewater the less permeable material at the base of the CID aquifer.

There are currently six production bores (three permanent and three sacrificial, including the sacrificial bores installed in September 1999) and four sumps in and around the E2 pit. In and around C1, there are seven production bores (six permanent and one sacrificial) and one sump. Two bores, located on Mesa W4, supply potable water for the mining camp (Figure 13.1).

The permanent and sacrificial bores are constructed of 300 mm ND blank and slotted ABS casing with in-line screens. The slotted and screened intervals range from 20 to 85 m bgl.

Dewatering at C1 commenced in 1996 with a similar arrangement of permanent and sacrificial bores, except that the permanent bores (PP201 to PP206) were sited upstream of the C1 pit and the sacrificial bores (SP201 to SP206) downstream of the pit. By the end of 1999, only five permanent and one sacrificial bore remained in service. Owing to the rise in waterlevels following the wet season, additional sumps were required to draw waterlevels down below the base of mining (Fig. A1.10).

Twenty-nine observation bores currently monitor waterlevels in the mining area. The vast majority of the observation bores are uncased, open holes within the CID.

Figure A1.10 Marillana Creek (BHP) borefield

Bore yield and quality (based on 1999 monitoring data)

The sacrificial and permanent dewatering bores pump up to 4100 kL/day, while the potable supply bores pump a combined abstraction of about 650 kL/day. The water quality ranges from 350 to 750 mg/L TDS.

Allocation and usage

The Groundwater Well Licence for the BHPIO Yandi Wellfield, GWL 89501, allows an annual abstraction of 14 500 000 kL from 24 bores. Between July 1998 to June 1999, total abstraction was 6 981 000 kL from bores and sumps (97% for dewatering purposes and 3% for potable supply), representing 48% of the licensed allocation.

Aquifer performance and status

In the mining areas of C1 and E2, dewatering has lowered the waterlevels close to the bottom of the Channel Iron Deposit aquifer. Waterlevels are relatively stable in both pits, except after high rainfall causing streamflow to recharge the aquifer and increase waterlevels.

The direction of flow in the CID aquifer has been reversed (toward the mining operations) for a distance of about 5 km downstream of the E2 mine. Owing to the effect of discharging water to the creek in this area, aquifer waterlevels beyond this point, are around 2 m higher than levels measured prior to the commencement of dewatering at E2 in 1991. The cone of depression is reported to extend up to 10 km up-gradient of the mining operations.

Jimblebar – GWL No. 94546

Aquifer type and location

The Jimblebar borefield is located approximately 50 km east of Newman. The borefield abstracts groundwater from the weathered Wittenoom Formation, Marra Mamba and Jeerinah Formations (Fig. A1.11).

Borefield purpose

The Jimblebar borefield abstracts water for dust suppression, ore handling and potable water supply for the mine and mining camp.

Borefield description

The Jimblebar borefield comprises five production bores. The bores are constructed of 150 – 200 mm ND PVC blank and slotted casing (Fig. A1.11). There is no information available regarding bore depths and screened intervals. Five observation bores, with depths ranging from 77 to 93 m bgl, are used to monitor the waterlevels.

Bore yield and quality (based on 1999 monitoring data)

The production bores pump up to 500 kL/day. The water quality ranges from 680 to 1215 mg/L TDS.

Allocation and usage

The Groundwater Well Licence for the Jimblebar borefield, GWL 94546, allows an annual abstraction of 340 000 kL from five bores. In 1999, total abstraction was 232 737 kL, representing 68% of the licensed allocation.

Aquifer performance and status

The waterlevels in the observation bores have been relatively stable over the last few years, with a subdued response to rainfall recharge. No long-term declining trends are apparent, suggesting that pumping and drawdown are in steady-state and that the current level of abstraction is sustainable.

Mount Whaleback – GWL No. 65148

Aquifer type and location

The Mount Whaleback dewatering borefield is located approximately 5 km west of Newman within the Whaleback mine area (Fig. A1.12). The borefield abstracts groundwater from mineralised Dales Gorge and Joffre units (orebodies) in the Brockman Iron Formation. The GWL also includes one bore (V18) located in a palaeovalley/ basement aquifer outside the mine area (Fig. A1.12).

Borefield purpose

The Mount Whaleback dewatering borefield aims to dewater the orebody aquifer, in order for mining to proceed below the watertable. The abstracted water is used for dust suppression and ore processing. Water abstracted from V18 has been used to supplement the potable water supply scheme. Previously, V18 was used for raw process water supply.

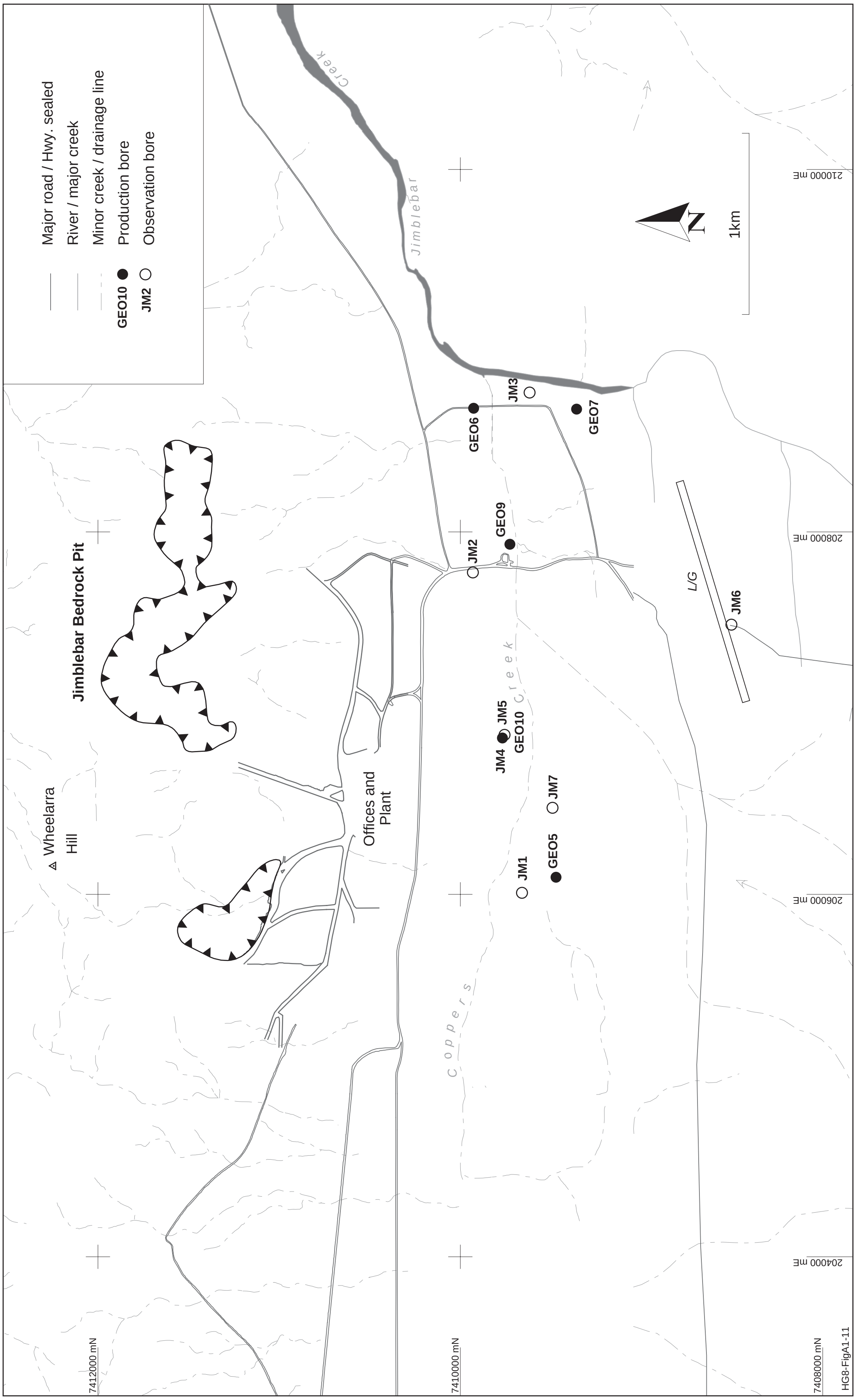


Figure A1.11 Jimblebar borefield

Borefield description

The Mount Whaleback dewatering borefields comprises fourteen production bores and one V line bore. There are sixty-two monitoring bores in the Whaleback mining area that monitor waterlevels (Fig. A1.12).

Bore yield and quality (based on 1999 monitoring data)

The Whaleback dewatering bores pump up to around 3000 kL/day with combined monthly abstraction ranging from around 9000 to 11 000 kL. The dewatering borefield quality ranges from 460 to 2800 mg/L TDS. The pH ranges from 6.5 to 8.2 (neutral) with some small volumes of low pH (around 4 to 5.5). The V line bore abstracts fresh groundwater (660 to 800 mg/L) with a neutral pH.

Allocation and usage

The Groundwater Well Licence covers the Whaleback dewatering and the V Line bores, GWL 65148, and allows an annual abstraction of 6 000 000 kL. In the twelve months to June 2000, total abstraction was 3 979 000 kL from the Whaleback dewatering bores and 207 000 kL from the one V line bore (V18). The total abstraction of 4 186 000 kL represents 70% of the licensed allocation.

Aquifer performance and status

Since dewatering commenced in 1984, waterlevels in the mine area have declined by 140 m. However, regional waterlevels (outside the mine area) are at an historical high, responding to recharge from the 1999/2000 wet season. This implies little to no influence of dewatering outside the pit. Waterlevels in the mine area will continue to be drawn down while mining and dewatering pumping continue.

Ophthalmia – GWL No. 65219

Aquifer type and location

The Ophthalmia Dam borefield is located approximately 10 km east of Newman (Fig. A1.13). The borefield, commissioned in the early 1970s, abstracts groundwater from alluvial and chemical sediments which have infilled the paleovalleys associated with the Fortescue River and its tributaries. Three bores also draw water from the Wittenoom Formation, the upper portion of which is in hydraulic connection with the overlying sedimentary units. Ophthalmia Dam was constructed in 1981 to artificially recharge the aquifer when pumping was exceeding, and expected to continue to exceed, the sustainable yield of the aquifer.

Borefield purpose

The Ophthalmia Dam borefield supplies potable and raw process water to the town of Newman, the Mount Whaleback mining operations, and Orebody 25.

Borefield description

The Ophthalmia Dam borefield comprises fourteen production bores. There are 137 observation bores, with 95 monitored monthly and 42 monitored quarterly.

Bore yield and quality

The Ophthalmia Dam bores currently pump 300 to 2300 kL/day. The water quality ranges from 700 to 2200 mg/L TDS.

Allocation and usage

The Groundwater Well Licence that covers the Ophthalmia Dam, GWL 65219, allows annual abstraction of 10 000 000 kL. In the twelve months to June 2000, total abstraction was 2 948 000 kL, representing 29% of the licensed allocation.

Aquifer performance and status

With the onset of pit dewatering at Whaleback in the mid to late 1980s, the demand for pumping from Ophthalmia declined. The recharge scheme has not been actively operated for some years, although regular dam spillway overflow results in enhanced recharge. Waterlevels fluctuate in response to seasonal recharge cycles but overall there has been little to no change in aquifer storage in recent years.

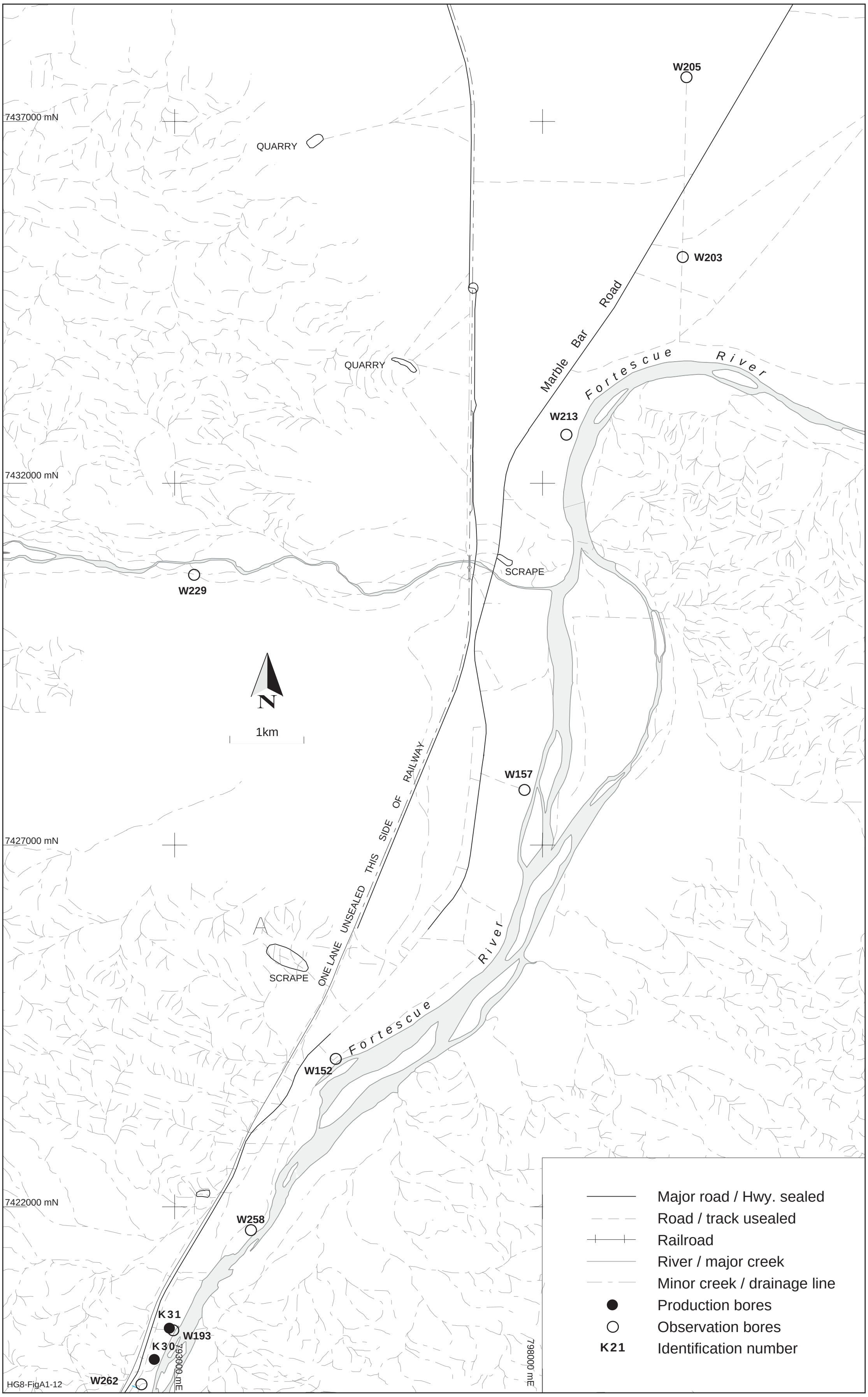


Figure A1.12 Mount Whaleback borefield

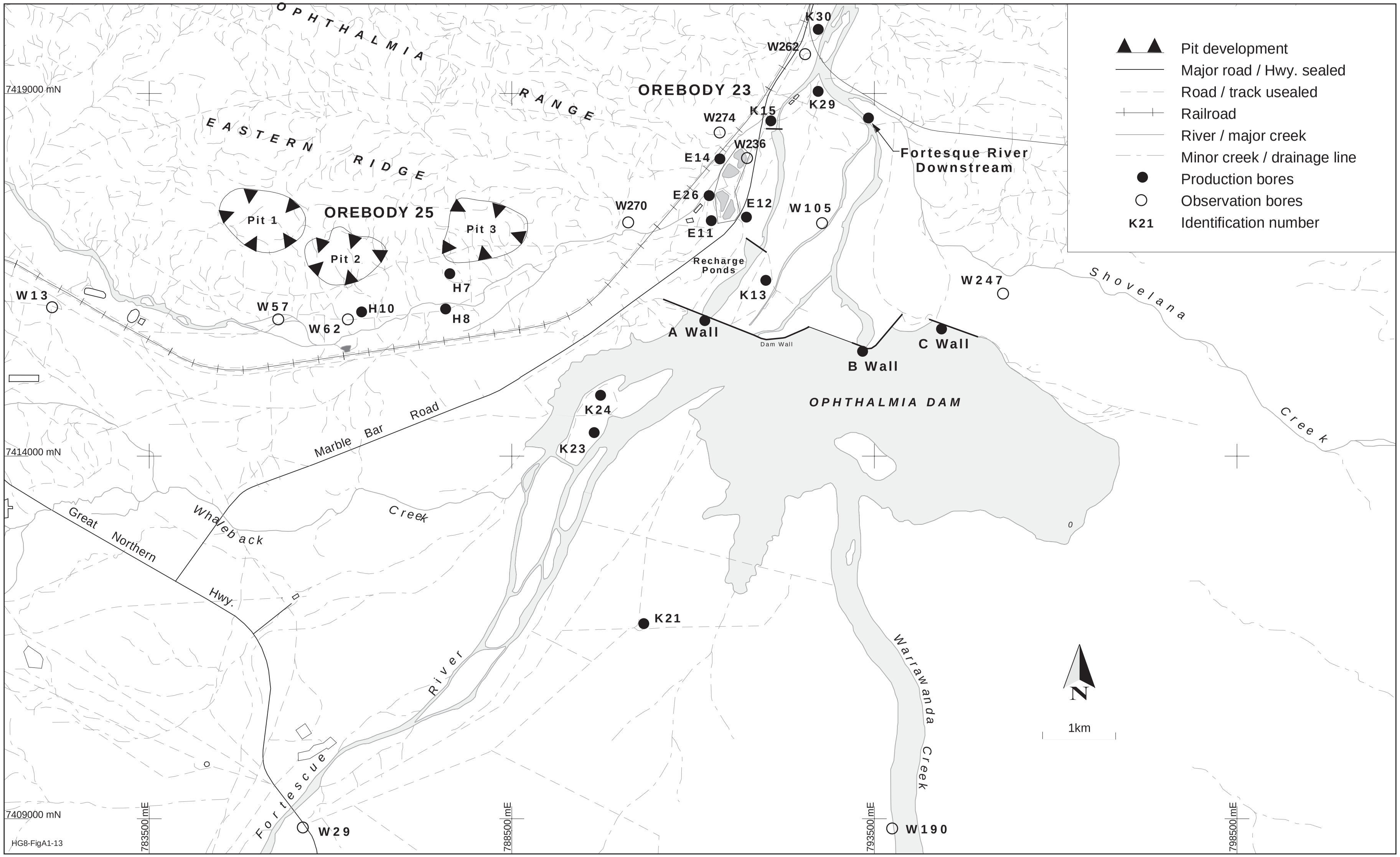


Figure A1.13 Ophthalmia borefield

2 Mine void case studies

Mount Goldsworthy Mine

Introduction

Most of the data and information used in this case study on the abandoned Mount Goldsworthy operation are from a technical paper titled 'The evolution of the water body in the final void of the Mount Goldsworthy Mine' (Waterhouse and Davidge, 1999).

The Mount Goldsworthy mine was the first major iron ore mine in the Pilbara. It operated for 20 years prior to closing in 1982. The abandoned town of Goldsworthy once had a population of 1000 people. The mine is located within the Ellarine Range that divides the alluvial plains extending south to the De Grey River and north to the Indian Ocean (Fig. A2.1). The De Grey is a major seasonal drainage system with important alluvial aquifers that supply potable water to Port Hedland. The smaller Pardoo Creek, which flows to the west of the mine and across the northern plain, has no interconnected aquifers. The old Goldsworthy borefield was hydraulically linked with the De Grey system.

The area falls within the semi-desert (tropical) meteorological climatic zone, which experiences high evaporation (3000 mm/yr) relative to rainfall (150 mm/yr). Rainfall is concentrated in the summer months from January to March and derived from isolated storms or large cyclonic disturbances.

Opencut mining resulted in a final void with dimensions 1200 x 500 x 200 m (depth). The mine void extended 177 m below the pre-mining watertable. On closure the void was allowed to slowly fill with water. Water levels have recovered by almost 60% (Fig. A2.1).

The entire mine area was rehabilitated by BHP and there is little evidence of the town site, mine infrastructure and borefield. The waste dumps have been reshaped, ripped and seeded. The pit was surrounded by a safety bund and fenced off to ensure that the public and livestock do not have access to the final void.

Hydrogeology

The mine is located in an elongate range of Archaean rocks including shale, volcanic rocks and banded iron-formations. The rocks have been subjected to tectonic deformation, which resulted in extensive fracturing and faulting. The orebody was a vuggy hematite that was more permeable than the host rocks. Pyritic shale was entirely removed during mining. The Archaean basement was considered an unprospective aquifer owing to the presence of 'dissolved toxic and aggressive salts' in the water. The direction of groundwater flow largely reflects the predominant fault direction. Saline groundwater occurs within shallow alluvial aquifers along the Pardoo Creek and on the northwestern plain.

The Mine water supply borefield was located 6 km south of the mine between Pardoo Creek and the De Grey River. The bores were located in the shallow alluvial aquifer of the De Grey River that is seasonally recharged from surface flows.

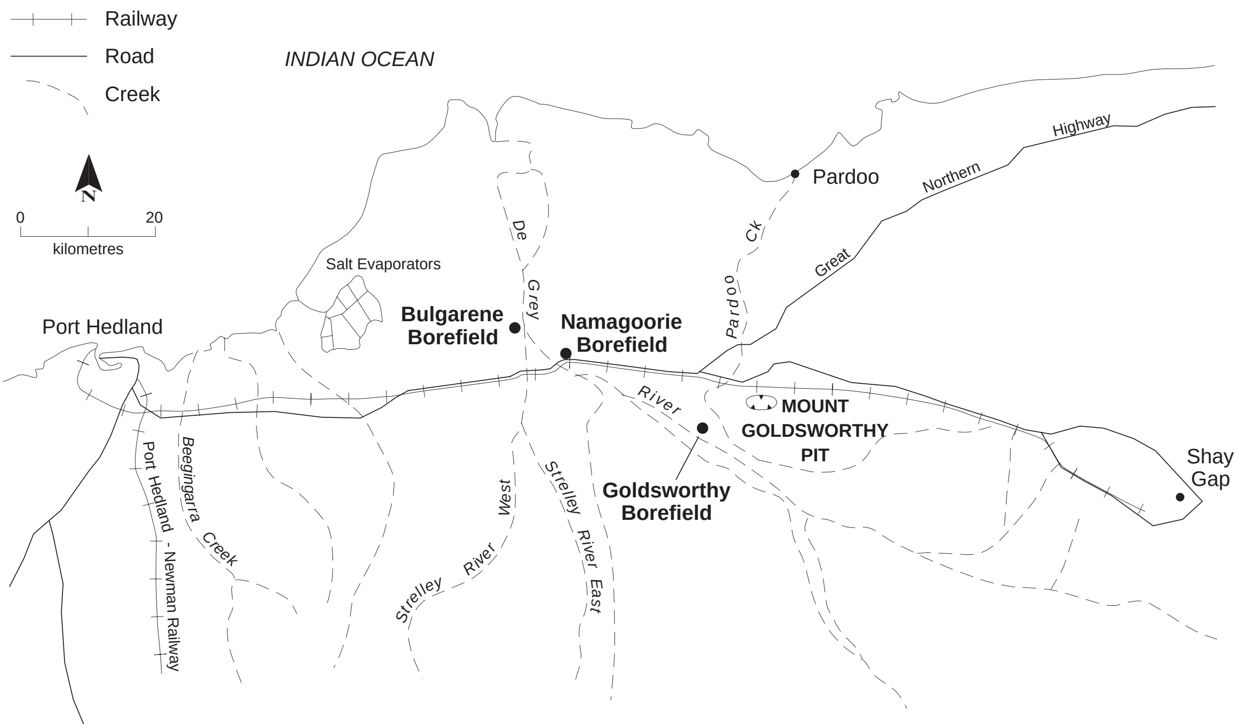
Few historic hydrogeological data are available for the mine area as mining pre-dated the current environmental reporting requirements for Western Australia. BHP has, however, recently initiated monitoring to comply with their corporate environmental responsibility.

Potential impact of mining void

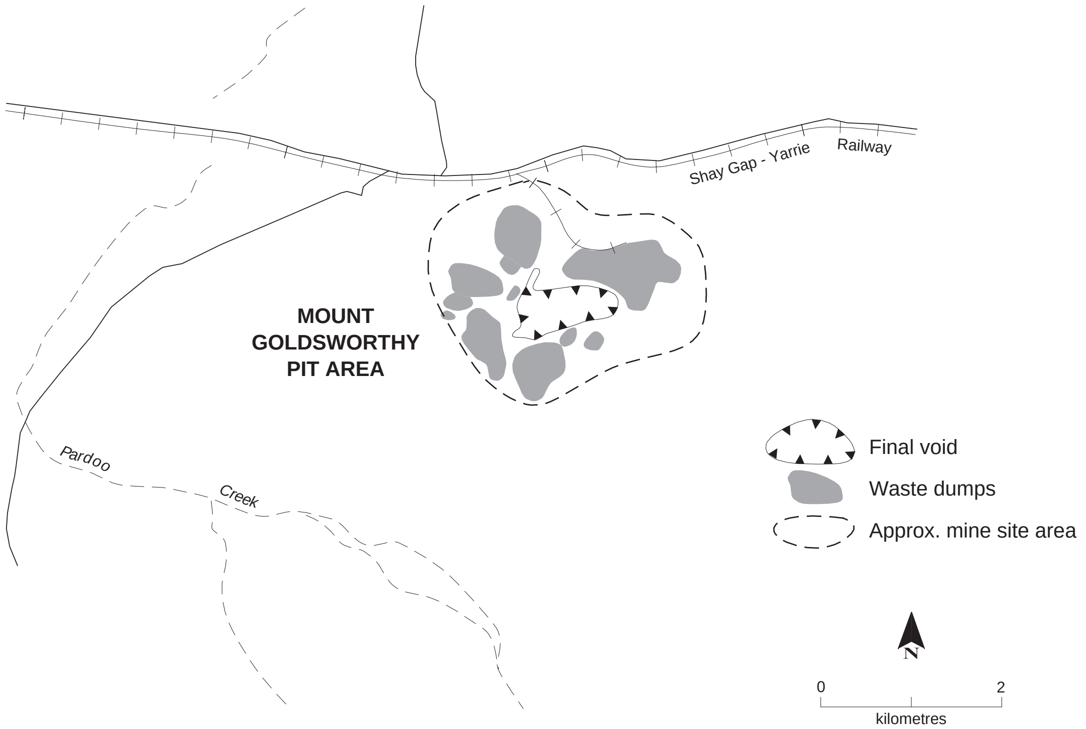
On the completion of mining, the pit was abandoned and has slowly filled with water. Water levels, recorded since 1992, are about 50 m below the pre-mining watertable (Fig. A2.2). The water is rising at a rate of 2.1 m/yr with no direct evidence of structurally controlled groundwater inflow. The rate of inflow will decrease with time as the waterlevel rises and the flow gradient towards the void decreases.

Since 1992, the void water salinity has been increasing at a rate of 200 mg/L/yr, although chemistry is not changing significantly (Fig. A2.2). There is a temperature gradient in the water body and a constant temperature of 22°C at a depth of 20 m. The pH is neutral (Table A2.1) and nutrient levels are low, which will minimise biological colonisation of the water body. The water body is well mixed with respect to the major ions (Table A2.1), but salt will probably eventually crystallise on the pit floor.

Conclusions



REGIONAL SETTING



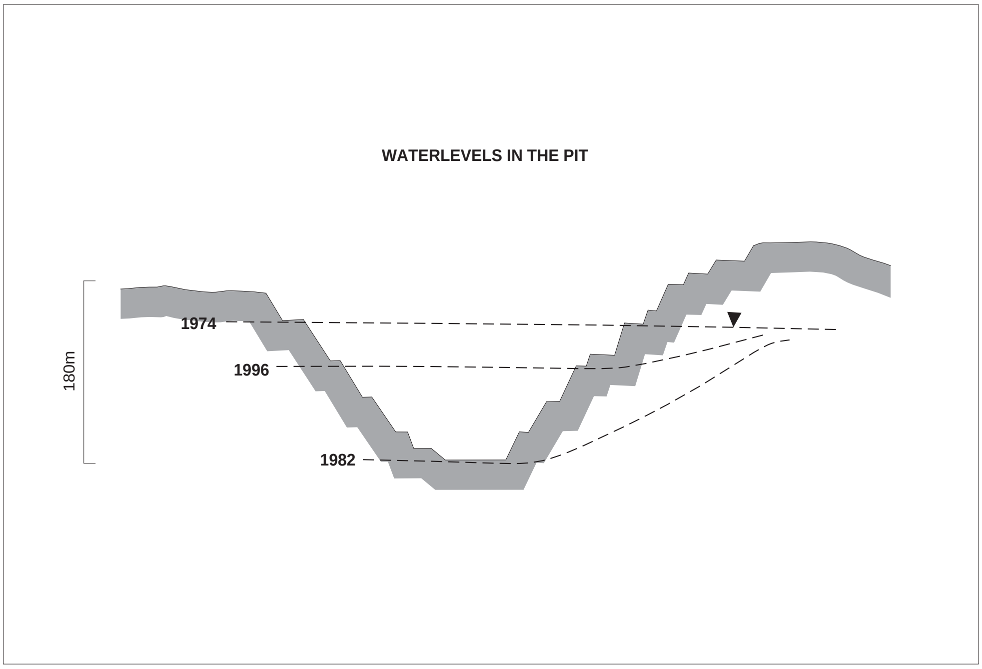
MINE SITE PLAN

HG8-FigA2-1

Figure A2.1 Mount Goldsworthy mine – location of final mine void (*after* Waterhouse and Davidge, 1999)

Table A2.1: Water quality in the mine void lake (1992/96)

Parameter	*Year*	*West wall seepage*	*Depth below surface (m)* ***0***	***15***	***35***	***90***
pH	1992	8.0	7.6	7.5	7.4	7.3
	1996	8.2	8.0	8.0	7.3	7.4
Salinity (mg/L TDS)	1992	4 400	4 900	4 800	4 800	4 900
	1996	4 900	N/a	5 600	5 600	5 600



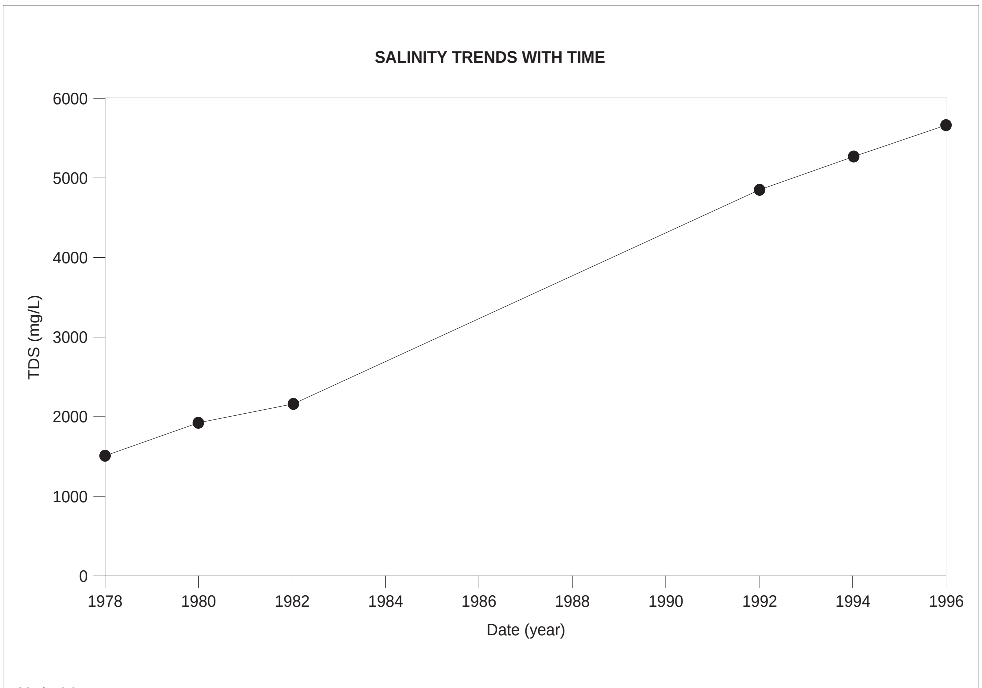


Figure A2.2 Mount Goldsworthy mine – trends within final mine void (*after* Waterhouse and Davidge, 1999)

After mining ceased in 1992, the Mount Goldsworthy mine void started to naturally fill with water. The void is about two-thirds full, with water becoming more saline. In the long-term (centuries), it is conceivable that a density-driven plume of saline groundwater could emerge from the pit along a structurally controlled permeable feature. The rate of plume movement would be limited by the rate of accession of cyclic salt to the void lake. At present, there is no risk to any regional water resources as the alluvial aquifers of the De Grey River are about 10 km to the west.

The Mount Goldsworthy mine void can be abandoned relatively safely to naturally re-establish equilibrium. Monitoring of the final void, which is relatively large and experiences typical Pilbara climatic conditions, is providing a valuable insight into what can be expected with the many other iron ore mines in the region. Mount Goldsworthy is an ideal site for research into hydrochemical changes that occur within fractured-rock mine void lakes. The only disadvantage is the lack of readily available historical mine and hydrogeological data.

Orebody 18

Introduction

Most of the data and information used in this case study relating to the Orebody 18 operation come from the Orebody 18 Consultative Environmental Review (BHP, 1996).

Orebody 18 is a proposed iron-ore mining operation located 32 km east of Newman in the East Pilbara. Mining will remove 116 Mt of iron ore over a 12–15 year period. Opencut mining will result in a final mine void that will be 4 km long, 500 m wide and 120 m deep. Dewatering will be required in the later stages of mine development to access ore reserves that extend to 43 m below the watertable.

On completion of mining, it is anticipated that the resulting pit lake will form a final surface area of 8 ha. The mine void will act as a groundwater sink with the salinity of the lake water to increase over time. Although, there are small areas of black pyritic shale in the area, these units will not be intersected in the pit and there is no potential for acid production.

Orebody 18 is located on the southeastern limits of the Ophthalmia Range (Fig. A2.3). The mine will be established on the slopes overlooking the alluvial plain between the Shovelanna and Jimblebar Creeks. The orebody is situated at the head of a catchment, with surface drainage to both the east and west. Streams generally flow after high intensity rainfall events.

The area in the subtropical summer rainfall zone experiences hot summers with periodic heavy rains and mild winters with occasional rainfalls. Annual rainfall is 300 mm and evaporation in the order of 3800 mm/yr.

Hydrogeology

Orebody 18 lies within the Brockman Iron Formation, which comprises banded iron-formation (BIF), chert, and minor shale bands. The orebody within the Shovelanna Syncline is bound by Mount McRae and Mount Sylvia Shale to the southeast, and steeply dipping shales and BIFs of the Weeli Wolli Formation in the northwest (Fig. A2.3). Valley-fill deposits, consisting of partially to entirely consolidated ferruginised silt, sand and gravel, overlie the Wittenoom Formation and Marra Mamba Iron Formation. Subsurface flow beneath the creek bed is not likely to be sustained after surface flow events, as regional waterlevels are at 50 m below surface.

The local groundwater system consists of four aquifers.

- Orebody 18 aquifer – the orebody itself (mineralised Dales Gorge BIF)
- Dolomite aquifer – formed along the eroded upper Wittenoom dolomite
- Shallow alluvial aquifer – formed by scree and alluvial clay deposits that contain minor calcrete developed below the watertable
- Marra Mamba aquifer – formed by the mineralised and fractured Marra Mamba BIF.

Shale intervals within the Mount McRae and Mount Sylvia Shales have low hydraulic conductivity that form an aquitard (hydraulic barrier) between the orebody and other local aquifers (Fig. A2.3). A difference in water quality and waterlevels suggests that the orebody aquifer has very limited connection with the other aquifers. The mine water supply borefield is located in the valleyfill to the south of the mine and will abstract groundwater from the Marra Mamba aquifer.

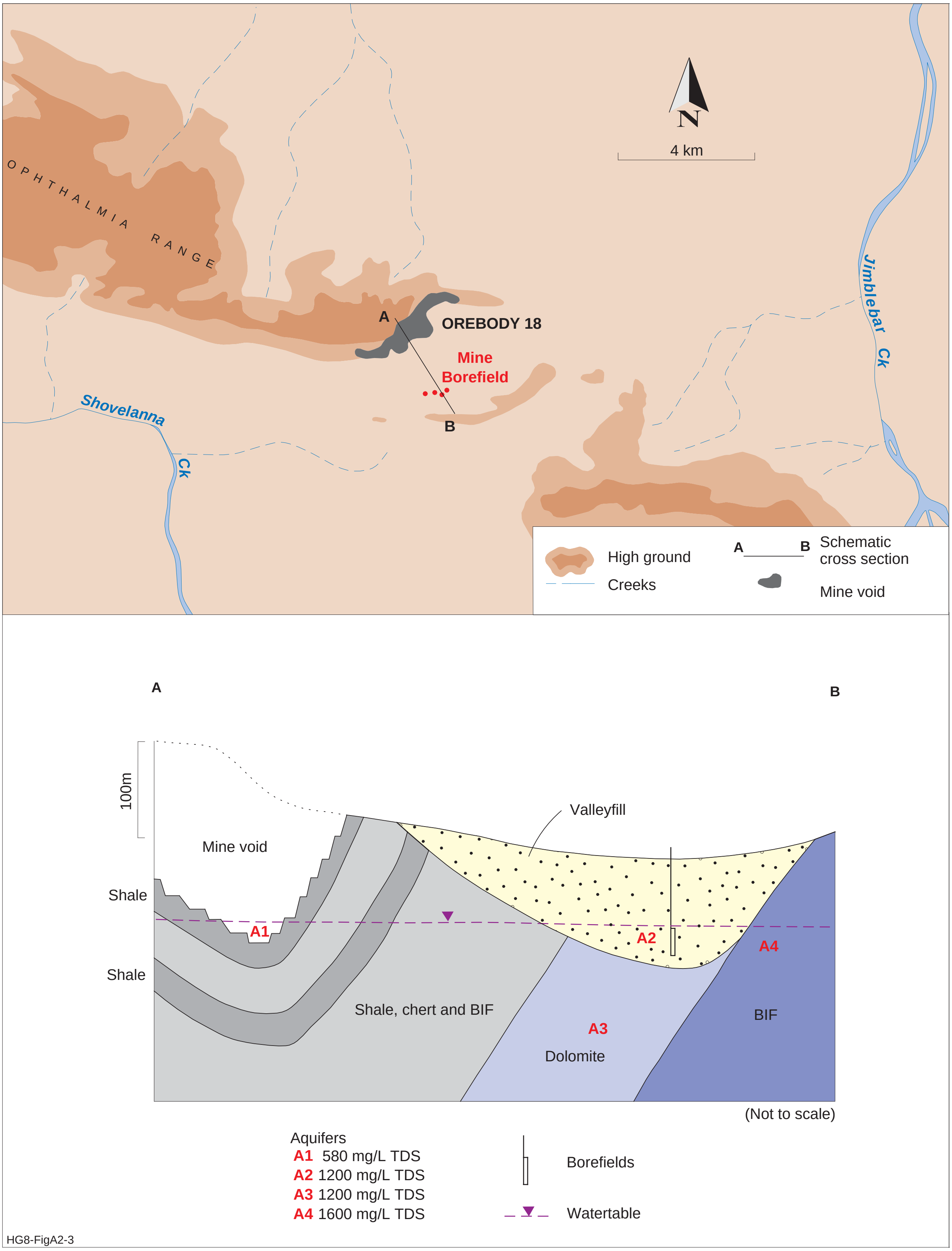


Figure A2.3 Orebody 18 – location and geology of mine (*after* BHP, 1996)

Potential impact of mining void

There is no indication that the final mine void will backfilled due to narrow widths and high pit wall configuration. The mine void will slowly fill with water on cessation of dewatering; however, the resultant pit lake should only be small. High evaporation rates and small groundwater inflow to the final void (groundwater sink) will result in a pit lake that will become progressively saline. The extent of this salinisation has not been modelled. There is potential for the development of hypersaline water, although the mine void should be hydrogeologically confined to the void and isolated from all neighbouring aquifers.

Conclusions

The final mine void at Orebody 18 will form a 'groundwater sink' that is hydrogeologically isolated from any other aquifer. Although the pit lake will become hypersaline over time, it will not have a significant impact on surrounding groundwater resources.

Orebody 23

Introduction

Most of the data and information used in this case study relating to the Orebody 23 operation are derived from the Orebody 23 Consultative Environmental Review (BHP, 1997a).

Orebody 23 is located 13 km northeast of Newman in the East Pilbara. Opencut mining began in 1992 with 3.4 Mt of detritals and Brockman ore recovered from above the watertable. In 1997, proposals were submitted for the mining of an additional 12 Mt of ore below the watertable. The mining will necessitate the removal of 102 Mt of overburden and waste rock over a period of four years producing a 130 x 95 x 140 m (deep) mine void. Dewatering will be required for the duration of the project, although the final void can be expected to fill with groundwater on cessation of mining.

Orebody 23 is on the southern side of the Ophthalmia Range, at the junction of Homestead Creek and the Fortescue River in Ethel Gorge (Fig. A2.4). The mine is about 2 km downstream of Ophthalmia Dam on the Fortescue River. The climate is subtropical-summer rainfall comprising hot summers with periodic heavy rain and mild winters with occasional rainfall. Annual rainfall is 300 mm and the evaporation is about 3800 mm/yr. All creeks are seasonal and flow only after major rainfall. Ophthalmia Dam impounds the Fortescue River upstream of Ethel Gorge. Surface flow in the Fortescue River near Orebody 23 results from releases, leakage or overflow from the dam and runoff generated downstream of the dam. The local vegetation consists of a few large shrubs and a rich array of small shrubs. The creek lines contain significant stands of River Red Gum and Coolibah woodlands.

Hydrogeology

The mineralisation at Orebody 23 lies within the Brockman Iron Formation (Fig. A2.5) that is flanked to the south by the Mount McRae and Mount Sylvia Shales, and to the north by the Whaleback Shale and Joffre Member (BIF). In the south, the basement rocks have been eroded and subsequently infilled with Tertiary sediments of fluvial and lacustrine origin. The southern pit wall intersects pyritic black shale that has potential for acid generation upon exposure to air, water and bacteria over a period of time.

The Fortescue River and its main tributaries (Homestead, Shovelanna, Whaleback and Warrawanda Creeks) all join before to cutting through the Ophthalmia Range in the 400 m-wide Ethel Gorge. The alluvial-filled palaeovalleys of these creeks form the regional groundwater drainage system. The alluvium is up to 90 m deep and groundwater flow is northwards through Ethel Gorge and ultimately to the Fortescue Marshes. The shallow calcrete is an important aquifer that is often separated from the alluvium by a confining clay sequence. Local, perched aquifers may develop for short periods when the alluvium within the active creek beds is saturated during river flow events. Recharge occurs both naturally through direct rainfall infiltration and river flow, as well as artificially via leakage from Ophthalmia Dam and recharge ponds 3 km upstream of Ethel Gorge (Fig. A2.4).

Some of the basement rocks, in particular the BIF, form local aquifers associated with mineralisation and structurally induced development of secondary permeability. In the south, the upper portion of the orebody is overlain by permeable detrital scree that lenses into the main alluvial sequence, resulting in hydraulic connection between aquifers (Fig. A2.5).

Potable water is supplied to the town of Newman from the borefield along Homestead Creek, 7 km upstream

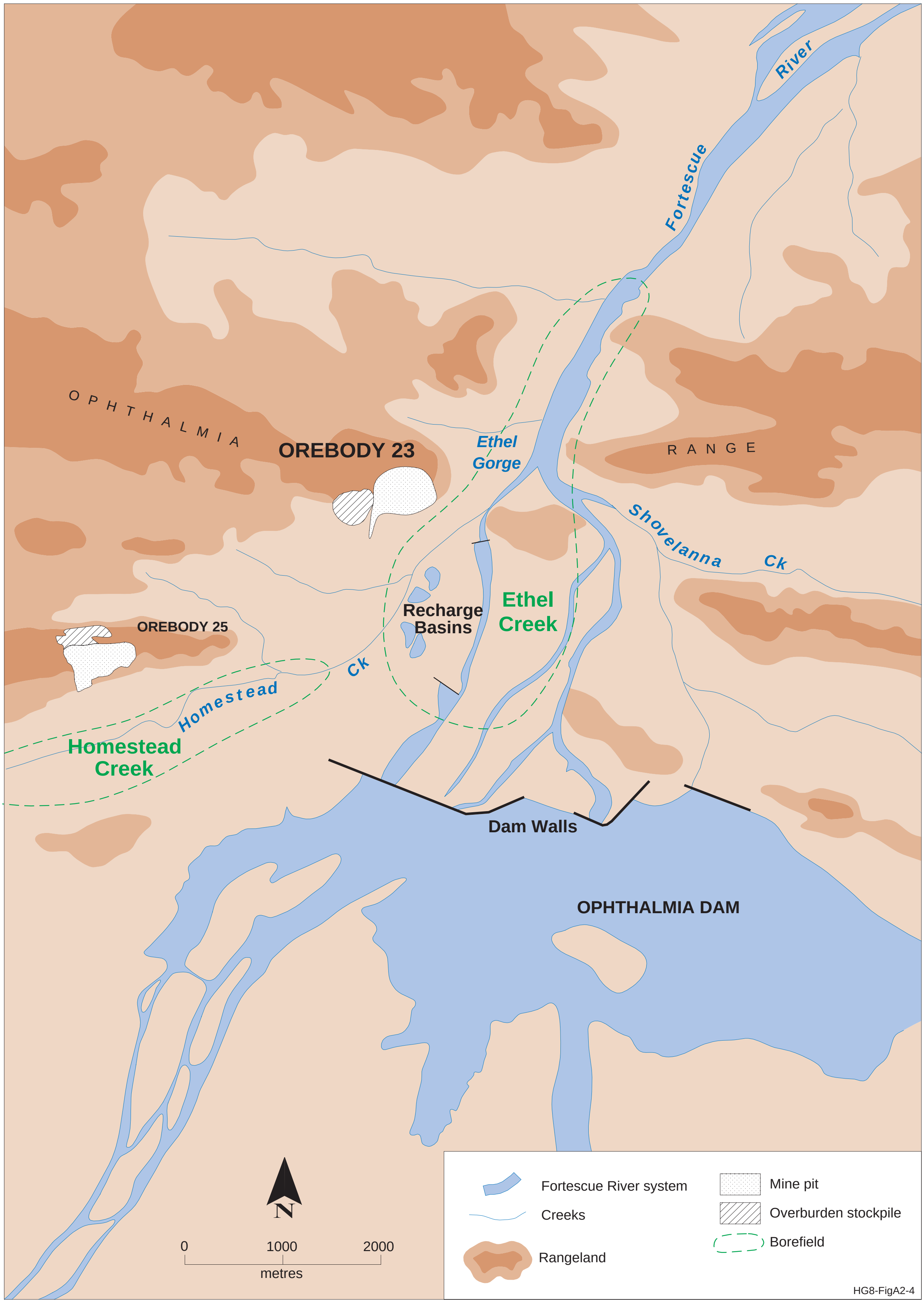


Figure A2.4 Location of the Orebody 23 mine site

of the proposed mine. The Ethel Gorge borefield, positioned in alluvium, supplies 14 000 kL/day to Mount Whaleback mine. Groundwater throughflow in Ethel Gorge prior to development of the borefield was estimated at 1000 to 2000 kL/day reducing to 500 to 700 kL/day on the commencement of abstraction. Evapotranspiration loss is estimated at 10 000 kL/day, as the creek system supports significant numbers of River Red Gum and Coolibah trees.

Potential impact of mining void

Groundwater modelling has indicated that mine dewatering will produce significant drawdowns impacting on the existing Ethel Gorge borefield. Outflow of groundwater from Ethel Gorge to the north will be effectively stopped, except during periods of heavy rainfall where shallow groundwater flows may occur in the alluvium. Throughflow will therefore have to be artificially supported during dewatering activities.

On completion of mining, waterlevels in the aquifer are expected to return to pre-mining levels within three years. The mine void will remain open and gradually infill with water. The lake water will progressively become saline due to evaporation rising from 1000 mg/L to about 10 000 mg/L after 100 years. Owing to hydraulic connection with the alluvial aquifer, the groundwater salinity immediately outside the pit will also increase in time and a saline plume may move down-gradient into the borefield (Fig. A2.6). Modelling predictions indicate that it may take 30 years for groundwater salinity immediately down-gradient of the pit to increase by 20%, and 100 years to increase by 50%. The overall impact will be limited provided there is adequate groundwater throughflow via artificial recharge from Ophthalmia Dam

The final waterlevel in the pit will be above the exposed Mount McRae Shale (pyritic shales), thus reducing the potential for long-term oxidation and acid production.

Conclusions

Mine closure and the abandonment of the opencut will result in the formation of a pit lake that will become saline over time. The resultant pit lake may adversely affect the adjacent shallow groundwater resource, currently a source of good quality water for urban and industrial use. A measurable impact may occur within 30 years and could be considered as significant within 100 years of mine closure. The nature of the mining operation precludes the back-fill option. The planned strategy of leaving the void to naturally fill with water therefore appears the most practical. The quick response time of the groundwater system means that compliance monitoring over a short period will permit early checking of modelling predictions. This will allow greater confidence in the long-term predictions and forewarn of any necessity for mitigation measures.

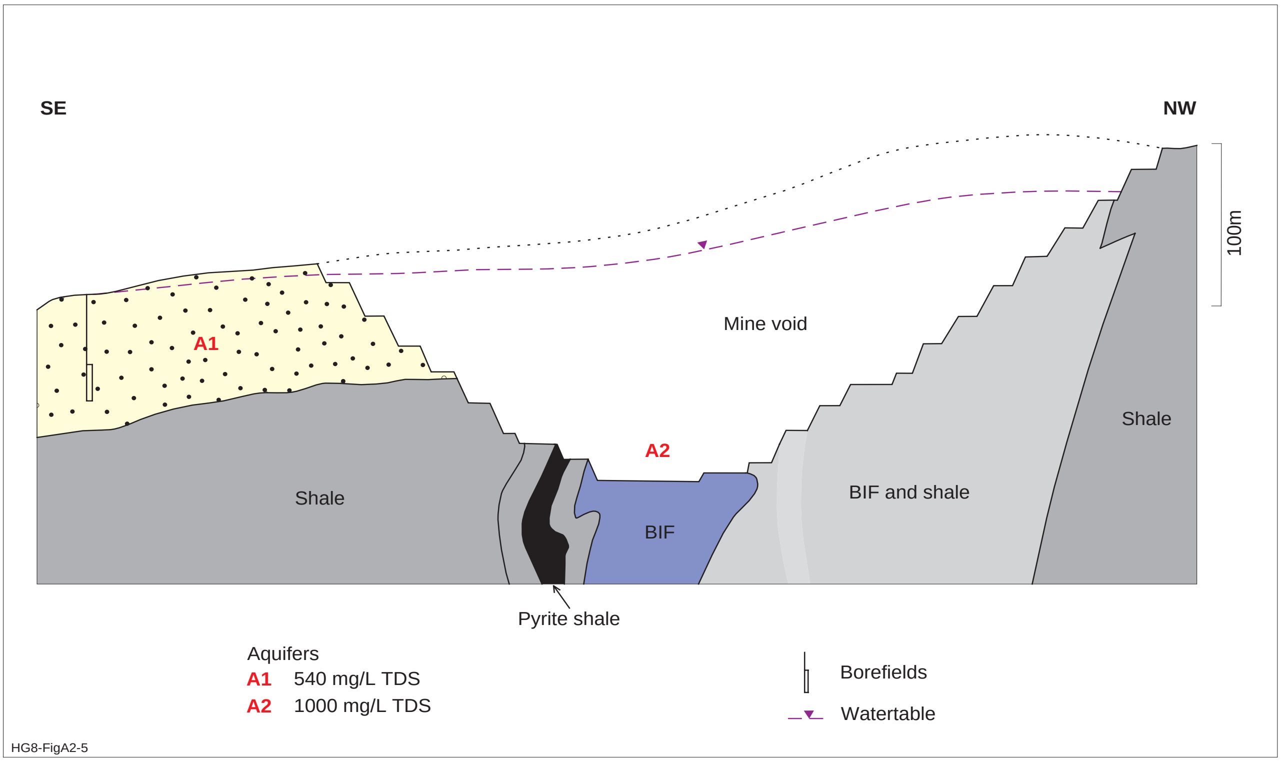


Figure A2.5 Cross section through Orebody 23 following mine closure

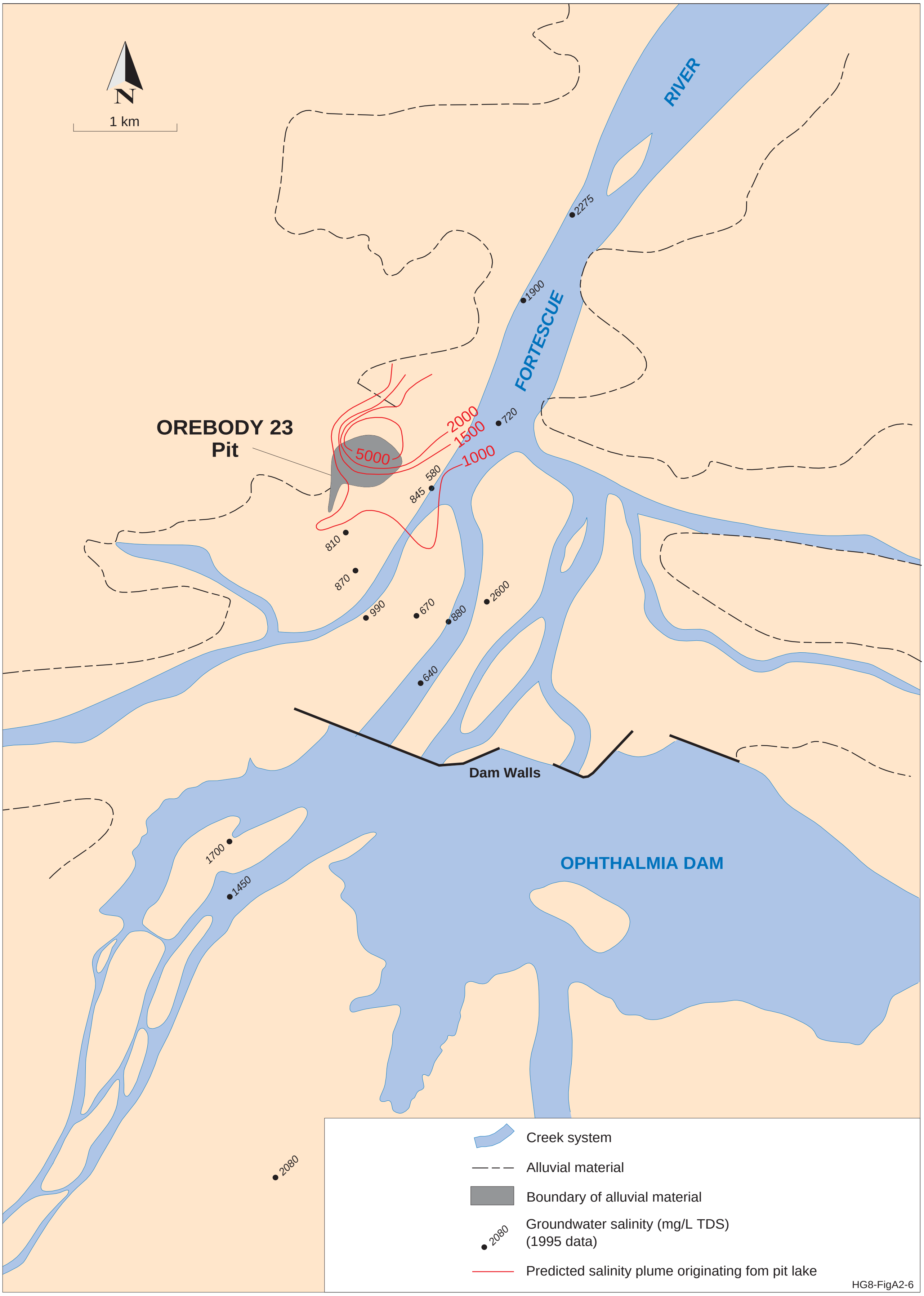


Figure A2.6 Predicted salinity plume after mining

Hope Downs Operations

Introduction

Most of the data and information used in this case study on the proposed Hope Downs operation come from the Hope Downs Public Environmental Review (Hope Downs Management Services, 2000).

The Hope Downs Project, 75 km northwest of Newman, is a proposed iron ore mining operation based around the Hope 1 deposit. The project will involve the opencut mining of both the Hope North and Hope South (Marra Mamba) orebodies (Fig. A2.7). When completely mined, the Hope North pit may have dimensions of 5500 x 250 x 240 m (deep) and the Hope South Pit (5000 m x 200 m x 130 m depth). The Hope North pit will extend 200 m below the watertable, whereas only a small portion of Hope South deposit lies below the watertable. It is anticipated that waterlevels will recover on completion of mining, but high evaporative losses within the pit lakes will prevent complete recovery.

The Hope 1 deposit is located within the southern half of the Weeli Wolli Creek catchment. The mine site comprises two systems of east–west trending hills and ridges with a vast area of outwash plain. Weeli Wolli Creek is an ephemeral stream that commonly carries substantial flood discharge.

The Hope North deposit is about 6.5 km southwest of Weeli Wolli Spring, which is located where Weeli Wolli Creek enters a relatively narrow gorge. The gorge forms the surface and groundwater outlet from the southern half of the Weeli Wolli catchment (Fig. A2.7). The spring is a permanent surface 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.

Although the region is classified as semi-arid to arid, it does experience periodic heavy rainfalls during summer owing to both monsoonal effects and cyclones. Annual rainfall of 330 mm is highly variable ranging from 140 to over 1000 mm. Annual evaporation exceeds 3000 mm.

The area contains two broad vegetation complexes. On the higher ground, there is continuous low Mulga woodland and tree steppe of *Eucalyptus brevifolia* (Snappy Gum) over spinifex. In the creeks, the dominant species are *E.camaldulensis* (River Red Gum), *E.microtheca* (Coolibah) *and Melaleuca argentea* (Paper bark), which are all considered to be phreatophytes.

Hydrogeology

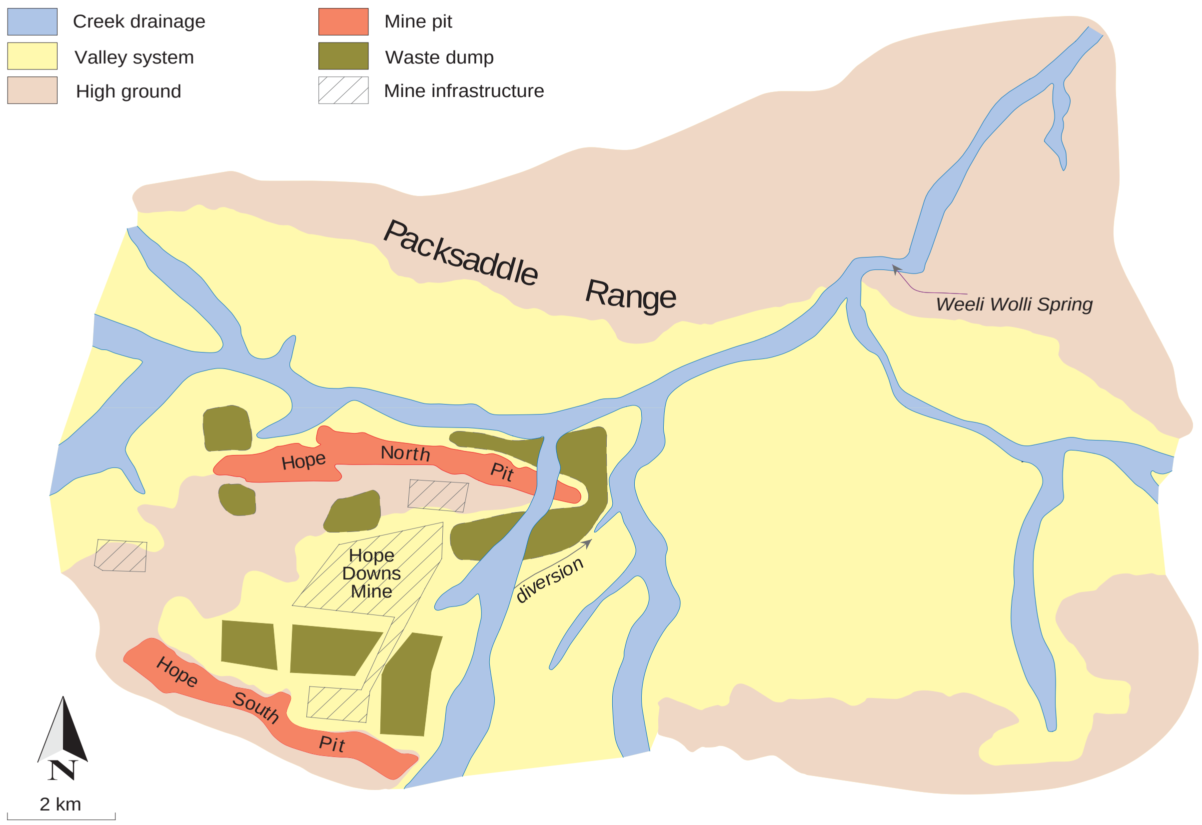
Rocks of the Hamersley Group occur within the Hope 1 area including the Brockman Iron and Marra Mamba Iron Formations. The Marra Mamba Iron Formation contains the ore deposits, with most mineralisation confined to the Mount Newman Member and the base of the West Angela Member. The mining areas are located on the northern limb of the Weeli Wolli Anticline and have undergone an additional series of folding. The two deposits also appear to be on a major northeast–southwest structural lineament that dictates the lower Weeli Wolli Creek drainage pattern. It is this lineament that appears to be responsible for the gorge in the Brockman BIF in which Weeli Wolli Spring is located.

The karstic dolomite within the Paraburdoo Member of the Wittenoom Formation is an important aquifer (Fig. A2.7). Other bedrock aquifers exist within the West Angelas Member (where manganiferous) and in fractured Marra Mamba Iron Formation, with the enhancement of permeability related to structural features.

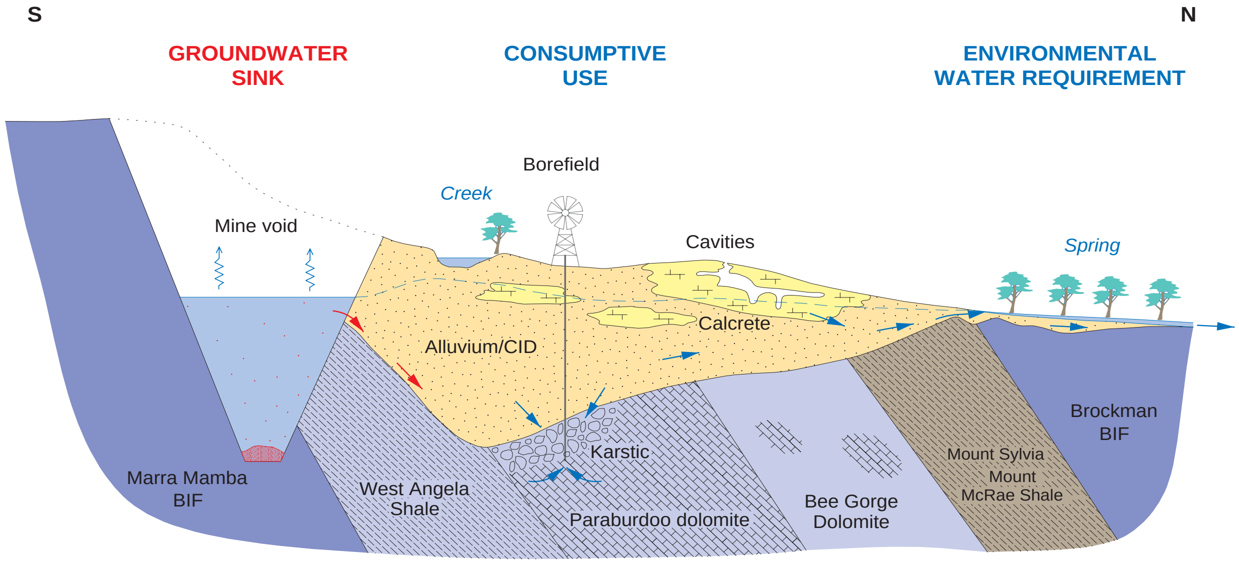
In places, many of these form high-permeability zones underlie the Tertiary valley-fill sediments. The pisolite and calcrete, where present below the watertable, also constitute a significant aquifer. The aquifer is recharged via direct rainfall infiltration and creek-line infiltration. Groundwater contours show the hydraulic gradients to be fairly steep in the upper catchment but decreasing downstream towards the proposed mines and Weeli Wolli Spring.

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



Hope Downs Mine Development



Schematic cross section of the Hope North - Weeli Wolli Spring area (Open void closure scenario)

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Figure A2.7 Mine layout and cross section from Hope North to Weeli Wolli Spring shallow watertable supports extensive stands of phreatophytic vegetation.

Both orebodies are significant local aquifers with relatively high permeability. The Hope North orebody is bounded on the southern side by low-permeability BIF, but to the north it is directly hydraulically linked to the regional aquifer. At Hope South the small “pods” of orebody below the watertable are contained within low-permeability BIF.

Dewatering will be necessary to maintain dry-mining conditions, as both deposits extend below the watertable (Fig. A2.8). In order to lower the watertable by 180 m at Hope North, it is anticipated that groundwater abstraction rates of between 30 and 110 ML/day will be required over a period of 22 years. This would lead to a drawdown of about 50 m at Weeli Wooli Spring, with shallow groundwater contribution to the spring ceasing in the first two years.

In addition, dewatering at Hope Downs will also dewater the proposed BHP water supply borefield east of the Mining Area C. This is not a major problem, with the mine-water balance at Hope Downs indicating 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 regard to the proposed mining of the Hope North deposit (Fig. A2.8). Weeli Wolli Spring is supported entirely by groundwater baseflow and this ecological water requirement is the major beneficial use of the regional aquifer. The environmental and cultural importance of the spring is such that groundwater abstraction would not be permitted to allow the spring to dry up. The spring will have to be artificially maintained if groundwater abstraction in the catchment up-gradient of the spring results in significant flow reduction. In fact, because of the very high hydraulic sensitivity of the spring, groundwater abstraction would not be allowed for consumptive use in close proximity to the spring.

The highly sensitive water balance within the catchment implies that the entire groundwater resource has to be 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 (up-gradient of the spring) or direct surface supplementation. However, the major concern is spring supplementation on the cessation of mining.

Groundwater modelling has indicated that could take 60 years for the waterlevels at the Hope North Pit to return 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 has made a commitment to artificially maintain the system for possibly twenty years after mining ceases.

After extensive modelling and testing of some 12 different scenarios, the proponent has agreed that the preferred management strategy is:

- Infilling the Hope North and Hope South pits to prevent the development of a ‘groundwater sink’.
- Floodwaters from the South West tributary to be diverted into the backfilled Hope North pit for at least 20 years to enhance waterlevel recovery.
- Importation of 20 ML/day from outside the catchment (possibly Marillana Creek and/or Weeli Wolli CID aquifer) for aquifer re-injection in the vicinity of the Hope North pit.
- Abstracting some 20 ML/day from the dolomitic aquifer in the upper reaches of the catchment for spring augmentation and aquifer re-injection in the calcrete up-gradient of the gorge.
- During mining operations, artificially recharging all surplus water into the dolomitic aquifer in the upper reaches of the catchment.
- If successfully implemented, this strategy should ensure that the spring flow is self-sustaining within 20 years.

Conclusions

The possible development of the Hope North mine constitutes one of the most difficult mine void closure scenarios in the State.

- The mine void will be backfilled to prevent the development of a ‘groundwater sink’.

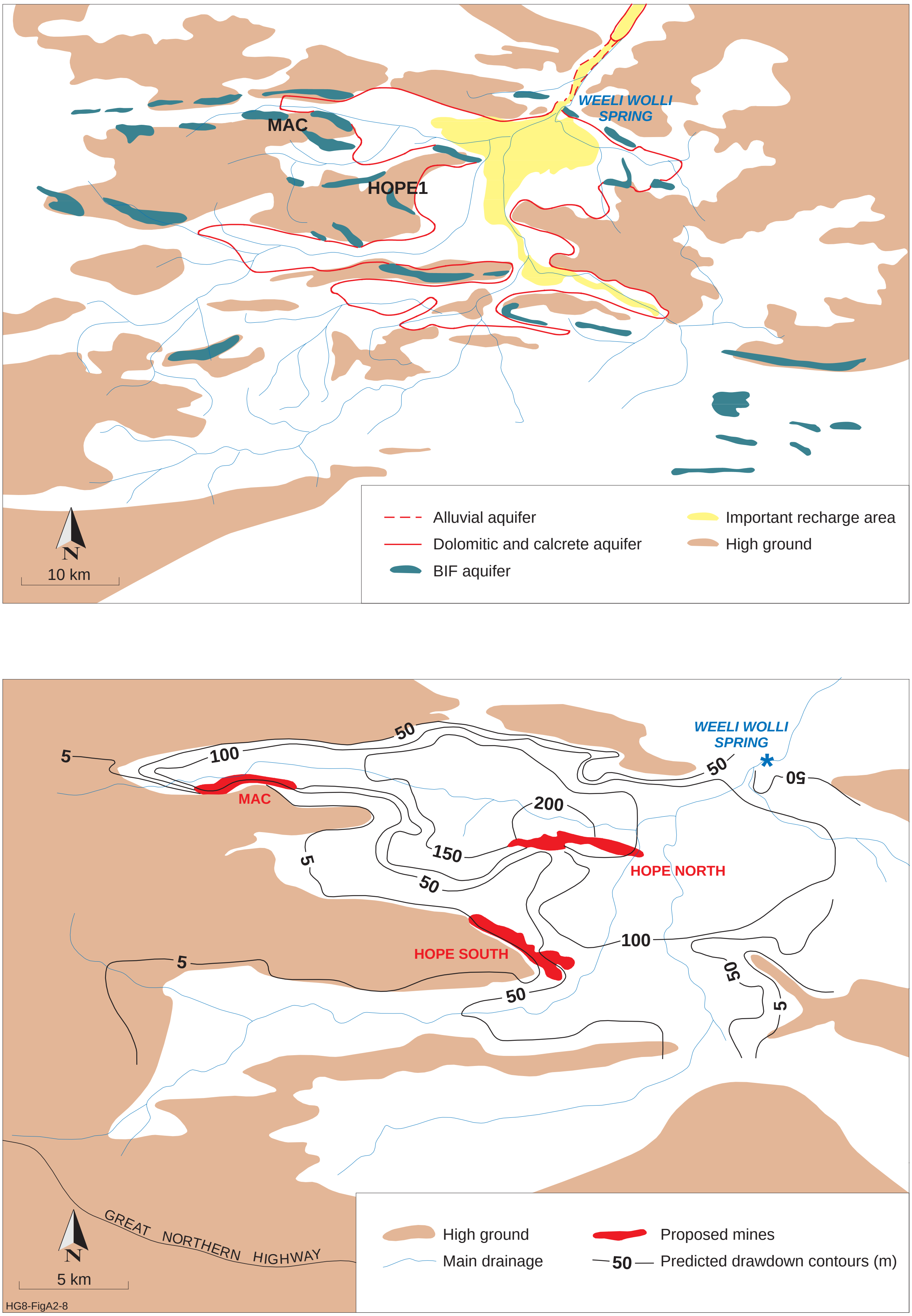

Figure A2.8 Aquifer distribution and predicted drawdown resulting from dewatering

- The void potentially has a direct hydraulic link to the adjacent unconfined aquifer.
- The adjacent aquifer is fully allocated to ecological water requirements.
- The linked ecological water use (Weeli Wolli Spring - a spring-fed wetland) has both great cultural and heritage value.

Yandi Operations

Introduction

Most of the data and information used in this case study on the BHP and HI Yandicoogina operations are from various unpublished reports for BHP (AGC Woodward-Clyde, 1995b; Colman Groundwater, 1997; BHP, 1998c) and Hamersley Iron (A. J. Peck and Associates, 1995; AGC Woodward-Clyde, 1994, 1995a, 1997c, 1998; Aquaterra, 2001).

The Yandi Operations are a good example of a 'groundwater throughflow' mine void. A number of mines extract pisolitic ore (CID) from beneath the watertable. The CID formed along the Marillana–Yandicoogina–Weeli Wolli Creek system, which about 150 km northwest of Newman (Fig. A2.9). The CID extends over 70 km with a width of 500–700 m and thickness of more than 50 m. Opencut mining is currently taking place at four sites along Marillana Creek, and ultimately mining will remove the entire CID. The very low overburden to ore ratio (0.2:1), though advantageous to mining, represents a disadvantage with regards to the backfilling of final mine voids. Current mine-closure plans have opted for partial infilling of the voids, in order to minimise pit lake surface area and maintain a degree of throughflow within the system. These plans involve the creation of a number of shallow elongated final voids.

Pit E2	2700 x 550 x 45 m	[final water depth 15 m]
Pit C1/2	4000 x 550 x 60 m	[final water depth 17 m]
Pit C5	2000 x 550 x 60 m	[final water depth 7 m]
Junction	7750 x 600 x 35 m	

The climate is semi-arid with very hot summers and mild to warm winters. Rainfall of about 250 mm/yr results from local convective storms and large-scale cyclonic events, and evaporation losses are high (3300 mm/yr). The vegetation is dominated by a tree steppe of Snappy Gum and mulga over spinifex, whereas the creeks contain major stands of phreatophytic vegetation. Apart from mining, land use is pastoral.

Marillana and Yandicoogina Creeks drain the Hamersley Range to the west and south of the mine. The Marillana Creek system drains eastward, where it joins the Weeli Wolli Creek, which flows northward before discharging into the Fortescue Valley (Fig. A2.9). Streamflow is seasonal with flows after heavy rains. Marillana Creek normally flows for a period of 30 to 60 days a year. Annual streamflow in the area around Yandi can range from negligible to tens of millions of cubic metres.

Hydrogeology

The iron ore deposits (CID) lie within Tertiary palaeochannels that are incised into shale, dolerite and banded iron-formation (BIF) of the Weeli Wolli Formation. The CID consists of three main facies: a basal conglomerate; basal clay pisolite; and the main pisolite ore zone (Fig. A2.9). The pisolitic units have well-developed joints and solution cavities (providing up to 25% open pore space) and near-horizontal clay layers varying in thickness and lateral extent. Downstream of Junction Deposit, the Marillana Creek CID joins the Weeli Wolli Creek CID before trending northeast towards the Fortescue River Valley. The Weeli Wolli Creek CID is less well defined and at greater depth, and plunges towards the north under the Fortescue River Valley.

Marillana Creek and other creeks occur within narrow strips of unconsolidated Quaternary alluvium. The alluvial bed within Marillana Creek varies in width from 150 to 400 m with depths of 5 to 20 m. The shallow alluvial aquifer associated with the various creeks is estimated to have a throughflow in the order of 5 m^3/day forming recharge/discharge points where the creeks cross the CID aquifer (Fig. A2.9).

The CID is the main aquifer with an estimated throughflow of 2.5 to 3 ML/day. The water within the CID is fresh, in the order of 500 mg/L TDS. A difference in salinity and water chemistry in the CID between Marillana Creek and Weeli Wolli Creek suggests that contributions due to throughflow may be small. The CID aquifer behaves as a fractured-rock aquifer, but over the long term it may show an unconfined response.

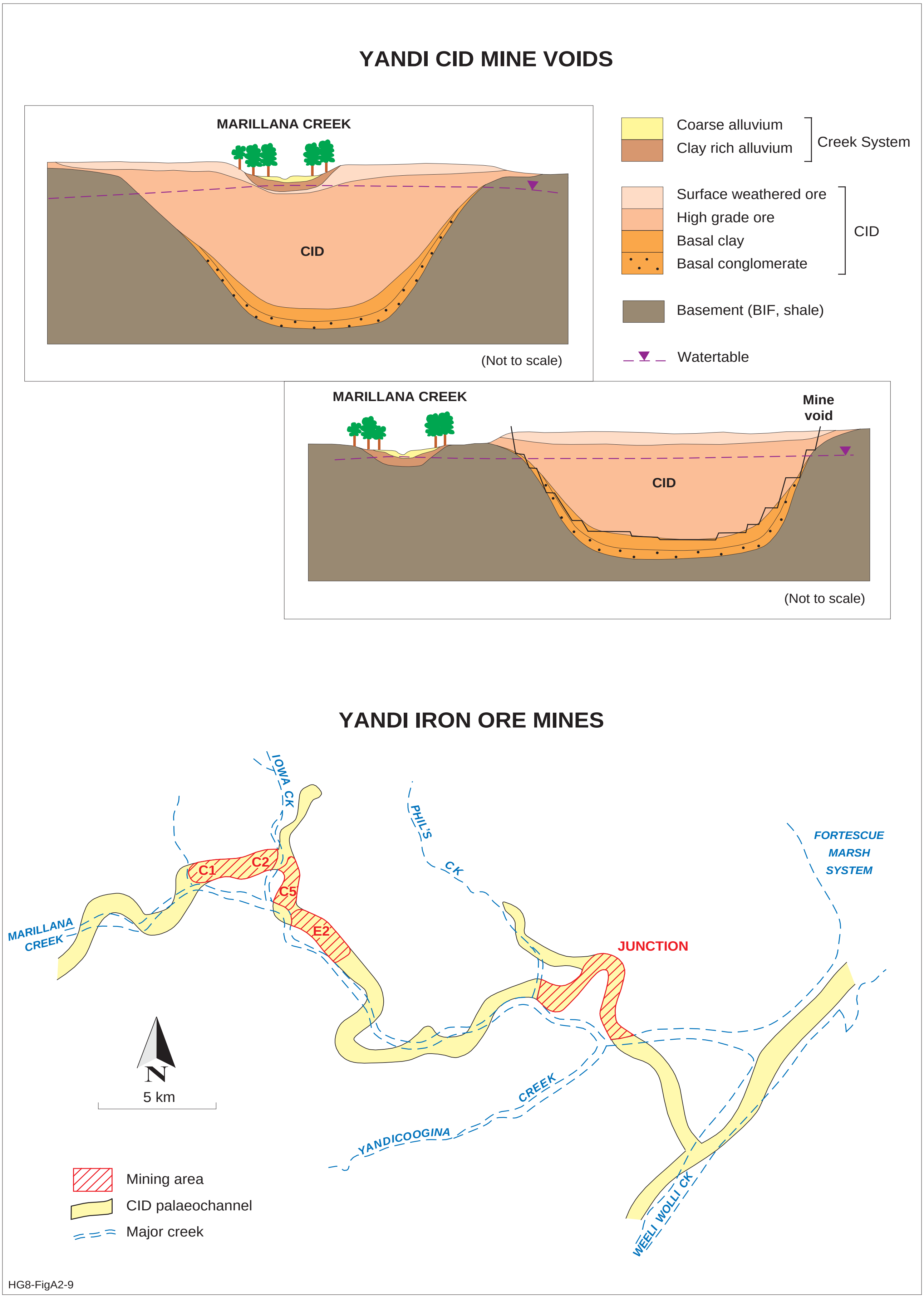

Figure A2.9 Yandi mine voids and distribution

The basement rocks (Weeli Wolli Formation) contain fractured-rock aquifers with hydraulic conductivity much lower than that of the CID or creek alluvium. The fractured-rock aquifer is highly localised and capable of providing significant bore yields.

Potential impact of mining voids

The Marillana Creek system is an important source of surface runoff to the Weeli Wolli Creek system, as well as a source of recharge to the Marillana Creek CID aquifer. The CID aquifer contains fresh groundwater that is an important groundwater resource. The contribution of the Marillana Creek CID aquifer to the throughflow in the main Weeli Wolli CID aquifer would appear to be relatively small.

The mining of pisolitic ore will effectively remove the aquifer. Modelling indicates that dewatering will result in significant drawdowns, but that waterlevels will recover within 15 years of the cessation of mining. Full recovery of waterlevels will be prevented by evaporation from the relatively shallow water bodies in the mine voids.

Evaporation losses will occur from all pits, including the Junction mine, where the infill material extends above the expected watertable. A total of 10 000 kL/day could be lost to evaporation; therefore, the mine voids will act as local groundwater sinks. However, apart from Pit C5, the impact will be small enough for an infrequent flood event to replenish aquifer levels and maintain adequate throughflow in the CID aquifer.

Evaporation of the pit lakes will in the long term result in an increase in salinity, as water is lost through evaporation and salt is left behind. Modelling indicates that the salinity of the pit lake water in mine void C5 (groundwater sink) will increase steadily from 500 mg/L to 14 000 mg/L after 250 years; at mine void E2 (partial groundwater throughflow) from 500 mg/L to 1600 mg/L after 90 years, stabilising at about 1800 mg/L; and at Junction mine (groundwater throughflow) to 2500 mg/L. The salinity of the groundwater leaving the Marillana Creek CID is not expected to exceed 2500 mg/L and this should be significantly reduced through mixing once it enters the main Weeli Wolli Creek CID aquifer. The degree of mixing will be dependent on the ratio of throughflow between the aquifers and will require a better understanding of the throughflow in the Weeli Wolli CID. Based on the predicted post-closure configuration, water quality in the Weeli Wolli CID should reach equilibrium within a short period of time (100 years).

Conclusions

Mine void closure strategies at the Yandi operations will result in a number of different hydrogeological voids. As much of the Marillana Creek CID aquifer will be removed during mining operations, closure strategies will have to ensure adequate groundwater throughflow to protect the down-gradient Weeli Wolli CID aquifer and maintain the beneficial use of the groundwater resource.

After mine closure, compliance monitoring of bores within Marillana and Weeli Wolli Creeks should detect changes in water quality. If closure predictions are not met, there is scope for implementing actions to mitigate any adverse environmental effects. Degradation of water quality beyond the compliance standard (should it occur) would not be irreversible. As the system will be managed as a groundwater throughflow system, decreasing evaporative loss in the voids should improve water quality with subsequent flow-on effects.