HYDROGEOLOGY
OF THE KURNALPI
1:250 000 SHEET

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Hydrogeology of the Kurnalpi
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Abstract

The KURNALPI* 1:250 000 sheet covers a part of the Yilgarn Craton that is characterized by north-northwesterly trending belts of Archaean greenstones intruded by granitoid rocks. Cainozoic surficial deposits form an extensive cover over the Precambrian bedrock and conceal Tertiary sedimentary rocks preserved in palaeochannels.

Fractured-rock aquifers occupy the greater part of the KURNALPI area, but they generally contain only minor groundwater supplies and these are difficult to locate. The basal sandstone unit in the palaeochannels is considered to contain the most prospective aquifers on KURNALPI. The groundwater resources of the Cainozoic surficial deposits are very small.

Most of the groundwater on the sheet area is saline to hypersaline and is currently used only for mining purposes. Fresh groundwater occurs in limited areas on KURNALPI, but brackish groundwater is more common, mainly in the upper reaches of some catchments.

The saline groundwater resources are being developed for use in ore processing, and so far eighteen borefields have been established to provide water to the mining industry.

KEYWORDS: hydrogeology, aquifers, palaeochannels, groundwater resources, Kurnalpi.

Location

The KURNALPI 1:250 000 hydrogeological sheet (SH/51-10 of the International Series) is bounded by latitudes 30°00' and 31°00'S and longitudes 121°30' and 123°00'E. The sheet area lies within the southern part of the Eastern Goldfields of Western Australia. The map is named after the abandoned gold-mining town, Kurnalpi, located in the centre of the sheet area.

The region is sparsely populated with only a few scattered small mining settlements and individual pastoral homesteads. Part of the mining and industrial area of Kalgoorlie–Boulder lies within the sheet area, and the residential area with a population of 25 016 in 1991 is located on Kalgoorlie to the west. The population of KURNALPI was, however, much larger during the goldrush at the turn of the century, when mining centres such as Kanowna supported a population of about 12 000.

Celebration Road, connecting Kambalda to Kalgoorlie, is the only sealed road on KURNALPI. Most of the mining centres and homesteads are linked to Kalgoorlie by graded roads but outside these areas there are only a few tracks.

The Trans Australia Railway crosses the southern portion of KURNALPI.

Sheep grazing is carried out over most of the area covered by the map sheet, while mineral exploration and mining are restricted to the greenstone areas.

Climate

The climate is semi-arid with hot, dry summers and cool to mild winters. At Kalgoorlie January is the hottest month with an average maximum temperature of 34°C and an average minimum of 18°C. July is the coolest month with an average maximum temperature of 17°C and an average minimum of 5°C. Frost occasionally occurs during the winter months.

Average annual rainfall decreases from about 260 mm in the southwest to about 220 mm in the northeast, and is 236 mm at Bulong. The southern part of the area has an average of 47 wet days per annum (Bulonl) and most of the rain falls between March and August during the passage of cold fronts. Summer rainfall occurs intermittently as a result of degenerated tropical cyclones or thunderstorms. Average annual potential evaporation increases from about 2700 mm in the south to 3000 mm.
in the north. Evaporation is greatest during the summer months of January and February and lowest during the winter months of June and July.

**Physiography**

Most of the area is gently undulating and of subdued relief, with elevations between 340 and 400 m AHD (Australian Height Datum). Areas of greenstones are characterized by low rolling ridges and breakaways which grade gently into wide alluviated valleys marked by chains of salt lakes. Lake Yindarlgooda and Lake Rebecca occupy large areas on KURNALPI. Areas underlain by granitoid rocks are generally flatter, with laterite plateaus and sandy plains, interrupted by monadnocks protruding slightly above the land surface. The only prominent topographic features are low breakaways, commonly found on the western margins of playa lakes and close to water divides.

Three major surface-water divides that cross KURNALPI separate the Roe, Rebecca, Raeside (in the extreme northeast) and Lefroy Palaeodrainages (Bunting et al., 1974; van de Graaff et al., 1977). These drainages once carried water east to the Eucla Basin but are now occupied by chains of playa lakes.

There are no permanent rivers; intermittent streamflow occurs only after major rainfall and the water runs into large claypans or playa lakes. Ponton Creek in the northeast corner of the sheet occasionally flows southeast to the Nullarbor Plain after heavy rainfall. Runoff from outcrops of bedrock may collect in gnamma holes or rockholes, and soaks and waterholes often occur next to rocky outcrops.

**Vegetation**

The vegetation of the eastern half of KURNALPI seems to have been little modified by man whereas in the western half it has been considerably altered during the last hundred years by grazing, mining and timber-gathering activities. The vegetation is quite diversified throughout KURNALPI and it is strongly controlled by soil type (Beard, 1975).

The northern two thirds of the area are dominated by mixed low woodland which include eucalypts, sheoak and mulga, the latter becoming more common in a northeasterly direction. Sandplains in this area support mallee and spinifex (Triodia). Slightly wooded succulent steppe of sheoak and saltbush (Atriplex) or bluebush (Maireana) is found around playa lakes in the western half of KURNALPI. The playa lakes in the eastern half of the sheet are bordered by a thickly-wooded succulent steppe consisting of mulga, sheoak, myoporum, and saltbush or bluebush.

The vegetation becomes denser south of Lake Yindarlgooda with open eucalypt woodland which includes salmon gum, gimlet and mallee, interspersed with saltbush or bluebush. The granitic terrain in the southeast is dominated by mixed eucalypt woodland with patches of mallee, grading into shrub steppe on sandplains.

The margins of playa lakes consist of saltbush–bluebush grading into shrubs and trees away from the lakes.

**History of water supply**

Obtaining sufficient fresh water was a constant problem during the goldrush of the 1890s. Only limited supplies of freshwater could be obtained from freshwater lagoons, small catchments, dams, gnamma holes and soaks. The potable water supplies for Kanowna, Bulong and Kurnalpi were obtained by desalination, in wood-fire condensers, of saline water from nearby playa lakes (Fielding, 1896). Kanowna and Balagundy also obtained water from a fresh water claypan near Kanowna (Fielding, 1896; Troy, 1897).

By 1897 a reservoir was constructed at Kanowna and another was in the process of construction at Bulong (Princep, 1898). Condensers were also installed at Gordon and Vosperton (Gindalbie), and a government well was sunk at Mulgarrie in 1898 (Troy, 1899). The following year drilling for groundwater was undertaken at Hayes New Find (Gindalbie) and Mulgarrie (Blatchford, 1900). The Public Works Department attempted to establish a borefield at Kanowna in 1901. Twenty-six bores were drilled up to 82 m in alluvium and weathered bedrock, but all were saline. After the completion of the Goldfields and Agricultural Water Supply (G&AWS) pipeline in 1903, potable water was possibly carted from Kalgoorlie but in remote areas more reservoirs were constructed, in particular at Mulgabbie, Emu Lake and Gindalbie (O’Brien, 1904, 1905).

In the early days of the Kalgoorlie field shallow wells were sunk in the bed of Hannan’s Lake to supply water to the nearby mines (Simpson, 1912). Water for batteries was also obtained from dewatering mines and dams.

During the 1980s the introduction of carbon-in-pulp and carbon-in-leach processing, by which low grades of gold-bearing ore can be treated using saline water, led to the resurgence of gold mining. To meet the need for large amounts of water, several borefields were established in the Tertiary sediments in palaeochannels located in the Roe Palaeodrainage, and in highly fractured greenstones such as those in the Trafalgar/Lakewood area and at Karonie.

Potable camp water supplies at the Karonie mine are obtained from saline borewater by desalinating with a reverse osmosis plant (K. H. Morgan and Associates, 1989a).

**Previous investigations**

Early contributions of the geology of KURNALPI include descriptions of gold-mining centres at Kanowna, Bulong, Mulgabbie, Kurnalpi and Golden Ridge. The first edition of the KURNALPI geological sheet was compiled between 1966 and 1968 by Williams (1970), and it includes the bibliography of previous publications. The Bureau of
Mineral Resources (BMR) published the results of an aeromagnetic survey in 1965 and an updated aeromagnetic map in 1987 (Australia BMR, 1965, 1987). A review of geological investigations, including the KURNALPI sheet, prior to 1972 was provided by Williams (1974). A report on the geological evolution of the Kalgoorlie–Boulder gold-mining district, comprising the southwest corner of the map sheet, was prepared by Keats (1987). Parts of the KURNALPI sheet area were mapped between 1987 and 1993 (Morriss, 1994; Smithies, 1994; Swager, 1994a,b; Ahmat, 1995a,b). The geology of the Archaean KURNALPI Terrane, which comprises most of the western margin of KURNALPI, was compiled in 1990 (Swager et al., 1990). The second edition of the KURNALPI 1:250 000 geological sheet was produced by Swager in 1995 (Swager, in press).

The earliest reports on groundwater were prepared in the first decade of gold mining (Troy, 1897; Simpson, 1898; Blatchford, 1900). Chemical analyses of groundwater on KURNALPI were published in 1916 (Simpson, 1916). After 1964 a number of investigations of pastoral stations were made (GSWA, unpublished reports). Hydrogeological maps, including the western third of KURNALPI, and the southern half of the map were compiled by Australian Groundwater Consultants in the late 1970s and early 1980s (Australian Groundwater Consultants, 1978, 1979, 1983). Further studies on groundwater potential of the region were carried out in the 1980s (Australian Groundwater Consultants, 1980, 1982; BHP Engineering and Australian Groundwater Consultants, 1984, 1988). In addition, numerous unpublished consultants’ reports on borefields were prepared during the 1980s. The Geological Survey of Western Australia carried out a major study of the groundwater resources in the Roe Palaeodrainage in the western part of the KURNALPI sheet in 1988. This study included a drilling program and geophysics (Kern et al., 1989; Street, 1988; Commander et al., 1992). The hydrogeology of the adjacent KALGOORLIE, BOORABBIN and WIDGIEMOOLTHA 1:250 000 sheets were compiled between 1992 and 1994 (Kern, 1995a,b,c).

Geology

Regional setting

The KURNALPI sheet covers part of the Yilgarn Craton. The area lies within the Eastern Goldfields Province (Griffin, 1990) and includes the Archaean granite–greenstone KURNALPI Terrane and the Kalgoorlie Terrane along most of the western margin of the map sheet (Swager et al., 1990).

KURNALPI is characterized by linear, northerly trending greenstone belts of Archaean supracrustal rocks comprising metamorphosed volcanic and sedimentary rocks. The areas between the greenstone belts are occupied by granitoid rocks. Proterozoic dykes cut both greenstone and granitoid rocks.

Cainozoic surficial deposits form an extensive cover over the Precambrian rocks, and include Tertiary sedimentary rocks preserved in palaeochannels located in palaeodrainages that once carried water eastwards to the Eucla Basin.

Archaean and Proterozoic

The greenstone belts contain metamorphosed and deformed sequences of mafic and ultramafic volcanic rocks (Ab); sedimentary rocks, and felsic volcanic and volcaniclastic rocks (Af); and minor chert and banded ironformation (Ac). Granitoid rocks (Ag), generally foliated, occupy about 30% of KURNALPI. Banded granitoid gneiss (An) is a minor rock type, restricted to a small area to the northeast. Minor quartz–feldspar porphyry intrusions occur as small dykes and sills, but locally may form substantial elongated stocks. The Archaean rocks are poorly exposed on KURNALPI owing to widespread surficial cover and extensive deep weathering.

Most of the Archaean rock units are deformed, and contain foliations, cleavages, and lineations. Regional-scale folds are clearly defined by lithological trends that have a preferred north-northwesterly direction in the greenstone belts (Swager and Griffin, 1990). The area is also affected by significant north-trending faults and shear zones, and by minor east–west faults. Except in the greenstone belt to the west these fracture zones are generally poorly exposed, and are largely inferred to exist to account for major contrasts in lithology and structure between adjacent areas.

Proterozoic mafic and ultramafic dykes (Ed) intrude the granite–greenstone terrane throughout the KURNALPI area. They are widespread, have a general east–west trend, and can be traced as aeromagnetic lineaments.

Most rock types have been lateritized and deeply weathered over much of the area, resulting in deep sections that are completely weathered to clay, or partially weathered with the original texture preserved. The weathered profile is commonly 30–40 m thick, but it reaches about 73 m at the Blair Nickel mine and 90 m in exploratory holes at Karonie (Meyer, 1989; K. H. Morgan and Associates, 1987). The weathered profile can be up to 110 m thick (Williams, 1970). The weathered granitoid profile is principally characterized by large thicknesses of kaolin which may extend down to 50 m. In places a quartz–rich grit may occur on the top of the fresh granitoid rock (Kern, in prep. b). The presence of saline groundwater is thought to affect the weathering process because the thickness of the weathered bedrock beneath palaeochannels and salinity both increase downstream (Kern and Commander, 1993).

Cainozoic

Tertiary sedimentary rocks

Tertiary sedimentary rocks deposited in valleys cut by Cretaceous to early Tertiary rivers form palaeochannels that are now concealed by Quaternary sediments. On the map these sediments are shown only where proved by
drilling and where they are inferred to be saturated. Their distribution between drillholes is interpreted.

Tertiary sedimentary rocks were first described by Blatchford (1898) in 'deep leads' at Kanowna. Following extensive drilling for placer gold in the lower part of the Roe Palaeodrainage, Smyth and Button (1989) described the Tertiary sediments but did not formalize the stratigraphic nomenclature.

Sediments in the Roe Palaeodrainage on KURNALPI have been described by Kern and Commander (1993). They consist of the basal Wollubar Sandstone (Tw) overlain by the Perkolilli Shale (Tp). The Wollubar Sandstone, which reaches 30 m in thickness, consists of unconsolidated quartz sand, with minor conglomerate, silt, clay, and lignite. The unit is late Middle to early Late Eocene in age. The Perkolilli Shale is a multicoloured clay with minor sandy clay beds and is up to 40 m thick. The unit becomes more sandy in the upper parts of the palaeochannels and is locally silicified or calcitized.

On KURNALPI the palaeochannels and their tributaries delineated by drilling in the Roe Palaeodrainage upstream of Lake Yindarlgooda vary in width from about 250 m to over 1600 m, and in depth from about 40 m in Line O, located in a tributary of the Yindarlgooda South Palaeochannel, to about 75 m (Line N), where bedrock is deeply incised (Commander et al., 1992). There are about 80 m of sediments near Lake Roe (Smyth and Button, 1989).

Sediments in the Raeside and Rebecca Palaeodrainages are very similar to those in the Roe Palaeodrainage (Rich and Taylor, 1986; Smyth and Button, 1989). The thickness of sediments increases eastward, reaching about 90 m in the Rebecca Palaeochannel and 100 m in the Raeside Palaeochannel in the northeast of KURNALPI.

Surficial deposits

Various Cainozoic surficial deposits (Cz and Qf) occur on KURNALPI (Swager, in press), where they form a veneer over the Archaean and Tertiary rocks. In elevated areas they are generally unsaturated and are not mapped. Only those units likely to contain groundwater are shown on the map.

High-level deposits (not mapped) of laterite, eluvium, and sandplain are widespread. The laterite occurs as plateaus of massive, ferruginous duricrust, bounded in part by breakaways, and as pisolithic soil in lower areas. The eluvium consists of quartzo-feldspathic sand derived by weathering and erosion of granitoid rocks, with scattered, small pebbles of granitoid rocks. Sandplains consisting of low dunes of yellow sand cover extensive areas on KURNALPI (Fig. 1), and are partly collian in origin.

Colluvial and alluvial deposits (Cz) occur in outwash fans and stream channels respectively. The colluvium consists of conglomerate, gravel, sand, and clay derived from the laterite profile and the underlying Archaean bedrock, and is generally less than 10 m thick. Alluvial deposits consist of unconsolidated sand, silt, and clay in the valley-flat environment, with interfingering conglomerate near bedrock outcrops. Where the course of a modern drainage system coincides with Tertiary palaeochannels, modern alluvial deposits overlie Tertiary sedimentary rocks.

Deposits associated with playa lakes and claypans (Qf) consist of saline and gypsicriferous clay and silt that may reach 9 m in thickness (Clarke, 1993). They usually overlie highly weathered Archaean rocks or the Perkolilli Shale of the palaeochannels. The margins of the lakes consist of stabilized dunes of unconsolidated sand, silt and gypsum derived from the desiccated surface of the playa lakes.

Hydrogeology

Groundwater occurrence

The KURNALPI area is underlain by weathered and fractured Archaean bedrock overlain locally by palaeochannel deposits and by widespread alluvium and lake deposits. The bedrock forms part of the Yilgarn Goldfields fractured-rock groundwater-province.

The fractured bedrock is characterized by secondary permeability resulting from tectonic and decompression fracturing enhanced by chemical dissolution along fracture lines. Fractured-bedrock aquifers occur more commonly in mafic, ultramafic, and granitic rocks than in sedimentary or felsic volcanic and volcaniclastic rocks. Open fractures occur to depths of 120 m and 150 m in greenstones in the Halfway Dam and Blair Nickel Borefields respectively (K. H. Morgan and Associates, 1988; Meyer, 1989), and probably to a similar depth along major faults and shear zones.

Minor mafic and ultramafic dykes occur in the southern half of KURNALPI. They are undeformed, typically appear to lack open fractures, and are possible hydraulic barriers to groundwater movement.

The Wollubar Sandstone is highly permeable and contains significant volumes of groundwater. It is the largest source of groundwater on KURNALPI. Minor amounts of groundwater occur in the alluvial and lacustrine deposits.

Direction of groundwater flow and variation in salinity are closely related to topography, whereas bore yields depend largely on the rock type.

Groundwater occurrence on KURNALPI is illustrated in Figure 2. Groundwater recharge is a very small proportion of rainfall; most of the rainfall is either directly evaporated or used by the vegetation, with a small component of runoff into claypans and playa lakes. Direct recharge principally takes place where the bedrock outcrops, and in the sandplains. Most recharge is likely to occur during heavy rainfall when it is enhanced by recharge from surface runoff and local flooding.

A regional watertable occurs on KURNALPI and the depth to the watertable ranges from less than 1 m in playa-lake environments to more than 50 m in elevated areas. It is as much as 58 m at Gindalbie. The regional watertable may be absent in high areas where the weathered and
fractured zone is unsaturated or where fractures are poorly developed.

Groundwater flow is towards the major palaeo-drainages and modern playa lakes where the watertable is close to the surface. Groundwater discharge occurs mainly by evaporation from playa lakes, and only a relatively small amount of water flows out of these areas through the palaeochannels.

The units on the accompanying map represent distinct hydrogeological units with lithological associations similar to those used on geological maps.

**Aquifer types**

**Granitoid rocks (Ag)**

The granitoid rocks occupy about 30% of KURNALPI, and they occur mainly in the northern and eastern parts. They are generally foliated and metamorphosed, and include granite, monzogranite, granodiorite, and minor pegmatite and quartz–feldspar porphyry. They are poorly exposed because extensive areas of granitic rocks are overlain by residual sandplains and colluvium (not mapped). In outcrop, granitoid rocks appear to be massive, with only minor foliations and joints, although widely spaced jointing is evident on aerial photographs. The most permeable horizon in the weathered zone may be a quartz grit occurring immediately above the relatively fresh bedrock (Kern, 1995b).

Pegmatite dykes (p) and quartz veins (q) are a minor but widespread component of the granitoid rocks. They tend to be well fractured and may form small but locally important aquifers. They are also present in the greenstone belts.

An extensive sandplain (not mapped) is well developed over lateritized and fresh granitoid rocks, but is unsaturated
Figure 2. Block diagram showing groundwater occurrence
except near playa lakes. The sandplain may enhance recharge of the underlying granitoid rocks. Where the granitoid rocks are lateritized, the regional watertable is deep and the lateritic soil profile is unsaturated.

Eluvium derived from the granitoid rocks occurs either as isolated patches or as large areas surrounding outcrops. The eluvium overlying granitoid rocks consists of coarse, gritty to loamy sands and may be up to 10 m thick. Often the loamy soils fill topographical depressions in the granitoid rocks and give rise to ephemeral, shallow, freshwater soakages, such as those at Wiladdy, Cardumina Soaks. Pastoral wells are commonly sited adjacent to outcrops of granitoid rocks where additional recharge from surface runoff occurs (e.g. Dingo Rock Well, Lords and Yindi Rock Bores), or close to drainage lines where the watertable is less than 10 m below the surface.

The watertable in areas of granitoid rocks can be deep in the upper reaches of catchments, and is as much as 37 m in Borderline Bore. Bore yields are generally small in granitoid rocks, and are less than 50 m³/day in the Karanje borefield (Table 1).

**Banded granitoid gneiss (An)**

Banded granitoid gneiss outcrops east of Pinjin Station homestead (Swager, 1994b). The gneiss has a mineralogical composition similar to granitoids, but is strongly banded and foliated. It is also highly recrystallized, indicating a lack of open fractures (Swager, C. P., 1994, pers. comm.). Only along the contact with greenstones are there pegmatite dykes and quartz veins which may form small local aquifers. Kurranjrong Well was sunk in deeply weathered gneiss but is now abandoned (Williams, 1970).

**Mafic and ultramafic rocks (Ab)**

Mafic and ultramafic rocks include metamorphosed basalt, amphibolite, komatiite, and schist, as well as metamorphosed mafic and ultramafic intrusives. The extrusive rocks are characterized by columnar jointing and pillow lavas. In outcrop, however, they are often highly weathered and the joints are filled by clay.

The water table is deep in the upper reaches of catchments, as much as 56 m at the Blair Nickel mine. Bore yields are variable and typically range between 100 and 500 m³/day (Table 1). The major borefields in mafic and ultramafic rocks are situated in the Trafalgar/ Lakewood area, where yields up to 330 m³/day in the Karanje borefield.

**Sedimentary, felsic volcanic and volcaniclastic rocks (Af)**

A complex succession of metamorphosed sedimentary rocks, and felsic volcanic and volcaniclastic rocks, is widespread in the greenstone belts. The felsic extrusive rocks include dacite and rhyodacite tuffs that tend to be relatively unjointed and have fine-grained weathering products. The sedimentary rocks are quartz-rich siltstones, sandstones, and polymictic conglomerates that are generally deeply weathered and soft. Dacite porphyry is more resistant to weathering and better exposed than the sedimentary rocks. The silcrete, ferricrete and underlying sand intersected in GSWA Line T (Kern et al., 1989; Kern and Commander, 1993) have been re-interpreted as being weathered sedimentary rocks of Archaean age.

The water table in sedimentary, felsic volcanic and volcaniclastic rocks can be deep in elevated areas, as much as 58 m at Gindalbie. Sedimentary, felsic volcanic, and volcaniclastic rocks generally constitute poor sources of groundwater owing to their clay-rich weathering products, although Halfway Dam and East Location 50 Borefields include production bores in these rocks. The exceptional good yield (790 m³/day) in Bore EDH2 in the Halfway Dam borefield occurs in sheared felsic volcanic rocks (K. H. Morgan and Associates, 1988).

**Chert and banded iron-formation (Ac)**

Chert and banded iron-formation are common only in the eastern half of KURNALPI where they are associated with mafic and ultramafic rocks and form prominent narrow ridges. Commonly they have well-developed joint systems and are not deeply weathered. A band of chert was intersected in an exploratory bore near Emu Dam (southern shore of Lake Yindarlgooda), producing yields up to 500 m³/day (Meyer, G. M., 1992, pers. comm.). Chert and banded iron-formation are not exploited on KURNALPI yet, but they may have local potential as fractured aquifers.

**Tertiary sedimentary rocks (Tw and Tp)**

The Wollubar Sandstone and its equivalents are the major aquifers in the region. They are confined over a large area by the relatively impermeable Perkolilli Shale and its equivalents. The aquifers are unconfined and partially saturated in the upper part of the palaeodrainages where the overlying Perkolilli Shale is sandy.

In the Roe Palaeodrainage the water levels in observation bores range from about 4 m below ground surface in exploratory bores in Line V near Lake Yindarlgooda to about 36 m in Line O, located in a tributary of Yindarlgooda South Palaeochannel (Commander et al., 1990). Groundwater flow in the Wollubar sandstone is generally eastward, in the direction of the original palaeodrainage, but in the Wollubar palaeochannel flow is southwestwards from Lake Yindarlgooda (Commander et al., 1992; Kern, 1995c) due to river capture, and groundwater is discharged into the Lake Lefroy system to the south. In the Yindarlgooda North Palaeochannel the potentiometric surface falls from about 333 m AHD near Hannan Lake to about 300 m AHD downstream of Lake Yinda. In the Hannan Palaeochannel the original potentiometric surface decreased from about 325 m AHD in the west to about 317 m AHD where it meets the Wollubar Palaeochannel and to about 314 m AHD at the southern boundary of the map sheet. Due to groundwater abstraction the current potentiometric head is about 2–3 m lower in both the Hannan and Wollubar Palaeochannels.
Bore yields from the Wollubar Sandstone are variable and range from about 600 to 1200 m³/day (Table 1). Short-term yields up to 5500 m³/day (Hannan Lake) have been recorded during pumping tests on KURNALPI. In the Roe Palaeodrainage bore yields increase downstream as the aquifer becomes thicker and wider, and the sand coarser.

The Rebecca and Raeside Palaeochannels contain sediments similar to the Wollubar Sandstone but they are not presently utilized as aquifers on KURNALPI.

**Surficial deposits (Cz and Ql)**

Laterite (not mapped) forms only a veneer in the greenstone belt, and therefore is saturated only where shallow groundwater occurs or in low lying areas. The Lakewood Borefield (Goult Pro) comprises two production bores within a shallow aquifer in laterite. Airlift yields up to 700 m³/day have been estimated in the area (K. H. Morgan and Associates, 1989b), but the yields are likely to decline during prolonged drought.

Alluvial and colluvial deposits are only partly saturated in low-lying areas where the thickness of the sediments is greatest.

**Lacustrine sediments**

Lacustrine sediments are intermittently saturated as the lakes are usually dry for most of the year and are replenished only after heavy rainfall. The regional watertable is close to the surface in playa-lake environments, whereas there may be a perched watertable in interbedded fine grained or clayey sediments, whereas there may be a perched watertable in adjacent playa-lake sediments, and in fractured and weathered bedrock. The salinity range of groundwater from the major borefields is given in Table 1.

**Groundwater quality**

**Salinity**

**Regional variation**

Groundwater on KURNALPI is mainly saline to hypersaline. The salinity ranges from 500 mg/L total dissolved solids (TDS) in elevated areas, to as much as 300 000 mg/L TDS in brines in palaeochannels, adjacent playa-lake sediments, and in fractured and weathered bedrock. The salinity range of groundwater from the major borefields is given in Table 1.
Potable water (<1000 mg/L TDS) on KURNALPI is generally restricted to the upper reaches of catchments where recharge is enhanced by residual sandplains overlying unweathered, fractured rocks. Occasionally fresh groundwater has been found along major drainages, such as in Christmas Bore (540 mg/L TDS) close to Lake Roe (Williams, 1970).

Brackish groundwater (1000–3000 mg/L TDS) commonly occurs in elevated areas, particularly in alluvium, schist, and fractured and deeply weathered mafic and ultramafic rocks (Williams, 1970).

Saline groundwater (3000–30 000 mg/L TDS) is widely distributed throughout KURNALPI and many pastoral bores and wells have groundwater salinities ranging from 3000 mg/L to 12 000 mg/L TDS.

Hypersaline groundwater (>30 000 mg/L TDS) occurs mainly in palaeochannels and in bedrock below and adjacent to alluvial flats and playa lakes such as those found in the Queen Lapage exploratory bores and Kanowna (Delta Gold) Borefields. Hypersaline groundwater also occurs in greenstone belts remote from playa lakes such as those in the Halfway Dam and East Location 50 Borefields.

The high salinity of groundwater in playa-lake environments results from the concentration of salts as water evaporates from the lakes. However, the salinity of the ephemeral lakes varies greatly. Many of the claypans may fill with fresh runoff, and the water may remain fresh or brackish, even though the underlying groundwater is saline (Williams, 1970). The water in the large playa lakes is generally saline and the salinity often approaches the saturation point of sodium chloride.

The salts in the groundwater system originate from marine aerosols; only a small proportion is derived from the weathering of bedrock (McArthur et al., 1989). The salts in the highly saline groundwater of the palaeochannels may have been accumulating for hundreds to thousands of years (Commander et al., 1994).

There seems to be little relationship between groundwater salinity and bedrock type. Limited data indicate that there is no appreciable variation with depth in fractured and weathered bedrock. Most salinity variations occur on a topographical and geographical basis.

The mapped salinity pattern is based on available data and does not take into account unrecorded bores that may have been abandoned after drilling because of high salinity or low yields.

Local variation

Groundwater salinity may vary markedly over short distances in fractured rocks. In the exploratory bores at the Kanowna (Delta Gold) borefield, it ranges from 27 000 to 207 000 mg/L TDS and possibly reflects the complexity of fracture systems or the proximity of palaeochannels. Consequently, it is difficult to map the groundwater-salinity pattern in the Archaean bedrock at a local scale.

Variation within aquifers

Based on data from shallow wells, the groundwater salinity in areas of elevated granitoid rocks is relatively low and ranges from about 2000 to 12 000 mg/L TDS throughout KURNALPI. This is probably because of the sandplain cover, which enhances recharge, and the relatively high elevation of the granitoid terranes.

The groundwater salinity in different types of greenstone aquifer tends to be highly variable, ranging from less than 1000 mg/L TDS (e.g. Bakers Well) to over 200 000 mg/L TDS throughout KURNALPI. Large, local variations in groundwater salinity are common — in the Kanowna (Delta Gold) Borefield it ranges from 27 000 to 207 000 mg/L TDS. The highest salinity (287 000 mg/L TDS) was recorded in exploratory bores in Archaean sedimentary rocks at the Queen Lapage mining centre situated adjacent to the Lake Yindarlgooda (Rockwater, 1988).

The groundwater salinity in the Tertiary sediments in the Roe Palaeodrainage increases from 41 000 mg/L TDS (Line O) in a tributary of the Yindarlgooda South Palaeochannel to about 200 000 mg/L TDS (Line M) near Lake Yindarlgooda (Fig. 3). The salinity in the Yindarlgooda North Palaeochannel decreases downstream from about 216 000 mg/L TDS in the Fimiston-Gidji Borefield located in a salt lake environment to 187 000 mg/L in Line V and 140 000 mg/L TDS in Line U, indicating significant lateral recharge of lower salinity groundwater from tributary palaeochannels (Fig. 3). The groundwater salinity also decreases downstream in the Yindarlgooda South Palaeochannel where it falls from about 197 000 mg/L TDS in Line M to 99 000 mg/L TDS in Line N. In the Hannan Palaeochannel the salinity also decreases downstream from 151 000 mg/L TDS in Line M to 99 000 mg/L TDS in the Hannan Lake Borefield to 124 000 mg/L TDS in Line L, reflecting local recharge. There is also apparent stratification of groundwater in the Wollubar Sandstone, with denser, high-salinity groundwater at the base of the aquifer (Commander et al., 1992).

The groundwater salinity in the Rebecca Palaeodrainage ranges from 200 000 to 300 000 mg/L TDS and there is also stratification with denser more saline groundwater at the base of the aquifer (Smyth and Button, 1989). Groundwater in the Raeside Palaeodrainage has not been tested on KURNALPI, but its salinity is likely to exceed 200 000 mg/L TDS.

Chlorine-36 and Carbon-14 isotope analyses have been carried out on water samples from Line M (Commander et al., 1994). The study indicates that the groundwater contains salts from Lake Yindarlgooda and that flow rates are of the order of 1 m/year.

Hydrochemistry

The results of chemical analyses of groundwater from 16 bores and wells are shown in Table 2, and the major ions are plotted as a percentage of their total milli-equivalents per litre concentrations on a trilinear diagram in Figure 4. In water from most of these bores and wells sodium...
chleride forms the greatest part of the dissolved solids. The proportions of the major ions in saline groundwater are close to the proportions in seawater.

Magnesium represents significant proportions in the groundwater composition. The proportion of bicarbonate is low in all bores and wells within fractured bedrock with the exception of Dingo Well. It is negligible in palaeochannel aquifers, especially in the more acidic groundwater, which contains free carbon dioxide.

The pH values in fractured and weathered Archaean bedrock range from 3.6 to 8.6. The pH values tend to be less widespread in palaeochannel system, ranging from pH = 4.6 in bore LW6, located in the Hannan Palaeochannel, to pH = 8.1 in Line O, which is situated in a tributary of the Yindalrgooda South Palaeochannel (Table 1). Low pH of groundwater causes severe metal corrosion. The pH can be raised, usually by adding lime. The preferred acidity for carbon-in-pulp/carbon-in-leach circuits for ore processing is between pH 9.0 and 9.5. High concentrations of sulfate and magnesium in mine-process water cause scaling problems.

**Groundwater development**

**Groundwater exploration**

Geophysical techniques have been used with varying success to locate palaeochannels on KURNALPI. Seismic methods have been used for delineating the palaeochannel profile across the valleys, but are slow and relatively expensive (Smyth and Button, 1989). Electrical methods for locating the presence of highly conductive (saline)
Table 2. Selected chemical analyses of groundwater

<table>
<thead>
<tr>
<th>Borewell</th>
<th>Aquifer</th>
<th>pH</th>
<th>EC (mS/m @ 25°C)</th>
<th>TDS (mg/L)</th>
<th>Total hardness (as CaCO₃)</th>
<th>Total alkalinity (as CaCO₃)</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>HCO₃⁻</th>
<th>Cl⁻</th>
<th>SO₄²⁻</th>
<th>NO₃⁻</th>
<th>SiO₂</th>
<th>B</th>
<th>F</th>
<th>H⁺</th>
<th>Fe</th>
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<td>Milky (a)</td>
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<td>8.4</td>
<td>1 180</td>
<td>6 020</td>
<td>677</td>
<td>NA</td>
<td>32</td>
<td>145</td>
<td>1900</td>
<td>55</td>
<td>445</td>
<td>2 690</td>
<td>880</td>
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<td>569</td>
<td>2 070</td>
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<td>NA</td>
<td>48</td>
<td>46</td>
<td>520</td>
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<td>765</td>
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<td>KFF7 (c)</td>
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<td>580</td>
<td>8 800</td>
<td>1 708</td>
<td>NA</td>
<td>140</td>
<td>330</td>
<td>2 300</td>
<td>45</td>
<td>493</td>
<td>3 740</td>
<td>590</td>
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<td>QLW2 (d)</td>
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<td>NA</td>
<td>683</td>
<td>8 740</td>
<td>78 800</td>
<td>239</td>
<td>25</td>
<td>140 300</td>
<td>14 650</td>
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<td>HW27 (e)</td>
<td>Sedimentary, felsic volcanic and volcaniclastic rocks</td>
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<td>NA</td>
<td>NA</td>
<td>1 300</td>
<td>3 600</td>
<td>34 250</td>
<td>82</td>
<td>40</td>
<td>66 500</td>
<td>3 850</td>
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<td>80 000</td>
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<td>NA</td>
<td>580</td>
<td>3 700</td>
<td>34 800</td>
<td>153</td>
<td>40</td>
<td>61 000</td>
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<td>192 000</td>
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<td>65</td>
<td>890</td>
<td>5 780</td>
<td>64 700</td>
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<td>79</td>
<td>112 000</td>
<td>8 790</td>
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<td>RNS (o)</td>
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<td>95 000</td>
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<td>203</td>
<td>621</td>
<td>3 800</td>
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<td>248</td>
<td>53 400</td>
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<td>8 770</td>
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<td>432</td>
<td>1 870</td>
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<td>4 600</td>
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<td>16 900</td>
<td>18 600</td>
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<td>42</td>
<td>742</td>
<td>7 580</td>
<td>58 900</td>
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<td>KR13 (s)</td>
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<td>15 300</td>
<td>140 000</td>
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<td>71</td>
<td>663</td>
<td>5 440</td>
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<td>167</td>
<td>87</td>
<td>80 900</td>
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<td>6</td>
<td>NA</td>
<td>NA</td>
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</tr>
</tbody>
</table>

Notes: (a) Milky Well; (b) Dingo Rock Well; (c) Karonie Borefield; (d) Queen Lupage test hole no. 2; (e) East Location 50 Borefield; (f) Kanowna Borefield; (g) Fimiston-Gidji Borefield; (h) Kanowna Borefield; (i) GSWA Line 50; (j) GSWA Line M; (k) GSWA Line N; (l) GSWA Line Q; (m) GSWA Line T; (n) GSWA Line U; (o) GSWA Line V; EC = Electrical conductivity; TDS = Total dissolved solids by calculation.
groundwater in palaeochannels produce satisfactory results at significantly lower cost than other methods, although deeply weathered bedrock can have the same characteristics (Street, 1989). Electromagnetic techniques such as magnetometric resistivity (Street, 1989) and transient electromagnetics (Smyth and Button, 1989) have been used successfully in the sheet area to locate palaeo-channels.

Preliminary exploratory drilling by rotary air-blast (RAB) is usually carried out to locate useful water supplies in bedrock areas. The bedrock aquifers generally contain minor groundwater supplies that are difficult to locate, and therefore require a large number of exploratory bores. The hydrogeology is likely to be complex, reflecting the variety of bedrock types, structure, degree of weathering, and wide range of salinities. Bore yields reflect the degree of fracturing and type of weathering (Table 1).

**Mining**

The majority of bores on KURNALPI have been drilled to obtain water for use in ore processing, the groundwater generally being too saline for other purposes. The borefields are therefore located close to major mining centres and obtain groundwater from Tertiary sediments in the palaeo-channels or from highly weathered and fractured Archaean bedrock.

In 1990 groundwater abstraction on KURNALPI from palaeo-channeals was about $3.8 \times 10^6$ m$^3$. The major users are the mines in the Golden Mile, which obtain their water supplies from the Lakewood, Fimiston–Gidji and Kaltails Borefields (Australian Groundwater Consultants, 1989, 1990a,b). Drawdown in borefields has been lower than predicted from short term pumping tests, indicating that significant inflow occurs from tributaries, weathered
and fractured bedrock, and by leakage from the overlying sediments. In 1990 groundwater abstraction from fractured and weathered bedrock was estimated to be about $1.65 \times 10^6$ m$^3$. The Blair Nickel and Halfway Dam Borefields are the major borefields in highly weathered and fractured bedrock, with bore yields in excess of 500 m$^3$/day.

All palaeochannels in the Roe Palaeodrainage west of Lake Yindalrgooda are exploited on KURNALPI. The Roe palaeochannel downstream of Lake Yindalrgooda and the Rebecca and Raeside Palaeochannels can be inferred to have groundwater resources similar to, if not larger than, those of the Wollubar Sandstone in Kalgoorlie area, but are undeveloped as they are remote from centres of demand and are mostly in granitic terrane unprospective for mineral deposits.

Groundwater obtained from mine dewatering is also used for ore processing and mining requirements. The major mine-dewatering activities are at the Hannan South Pit with groundwater abstractions in the order of about $450 \times 10^6$ m$^3$ in 1988 (K. H. Morgan and Associates, 1990) and at Kanowna (QED Mining Company) with an estimated groundwater abstraction in excess of $100,000$ m$^3$ in 1992. Dewatering will result in major changes to the groundwater regime where pits are being excavated below the watertable. On cessation of mining and dewatering, however, these pits will eventually fill with water to the level of the regional watertable. Groundwater abstraction from shallow bores downstream of the Kaltails tailings dam was in excess of $365 \times 10^6$ m$^3$/year when it was first commissioned to recover seepage loses.

Disposal of tailings occurs at mine sites, and seepage of highly concentrated saline water from unlined dams may cause contamination. Current practice is to line the tailings ponds to minimize leakage, and keep the salts stored within the tailings. Other potential contaminants include cyanide and metal-cyanide complexes.

**Pastoral**

Because of the relatively high salinity and the low yield of wells and bores, the majority of pastoral stations on KURNALPI are dependent on surface water for stock. The main sources are dams located along drainageways and alluvial flats. There are only a few shallow bores and wells in the area; most of them located in granitoid rocks in the northern half of the sheet area, but now mainly abandoned. Water for pastoral purposes is provided seasonally by gnamma holes, waterholes, rockholes, soaks, and lagoons.

**Further development**

On KURNALPI the basal sandstone unit in the palaeochannels is considered to be the most prospective aquifer for further development. It is readily located, exploited, and managed, and sustainable yields are much more likely than from weathered and fractured bedrock. The groundwater resources in the Roe Palaeodrainage are sufficient for current and planned mining developments, and future developments include a proposal to use $10 \times 10^6$ m$^3$/year for the development of the Bulong Nickel deposit which will be met by groundwater from palaeochannels (near Lake Yindalrgooda) east of current borefields. The Rebecca and Raeside Palaeodrainages appear to have the capacity to supply large quantities of groundwater.

The weathered and fractured bedrock aquifers on KURNALPI contain mainly saline to hypersaline groundwater. Low-salinity groundwater can be found in elevated outcrops of granitoid rocks and adjacent eluvium but yields in these areas are generally very small. Groundwater yields in the highly weathered and fractured bedrock aquifers depend on intersecting water-bearing fractures, and locating them is costly because several bores may be needed before the required supply is obtained.

**Groundwater resources**

Most of the groundwater on KURNALPI is saline to hypersaline and suitable for use only in industry, mining, and ore processing. Limited quantities of low-salinity groundwater are found in upland areas of granitoid rocks and perched aquifers, but they are usually difficult to locate.

Because the annual recharge from rainfall is very small, groundwater resources on KURNALPI are considered in terms of groundwater in storage, but only a proportion of this is economically recoverable.

The potential resources in fractured granite–greenstone bedrock are very difficult to estimate reliably on a regional scale because of the localized and discontinuous nature of fracture systems. This variability limits the extent of groundwater storage in fractured rocks.

BHP Engineering and Australian Groundwater Consultants (1988) determined a specific yield of 0.005 for the fractured-rock aquifers, based on aquifer testing. From this they calculated the total groundwater storage in fractured bedrock within 100 km of Kalgoorlie, and estimated the economically commandable groundwater reserves to be about $40 \times 10^6$ m$^3$, including about $13 \times 10^6$ m$^3$ on KURNALPI. Groundwater in the fractured rocks probably represents about 3% of the total groundwater resources of the region. BHP Engineering and Australian Groundwater Consultants (1988) also estimated a specific yield for the weathered-bedrock aquifers ranging from 0.001 to 0.005. From this they calculated the total economically commandable groundwater reserves within 100 km of Kalgoorlie to be about $60 \times 10^6$ m$^3$, including some $20 \times 10^6$ m$^3$ on KURNALPI. Groundwater in the weathered bedrock probably represents about 5% of the total groundwater resources of the area.

The Wollubar Sandstone and its equivalents in the Rebecca and Raeside palaeodrainages represent by far the largest groundwater resources on KURNALPI in terms of commandable groundwater reserves. The groundwater resources in the Roe Palaeodrainage west of Lake Yindalrgooda are estimated to range from $3.1$ to $6.7 \times 10^6$ m$^3$ per kilometre of channel length, based on a specific yield of 0.2 (Commander et al., 1992), and these...
resources are likely to increase east of Lake Yindarlgooda. Similar estimates are obtained in the Rebecca Palaeo-channel \((4.8 \times 10^6 - 6.4 \times 10^6 \text{ m}^3 \text{ per kilometre of channel length})\) and in the Raeside Palaeochannel (about \(4 \times 10^6 \text{ m}^3 \text{ per kilometre of channel length}\)) on the sheet area. The estimated volume of groundwater in storage is conservative because it does not include groundwater made available by pumping-induced inflow from the adjacent and underlying weathered and fractured bedrock, or by leakage from the overlying sediments. On a regional scale the groundwater resources in the Tertiary sedimentary rocks probably represent more than 90% of the total groundwater resources on KURNALPI.

Cainozoic surficial deposits are saturated only in low-lying areas where they are thickest, and therefore it is difficult to reliably estimate their groundwater resources. The specific yield of these sediments is probably less than 0.05 owing to the high clay content, and it is likely that the commandable groundwater resources are less than 3% of the total groundwater resources on KURNALPI.
References


AUSTRALIA BMR, 1965, Maps showing the results of an airborne magnetic and radiometric survey of the Kalgoorlie 1:250 000 area, W.A. 1957: Australia BMR, Record 1965/31 (unpublished).

AUSTRALIA BMR, 1987, Total magnetic intensity, Kurnalpi, W.A.: Australia BMR, 1:250 000 map.

AUSTRALIAN GROUNDWATER CONSULTANTS PTY LTD, 1979, Preliminary appraisal of complete water resources of Kalgoorlie area “2”: Western Australia, Public Works Department, Report (unpublished).


BEARD, J. S., 1975, The vegetation of the Nullarbor area: University of Western Australia Press, Vegetation Survey of Western Australia, 1:1 000 000 Series, Map and Explanatory Memoir, 104p.


K. H. MORGAN and ASSOCIATES, 1988, Annual report on monitoring of Halfway Dam borefield, Hannan South gold mine,


