

Mid West Minerals Province - Groundwater Resource Appraisal

Prepared by

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DISCLAIMER: This report has been compiled in response to requests from the public for the previously unpublished Water and Rivers Commission report HR129 from 1999. Interpretations contained in this report are based on data up until 1997.

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This report was prepared by Seth Johnson and Phil Commander of the Water Resource Management Division. The report is based on an unpublished Water and Rivers Commission report (HR129) that was compiled by the same authors in 1999.

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1 Introduction

The Mid-West region is a centre for future development with a number of significant mineral resources including mineral sands, gold, copper, zinc, iron ore and gas, and potential for industrial processing and irrigated horticulture. All these activities depend on availability of groundwater resources. This report aims to provide an overview of groundwater occurrence, potential yield, quality, and current use of groundwater resources in the study area, with a particular emphasis on the mining industry. It includes data on groundwater use by the mining industry in the Murchison, compiled from annual reports submitted by mining companies as part of licence conditions.

The Department of Resources Development funded part of this study specifically for the Mid-West Regional Minerals Study. This appraisal was initially completed in 1999; however, constant requests from the mining industry have necessitated placing the report on the Department of Water website. In the next two years, it is proposed to conduct another review of the monitoring data related to the Mid West mining industry focused primarily on iron ore mine expansion across the region.

The Mid-West Region is located in the central-western portion of Western Australia. The study area has a population of about 50 000 people with more than half residing in the regional centre of Geraldton. Other towns in the area service the coast, the agricultural area (wheatbelt), and the mining and pastoral areas (Fig.1). The major industries in the region include gold and mineral sands mining, broad-acre farming, livestock production, tourism and fishing.

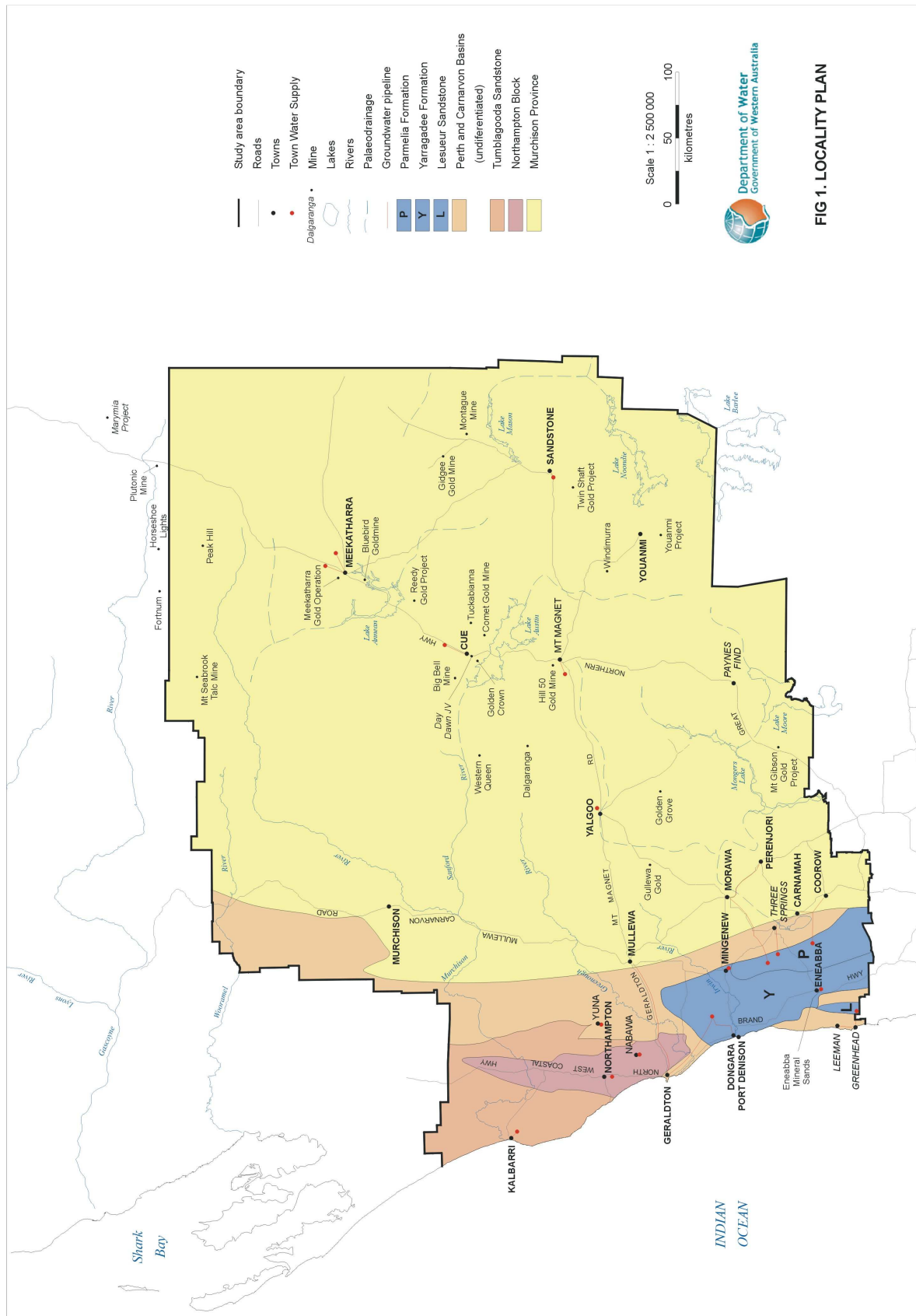


Figure 1. Locality plan of Mid West Minerals Province

2 Previous investigations

The earliest reports on groundwater are related to water supplies for mines and batteries in the Meekatharra (Maitland, 1908; Clarke, 1916; and Ellis, 1936a, 1936b) and Mt Magnet area (Jutson, 1914). The first description of the regional hydrogeology and the availability of groundwater in the Murchison was detailed by Morgan (1966), who undertook bore siting for various pastoral leases in the area. This was followed by Sanders (1969, 1973, 1974) who conducted a number of investigations focusing on groundwater in the calcrete drainages, east of Meekatharra.

Swarbrick (1964), Allen (1979), Commander (1981), Allen et al. (1992) and Nidagal (1994) have reported on the hydrogeology and groundwater resources of the northern Perth Basin to the east and south of Geraldton. The regional hydrogeology of the Carnarvon Basin was previously described by Allen (1987).

Baxter (1971) described the hydrogeology of the Murgoo 1:250 000 sheet. Laws (1992) and Johnson (1998) described the hydrogeology and availability of groundwater for the pastoral industry in the Murchison and in the Sandstone-Yalgoo-Paynes Find regions to the south. The hydrogeology of the wheatbelt in the south of the study area on the Perenjori 1:250 000 sheet was mapped and described by Commander and McGowan (1991).

Regional assessments of the groundwater resources were compiled for national reviews (AWRC, 1987). Panasiewicz (1997) estimated groundwater resources in the Murchison Region (comprising the Murchison, Greenough and Irwin Catchments), mainly relating to town water supplies.

Most other reports on groundwater in the area are unpublished reports covering work carried out to locate water supplies for pastoral leases, road construction, individual mines, and town water supplies operated by the Water Corporation. Other unpublished reports review performance of borefields supplying towns and mining operations in the study area.

3 Physical environment

3.1 Climate

The coastal area experiences a Mediterranean-type climate with hot, dry summers and cool, wet winters. Conditions become progressively drier in winter and hotter in summer towards the east, hence the inland areas are classified as semi-arid to arid. Annual rainfall varies from about 500 mm on the coast to less than 200 mm inland, north of Meekatharra. Most of the rain occurs during the winter months from cold fronts associated with low-pressure systems from the southwest, while periodic summer rainfall results from tropical rain depressions or thunderstorm activity. The rainfall pattern throughout the region is highly irregular, and in some years there are often extended periods of drought. The potential evaporation generally exceeds precipitation by an order of magnitude ranging from about 2500 mm at the coast to 4000 mm in the northeast.

3.2 Topography and drainage

The regional topography and drainage patterns are controlled by the geological structure and geological history of the region. In broad terms the Mid-West Region can be subdivided into a coastal plain, coastal plateau, and a partially dissected interior plateau coinciding with the geologically-distinct superficial formations, Mesozoic sediments of the Perth Basin, and Precambrian rocks of the Yilgarn Craton. In detail, various geomorphological areas have been recognised by Jennings and Mabbutt (1986), Curry et al. (1994) and Payne et al. (1998).

The coastal plain is up to 20 km wide, and rises gently to about 50 m above sea level along the edge of the coastal plateau. It is characterised by gently undulating sand dunes that form sub-parallel to the coastline. The coastal plateau reaches a maximum elevation of about 300 m and is characterised by a relatively flat sandplain interspersed by ridges and mesas formed by resistant strata. The interior plateau is generally of low relief and characterised by large playa lakes occupying broad alluvial valleys, known as palaeodrainages, between erosional escarpments (breakaways) of lateritised bedrock highs.

The majority of region is externally draining to the west into the Murchison, Greenough, and Irwin River catchments, and subsequently to the Indian Ocean. All drainages are ephemeral, except the Murchison River is intermittent and may flow for long periods after heavy rainfall. The remainder of the area, mainly in the east and southeast, is characterised by internal drainage into inland salt lakes such as Lake Moore and Lake Austin. The direction of flow in these broad alluviated valleys ranges from southwest-flowing in the west to southeast-flowing in the east. A number of these drainages in the

east, including Lake Mason and Lake Noondie, form the headwaters of the Raeside and Carey Palaeodrainages which subsequently discharge into the Eucla Basin (Johnson *et al.*, 1999).

4 Regional geology

Most of the area lies within the Murchison Province, which is the westernmost of three granite-greenstone terranes in the Archaean Yilgarn Craton (Watkins, 1990). In the north and northwest, the Murchison Province is in tectonic contact with the Narryer Gneiss Complex of the Western Gneiss Terrane (Myers, 1990), whilst to the northeast the granite-greenstone rocks are overlain by Proterozoic sediments of the Nabberu Basin (Gee, 1990). Overlying the basement rocks, in particular along the palaeodrainages, are alluvial, colluvial and calcrete deposits of Cainozoic age.

Sedimentary rocks of the Northern Perth Basin underlie the western portion of the study area. The inland extent of these sediments is marked by the Darling Fault. In the west, sediments of both the Perth and Carnarvon Basins, principally the Tumblagooda Sandstone, flank the granitic Northampton Block. In the northwest of the study area, Carnarvon Basin sediments overlie the Yilgarn Craton. The generalised stratigraphy of the rock units has been summarised and simplified in Table 1, on the basis of hydrogeological significance.

4.1 Stratigraphy and structure

The Archaean rocks of the Murchison Province comprise linear to arcuate, north to northwest-trending greenstone belts, which have been intruded by granitoid rocks (Fig. 1). The greenstones occur beneath 40% of the Murchison Province and contain metamorphosed and deformed sequence of mafic to ultramafic volcanic rocks, felsic volcanic rocks and metasedimentary rocks, including chert and banded iron-formations (BIF). Granitoids occur beneath the remaining 60% of the area and comprise plutons of mainly equigranular to porphyritic adamellites with minor occurrences of granite, gneiss and migmatite.

The Narryer Gneiss Complex consists of migmatite, banded-gneiss and quartzite of Archaean age, which is believed to be derived from deformation of a coarse-grained granite (Myers, 1990).

Lower Proterozoic sediments of the Glengarry Sub-basin of the Nabberu Basin occur in the northeast, where they unconformably overlie the Archaean basement. These sediments comprise metamorphosed highly deformed sandstone, shale, banded iron-formation and basalt, which were deposited during four episodes of sedimentary-tectonic basin evolution.

The Northampton Block is a relatively small area of Proterozoic crystalline basement that occurs in the west of the study area. The metamorphosed granulite, granite and migmatite rocks form part of a linear ridge that separates the Perth and Carnarvon Basins.

Table 1. Generalised stratigraphy and hydrogeology

Age	Name	Lithology	Hydrogeology
Quaternary	Alluvium	Fine to coarse-grained sand with lenses of clay and gravel	Major surficial aquifer in stream channels and palaeodrainages; fresh to saline groundwater; used for pastoral supplies
Late Tertiary	Calcrete	Sheet calcrete	Major surficial aquifer in palaeodrainages; fresh to saline groundwater; large supplies utilised by mining industry
Early Tertiary	Palaeochannel deposits	Grey plastic clay overlying fine to coarse, carbonaceous, basal sands	Major confined sedimentary aquifer in palaeodrainages; saline to hypersaline; large supplies from sands; suitable for mining industry
Cretaceous	Parmelia Formation	Interbedded sandstone, siltstone and shale	Significant confined sedimentary aquifer in Perth Basin; fresh to marginal groundwater; very large supplies
Jurassic	Yarragadee Formation	Interbedded sandstone, siltstone and shale	Significant confined sedimentary aquifer in Perth Basin; fresh to marginal groundwater; very large supplies
Triassic	Lesueur Sandstone	Sandstone	Significant confined sedimentary aquifer in Perth Basin; fresh groundwater; large supplies
Silurian	Tumblagooda Sandstone	Sandstone with local interbeds of siltstone	Significant confined sedimentary aquifer in Perth and Carnarvon Basins; brackish groundwater; fresh to marginal in recharge zone; very large supplies
Proterozoic	Northampton Block	Granite, gneiss and dolerite	Minor local fractured-rock aquifer in linear belt separating the Perth and Carnarvon Basins; fresh to saline groundwater; small supplies from fractures
Archaean	Granitoids	Granitoid rocks intruded by quartz veins and dolerite dykes	Minor local fractured-rock aquifer in plutons; fresh to saline groundwater; moderate supplies from weathering profile and fractures
	Greenstones	Mafic to ultramafic volcanics, felsic volcanics, and metasedimentary rocks including chert and BIF	Minor local fractured-rock aquifer in linear, fault-bounded belts; fresh to saline groundwater; moderate to large supplies from fractures and shear zones
	Migmatites and gneiss	Foliated and deformed granitic gneiss rocks	Very minor fractured-rock aquifer in linear belts; part of Narryer Gneiss Complex; brackish to saline groundwater; small supplies from weathering profile and fractures

The Permian sediments of the Carnarvon Basin (Byro Group) consist of a series of sandstone, conglomerate, siltstone, claystone, carbonaceous shale and some glacial erratics (Hocking, 1990). In the northeast of the basin, the sediments rest unconformable on the Archaean bedrock in a down-faulted synclinal zone known as the Byro Sub-basin. At the coast, near Kalbarri, there are prominent outcrops of the Silurian Tumblagooda Sandstone, which is the oldest rock unit in the Perth and Carnarvon Basins.

The sedimentary rocks of the Northern Perth Basin occur to the west of the Darling Fault and Yilgarn Craton. The Phanerozoic sediments, including the Lesueur Sandstone, Cattamarra Coal Measures, Yarragadee Formation, Parmelia Formation and Tumblagooda Sandstone, are deposited as a series of interbedded sandstone, siltstone, claystone and shale. The top of the Yarragadee Formation has been eroded, weathered and lateritised and it is unconformably overlain on the coastal plain by the superficial formations.

Most of the Archaean bedrock is largely obscured beneath a cover of Cainozoic deposits, which infilled the palaeodrainages during the early Tertiary. The palaeochannel sediments, where explored at Mt Gibson, have a thickness of up to 100 m and typically comprise an upper and lower sequence. The lower sequence comprises a basal, alluvial sand of Eocene age, which is confined by a plastic clay of lacustrine origin. The upper sequence of unconsolidated alluvium and calcrete has a variable thickness of up to 20 m thick, and reflects a slope-wash and valley calcrete environment. This sedimentary sequence is very similar to that observed in the Northern Goldfields region by Johnson *et al.* (1999).

Alluvial deposits occur along the valleys of the Greenough, Irwin and Murchison Rivers. In the east, there are thick sections of alluvium comprising channel fill within the palaeodrainages. Colluvium occurs marginal to rock outcrops, where it forms a thin veneer over fresh and weathered bedrock. Laterite and silcrete are often developed as a capping on the kaolinised weathered profile. The cappings are sometimes preserved as mesas and breakaways along the major drainage divides and may be overlain by thin sheets of eolian sand.

5 Hydrogeology

5.1 Source of data

In addition to the published sources of geological and groundwater information, 220 reports held by Water and Rivers Commission containing groundwater information related to mine and town water supplies in the Mid-West Region were consulted. Other sources of information included GSWA town water supply investigations, Water Corporation groundwater scheme reviews, and bore information stored in the Water and Rivers Commission's water point database (AQWABase).

5.2 Occurrence of groundwater

Groundwater occurs throughout the study area. It may occur within sparse fractures in the basement rocks; within fractures and secondary porosity produced by chemical alteration in the weathering profile; within karstic features developed in calcrete; and within primary porosity in the alluvial, colluvial and palaeochannel sediments. There are also significant aquifers present within sedimentary basins occurring as discrete formations of sandstone or limestone.

The groundwater flow systems throughout the area are maintained by rainfall recharge. Groundwater recharge is difficult to estimate as it constitutes a very small proportion of rainfall, most of which is either directly evaporated or utilised by the native vegetation, with a small component of runoff into rivers, claypans and playa lakes. Most recharge is likely to occur during heavy rainfall when it is enhanced by recharge from surface runoff and local flooding.

In the coastal plain and coastal plateau, groundwater discharges from the unconfined aquifers by subsurface flow into river pools, by evapotranspiration, and outflow along the coast. Whereas on the inland plateau, groundwater discharge is dominated by evaporation from playa lakes, and only a relatively small amount of throughflow is apparent within the palaeochannels.

5.3 Main aquifers

The location of large groundwater supplies, irrespective of salinity, is dependent on the presence of suitable groundwater-yielding rock types and site-specific geological conditions, such as the presence of fractures or shear zones. The main aquifers identified in the study area are listed in Table 1 with a brief description of groundwater occurrence, groundwater salinity and yield characteristics. The location of the major aquifers in the Perth Basin, together with areas underlain by Tumblagooda Sandstone is

shown in Figure 1. Other areas in the Northern Perth Basin, shown as undifferentiated on Figure 1, are relatively poorly known, but are considered to contain low yielding aquifers with high groundwater salinity. The Murchison Province, which comprises the majority of the study area, comprises fractured rock, with alluvium, calcrete and palaeochannel aquifers occurring along the rivers and palaeodrainages shown.

5.3.1 Alluvium

Alluvium, which forms the upper sequence of the Cainozoic stratigraphy within the palaeodrainages, generally consists of fine to coarse-grained quartz sand with lenses of gravel, silt, and clay. In places, the alluvium is interfingered by outwash fans, talus and scree-slope deposits (colluvium) that occur marginal to bedrock and extend downslope to the alluvium-filled palaeodrainages. The thickness of alluvium ranges from about 5 to 20 m, depending on its location in the drainage system. Bore yields are likely to be highly variable, possibly up to 100 kL/day, dependent on sorting and clay content. Groundwater salinity is also variable ranging from potable, such as utilised for the Mount Magnet town water supply, to saline (greater than 7000 mg/L TDS) in the lower reaches of the palaeodrainage systems.

In the Northern Goldfields, Johnson *et al.* (1999) noted that the alluvial aquifer is an important component of the hydrogeological cycle, as it contains significant quantities of low-salinity groundwater. The aquifer in the study area is generally under-utilised for mineral processing owing to its low permeability; however, most stored groundwater is often obtained through leakage into more-permeable, underlying features, such as palaeochannel sands and fractured-rock aquifers.

5.3.2 Calcrete

Calcrete is a carbonate rock formed by the *in situ* replacement of valley-fill debris by magnesium and calcium carbonate precipitated from percolating carbonate-saturated groundwater (Mann and Horwitz, 1979). It generally occurs at the margins of present day salt lakes, and locally in some of the main sub-catchments in the palaeodrainages. Bodies of calcrete are generally less than 10 m in thickness; extend over areas of 1 km² to over 100 km², such as near Yarrabubba Homestead. Karstic features, including sinkholes and gilgai structures, are common features with the calcrete aquifers.

Calcrete has a well-developed secondary porosity and high permeability, and forms an excellent aquifer with bore yields in excess of 1000 kL/day. As calcrete is generally located in the lower reaches of the groundwater flow systems, it usually contains brackish groundwater between 2000-6000 mg/L TDS (Sanders, 1969). There are small potable supplies, such as in the town water supplies for Meekatharra and Cue, where the calcretes have good recharge due to runoff and are above the local base-level of groundwater drainage. In general, calcrete aquifers can provide readily obtainable, large supplies of brackish groundwater suitable for watering stock and mineral processing.

5.3.3 Palaeochannel deposits

The Tertiary sediments within the palaeodrainage systems are poorly documented throughout the area, however the stratigraphy and hydrogeology is likely to be similar to the Carey and Raeside Palaeodrainages (Johnson *et al.*, 1999). In the Mt Gibson gold mine borefield, the palaeochannel comprises a basal, coarse to fine-grained, carbonaceous, alluvial sand which is overlain by a confining layer of dense, kaolinitic clay up to 40 m thick. The basal sands range in thickness from 10 to 40 m, and become thicker, broader and coarser downstream (G.R.C., 1988).

Bore yields from the palaeochannel sand aquifer in the Mt. Gibson borefield range from 100 to 1000 kL/day, with yields increasing further downstream (G.R.C., 1988). Groundwater salinity within the palaeodrainages increases downgradient of salt lakes from 30 000 mg/L to over 100 000 mg/L TDS. The aquifer in the northern Goldfields is capable of producing large and consistent yields (Johnson *et al.*, 1999). However, the palaeochannel aquifer is poorly explored in the Mid-West Region and its usefulness is mainly restricted to the mining industry due to the hypersalinity.

5.3.4 Parmelia Formation

The Parmelia Formation consists of as much as 400 m of interbedded sandstone and shale, containing fresh groundwater, except adjacent to the Darling Fault in the extreme southeast. Groundwater is recharged directly from rainfall on the overlying sandplain, and groundwater appears to discharge in the subsurface to the Yarragadee Formation, in springs along the western margin of the aquifer, and by groundwater flow to the south. The aquifer is used for town water supply to Mingenew, Morawa-Perenjori, Three Springs, and Carnamah-Coorow, for farm water supply, and irrigation of wildflowers.

5.3.5 Yarragadee Formation

The Yarragadee Formation is an extensive aquifer of the Perth Basin containing large volumes of fresh to brackish groundwater in storage. The formation is up to 3000 m thick, and extends from the Allanooka area (Geraldton Water Supply) to the Perth Metropolitan area. Allen (1979) provides a more detailed description of the geology and hydrogeology of the Yarragadee Formation in the area north of the Irwin River.

The Yarragadee Formation is a multi-layered aquifer with groundwater occurring within beds of fine to coarse-grained sandstone confined between thick sequences of shale and siltstone. Recharge is from direct infiltration of rainfall and surface runoff, where the formation is exposed, as well as by vertical leakage from overlying formations. The direction of flow in the aquifer is predominantly to the west with some upward leakage into the overlying superficial deposits towards the coast. Nidagal (1994) noted that most groundwater discharges from the Yarragadee Formation into the Tamala Limestone, with minor discharge into the Cattamarra Coal Measures across the Beagle Fault.

Groundwater in the Yarragadee Formation is typically fresh to marginal with a salinity ranging from about 500 to 1500 mg/L TDS. There is a marked increase in salinity along the flow-lines with salinity exceeding 1500 mg/L in the discharge areas adjacent to the coast. Groundwater salinity is also known to vary within the different sandstone beds, and there is general trend of increasing salinity with depth. The depth to watertable on the coastal plateau is greater than 100 m, which has precluded large-scale private development, whereas on the coastal plain the watertable is shallower. Bore yields from the Yarragadee Formation are generally very large with yields of up to 6000 kL/day achieved at Eneabba.

Groundwater from the Yarragadee Formation is supplied to Geraldton (and Morawa), Dongara-Denison, and Eneabba.

5.3.6 Lesueur Sandstone

The Lesueur Sandstone occupies a limited area in a strip about 10km from the coast south west of Eneabba (Fig.1). The formation comprises about 500m of sandstone, and is in hydraulic connection with the overlying Eneabba Formation which is an interbedded sequence of sandstone and shale. Groundwater recharge takes place on the outcrop areas around Mt Lesueur and groundwater flow is northwards. Groundwater salinity in the area is less than 1000 mg/L. Bore yields are potentially large; apart from a few farm bores, the only production is for Greenhead-Leeman scheme supply.

5.3.7 Tumblagooda Sandstone

The Tumblagooda Sandstone occurs in both the Perth and Carnarvon Basins, and comprises a partially silicified, medium to coarse-grained sandstone. It occurs on the flanks of the Northampton Block and at depth beneath the western Carnarvon Basin.

Groundwater occurs in the primary porosity of the sandstone, which has been enhanced as a result of secondary fracturing. Recharge to the Tumblagooda Sandstone is by direct infiltration of rainfall and surface runoff in outcropping areas, and downward leakage during flooding of the Murchison River. Fresh to brackish groundwater is limited to these areas of outcrop, however, the salinity is known to increase with depth and distance from the recharge area.

Groundwater from the Tumblagooda Sandstone is used for town water supply to Kalbarri.

5.3.8 Fractured-rock aquifers

The main fractured-rock aquifers are the granitoid and greenstone rocks of the Murchison Province, and the gneisses and migmatites of the Northampton Block.

Granitoids

The granitoid rocks consist of even-grained to porphyritic granite and adamellite. They are lateritised and deeply weathered, up to 30 m thick, and characterised by a thin duricrust or silcrete over a variable thickness of sandy kaolinitic clay. This weathering profile has developed through the chemical breakdown of the crystalline bedrock during Tertiary and Quaternary times. Groundwater can be generally obtained from the quartz-rich grit at the base of the weathering profile, although some groundwater may also be present in open joints and fractures within the upper 5-10 m of the fresh bedrock.

Bore yields from the weathering profile are generally small, up to 100 kL/day, although larger supplies may be available from lineaments, faults or shear zones within the fresh bedrock. Large supplies are often difficult to locate in the granitoids because of their homogeneity and generally sparse fracturing. The salinity of the groundwater ranges up to 5000 mg/L TDS with lower salinity water occurring along the drainage divides, and increasing in salinity towards the drainage lines.

Greenstone

The greenstones comprise mafic and ultramafic volcanics, felsic volcanics, volcanoclastics and metasedimentary rocks, including cherts and banded iron-formations. They occur in major north-south trending belts throughout the study area. Locally, these rocks have a deep weathering profile which consists predominantly of dense clay, except over ultramafics which are capped by a vuggy silcrete.

Small groundwater supplies are generally obtainable from near the base of the weathered zone and in the immediately underlying fractured rocks. Large supplies of up to 1500 kL/day have been obtained from bores, up to 100 m deep, located within highly fractured and sheared basalts, cherts and banded iron-formation (A.G.C. Woodward Clyde, 1995). The salinity generally ranges from 200 to 4000 mg/L TDS beneath catchment divides, however salinities in excess of 15 000 mg/L TDS have been obtained in low-lying areas.

Gneiss and migmatite

Groundwater in the Narryer Gneiss Complex generally occurs within the weathered profile, which has a high clay content, but the gritty-layer found at the base of the granitoid weathering profile, is generally absent. As a result, supplies are usually less than 10 kL/day with salinities generally ranging between 1000 and 7000 mg/L TDS, although less saline groundwater (1000 mg/L TDS) can be obtained beneath drainage divides. The weathering profile on the Northampton Block has been largely removed by erosion; hence, groundwater occurrence is related to the presence of poorly-developed fracture systems.

6 Groundwater resources

6.1 Detailed estimates - Perth Basin

The major groundwater resources in the study area are in the Yarragadee and Parmelia Formations in the northern Perth Basin (Fig. 1). These groundwater resources have been estimated on the knowledge of the aquifers derived from exploratory drilling, and the applicability of interpolating data between widely-spaced boreholes. Resource estimates have been made for the purposes of allocation, and are the basis of the management plan for the Arrowsmith Groundwater Area (WAWA, 1995). The current resource estimates in the management plan, and draft allocation plan for the Allanooka Groundwater Subarea, are broadly consistent with the resource estimates made by Allen *et al.*, 1992 (Table 2).

Table 2. Sustainable groundwater resources in the Northern Perth Basin (in GL/yr)

Aquifer	Allen et al., 1992	Arrowsmith GWA (WAWA, 1995)	Panasiewicz 1997*
Parmelia Formation	42	52	-
Yarragadee Formation	110	84.3	88
Cattamarra & Eneabba Fms.		3.5	20
Lesueur Sandstone	7	2	-
TOTAL	159	149.8	108*

* estimate made for area to the north of Arrowsmith River only

Licensed allocation in the Arrowsmith Groundwater Area at June 1995 was 54.8 GL/yr leaving 97 GL/yr available for private use (WAWA, 1995). Revised allocations for the Allanooka Subarea (Draft Allocation Plan, 1998) leave 21.9 GL/yr available for private use, with a public water supply component of 12 GL/yr (current) and 8 GL/yr (future).

6.2 Broadscale estimates

Groundwater resource estimates for the rest of the area (Table 3) have only been made on a broadscale for national (AWRC, 1987), State (Allen *et al.*, 1992), and regional reviews (Bestow, 1992; Panasiewicz, 1997), and these cannot be used for allocation or planning purposes. They are only useful a guide to comparison on a regional basis. There are no large single groundwater sources (other than the Perth Basin aquifers discussed above) that have been studied in sufficient detail to give firm resource estimates. These reviews identified the possible renewable resources in surficial, sedimentary and fractured-rock aquifers within defined salinity ranges. They do not identify the location of major aquifers, and are useful mainly for identifying the order of magnitude of available groundwater resources.

Table 3. Broad scale groundwater resource estimates for Yilgarn-Murchison

Aquifer	Groundwater Resources (a) (AWRC,1987)		Groundwater recharge (b)	Renewable resource (c)
	Major Resources	Minor Resources	(Bestow, 1992)	(Panasiewicz, 1997)
Calcrete				4.5
Valley-fill (alluvium & palaeochannel)	17	27		39.7
Fractured	7	289		9
TOTAL	24	316	84.8	53.2

(a) includes Yilgarn-Murchison groundwater province to the east of the study area

(b) estimates for about 1/3rd of the area (4 x 1:250 000 sheets along eastern boundary of study area)

(c) Murchison and Greenough catchments only

The areas used for deriving the resource estimates shown in Table 3 are not directly comparable, although the methods used are broadly comparable. AWRC (1987) used recharge rates ranging up to 1% of rainfall, and Bestow (1992) used rates up to 0.9%, while Panasiewicz's (1997) estimates are stated to be based on those of AWRC, but appear to be smaller. These estimates have been made with little consideration of the actual distribution of aquifers.

Groundwater resources in the Northampton Block area are generally small and cannot be satisfactorily estimated on a regional basis. Groundwater availability is on a site specific basis.

Allen et al. (1992) quoted a groundwater resource in the Tumblagooda Sandstone of 41 GL/yr. This was based on the aquifer area, using a relatively high recharge rate derived from the low groundwater salinity in the aquifer at Kalbarri. However a sustainable yield of this magnitude this has yet to be proven. Much of the aquifer lies under a National Park, and there is therefore no bore information. Panasiewicz (1997) similarly gives renewable resource of 29 GL/yr for the Tumblagooda Sandstone.

Specific estimates are not given for the remainder of the Perth Basin (undifferentiated in Figure 1), where the aquifers have not been studied in sufficient detail, but are considered to contain small resources of relatively high salinity groundwater.

7 Groundwater development

7.1 Public water supplies

In general, there are adequate supplies of potable groundwater to meet consumer demand throughout the Mid-West region. The demand for potable groundwater is related to population density with most groundwater consumed by the towns of Geraldton, Dongara and Meekatharra. All town water supplies in the region are currently obtained through groundwater schemes operated by the Water Corporation. The potable water requirements for most of the mine sites throughout the region are obtained from groundwater, mainly from elevated weathered and fractured-rock aquifers.

Most of the towns on the coastal plain and coastal plateau obtain their potable groundwater from the Perth Basin. Geraldton is the largest consumer of potable groundwater in the region with 8.3 GL used in 1993 from the Allanooka groundwater scheme (Yarragadee Formation). In addition, the Water Corporation currently supplies another 1.1 GL/yr of potable groundwater from the Perth Basin to meet the demand of Dongara, Denison, and Eneabba (Yarragadee Formation), Mingenew, Morawa, Perenjori, Three Springs, Carnamah, and Coorow (Parmelia Formation), Greenhead and Leeman (Lesueur Sandstone). Mullewa is supplied both from the Allanooka scheme and the Wicherina Borefield (Permian sediments).

There are several town water supplies obtained from weathered and fractured-rock aquifers. The Northampton town water supply draws potable groundwater from fractures within granitoid rocks of the Northampton Block. Potable groundwater supplies for Yalgoo and Sandstone are located within weathered and fractured greenstone rocks.

The town water supplies for Cue, Meekatharra and Mount Magnet are obtained from calcrete bodies within alluviated drainage systems. Potable groundwater usage in these mining towns is variable and closely related to mining activity reflecting the state of confidence in the mineral industry, with the highest levels of abstraction experienced during periods of peak production. It is important to note that these town water supplies are positioned amongst high-density mining operations, however to date, there has been no evidence of interference between borefields resulting in over-exploitation of any aquifer.

East of the Darling Fault, there are relatively high concentrations of nitrate in all the town water supplies, at levels exceeding the 45 mg/L standard for drinking water. It can be inferred that most potable groundwater in the eastern portion of the Mid-West region contains similar high nitrate levels. The likely sources of the nitrates may be related to nitrate-fixing bacteria associated with soil crusts and termite mounds (Jacobson, 1993) and to nitrate-fixing vegetation. Locally, around stock watering points, there may be nitrate contamination from animal faeces.

The location of potable water supplies for prospective mine sites is an important consideration during the initial phase of mine development. In general, sufficient supplies of potable to marginal groundwater have been located reasonably close to mine sites throughout the area, with the majority of domestic water supplies on mine sites abstracted from fractured-rock and calcrete aquifers. In localities where there are poor prospects for locating potable water, small-scale desalination of groundwater can also be used for some domestic supplies.

Domestic supplies on farms and pastoral stations are usually provided by rainwater tanks supplemented by potable groundwater, if available. Low-salinity groundwater is often used for sanitary purposes and for maintaining the gardens and orchards around the homestead.

7.2 Irrigation water supplies

The presence of suitable groundwater supplies is only one factor in the prospective development of horticulture. A number of other socioeconomic and environmental factors must be taken into account prior to development, such as climate, soil type, soil structure, infrastructure requirements, labour and market proximity.

Current horticultural development is restricted to the Dongara-Irwin area and the Northampton-Chapman Valley area. There appears to be significant potential for additional irrigation in the lower Irwin Valley, using groundwater from the Yarragadee Formation (Commander, 1996). Wildflowers have also been grown under irrigation from the Parmelia Formation west of Coorow, and there is potential for further irrigation development from this source.

Development for irrigation in the Northampton-Chapman Valley area depends on site-specific location of relatively low supplies from Jurassic sediments or the granitic bedrock. Potential for commercial development is likely to be restricted to high value crops with low water use.

The prospects for irrigation development diminish further inland, as the climate is more arid and the soils become less fertile. The calcrete aquifer at Paroo in the east of the study area was investigated to assess the potential for irrigation similar to that at Wiluna, where in 1969 Desert Farms established citrus orchards irrigated from a calcrete aquifer. Generally the groundwater salinity in the higher yielding calcrete aquifers is likely to restrict irrigation to fodder crops, such as lucerne and rhodes grass, and various types of trees.

It is suggested that for commercial irrigation, aquifers with production bores capable of yielding at least 500 kL/day are required to ensure peak demand during dry periods. The groundwater salinity requirements are dependent on crop type; citrus requires less than 1000 mg/L TDS, whereas fodder crops use groundwater up to 3000 mg/L TDS. Groundwater supplies capable of meeting these criteria are restricted to local areas within the calcrete and alluvium.

7.3 Stock water supplies

The pastoral industry is reliant on groundwater with about 4000 bores drilled in the Wheatbelt, and about 1000 bores and wells constructed throughout the inland pastoral areas. Much of the groundwater in the Wheatbelt is saline, and the proportion of those bores in use is small. The distribution of stock bores and wells in the pastoral areas has been dictated more by the paddock system, rather than by the availability of groundwater (Johnson, 1998). Therefore, in the pastoral areas most bores and wells tend to be concentrated in the low-lying areas of alluvium rather than the topographically higher, colluvial soils, or areas of bedrock outcrop. In general, suitable groundwater supplies are easily located, but many exploratory sites have been abandoned due to drilling problems, inadequate supplies, or unacceptable salinity.

Most bores and wells used by the pastoral industry are less than 30 m deep and are typically equipped with windmills, which yield up to 10 kL/day. Larger supplies in excess of 20 kL/day are available from areas of calcrete and thick alluvium. Groundwater with salinity up to 7000 mg/L TDS can be utilised for stock watering. Domestic supplies usually rely on rainwater tanks supplemented by potable groundwater, if available.

The groundwater salinity is generally lower in the northern part of the pastoral areas, reflecting external drainage in the Murchison River, whereas in the south where the drainage is internal to salt lakes, the salinity is higher.

7.4 Mining industry

7.4.1 Perth Basin mineral sands

The mineral sands mining operations at Eneabba are the largest users of groundwater in the region, with a current allocation of 19.5 GL/yr. The groundwater is obtained from the Yarragadee Formation below the mineral sand deposits by bores as much as 600 m deep which obtain yields up to 6000 kL/day. Groundwater salinity ranges from about 400 to 900 mg/L.

Mining began in 1973, and by 1976 there were three operations drawing a combined amount of 10 GL/yr. The groundwater is used in the wet plant to separate the heavy minerals and to transport tailings (slimes). Groundwater is also pumped for dredge pond make-up water at the Eneabba West operation. Part of the groundwater abstraction is recirculated by leakage back into the aquifer from the tailings.

Mining is projected to continue to the north of the current operations with groundwater usage at least at current levels.

7.4.2 Murchison Province

The mining industry is also the largest groundwater user in the inland of the Mid-West region. There are over 20 operating gold mines, two talc operations and one base metal mine within the Murchison Groundwater Province, which are all currently using groundwater for ore processing. In addition, there are a number of new mineral projects planned for development in the next five to ten years.

An important consideration in the economic viability of any mine operation is the securing of adequate, long-term groundwater supplies. During the early phase of mine development, it is often critical to locate and establish substantial groundwater resources of suitable quality for ore processing and smaller supplies of low-salinity groundwater for domestic purposes. Other important considerations include the distance of the water supply from the mill site and water-quality limitations.

Groundwater usage

The groundwater requirements of individual mine operations are highly variable, ranging from 30 000 kL/yr for talc processing to over 2.7 GL/yr for large-scale gold operations. Most gold mines use less than 1 GL/yr over periods of five to ten years, whereas a few larger-scale operations may use up to 3 GL/yr for 15 years or more. Most of this groundwater is obtained from pits, shafts and borefields, and is used for dust suppression, ore beneficiation, ore processing, domestic usage and specialised industrial use after desalination.

The variability in groundwater usage for ore treatment is largely related to the metallurgical process, and the quantity and type of mineralised ore. The carbon-in-pulp and carbon-in-leach techniques for processing of gold ore are capable of using saline to hypersaline groundwater. However, there is increasing cost (with increasing salinity and magnesium content) associated with the need to add reagents to raise pH.

As part of this study, all available monitoring reports and wellfield reviews for the region were consulted to evaluate the amount of groundwater abstracted by the mining industry. These reports are provided by the mining companies as part of their licensing requirements and are retained in the Water and Rivers Commission records system. The data search mainly focused on groundwater consumers with an allocation of greater than 100 000 kL/yr, as allocations less than 100 000 kL/yr are not frequently monitored.

The demand for groundwater by the mining industry has increased substantially from 0.6 GL in 1983 to 25.3 GL in 1994 (Figure 2). There are various reasons for the significant increase in groundwater usage, including the discovery of new gold deposits (such as Plutonic and Marymia), new technology in mineral processing (carbon-in-pulp and carbon-in-leach) and the resultant ability to process lower-grade gold ore from previously abandoned mine-workings. The lower groundwater abstraction shown for 1996 and 1997 in Figure 2, are due both to incomplete reporting, as well as decommissioning of high-yielding borefields and dewatering operations, such as Gossan Hill and Reedy Gold Mine.

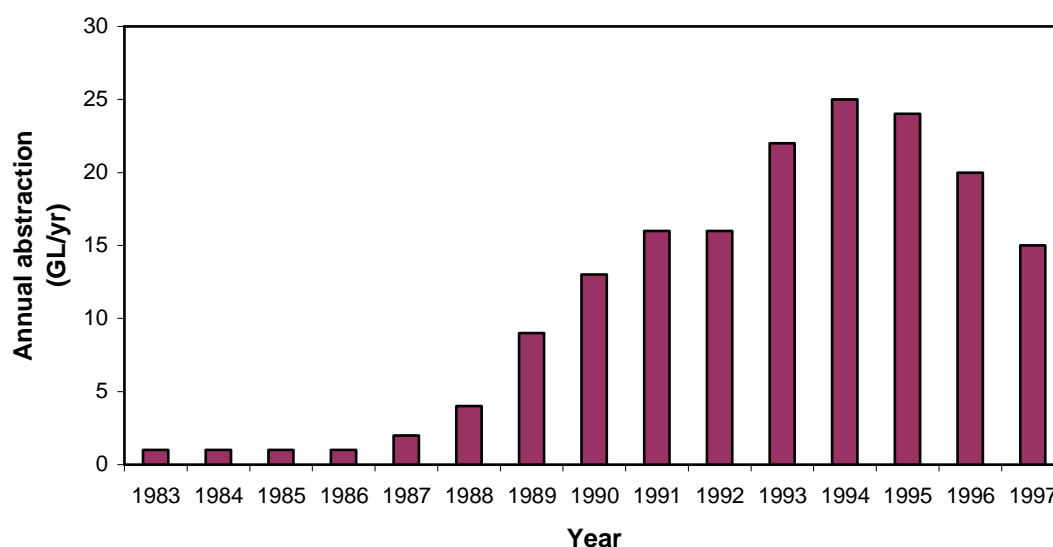


Figure 2. Groundwater abstraction at mining operations. Note: data for 1997 and 1998 is incomplete.

The cumulative groundwater abstraction by the mining industry in the Murchison between 1983 and 1997 has been estimated at 165 GL (Appendix 1). The large-scale, long-term gold mining operations have historically abstracted more than 2 GL/yr and are the prime groundwater consumers in the area, such as Big Bell Mine abstracting 19 GL over nine years and Plutonic Gold Operations using 17 GL over seven years. In contrast, the base metal mine at Golden Grove has abstracted about 8 GL over eight years, while the talc mine at Mt Seabrook only abstracts about 30 000 kL/yr.

The major mining operations are distributed throughout the Murchison Groundwater Province (Fig. 3), with a concentration of mining activity around the towns of Mt Magnet, Cue and Meekatharra. The greatest number of mining operations is around the town of Cue, which has five major borefields within a 50 km radius of the town site, including Big Bell and Tuckabianna. In general, there are large distances (greater than 50 km) between mining operations which ensures there is little or no competition for groundwater resources.

A finding of this study is that reduced usage or decommissioning of process borefields occurs as alternative water sources are obtained from dewatering of mining operations. At Golden Grove, the process borefield (Badja) was decommissioned in 1994, as their groundwater requirements of 1 GL were supplied by dewatering of the Gossan Hill Decline and Scuddles Mine Shaft. Another example is at Plutonic Operations, where abstraction from the process borefields (No. 1 and No. 2) has reduced by 70 % since commencement, as additional groundwater is provided via dewatering of their open-cut mines.

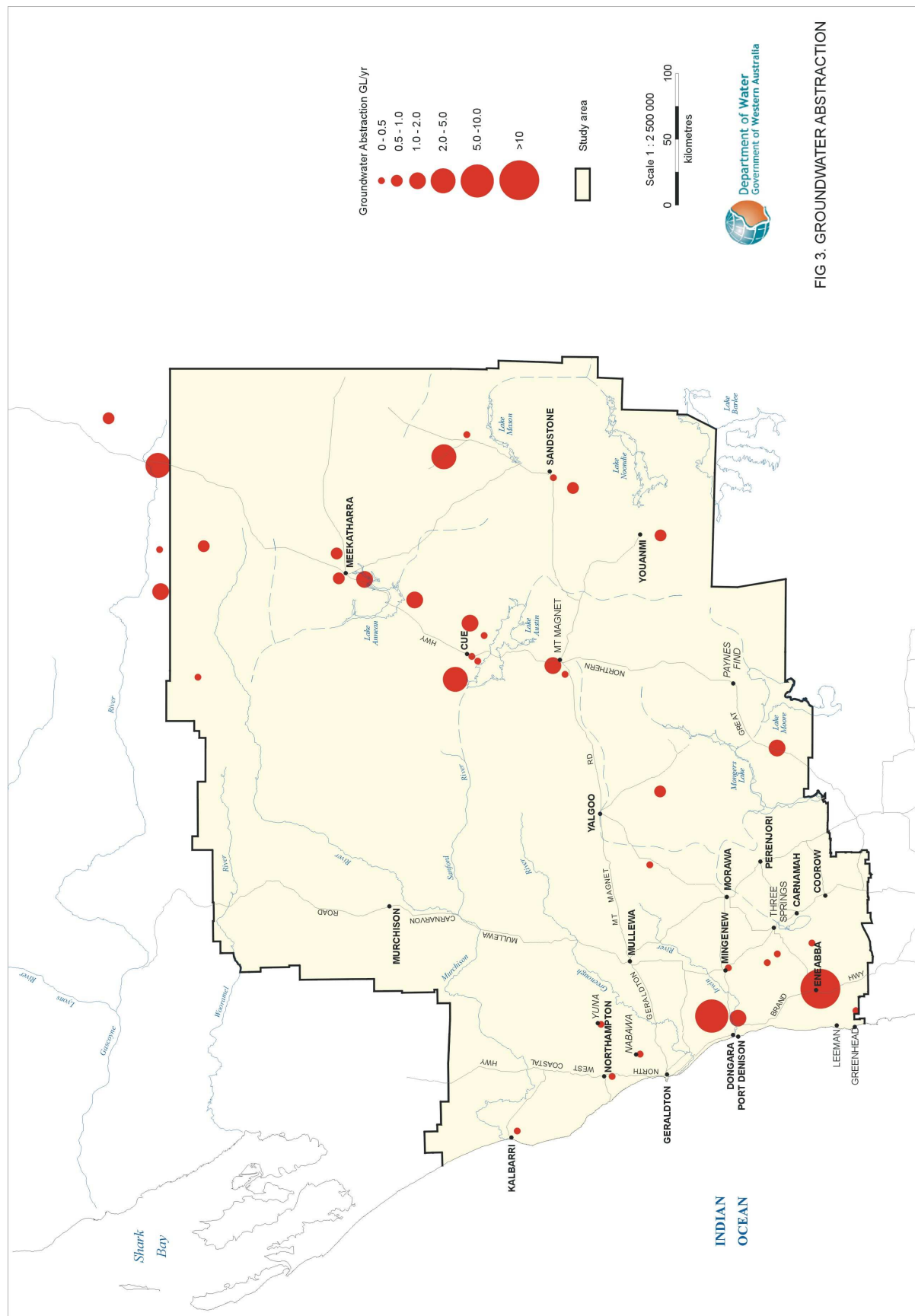


FIG 3. GROUNDWATER ABSTRACTION

Figure 3. Groundwater abstraction at mining operations

The salinity of groundwater used in mineral processing is highly variable depending on the processing techniques and the availability of groundwater. Groundwater salinity is not an issue in the processing of gold ore, since the introduction of carbon-in-pulp (CIP) techniques, however, lower salinities are preferred in order to reduce reagent costs. Gold mining operations throughout the Murchison Province generally use groundwater with salinity less than 5000 mg/L TDS (Fig. 4). However, groundwater up to 150 000 mg/L TDS has been abstracted for dewatering purposes from St George Pit at Hill 50 Gold Mine on the banks of Lake Austin.

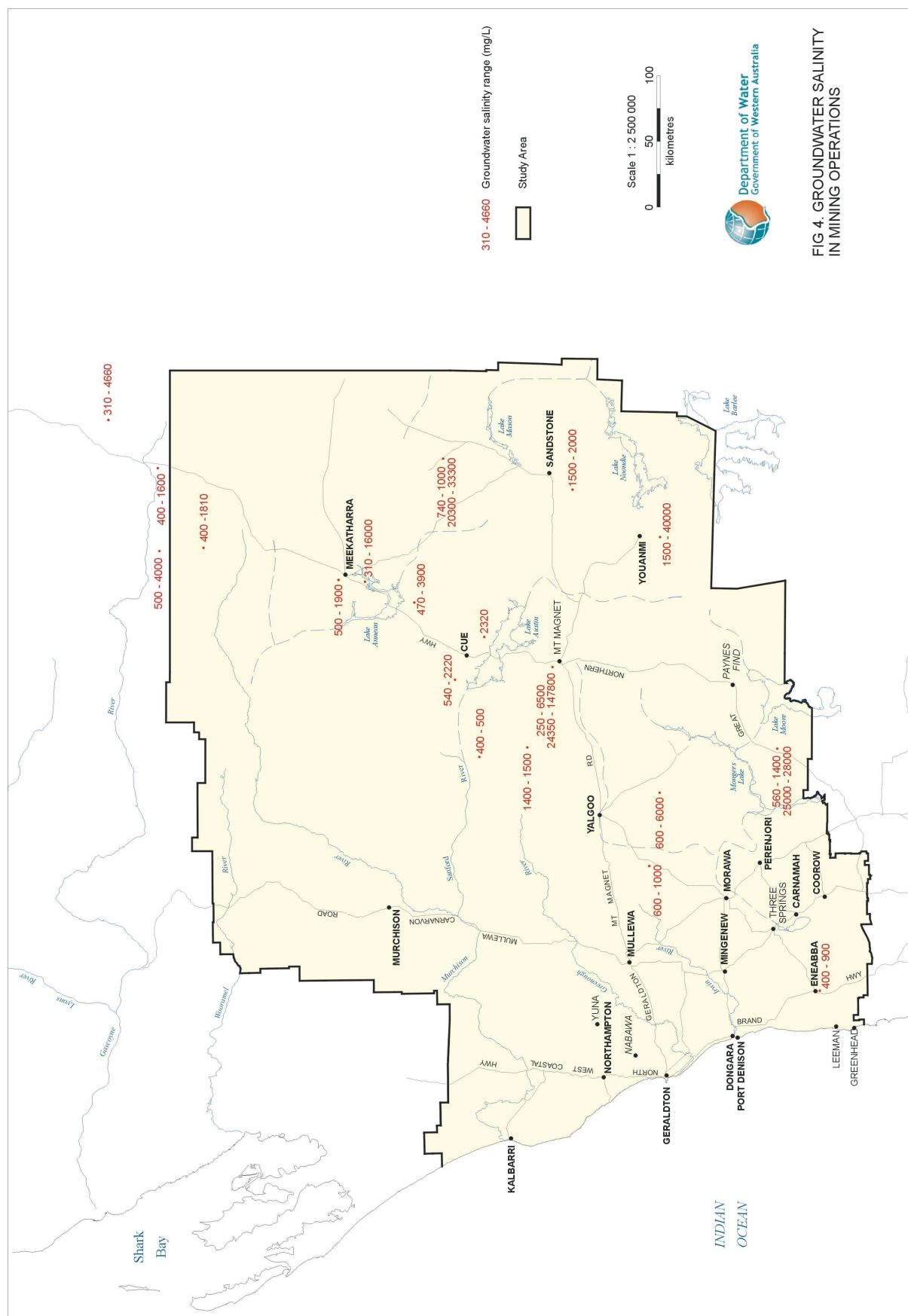
Groundwater salinity is highest in the south, and tends to decrease towards the north of the Murchison Province (Fig. 4). On a localised scale, there is low salinity groundwater present beneath catchment divides and higher salinity along the palaeodrainages. The groundwater salinity is likely to increase with depth, however, the variation in salinity with depth is poorly understood.

In summary, groundwater demand has increased significantly since the early 1980's as a result of new technologies in mineral exploration, ore extraction and processing. The annual groundwater usage by most gold mining operations is about 1 GL/yr with some larger-scale operations utilising more than 2 GL/yr. Groundwater usage is well distributed throughout the area; however, there are areas of concentrated mining activity around the towns of Cue and Meekatharra. There is no evidence to suggest that groundwater users are experiencing interference from near-by borefields, as there are large distances between mining operations, and adjacent operations often do not abstract from the same aquifer. This situation contrasts with the Northern and Eastern Goldfields where there is potential competition from adjacent borefields (Johnson et al., in prep; Ion, 1998).

Current licensed allocation

Groundwater resources utilisation and conservation in Western Australia is administered by the Water and Rivers Commission in accordance with the Rights in Water and Irrigation Act 1914, the Water Authority Act 1984, and the Water Agencies Restructure (Transitional and Consequential Provisions) Act 1995.

The study area lies entirely within proclaimed Groundwater Areas. The southern coastal area (south of Geraldton – Mt Magnet Road) is in the Arrowsmith Groundwater Area (WAWA, 1995), while the area to the north of Geraldton and Mullewa is within the Gascoyne Groundwater Area. The eastern part of the study area, which includes all mining operations, is in the East Murchison Groundwater Area. The management objectives are twofold: to ensure that groundwater resources, and environmental features reliant on them, are not degraded through over use; and to ensure that resources are allocated in an equitable manner.



As of February 1996, there were 110 current groundwater production licences in the Murchison Groundwater Province with a total allocation of 66.9 GL/yr (Table 4). Mining use of groundwater is listed under four categories: process water, dewatering, dust suppression and camp water. Process water supplies are used in the treatment of ore and are believed to account for 55 % of total allocations. However, as discussed in the previous section, groundwater obtained from dewatering and licensed for dust suppression is often used to supplement groundwater from the process borefields. It is therefore difficult to provide meaningful estimates of groundwater usage, as the monitoring reports supplied to the Commission rarely provide sufficient information on the use of abstracted groundwater.

Mining camp water requirements are generally very small, less than 20 000 kL/yr, comprising only 1 % of total allocation which suggests that 65.2 GL/yr is allocated for various mining purposes. In addition, the Water Corporation is currently allocated 1.2 GL/yr for providing the town water supplies of Meekatharra, Cue, Mt Magnet and Sandstone (Table 4).

Table 4. Groundwater usage by mining industry (based on allocation data)

Purpose	Allocation GL/yr	Percentage of total allocation
Process water	36.5	55
Dewatering	24.4	36
Dust Suppression	4.3	6
Town water supply	1.2	2
Camp water	0.5	1
Total	66.9	100

Even though the mining industry has an annual allocation of 65.2 GL/yr, it is important to note that only a portion of this groundwater is abstracted. Based on groundwater abstraction figures for 1995 (25.3 GL), it would appear that most mining companies only utilise about 40 % of their allocation. There are, however, several mines which have exceeded their annual allocation due to increased groundwater demand associated with ore processing. In all cases, groundwater abstraction only exceeds allocation for a short period and there is no need to modify the production licence. However, if the situation of abstraction exceeding allocation continues over two review periods then the licensee is required to apply for a modification to their allocation.

Aquifers

The water requirements for mining projects have been obtained from a variety of hydrogeological environments, and include fractured and jointed quartz veins (Plutonic Limited, Gidgee gold project; Mackie Martin and Associates, 1986); palaeochannel

sands (Mt Gibson gold project; Groundwater Resources Consultants, 1988); and calcrete (Yeelirrie Uranium Project; A.G.C., 1981). Groundwater yields of up to 1300 kL/day are obtainable from the fractured-rock and calcrete aquifers, compared with sustainable yields of 300 to 900 kL/day from bores in the palaeochannel sand aquifer. The groundwater salinity ranges from 900 to greater than 40 000 mg/L TDS with lower salinity groundwater present in the fractured-rock aquifers.

Most of the groundwater used by the mining industry in the Murchison is drawn from the fractured-rock aquifer and this is the favoured source of supply for large-scale operations (Table 5). There are also groundwater supplies currently abstracted from borefields established in alluvium and calcrete aquifers. In contrast to the Northern Goldfields region, there is only one borefield developed in the palaeochannel aquifer (at Mt Gibson Gold Mine). However, there is currently extensive groundwater exploration in part of the Austin Palaeodrainage for the proposed Windimurra vanadium deposit.

Table 5. Cumulative groundwater abstraction from each aquifer type

Aquifer	Abstraction from 1983 to 1997 (GL)	Percentage of total abstraction
Fractured-rock	109	61
Alluvium	33	19
Calcrete	25	14
Palaeochannel	10	6
Total	177	100

The high percentage of groundwater supplies abstracted from the fractured-rock aquifers was a major finding of this study, which is quite different from the adjacent Northern Goldfields region where most supplies are obtained from palaeochannels (Johnson *et al.*, 1999). A large proportion of this groundwater is abstracted via mine dewatering, while most of the process borefields are located in the fractured-rock aquifer towards the north of the project area, including Fortnum, Horseshoe Lights and Plutonic.

Fractured-rock aquifers are hydrogeologically complex with groundwater occurrence related to primary fracturing and secondary weathering of the basement rock. Most groundwater from the fractured-rock aquifer is obtained through dewatering of highly-permeable mineralised zones, granitoid/greenstone contacts, fault and shear zones (Table 6). There are also large volumes of groundwater abstracted where pumping from fractures in fresh bedrock induces downward leakage from the weathering profile and from overlying alluvium and calcrete (such as Peak Hill). There are a number of borefields developed in weathered products and permeable zones of the weathered profile, including the vuggy siliceous caprock over ultramafic lithologies at Fortnum.

Table 6. Groundwater abstraction from fractured-rock environment

Fractured-rock environment	Abstraction from 1983 to 1997 (GL)
Mineralised zone	33
Fault and shear zone	29
Lithological contact	17
Leakage from alluvium	16
Weathered profile	14
Total	109

Other sources of process water

Groundwater abstraction can also be optimised by utilising alternate water supplies including pit dewatering, reclaimed water from tailings, and water from inundated mine voids.

The dewatering of opencut mines is necessary to gain access to mineralised zones and to ensure wall and slope stability during excavation. The amount of dewatering required is dependent on the presence of water-bearing structures with groundwater abstracted using perimeter bores, in-pit sumps, horizontal drainage holes and pumping from abandoned shafts. Allen (1996) noted that the presence of groundwater in shear zones and in highly weathered mineralised zones has also lead to many dewatering problems in underground mines.

Groundwater obtained from mine dewatering is used for ore processing and mining requirements, principally dust suppression. There are 43 licences issued for dewatering covering a total allocation of 24.4 GL/yr (Table 4), although actual abstraction is very much less. Inconsistencies in the collection of licensing statistics do not allow assessment of quantities discharged from the mine site, only those used within the mine.

Major changes to the groundwater regime are made where pits are being excavated below the watertable. After mining and dewatering is complete, there will be gradual inundation to a level at which groundwater inflow is balanced by evaporative loss and outflow. Because of the high evaporation, the salinity of open water in the pit will gradually rise until a dynamic equilibrium is reached.

There is also scope for abandoned mine voids to act as surface-water reservoirs for the long-term capture of stream flow and rainfall associated with intense rainfall events. Various mining companies throughout the region already use these supplies to supplement process water. In the Northern Goldfields region, it was found that the potential for inundation is greatest for pits low in the landscape, where surface flows can be diverted (Johnson *et al.*, 1999). However, many of the pits are often relatively high in the landscape, and therefore do not command large catchments.

Water quality is an issue that may depend on interaction of water with the pit material. There is potential to create acidic conditions and take into solution heavy metals, as well as an increase in salinity. Where groundwater flows into pits, stratification may also occur with lower salinity surface water overlying more-saline groundwater.

While there are no specific legislative requirements at present for utilising water in mine voids, the matter has been under consideration by the Department of Industry and Resources, Environmental Protection Authority and the Department of Water. There are existing environmental and geotechnical guidelines to be followed under Department of Industry and Resources legislation in respect to mine rehabilitation and closure, and water abstraction has to be licensed by the Department of Water.

7.5 Industrial development

Industrial development is likely to take place in the Geraldton Region where the port facilities and population are located. The closest source of low salinity groundwater is the Yarragadee Formation aquifer, which is currently utilised by the Allanooka Borefield. The draft Groundwater Allocation Plan indicates 21.9 GL/yr is available for private use from the Allanooka Subarea, in addition to the 20 GL/yr currently allocated or reserved for future scheme use. There are also large unallocated resources in the aquifer south of the Irwin River in the Twin Hills Subarea.

Developments under consideration for the region include iron and steel industries based on the Talling Peak and Mt Gibson deposits. These would require water for the steel mill, and possibly for a slurry pipeline, which has been suggested to transport the ore.

Coal deposits at Eneabba and in the Irwin River area could be developed for on-site power generation. Groundwater resources exist in close proximity to the Eneabba deposits, either from the Cattamarra or Eneabba Formations, but the development of the Irwin River deposits may require water to be piped from the Yarragadee Formation.

8 Conclusions

The largest low salinity groundwater resources in the study area are in the Northern Perth Basin between Eneabba and Allanooka. There is considerable scope of increased usage of the groundwater resources in the Northern Perth Basin for irrigation or water supply to the Geraldton area for industrial and urban development. Though there is a need for additional groundwater exploration in the Casuarina area, about 30km northeast of the Geraldton town water supply, to improve understanding about the groundwater resources and develop a monitoring network in the northernmost part of the Yarragadee Aquifer.

There are significant groundwater resources available for utilisation by the mining industry throughout the region. In combination with the large distances between most mining operations and variability in aquifer distribution, it is anticipated that no mining operation will have any problem locating a long-term supply of groundwater and will encounter minimal interference between neighbouring borefields.

Most of the groundwater for mining in the Murchison is drawn from the fractured-rock aquifer and is the favoured source of supply for large-scale operations. There are also groundwater supplies currently abstracted from borefields established in alluvium and calcrete aquifers. In contrast to the Northern Goldfields region, there is only one borefield developed in the palaeochannel aquifer. The palaeochannel aquifers in the Murchison are poorly known by comparison with those in the Eastern Goldfields.

There is considerable pressure for small scale horticultural development in the Chapman Valley area and Northampton Block, however there are only comparatively localised and small groundwater resources, which are likely to be suitable only for high value crops. Groundwater is available throughout the area for pastoral supply except in low-lying areas of the wheatbelt where the salinity is too high. Groundwater is available for town water supplies, but has to be piped considerable distances to towns in the northern Wheatbelt.

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Appendix 1

Groundwater usage by individual mining operations (1983-1997)

Mining Operation	Cumulative abstraction 1983 – 1997 (GL)	Years of abstraction	Annual abstraction (GL/yr)
Big Bell	19.5	9	2.17
Plutonic	18.8	7	2.69
Hill 50	16.1	11	1.46
Bluebird	15.4	10	1.54
Mt Gibson	14.8	11	1.35
Meekatharra	14.8	15	0.99
Gidgee	14.0	6	2.33
Tuckabianna	12.1	9	1.34
Reedy Gold	11.1	11	1.10
Golden Grove	7.7	8	0.96
Peak Hill	6.0	9	0.67
Fortnum	4.1	4	1.02
Marymia	2.7	4	0.68
Twin Shafts	2.6	4	0.65
Youanmi	2.1	3	0.70
Horseshoe Lights	1.2	6	0.20
Day Dawn JV	0.7	2	0.35
Gullewa	0.5	3	0.17
Mt Seabrook	0.3	10	0.03
Montague	0.3	2	0.15
Comet Gold	0.2	1	0.20
Golden Crown	0.1	2	0.05
TOTAL	165		

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