HYDROGEOLOGY
OF THE WIDGIEMOOLTHA
1:250 000 SHEET

by
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1:250 000 hydrogeological map of WINDERMOUTH (in pocket)

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Hydrogeology of the Widgiemooltha
1:250 000 sheet

by

A. M. Kern

Abstract

The Widgiemooltha 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. A portion of the Proterozoic Albany–Fraser Orogen lies in the southwest corner of Widgiemooltha, and there are also small areas of Proterozoic clastic sediments. 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 Widgiemooltha area, but they generally contain only minor groundwater supplies, and these are difficult to locate. The basal sandstone, carbonate and spongolite units in the palaeochannels are considered to be the most prospective aquifers on Widgiemooltha. 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. There is no fresh groundwater on Widgiemooltha, but limited areas of brackish groundwater exist in the upper reaches of some catchments.

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

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

Location

The Widgiemooltha 1:250 000 hydrogeological sheet (SH/51-14 of the International Series) is bounded by latitudes 31°00' and 32°00'S and longitudes 121°30' and 123°00'E. The sheet area lies within the southern part of the Eastern Goldfields Province of Western Australia. The map is named after a former mining locality, Widgiemooltha, which is situated on the Coolgardie–Esperance Highway near the southwestern end of Lake Lefroy.

The western part of the sheet is dominated by mining activities. Kambalda is the major centre for the area with a population of 4298 in 1991. The region is linked by road to the larger towns of Kalgoorlie, Coolgardie and Norseman. Most of the mining centres can be reached by graded roads, but outside mining areas there are only a few tracks. The Kalgoorlie–Norseman and the Trans-Australian railway lines cross the western and northeastern portions of Widgiemooltha respectively. The Goldfields Water Supply (GFWS) pipeline from Coolgardie to Norseman follows the Coolgardie–Esperance Highway with a branch to Kambalda.

Pastoral properties carrying sheep occupy most of the northwestern two thirds of Widgiemooltha, and the Fraser Range in the southeast.

Climate

The climate is semi-arid with hot, dry summers and cool to mild winters. January is the hottest month with an average maximum temperature of 33°C and an average minimum of 18°C at Kalgoorlie. 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 280 mm in the south to about 240 mm in the northeast, and is 267 mm at Widgiemooltha. The area has an average of 46 wet days per year and most of the rain falls between March and August, during the passage of cold fronts. Summer rainfall occurs intermittently as a result of remnant tropical cyclones and thunderstorms. Average annual potential evaporation increases from about 2300 mm in the
southwest to 2700 mm in the northeast. Evaporation is greatest during the summer months of January and February and lowest during the winter months of June and July.

**Physiography**

The **WIDGIEMOOLTHA** sheet covers large areas of playa lake systems, dominated by Lakes Lefroy and Cowan. The highest area is the Fraser Range reaching 525 m AHD. In the western half of the area the land falls from Yilmia Hill (448 m AHD) near Kambalda to an elevation of 260 m AHD at Lake Cowan. With the exception of the Fraser Range, most hills are developed upon greenstones and mainly occur along the western and northern margins of **WIDGIEMOOLTHA**. These hills tend to occur in small ranges trending north-northwest, with a relief of about 100 m. Banded iron-formation forms the most prominent ridges. The Fraser Range consists of chains of exposed bosses of basic rocks trending southwest to northeast.

The drainage system is characterized by extensive alluviation and chains of playa lakes. The drainages were once more active and flowed northeast to the Eucla Basin (Bunting et al., 1974; van de Graaff et al., 1977). Isolated outcrops of flat-lying Tertiary sedimentary rocks, and laterite, silcrete and calcrete, form small plateaus, particularly adjacent to drainage systems and breakaways. The margins of the playa lakes (mainly the eastern sides) contain dune deposits of quartz sand and gypseum.

There are no permanent rivers; intermittent streamflow occurs only after major rainfall and the water runs into large ephemeral claypans and playa lakes. Runoff from outcrops of bedrock may collect in gnamma holes or rockholes, and soaks and water holes often occur next to rocky outcrops.

**Vegetation**

The **WIDGIEMOOLTHA** sheet area is occupied by mostly uncleared or regenerated vacant Crown land which has been used for grazing and timber gathering. The vegetation is quite diversified throughout the sheet area and is controlled by soil type (Beard, 1975; Newbey et al., 1984). It consists mainly of eucalypt woodland, which includes salmon gum, gimlet and mallee, and broad plains of saltbush (*Atriplex*) and bluebush (*Maireana*). The Fraser Range is covered mainly by eucalypt woodland with patches of scrub on hilltops. The woodland in the eastern half of **WIDGIEMOOLTHA** often includes patches of mallee and spinifex (*Triodia*). Small communities of sheoak are also found in the northeast. The playa lakes are bordered by saltbush and numerous varieties of samphire 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. Large water reservoirs, locally known as tanks and dams, were constructed at Widgiemooltha and 50-Mile Rock by the Public Works Department in 1897–1898 (Princep, 1898). Potable water was also obtained by desalination, in woodfire condensers, of brackish and saline groundwater water from shafts and salt lakes. During the early stages of mining, St Ives, Paris Group and Loves Find had to rely for water on Hopbush Gnamma Hole, Binyarinyinna and Yallaburra Soaks (Clarke, 1925). Water supplies for St Ives were also carted in camel-drawn wagons from Government Dam at Widgiemooltha in 1920 pending the erection of a condensing plant and the excavation of a dam (Clarke, 1925). A borefield was also established at St Ives by 1925. The Mt Monger mining centre relied mainly on pastoral dams for its water supply. The Goldfields Agricultural Water Supply (GAWS) pipeline was extended from Coolgardie to Norseman in 1937, serving the township of Widgiemooltha and other small railway sidings, mining centres and pastoral properties along its route.

In the late 1960s nickel mining was established at Kambalda, and the town connected to the GFWS pipeline in 1967. 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, borefields were established in the Wollubar and Mt Morgan Palaeochannels, in the Lefroy Palaeochannel near Higginsville and downstream of Lake Randall. In addition, several borefields were established in highly fractured greenstones such as those in the St Ives area.

Following the sudden demand for large amounts of groundwater in the Eastern Goldfields region a survey of water availability and projected demand was carried out (BHP Engineering and Australian Groundwater Consultants, 1984, 1988). This indicated that the uncommitted palaeochannel groundwater resources on **WIDGIEMOOLTHA** could accommodate large borefield developments.

**Previous investigations**

The first edition of the **WIDGIEMOOLTHA** geological sheet, compiled in the early 1960s, (Sofoulis, 1966), includes a 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 1985 (Australia BMR, 1965, 1985). A review of geological investigations of areas including **WIDGIEMOOLTHA** that were carried out before 1972 was prepared by Williams (1974). The **WIDGIEMOOLTHA** sheet was remapped between 1979 and 1984 (Griffin, 1989) concurrently with the Lake Lefroy and Cowan 1:100 000 geological sheets (Griffin and Hickman, 1988; Griffin, 1988), which cover the western portion of **WIDGIEMOOLTHA**. The geology of the Archaean granite-greenstone terrane of the Lake Lefroy and Cowan 1:100 000 sheets was further described by Griffin (1990a) and Swager et al. (1990).
The hydrogeology of the western part of WIDGIEMOOLTHA was first described by Clarke (1925). Reports on water supplies on Binneringie and Madoonia Downs Stations in the centre of WIDGIEMOOLTHA were prepared by Berliat (1954 and 1971). Hydrogeological inspections were also carried out in the northeast on Cowarna Downs (Barnett, 1978) and Coonana Stations (McGowan, 1982). A hydrogeological map covering a large portion of the northern half of WIDGIEMOOLTHA was prepared by Australian Groundwater Consultants for Freeport of Australia Inc. in 1983 (Australian Groundwater Consultants, 1983). Further studies on the groundwater potential of the Eastern Goldfields were carried out in the 1980s (BHP Engineering and Australian Groundwater Consultants, 1984, 1988) and they include parts of WIDGIEMOOLTHA. In addition, numerous unpublished consultants’ and mining companies’ reports were prepared in the 1980s. In 1988 the GSWA carried out a major study of the groundwater resources of the Kalgoorlie region. This study included an appraisal of the Wollubar Palaeochannel (Commander et al., 1992).

Geology

Regional setting

The WIDGIEMOOLTHA sheet covers part of the Yilgarn Craton. Most of the sheet area lies within the Eastern Goldfields Province (Griffin, 1990b) and includes the granite–greenstone Kalgoorlie Terrane (Swager and Griffin, 1990; Swager et al., 1990). The southwestern corner of the map sheet is part of the Albany–Fraser Orogen (Myers, 1990).

The Eastern Goldfields Province is characterized by linear, northerly trending belts of Archaean supracrustal rocks comprising metamorphosed volcanic and sedimentary rocks, with intervening areas occupied by granitoid rocks. During the Proterozoic the Archaean crust was intruded by dykes and affected in the southeast by the Albany–Fraser Orogen and later clastic sediments were deposited. A variety of early Tertiary sediments was deposited in valleys cut by drainage systems that once carried water eastwards to the Eucla Basin. Cainozoic surficial deposits form an extensive cover over the Precambrian rocks and Tertiary sedimentary rocks in palaeodrainages outlined by the playa lakes.

Archaean and Proterozoic

The greenstone belts contain metamorphosed and deformed sequences of mafic and ultramafic volcanic rocks (Ab); sedimentary rocks (including the Merougi Conglomerate), and felsic volcanic and volcaniclastic rocks (Af); and minor chert and banded iron-formation (Ac). A variety of granitoid rocks (Ag), generally foliated, occupy about 30% of WIDGIEMOOLTHA. Gneiss (An) is a minor type, restricted to the margins of some granitoid bodies in the west. The Archaean bedrock is rather poorly exposed on WIDGIEMOOLTHA owing to widespread surficial cover and extensive deep weathering.

Cainozoic

Tertiary sedimentary rocks

A variety of Tertiary sediments (T, TEr and Tw) was deposited in valleys cut by Cretaceous to early Tertiary drainages which once flowed to the Eucla Basin. These sediments are widely distributed on WIDGIEMOOLTHA, and the upper parts of the strata are exposed in low cliffs and on lake floors (Griffin, 1989). On the map these sediments are shown only where they outcrop or are proved by drilling, and where they are inferred to be saturated. Their distribution is interpreted between drillholes.
The sedimentary sequences in the Lefroy, Cowan and Roe Palaeodrainages are different reflecting various conditions of deposition.

Upstream of Lake Lefroy the Lefroy Palaeodrainage contains a non-marine basal sandstone assigned to the Werrilup Formation (T), and over lain by clay. The unit is equivalent to the Wollubar Sandstone (Tw) described in the Roe Palaeodrainage (Kern and Commander, 1993). The sandstone consists of coarse- to fine-grained quartz sand which is up to 48 m thick in the Wannaway Borefield (K. H. Morgan and Associates, 1991). Locally the formation includes a sequence of carbonaceous clay and lignite up to 30 m thick (K. H. Morgan and Associates, 1989a). The overlying clay unit is a multicoloured clay with minor sandy clay beds, and is up to 30 m thick in the area. The unit is more sandy in tributaries such as in the Mt Morgan Palaeochannel (Forbes et al., 1991). The clay unit is lithologically and stratigraphically very similar to the Perkolilli Shale (T) in the Roe Palaeodrainage (Kern and Commander, 1993).

Beneath Lake Lefroy the basal lignitic marginal marine to non-marine Pidinga Formation (T) interfingers with the marine Hampton Sandstone (T), and is over lain by the Princess Royal Spongolite (TEr) and the Redmine Group (Clarke, 1993). In Lake Lefroy the Pidinga Formation has a maximum known thickness of 60 m and consists of laminated red-brown to green silts, white, grey or black clays and silts, and lignite. The Hampton Sandstone is up to 24 m thick and consists of coarse to fine sand and laminated silt. The Princess Royal Spongolite reaches a thickness of 35 m and consists of siliceous sponge spicules with lesser amounts of silt and clay.

The Lefroy Palaeochannel downstream of Lake Randall was infilled only with marine sediments consisting of the Hampton Sandstone overlain by the Princess Royal Spongolite (Jones, 1990). The thickness of the sequence is 72 m in the Karonie Borefield (K. H. Morgan and Associates, 1989b).

The basal sediments in the Cowan Palaeodrainage on WIDGIEMOOLTHA consist of the Werrilup Formation which interfingers with the Norseman Limestone (T) (Clarke, 1993). The Werrilup Formation consists of sand, silt and carbonaceous clay with lenses of lignite, and is over lain by the Princess Royal Spongolite in the northern end of Lake Cowan. The Norseman Limestone ranges from skeletal wackestone and grainstone to calcareous sandstone, and is up to 37 m thick beneath Lake Cowan (Clarke, 1993). Drilling by Western Mining Corporation indicates that the Cowan Dolomite occurs within the later Tertiary lacustrine sequence, and is thus part of the overlying Redmine Group (Clarke, 1993).

The sediments in the Wollubar Palaeochannel (part of the Roe Palaeodrainage) consist of the basal Wollubar Sandstone (Tw) overlain by the Perkolilli Shale (Kern and Commander, 1993). The Wollubar Sandstone consists of unconsolidated quartz sand, with minor conglomerate, silt, clay and lignite. The Perkolilli Shale is a multicoloured clay with minor sandy clay beds. The thickness of the Tertiary sediments in the Wollubar Palaeochannel ranges from about 18 m near Wollubar, where most of the sediments were removed by erosion, to about 55 m north of Mt Martin (Commander et al., 1992).

Surficial deposits

A variety of Cainozoic surficial deposits (Cz and Ql) occur on WIDGIEMOOLTHA (Griffin, 1989), where they form a veneer over the Archaean, Proterozoic and Tertiary rocks. Cainozoic surficial deposits that occur in elevated areas are generally unsaturated and are not mapped. Only those units likely to contain groundwater are shown on the map.

High-level deposits of laterite, eluvium and sandplain are widespread. The laterite occurs as plateaux of massive, ferruginous duricrust and is well developed over deeply weathered bedrock and Tertiary sediments. Calcareous and siliceous duricrusts are less common but are also widely distributed. The eluvium consists of quartzofeldspathic sand derived by weathering and erosion of granitoid rocks, with scattered, small pebbles of granitoid rocks. Sandplains consisting of low dunes of yellow sand mainly cover granitoid terrain (Sofoulis, 1966) and are partly eolian in origin.

Colluvial and alluvial deposits (Cz) occur in outwash fans and stream channels respectively (Fig. 1). The colluvium consists of conglomerate, gravel sand and clay derived from the lateritic profile and the underlying Archaean and Proterozoic bedrock, and is generally less than 10 m thick. Alluvial deposits consist of unconsolidated sand, silt and clay in the valley-flat environment, with interfinger ing conglomerate near bedrock outcrops. They are confined mainly to the upper reaches and breakaways, and deltaic accumulations along the playa lakes are rare.

Post Eocene fluviolacustrine sediments have been identified by Clarke (1993) and they form the Redmine Group. Up to 26 m of predominantly red-brown silts, clays, sands and gravels are present beneath Lake Lefroy, and similar thickness occur beneath Lake Cowan.

Deposits associated with playa lakes and claypans (Ql) consist of saline and gysiferous clay and silt that may reach 9 m in thickness and they correlate with the Beta Island Member, Roysalt and Polar Bear Formations of the Redmine Group (Clarke, 1993). The margins of the lakes consist of stabilized dunes of unconsolidated sand, silt and gypsum derived from the desiccated surface of playa lakes.

Hydrogeology

Groundwater occurrence

The WIDGIEMOOLTHA area is underlain by weathered and fractured Archaean and Proterozoic bedrock overlain by widespread Tertiary sedimentary rocks in palaeo-channels and Cainozoic alluvium and lake deposits. The bedrock forms part of the Yilgarn–Goldfields and Albany–Fraser fractured-rock groundwater provinces.
The fractured bedrock aquifers are 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 granitoid rocks than in sedimentary or felsic volcanic and volcano-clastic rocks. Open fractures occur up to 150 m in the Foster mine and St Ives Borefield (Roberts, 1990; Forbes and Roberts, 1990), and probably to a similar depth along major faults and shear zones.

Major mafic and ultramafic dykes occur throughout the granite–greenstone terrane. They are undeformed, generally appear to lack in open fractures, and are possible hydraulic barriers to groundwater movement.

The Tertiary sandstone, carbonate and spongolite units are highly permeable and generally saturated, containing significant volumes of groundwater. They form the largest source of groundwater on WIDGIE MOOLTHA. 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 WIDGIE MOOLTHA is illustrated on Figure 2. Groundwater recharge is a very small proportion of rainfall; most of the rainfall either evaporates directly or is used by thick vegetation, with minor amounts of runoff into claypans and salt lakes. Direct recharge takes place principally where the bedrock outcrops and in areas of sandplains. Most of the recharge is likely to occur during heavy rainfall events when it is enhanced by recharge from surface runoff and local flooding.

A regional watertable on WIDGIE MOOLTHA occurs at a depth ranging from less than 1 m in playa lake environments to more than 50 m in elevated areas. The regional...
Figure 2. Block diagram showing groundwater occurrence
Watretable may be absent in high areas where the weathered and fractured zone is unsaturated or where and the fractures are poorly developed.

Groundwater flow is towards the major valleys containing salt lakes where the watertable is close to the surface. Groundwater discharge occurs mainly by evaporation from salt lakes, and a relatively small amount of water flows out of the area 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 WIDGEMOOLTHA. They are generally foliated and meta-morphosed, and include granite, monzogranite, grano-diorite and minor syenite and pegmatite. They are poorly exposed and extensive areas of granitic rocks are overlain by residual sandplains and colluvium (not mapped). In outcrop granitoid rocks appear to be massive, with 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 lying immediately above the relatively fresh bedrock (Kern, 1995a).

Quartz veins are a minor, but widespread, component of the granitoid rocks. These tend to be well fractured and may form small but locally important aquifers. They are also present in the greenstone belts.

Small intrusions of porphyry and pegmatite are numerous in the greenstone sequence. They occur as either dykes or irregular masses. They tend to be well fractured and may form small but locally important aquifers.

Numerous sandplains (not mapped) are developed over thin laterite and granitoid rocks (Sofoulis, 1966), but are unsaturated except near playa lakes. 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 gritty soils fill topographic depressions in the granitoid rocks and give rise to ephemeral, shallow, fresh-water soaks. Pastoral wells are commonly sited adjacent to outcrops of granitoid rocks where additional recharge from surface runoff occurs, 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 39 m in bore CD2303 in the St Ives Borefield.

Granitoid rocks have been tested only at St Ives on WIDGEMOOLTHA. The best supplies (up to 200 m³/day) are obtained from the highly fractured fresh rock where open fractures may occur up to a depth of 200 m (Forbes and Roberts, 1990).

**Gneiss (An)**

Gneiss of Archaean age is generally poorly exposed on WIDGEMOOLTHA and its distribution is restricted to the margins of some granitoid bodies in the western part of the map sheet. In outcrop the fresh rock is characterized by strong foliation and high proportion of pegmatite veins which locally make up to 50% of the outcrop. The gneiss is also more strongly deformed than the granitoids. Weathered gneiss would contain layers of quartz as well as quartz and pegmatite veins which may be considered to be prospective for groundwater.

**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. However, in outcrop they are commonly highly weathered and the joints are filled by clay.

The watertable is deep in the upper reaches of catchments, and is as much as 54 m in Chippys Bore. Bore yields in mafic and ultramafic rocks on WIDGEMOOLTHA are variable, but generally range from 100 to 500 m³/day (Table 1). The major borefields in these rocks are situated east of St Ives and northwest of the Junction Mine, where bore yields of up to 1000 and 1750 m³/day respectively are obtained.

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

A complex succession of metamorphosed sedimentary rocks, including the Merougil Conglomerate and felsic volcanic and volcaniclastic rocks is widespread in the greenstone belts. The felsic extrusive include dacite and felsic tuffs that tend to be relatively unjointed and have fine-grained weathering products. The sedimentary rocks are derived from quartz-rich siltstones, sandstones and polymeric conglomerates that are generally deeply weathered and soft. Quartz–feldspar porphyries are likely to be more resistant to weathering and better exposed than the sedimentary rocks.

Sedimentary, felsic volcanic and volcaniclastic rocks generally constitute poor sources of groundwater owing to their clay-rich weathering products. However, yields ranging from about 200 to 600 m³/day have been intersected in fine-grained metasedimentary rocks south of Bald Hill (Rockwater, 1989) and supplies up to 1088 m³/day were obtained from a bore in the St Ives Borefield (Table 1).

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

Chert and banded iron-formation are commonly associated with silicified shale. Banded iron-formation is particularly...
Table 1. Summary of data from borefields supplying mine water

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Borefield</th>
<th>Number of tested exploratory bores (b)</th>
<th>Number of production bores</th>
<th>Production bores (a)</th>
<th>Depth range (m)</th>
<th>Yield (m³/day)</th>
<th>Salinity (mg/L TDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granitoid rocks</td>
<td>St Ives</td>
<td>1</td>
<td>200</td>
<td>190</td>
<td>20 - 40</td>
<td>108</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Bald Hill</td>
<td>5</td>
<td>16 - 40</td>
<td>200 - 620</td>
<td>110 - 182</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>Mafic and ultramafic rocks</td>
<td>Mt Mongar</td>
<td>3</td>
<td>80 - 82</td>
<td>104 - 225</td>
<td>37 - 60</td>
<td>35</td>
<td>3</td>
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<tr>
<td></td>
<td>Karoole</td>
<td>4</td>
<td>95</td>
<td>55</td>
<td>5 - 30</td>
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<td>3</td>
</tr>
<tr>
<td></td>
<td>Toorak</td>
<td>2</td>
<td>100 - 102</td>
<td>138 - 690</td>
<td>158 - 260</td>
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<tr>
<td></td>
<td>St Ives</td>
<td>5</td>
<td>132 - 204</td>
<td>190 - 1,840</td>
<td>20,000 - 55,000</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Junction West</td>
<td>4</td>
<td>81 - 103</td>
<td>80 - 1,720</td>
<td>24,000 - 34,000</td>
<td>34</td>
<td>4</td>
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<tr>
<td></td>
<td>Bald Hill</td>
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<td>19 - 42</td>
<td>160 - 600</td>
<td>62,000 - 135,000</td>
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<td>3</td>
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<tr>
<td>Woodline beds</td>
<td>Woodline Beds</td>
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<td>55 - 100</td>
<td>100 - 32</td>
<td>42,000 - 159,000</td>
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<td>3</td>
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<tr>
<td>Eocene sedimentary rocks</td>
<td>Jubilee</td>
<td>4</td>
<td>35 - 49</td>
<td>600 - 760</td>
<td>44,000 - 53,000</td>
<td>53</td>
<td>5</td>
</tr>
<tr>
<td>(Wollubar Sandstone/Hampton Sandstone)</td>
<td>East Location 48</td>
<td>12</td>
<td>81 - 43</td>
<td>880 - 1,300</td>
<td>34,000 - 130,000</td>
<td>130</td>
<td>10</td>
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<td>460 - 1,050</td>
<td>192,000 - 209,000</td>
<td>209</td>
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</table>

Notes:
(a) exploratory bore data where no production bores
(b) not including dry, uncased bores

The Woodline beds consist of arenaceous and argillaceous metasedimentary rocks with minor evaporite. From recent exploratory drilling for groundwater, Roberts and Moore (1991) believed there were good groundwater prospects. Where drilling was carried out, the regional water table is deep, as much as 54 m in exploratory bores adjacent to WMC bore Water 502. The estimated potentiometric head in the Woodline beds area is about 280–290 m AHD.

Fraser Complex (Ba)

Granulite and amphibolite facies rocks of the Fraser Complex are exposed in the southeast corner of WIDGIEMOOLTHA where they form prominent ridges. The Fraser Complex has not been tested on WIDGIEMOOLTHA, but a few bores were drilled north and east of the Fraser Range Homestead on the adjacent NORSEMAN sheet. Granulite is generally weathered up to 25 m and the best supplies (50–200 m³/day) are from the fractured fresh bedrock (GSWA data).

Dalyup Gneiss (En)

The Dalyup Gneiss is derived largely from granite with pegmatite veins and minor components of sedimentary origin (Meyers, 1995). The rock unit was strongly deformed during the Albany–Fraser Orogen. There only a few outcrops on WIDGIEMOOLTHA, indicating the Dalyup Gneiss is most likely weathered and would contain layers of quartz, and quartz and pegmatite veins considered prospective for groundwater.

Woodline beds (Ew)

The Woodline beds consist of arenaceous and argillaceous metasedimentary rocks with minor evaporite. From recent exploratory drilling for groundwater, Roberts and Moore (1991) believed there were good groundwater prospects. Where drilling was carried out, the regional water table is deep, as much as 54 m in exploratory bores adjacent to WMC bore Water 502. The estimated potentiometric head in the Woodline beds area is about 280–290 m AHD.

Tertiary sedimentary rocks (T, TEr and Tw)

The sandstone, carbonate and spongolite units in the Lefroy and Cowan Palaeodrainages as well as the Wollubar Palaeochannel form major aquifers on WIDGIEMOOLTHA. The units are confined only where they are overlain by relatively impermeable clayey deposits, such as upstream of Lake Lefroy. In the Wollubar Palaeochannel the Wollubar Sandstone is unconfined and partly saturated where the overlying Perkolilli Shale is thin or absent. The Princess Royal Spongolite is possibly a minor aquifer where saturated.

In the Lefroy Palaeodrainage the potentiometric surface falls from about 300 m AHD to 293 m AHD in the Mt Morgan Palaeochannel. In the Lefroy Palaeochannel it is about 295 m AHD in the Wannaway Borefields and about 273 m AHD in the Karonie Borefield. There are local variations in depth to the water table due to the topography. The standing water level in observation bores ranges from 8 to 15 m below ground surface in the Karonie Borefield (Australian Groundwater Consultants, 1988), 5 to 17 m in the Mt Morgan Borefield (Forbes et al., 1991) and 8 to 16 m in the Wannaway Borefield (K. H. Morgan and Associates, 1991a).
et al., 1992). Near Wollubar, where the confining bed and the upper part of the Wollubar Sandstone have been removed by erosion, the watertable is close to the surface, and the potentiometric heads indicate groundwater discharge into Lake Lefroy.

Bore yields from Tertiary sedimentary rocks are variable and range from about 450 to 1200 m³/day (Table 1). Short-term yields up to 2000 m³/day have been recorded during pumping tests on WIDGIEMOOLTHA. Bore yields increase where the aquifer becomes thicker and wider, and the sand coarser.

The Norseman Limestone, the Princess Royal Spongolite, and the Werribalup Formation have not been tested for groundwater on WIDGIEMOOLTHA, but they are likely to form major aquifers where they are saturated, due to the high porosity of the strata. The basal Pidinga Formation generally forms an aquiclude, except where the formation contains lenses of gravelly sand.

**Surficial deposits (Cz and Q1)**

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

Lacustrine sediments are intermittently saturated as the lakes are usually dry for much of the year and are replenished only after heavy rainfall. The regional water table in lacustrine sediments is close to the surface in playa lake environments, whereas there may be a perched watertable in lagoons and claypans, such as in Hogans Lagoon (Griffin, 1989).

The sediments are generally fine grained or argillaceous, and bore and well yields are likely to be low. They are not utilized as aquifers on WIDGIEMOOLTHA, except in the Revenge Pit where groundwater is pumped intermittently from lacustrine sediments (Roberts, 1990).

**Groundwater quality**

**Salinity**

**Regional variation**

Groundwater on WIDGIEMOOLTHA is mainly saline to hypersaline. The salinity ranges from 1000 mg/L total dissolved solids (TDS) in granitic eluvium adjacent to monadnocks to as much as 350 000 mg/L TDS or more in brines in palaeochannels and playa lake sediments, and in adjacent fractured and weathered bedrock. The salinity range of groundwater from the major borefields is given in Table 1.

Potable groundwater (<1000 mg/L TDS) is not known on WIDGIEMOOLTHA, but brackish groundwater (1000–3000 mg/L TDS) occurs in perched aquifers and small elevated areas of enhanced recharge composed mainly of unweathered, fractured rocks, such as in the Fraser Range and along the northern margin of the sheet area. Elsewhere the elevated areas contain mainly saline groundwater (3000–30 000 mg/L TDS). Hypersaline groundwater (>30 000 mg/L TDS) is widely distributed throughout WIDGIEMOOLTHA where it occurs in palaeochannels, and in bedrock adjacent to and below alluvial flats and playa lakes. The highest salinity (365 000 mg/L TDS) was recorded in lacustrine sediments in the Revenge Pit (Roberts, 1990).

The high salinities of groundwater in playa-lake environments result from concentration of salts as water evaporates from the lakes, but 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. Hogans Lagoon is such an example (Griffin, 1989). 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 rock. In production bores within mafic and ultramafic rocks at the St Ives and Junction West Borefields, the groundwater salinity ranges from 20 000 to 95 000 mg/L and from 240 000 to 340 000 mg/L TDS respectively, and possibly reflects the complexity of fracture systems or the proximity of Lake Lefroy. Consequently, it is difficult to map the groundwater-salinity pattern in the Archaean and Proterozoic bedrock at a local scale.

**Variation within aquifers**

Based on the data from shallow wells, the groundwater salinity in areas of elevated granitoid rocks is relatively low and ranges from about 1000 to 20 000 mg/L TDS throughout WIDGIEMOOLTHA. This is probably because of the sandplain cover, which enhances recharge, and the relatively high elevation of the granitoid terranes.

The groundwater salinity is likely to be low (1000–10 000 mg/L TDS) in the Fraser Range due to the high elevation as indicated by low salinity bores (3000 mg/L TDS) northeast of the Fraser Range Homestead on the adjacent NORSEMAN sheet (GSWA data). The groundwater
salinity in the Woodline beds in WMC bore Water 502 was 42 000 mg/L TDS (Roberts and Moore, 1991).

The groundwater salinity in the greenstone belts tends to be highly variable, ranging from about 5000 to over 300 000 mg/L TDS. Large local variations in groundwater salinity are common, such as in the St Ives Borefield where the salinity ranges from 20,000 to 95,000 mg/L TDS. The highest salinity (344 000 mg/L TDS) was recorded in a production bore in fractured ultramafic rocks at the Junction West Borefield adjacent to Lake Lefroy.

The groundwater salinity in the Tertiary sediments is very variable. The groundwater salinity in the Lefroy Palaeochannel ranges from about 150 000 to 230 000 mg/L TDS based on bore data, and it can be as much as 300 000 mg/L TDS under the playa lakes (Fig. 3).

The groundwater salinity in the Mt Morgan Palaeochannel increases downstream from about 34 000 mg/L TDS to the west to about 220 000 mg/L TDS near playa lakes (Fig. 3).

The groundwater salinity in the Wollubar Palaeochannel is highly variable on WIDGEMOOLTHA (Fig. 3). It is lowest (44 000–53 000 mg/L TDS) in the Jubilee Borefield where the groundwater flow is from the west, and highest (111 000–118 000 mg/L TDS) in the Mt Martin Borefield where the groundwater flow is from the Yindarlgooda and Hannan Palaeochannels to the north (Kern, 1995b).

The Cowan Palaeochannel can be inferred to have a groundwater salinity range similar to the Lefroy Palaeochannel.
Hydrochemistry

The results of chemical analyses of groundwater from 15 sampling points are presented in Table 2, and the major ions from the chemical analyses are plotted on tri-linear diagrams in Figure 4. In water from most of these bores and wells sodium chloride forms the greatest part of the dissolved solids. The composition of major ions of saline groundwater is close to that found in seawater.

The proportion of bicarbonate is low in bores and wells within fractured bedrock. It is negligible in palaeochannel aquifers, especially in the more acidic groundwater which contains free carbon dioxide. The proportion of calcium is generally very small. Magnesium also represents small proportions in the groundwater composition. Chippys Bore is characterized by a slightly higher proportion of magnesium when compared with the chemical composition of other bores and wells.

The pH of groundwater ranges from neutral to strongly acidic. The pH is lowest (pH = 3–4) in the Wollubar Sandstone and the Woodline Beds. McArthur et al. (1991) suggested that the high acidity in the region is caused by ferrolysis when saline anoxic groundwater rich in dissolved Fe\(^{2+}\) is mixed with fresh meteoric water. Low groundwater pH, which causes severe metal corrosion, 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 WIDGIEMOOLTHA. Electrical methods provide a relatively low-cost method of locating highly conductive (saline) groundwater in palaeochannels, although deeply weathered bedrock can have the same characteristics. Techniques such as airborne electromagnetic surveys (GEOTEM) and transient electromagnetic were used successfully by Western Mining Corporation on the sheet area.

Preliminary exploratory drilling by rotary airblast (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. One hundred thirty-six exploration holes were drilled in the St Ives Borefield prior to constructing six production bores (Forbes and Roberts, 1990). 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 WIDGIEMOOLTHA were drilled to obtain water for mineral processing. The groundwater is generally too saline for other purposes. The borefields are located close to major mining centres and obtain groundwater from Tertiary sediments in the palaeochannels or from highly weathered and fractured Archaean and Proterozoic bedrock.

In 1989 groundwater abstraction on WIDGIEMOOLTHA from the palaeochannels was about 3.5 \(\times 10^6\) m\(^3\). The major users are the Hampton and Newmont Mines, which obtain their water supplies from the Jubilee and East Location 48 Borefields respectively. Drawdown in borefields generally 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. Groundwater abstraction from fractured and weathered bedrock was estimated to be about 1.5 \(\times 10^6\) m\(^3\) in 1989. The St Ives and Junction West Borefields are the major borefields developed within highly weathered and fractured bedrock, and have bore yields in excess of 500 m\(^3\)/day.

The largest groundwater supplies are found in Tertiary palaeochannel aquifers. Results from pumping tests in the Lefroy Palaeodrainage upstream of Lake Lefroy indicate short-term yields from 200 to 2000 m\(^3\)/day and long-term yields from 100 to 1000 m\(^3\)/day. In most pumping tests the aquifer responses indicate confined conditions which are likely to remain after several years of pumping.

The Wollubar Palaeochannel is extensively developed on WIDGIEMOOLTHA but only small sections of the Lefroy Palaeodrainage are developed. The Cowan Palaeochannel can be inferred to have groundwater resources similar to those of the Lefroy Palaeodrainage.

The groundwater in storage in the palaeochannels is very large in comparison with the estimated recharge. Pumping is likely to induce significant inflow from tributaries, weathered and fractured bedrock, and by leakage from the overlying clayey sediments.

Groundwater obtained from mine dewatering is also used for ore processing and mining requirements. The major mine dewatering activities are at the Victory Complex and Foster Mine where the groundwater abstraction was about 1.3 \(\times 10^6\) m\(^3\) in 1989 (Roberts, 1990), and at the Poseidon South Pit at Higginsville (K. H. Morgan and Associates, 1991).

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.

Disposal of tailings at mine sites and seepage of highly concentrated saline water from unlined dams can 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.
Table 2. Selected chemical analyses of groundwater

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<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>HCO₃⁻</th>
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</tbody>
</table>

Notes: (a) St Ives Borefield; (b) St Ives Borefield; (c) Karnilbinia mine water bore; (d) Karnion mine water bore; (e) Unnamed bore south of salt lakes; (f) St Ives Borefield; (g) Foster mine dewatering bore; (h) Junction West Borefield; (i) Water 502 test bore at Woodline Beds; (j) Jubilee Borefield; (k) Mt Martin Borefield; (l) Karnion Borefield; (m) Mt Morgan Borefield; (n) Wannaway Borefield; EC = Electrical conductivity; TDS = Total dissolved solids by calculation
Pastoral

Because of the relatively high salinity and low yield of wells and bores, the majority of pastoral leases on WIDGIE MOOLTHA are dependent on surface water for stock. The main sources are therefore from dams located along drainages and alluvial flats, and to a lesser extent from contour drains, rock walls and marginal dams constructed on or adjacent to massive granite outcrops, such as at Binneringie (Berliat, 1954). There are only a few scattered shallow bores and wells in the area, and most are now abandoned. Water for pastoral purposes is provided seasonally by gnamma, water and rock holes, soaks and lagoons.

Further development

The sandstone, carbonate and spongolite units in the palaeochannels are considered the most prospective aquifers on WIDGIE MOOLTHA. The palaeochannel aquifers are readily located, exploited, and managed, and sustainable yields are much more likely than from weathered and fractured bedrock. The groundwater resources in the Wollubar Palaeochannel of the Roe Palaeodrainage are almost fully utilized. The groundwater resources in the Lefroy Palaeodrainage are undeveloped and are sufficient for current and future mining developments. Potential for development is inferred to exist in the Cowan Palaeodrainage.
The weathered and fractured bedrock aquifers on **WIDGIEMOOLTHA** 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 often several bores must be drilled before the required supply is obtained.

**Groundwater resources**

Most of the groundwater on **WIDGIEMOOLTHA** 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, granulite and amphibolite facies rocks in the Fraser Range, and perched aquifers, but they are usually difficult to locate.

Because the annual recharge from rainfall is very small, groundwater resources on **WIDGIEMOOLTHA** are considered in terms of groundwater in storage. Only a proportion of this groundwater 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 $6 \times 10^6$ m$^3$ on **WIDGIEMOOLTHA**. Groundwater in the fractured bedrock 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, and calculated the total economically commandable groundwater reserves within 100 km of Kalgoorlie to be about $60 \times 10^6$ m$^3$, including about $9 \times 10^6$ m$^3$ on **WIDGIEMOOLTHA**. Groundwater in the weathered bedrock probably represents about 5% of the total groundwater resources of the area.

**Tertiary sedimentary rock aquifers** contain by far the largest groundwater resources on **WIDGIEMOOLTHA**. The groundwater resources in the palaeochannels on **WIDGIEMOOLTHA** are estimated to be at least $1.5 \times 10^6$ m$^3$ per kilometre of channel length (**BHP Engineering and Australian Groundwater Consultants, 1988**), giving a total of approximately $750 \times 10^6$ m$^3$ of groundwater in storage for an aggregate channel length of 500 km. Therefore it can be inferred that on a regional scale the groundwater resources in the Tertiary sedimentary rocks represent more than 90% of the total groundwater resources on **WIDGIEMOOLTHA**. In addition to the groundwater storage in the palaeochannels, groundwater will be available by inflow induced by pumping from the adjacent and underlying weathered and fractured bedrock, or by leakage from the overlying sediments.

*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 5% of the total groundwater resources on **WIDGIEMOOLTHA**.
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