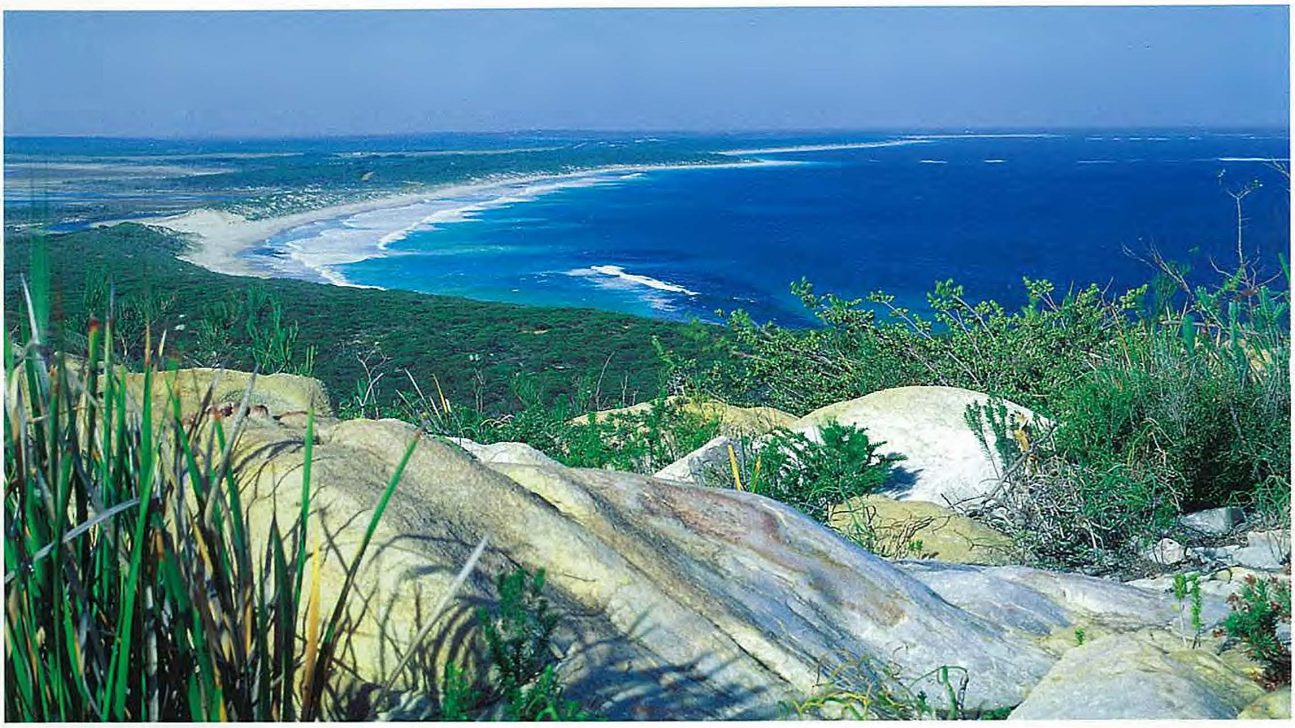
GOVERNMENT OF WESTERN AUSTRALIA

# Hydrogeology of the Ravensthorpe 1:250 000 Sheet



Hydrogeological Map Explanatory Notes Series

Water and Rivers Commission Report HM 4

1998

Water and Rivers Commission

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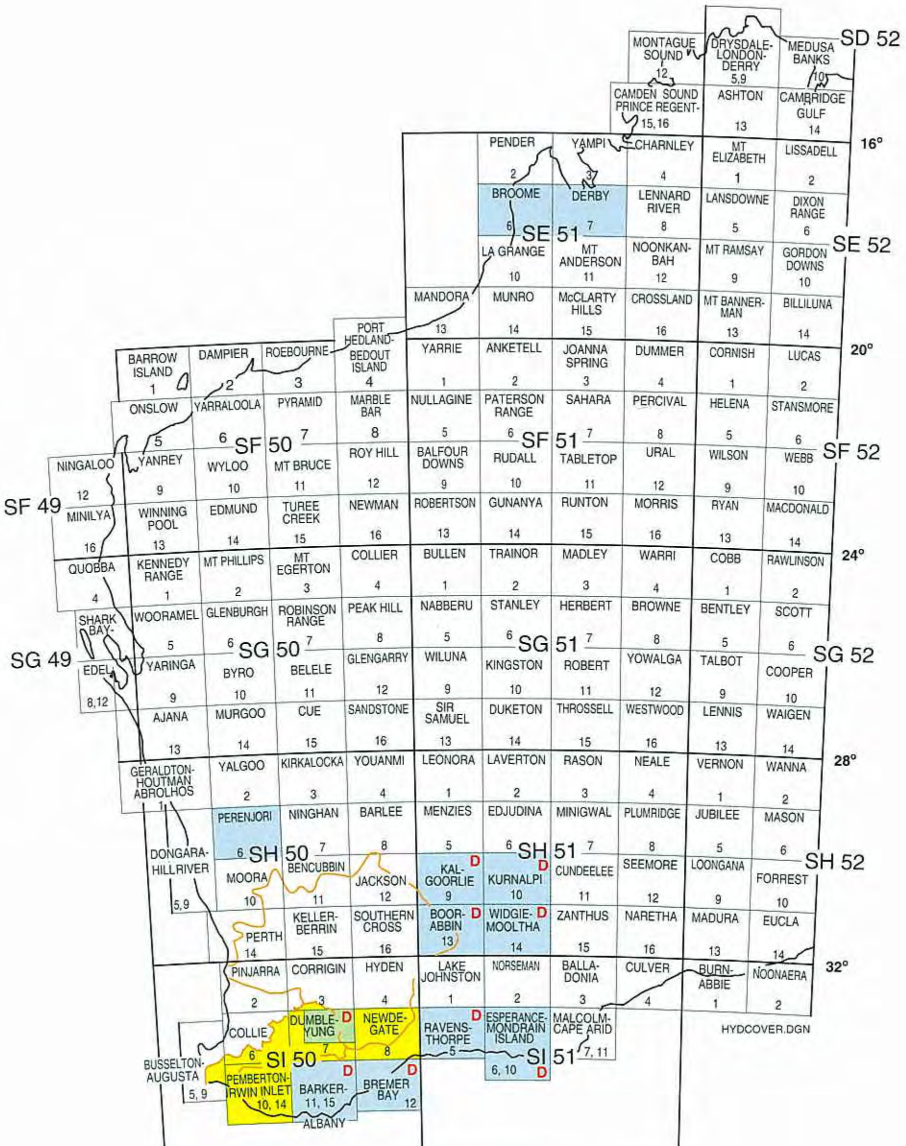


*Cover Photograph: Kundip Quartzite outcrop on East Mount Barren, overlooking Culham Inlet and Hopetoun on the South Coast.*

# Hydrogeology of the Ravensthorpe 1:250 000 sheet

by

S.L. Johnson

Water and Rivers Commission
Resource Investigation Division

WATER & RIVERS COMMISSION
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES
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# HYDROGEOLOGY OF THE RAVENSTHORPE 1:250 000 SHEET

by

S. L. JOHNSON

## Abstract

The RAVENSTHORPE 1:250 000 hydrogeological sheet covers the southern portion of the Yilgarn Craton, parts of the Albany–Fraser Orogen and the Bremer Basin. The rocks include weathered and fractured greenstone, gneiss, granitoid and schist, fractured and fissured banded iron-formation and quartzite, and siltstone, sand, silt and clay. Cainozoic surficial sediments form an extensive cover concealing Archaean and Proterozoic basement, and Tertiary sedimentary rocks preserved in broad palaeodepressions.

Fractured-rock aquifers occupy the greatest part of the RAVENSTHORPE area but contain only minor groundwater supplies that are difficult to locate. The shoreline and spongolite facies of the Tertiary Pallinup Siltstone and basal sands of the Werillup Formation are considered to be the most prospective aquifers on RAVENSTHORPE; however, they have limited extent and distribution. Quaternary coastal sediments contain small supplies of groundwater which are predominantly located around Hopetoun and to the east of Stokes Inlet.

Most of the groundwater on RAVENSTHORPE is saline and not utilised, except for small resources suitable for watering stock. Fresh groundwater is limited to the coastal areas, and includes the town water supply for Hopetoun. Brackish to saline groundwater, utilised by the farming community for watering stock, occurs in the higher rainfall areas of the south and beneath localised catchment divides. Small groundwater supplies perched above the regional watertable, and seasonal in occurrence, may be found sporadically throughout the sand plain.

**Keywords:** hydrogeological maps, groundwater, aquifers, salinity, Ravensthorpe

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**Figure 1. Location map**

# 1 Introduction

## 1.1 Location

The RAVENSTHORPE* 1:250 000 hydrogeological sheet (SI 51-5 of the International Series), which is bounded by latitudes 33°S and 34°S and longitudes 120°E and 121° 30'E, lies in the South Coast Agricultural District of Western Australia. Land use in the area is dominated by grain cropping and sheep farming, with cattle production in the higher rainfall, southeastern areas. The map sheet takes its name from the former copper-mining town of Ravensthorpe, located 50 km inland of the coast in the west, which is the most populated centre on RAVENSTHORPE. Ravensthorpe and Hopetoun, a small coastal tourist town, are the major service centres for the local agricultural, fishing and mining industries. There are small communities at Jerdacuttup, Munglinup and Cascade but the remainder of the map sheet is sparsely populated. The Fitzgerald River National Park, which occupies the southwestern corner of RAVENSTHORPE, and the settlement of Hopetoun attract a seasonal influx of tourists and recreational fisherman.

The sheet area is reached via the South Coast Highway which connects Ravensthorpe to Esperance, 186 km to the east, and other centres to the west (Fig. 1). The Ravensthorpe–Lake King Road connects Ravensthorpe with inland centres, and a sealed road links Ravensthorpe with Hopetoun. The rural areas and Fitzgerald River National Park are connected by a network of gravel roads.

## 1.2 Climate

The area has a Mediterranean-type climate with cool, wet winters and warm to hot, dry summers. Conditions become progressively drier in winter and hotter in summer towards the north of the sheet, while in coastal areas climatic extremes are moderated by cooling southerly winds. The average monthly minimum and maximum temperatures for Ravensthorpe range from 14° to 29°C during summer months, and from 7° to 16°C during winter months.

The average annual rainfall is 549 mm at Young River, 508 mm at Hopetoun, 425 mm at Ravensthorpe and 346 mm at Lake King, 10 km west of the northwestern corner of RAVENSTHORPE. This highlights the sharp decrease in rainfall from south to north across the map sheet. Most of the rain occurs during the winter months from cold fronts associated with low-pressure systems from the Southern Ocean, while periodic summer rainfall results from tropical rain depressions or thunderstorm activity. The wettest month is June and the driest, January. A possible rain shadow, east of the Barren and Ravensthorpe Ranges, may explain the lower rainfall at Hopetoun, compared with the coastal towns of Bremer Bay and Esperance.

Average annual potential evaporation increases from about 1700 mm at the coast to 2100 mm in the north. Evaporation is greatest during the summer months of January and February and lowest during the winter months of June and July.

## 1.3 Physiography

Most of the area is characterised by flat to gently undulating sandplain which rises gradually from sea level to about 300 m above Australian Height Datum (AHD). The Phillips, Steere, Jerdacuttup, Oldfield, Young and Lort rivers which flow southwards to the Southern Ocean (Fig. 2) are incised into the sandplain. Throughout RAVENSTHORPE numerous granite monadnocks protrude slightly above the land surface with greenstone and banded iron-formation forming prominent hills and ridges, such as Mount Desmond (340 m), Mount Benson (404 m) and Overshot Hill (377 m), in the Ravensthorpe Range. In the southwestern corner of RAVENSTHORPE, the jagged peaks of the Barren Ranges form significant topographic features including No Tree Hill (270 m), Eyre Range (290 m) and East Mount Barren (311 m).

The coastline is divided by numerous rocky headlands into asymmetrical bays with sandy beaches. A narrow coastal plain extending 5 to 10 km inland comprises a large number of saline lakes, such as Lake Shaster and the Jerdacuttup Lakes, situated behind eolian sand dunes up to 100 m high. The inland extent of the coastal plain is marked by a low scarp, up to 40 m high, which is discontinuous to the west where the Esperance Sandplain and coastal plain merge (Nicholas and Gee, *in prep.*).

* *sheet names are printed in capitals to distinguish them from similar place names*

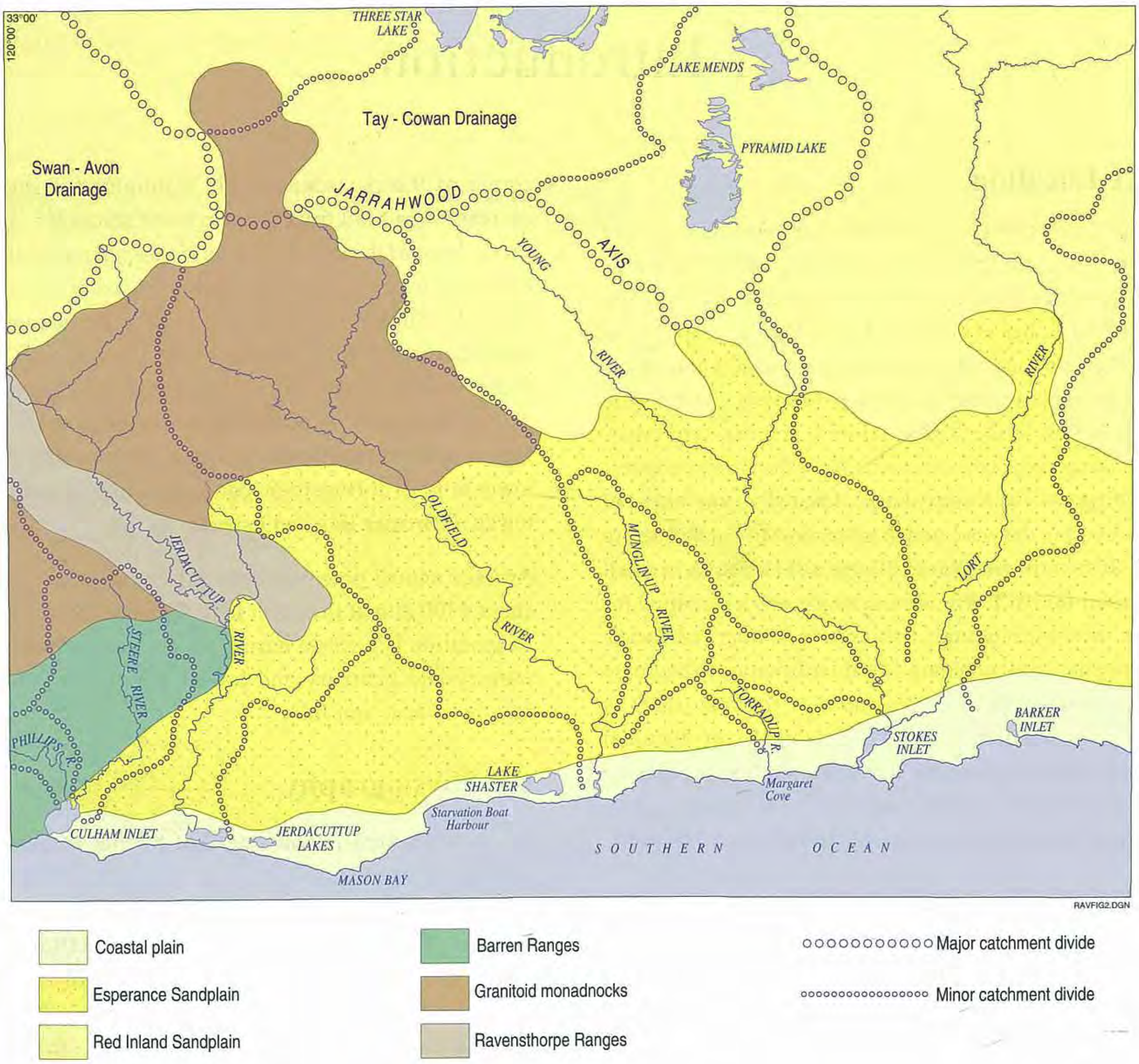


**Figure 2. Physiography**

The Esperance Sandplain extends about 30 to 40 km inland from the coastal plain and is characterised by flat to gently undulating topography which has been deeply incised by south flowing rivers forming steep gorges and river terraces. The numerous claypan depressions on the Esperance Sandplain are believed to have been formed by ground subsidence due to leaching out of carbonate sections in the underlying Tertiary sediments by percolating rainwater (Morgan, 1969), and these give rise to semi-permanent fresh to brackish perched water. Inland of this sandplain is the Red Inland Sandplain, also referred to as the Mallee District (Beard, 1979), comprising red loam over calcareous loess and characterised by broad valleys occupied by playa lakes.

A major surface-water divide which crosses RAVENSTHORPE and separates the northward-flowing internal drainage, part of the Tay–Cowan Palaeodrainage, from the southward directed drainage systems (Fig. 2). This corresponds to the Jarrahwood Axis along which uplift occurred during the Tertiary (Cope, 1975). The internal drainage to the north of the Jarrahwood Axis is occupied by salt lakes, such as Lake Tay and Three Star Lake, forming broad, flat-floored valleys.

River courses and drainage systems are well developed to the south of the Jarrahwood Axis with youthful rivers dissecting the southward sloping topography, which is known as the Ravensthorpe Ramp (Cope, 1975). The

Lort River is the most extensive river system on RAVENSTHORPE with its headwaters approximately 100 km inland. The incised river valleys range up to 60 m deep in the southern part of the Esperance Sandplain. Unusual river configurations, particularly the upper third of the Lort River in the vicinity of the Jarrahwood Axis, result from stream capture and the reversal of the previous northerly flow direction.

## 1.4 Vegetation

The natural vegetation of RAVENSTHORPE is predominantly scrubland heath with local woodlands of small eucalypts (Beard, 1979). Since the 1960s much of the native vegetation of the southern and eastern portion of RAVENSTHORPE has been cleared for agriculture.

The coastal area and lower sandplain comprises coastal dune scrub of *Scaevola crassifolia*, *Eucalyptus angulosa* and *Acacia cyclopsis*, and low scrub heath with *Banksia speciosa* dominant, while coastal swamps are colonised by the paperbark tree *Melaleuca parviflora*. The Esperance sandplain is characterised by *E. tetragona* mallee heath, except in areas with deep sands where *Banksia* and 'Christmas Tree' (*Nuytsia floribunda*) dominate, and in swamps, depressions and valley bottoms where patches of yate (*E. occidentalis*) occur. In the north of the sheet, the Red Inland Sandplain is typically covered with mallee and woodland of *E. eremophila*, *E. pileata* and *E. oleosa* with the playa lakes bordered by saltbush.

The ridges formed by greenstone are dominated by a low mallee thicket of *E. preissiana* and *E. lehmannii*, with the hillside slopes covered in mallee (*E. nutans* and *E. gardneri*) and sclerophyll woodlands of York Gum (*E. loxophleba*) and Salmon Gum (*E. salmonophloia*). The Fitzgerald River National Park in the southwest corner of the sheet has a diverse flora with various *Eucalyptus*, *Proteaceae*, *Myrtaceae*, *Dryandra* and *Hakea* species, which are closely associated with soils of the Mount Barren metasedimentary rocks.

## 1.5 Previous investigations

The sheet area has been geologically mapped at 1:250 000 scale (Thom *et al.*, 1977) while the southwestern part of RAVENSTHORPE has recently been remapped at 1:100 000 scale (Witt, 1997). Myers (1995) provided a regional interpretation at 1:1 000 000 scale using aeromagnetic and radiometric data published by the Australian Geological Survey Organisation (AGSO).

Mineral exploration has provided the most comprehensive insight into the geology of RAVENSTHORPE. Most mineral exploration has centred on the Ravensthorpe greenstone belt around the historic copper, gold and silver centres of Kundip and Desmond. The Plantagenet Group sedimentary rocks in the northern portion of RAVENSTHORPE were explored for lignite by Griffin Coal Mining Ltd (1981) and Elixir Holdings Pty Ltd (1990). The area south of Springdale Road between Jerdacuttup Lakes and Margaret Cove, including Mason Bay and Starvation Boat Harbour, was explored for heavy-mineral sands and drilled extensively in the early 1990s by Cable Sands WA (Harewood, 1994).

The earliest report on the regional hydrogeology was by Probert (1965) who gave an appraisal of groundwater resources in the Ravensthorpe District area. A bore census and regional mapping were conducted by Sanders (1968) to provide a hydrogeological assessment of the Tertiary sediments in the southeastern corner of RAVENSTHORPE. This information was incorporated in the first hydrogeological map of the Ravensthorpe region (Morgan, 1969) which showed the generalised relationship between rainfall, topography, geology and regional groundwater salinity.

The first exploratory drilling for water at Hopetoun was carried out by Morgan (1965). Subsequent drilling located the Town Borefield, 3 km northwest of Hopetoun, in Quaternary limestone and calcareous sands (Hirschberg, 1980). Further exploratory drilling, northeast of the town site, resulted in the establishment of the Oldfield Borefield (Smith and Davidson, 1987). Drilling to locate stock-quality groundwater has been carried out during drought periods (Lord, 1971; Davidson, 1977; Laws, 1987). Unpublished Geological Survey of Western Australia (GSWA) hydrogeological reports describe groundwater prospects on approximately 50 private farms in the area and groundwater prospects for Ravensthorpe, Hopetoun, Jerdacuttup and Munglinup.

In 1995 additional exploratory drilling was undertaken in the Bremer Basin as part of the South Coast Water Deficiency and GSWA Groundwater Exploration Initiative programs (Baddock *et al.*, 1995; Panasiewicz *et al.*, 1996; Koomberi, 1996). In this two-stage program, 44 bores with an aggregate depth of 880 m were drilled to evaluate the groundwater potential of the Tertiary sediments and fractured-rock aquifers on RAVENSTHORPE. A successful production bore (SCP2) was constructed at the intersection of Middle and Bedford Harbour Roads to supply stock quality groundwater for the eastern Jerdacuttup farming community.

Salinisation is a widespread problem in the southwest of Western Australia and is particularly severe on the south coast, so there is a need to better understand the hydrogeology of the region. The National Landcare Program has provided funding for the Hydrogeological Mapping Project of 1:250 000 hydrogeological series maps for MOUNT BARKER–ALBANY (Smith, 1995), BREMER BAY (Dodson, 1996), ESPERANCE–MONDRAIN ISLAND (Baddock, 1996), RAVENSTHORPE (Johnson, 1996), NEWDEGATE (Dodson, *in prep.*) and PEMBERTON (De Silva, *in prep.*). Agriculture Western Australia (AgWA) has investigated salinity and waterlogging (Short, 1997; McFarlane *et al.*, 1994; Hearn, 1991), mapped landform systems (Nicholas and Gee, *in prep.*) and prepared catchment management strategies (Platt *et al.*, 1996).

## 1.6 Map compilation

The hydrogeological map of RAVENSTHORPE depicts aquifer distribution and type, watertable level and topographic contours in metres AHD, groundwater salinity (isohalines), groundwater point data distribution and cadastral data. Data used in the compilation and interpretation of the map include: topocadastral data from Department of Land Administration; geology from GSWA (Thom *et al.*, 1977; Myers, 1995 and Witt, 1997); bore data from the Water and Rivers Commission water point database (AQWABase); AgWA Esperance Branch bore and piezometer data, and landform systems mapping (Nicholas and Gee, *in prep*); AGSO aeromagnetic and radiometric data; and WAMEX mineral exploration drilling data and reports from the Department of Minerals and Energy.

The RAVENSTHORPE hydrogeological map is, at the 1:250 000 scale, a generalisation of the data which have been entered into a digital database and stored as graphical layers of information at various scales. Appendix 1 shows scales of capture for each graphical layer. The digital data can be augmented and maps of catchments or specific areas can be reproduced at any scale for land and water resource management and planning. Interpretation of the data was conducted at 1:50 000 scale in the southern half of the map sheet, but at 1:100 000 scale in the northern half due to sparse data distribution. This difference should be considered when working with larger scales. The hydrogeological boundaries, watertable-level contours and groundwater isohalines are interpretive, and must be taken as approximate. The accuracy of the interpretation can be gauged from the density of bores and mineral exploration holes which provided useful geological information.

# 2 Geology

## 2.1 Regional setting

RAVENSTHORPE covers part of the Yilgarn Craton and Albany–Fraser Orogen (Fig. 3). The southern part of the Yilgarn Craton, comprising late Archaean granite–greenstone rocks and cross-cutting Proterozoic dolerite dykes of the Widgiemooltha dyke swarm, is unconformably overlain by Upper Proterozoic metasedimentary rocks of the Mount Barren Group (Myers, 1995). The Biranup Complex, part of the Albany–Fraser Orogen, underlies the southeast portion of the sheet and is separated from the Archaean granite–greenstones and Mount Barren Group by the northeast-trending Jerdacuttup Fault (Witt, 1997).

Cainozoic deposits comprise Early Tertiary sedimentary rocks of the Plantagenet Group of the Bremer Basin (Hocking, 1990) and surficial sediments. The Plantagenet Group forms a discontinuous cover over the Precambrian rock in the south of the sheet and comprises two distinct lithofacies; the Werillup Formation and the Pallinup Siltstone (Table 1). The Werillup Formation, which is overlain by horizontally bedded Pallinup Siltstone, infilled pre-existing Cretaceous to Early Tertiary palaeodrainages and broad drainage depressions formed during the continental breakup between Australia and Antarctica.

**Table 1. Stratigraphy**

| *Age* | *Formation* | *Maximum thickness intersected (m)* | *Lithology* |
|---|---|---|---|
| Quaternary | Alluvium *(Qa)* | 13 | Silt, sand and gravel |
| | Coastal sand *(Qs)* | 40 | Sand, limestone |
| | Lacustrine *(Ql)* | 6 | Clay, silt |
| | Eolian dune *(Qd)* | 11 | Fine sand |
| | ~~~~~~*unconformity*~~~~~~ | ~~~~~~ | ~~~~~~ |
| Cainozoic | Alluvium, colluvium minor sandplain *(Cza)* | 25 | Sand, gravel, clay |
| | ~~~~~~*unconformity*~~~~~~ | ~~~~~~ | ~~~~~~ |
| Tertiary— Eocene | Plantagenet Group | | |
| | Pallinup Siltstone | | |
| | Shoreline facies *(TPps)* | 16 | Fine sand, silt, clay |
| | Spongolite facies *(TPpg)* | 9 | Spongolite, clay |
| | Siltstone facies *(TPp)* | 28 | Siltstone, sandstone, claystone |
| | Werillup Formation *(TPw)* | 34 | Sand, gravel, lignite and carbonaceous clay |
| | ~~~~~~*unconformity*~~~~~~ | ~~~~~~ | ~~~~~~ |
| Proterozoic | Mafic dykes *(Pd)* | - | Dolerite, gabbro |
| | ~~~~~~*unconformity*~~~~~~ | ~~~~~~ | ~~~~~~ |
| | Mount Barren Group | | |
| | Kybulup Schist *(PBy)* | - | Phyllite, schist, dolomite |
| | Kundip Quartzite *(PBk)* | - | Quartzite |
| | ~~~~~~*unconformity*~~~~~~ | ~~~~~~ | ~~~~~~ |
| | Albany–Fraser Orogen | - | |
| | Granitoid gneiss and granite *(Png)* | - | Gneiss, granite, sandy clay |
| Archaean | Yilgarn Craton | | |
| | Granitoid gneiss *(An)* | - | Gneiss, schist, clay |
| | Granite *(Ag)* | - | Granite, sandy clay |
| | Chert and banded iron-formation *(Ac)* | - | Chert, banded iron-formation |
| | Sedimentary and felsic volcanics *(As)* | - | Sandstone, shale, siltstone, dacite and rhyolite |
| | Mafic and ultramafic rocks *(Ab)* | - | Basalt, amphibolite, peridotite |

Note: (-) thickness is not determined

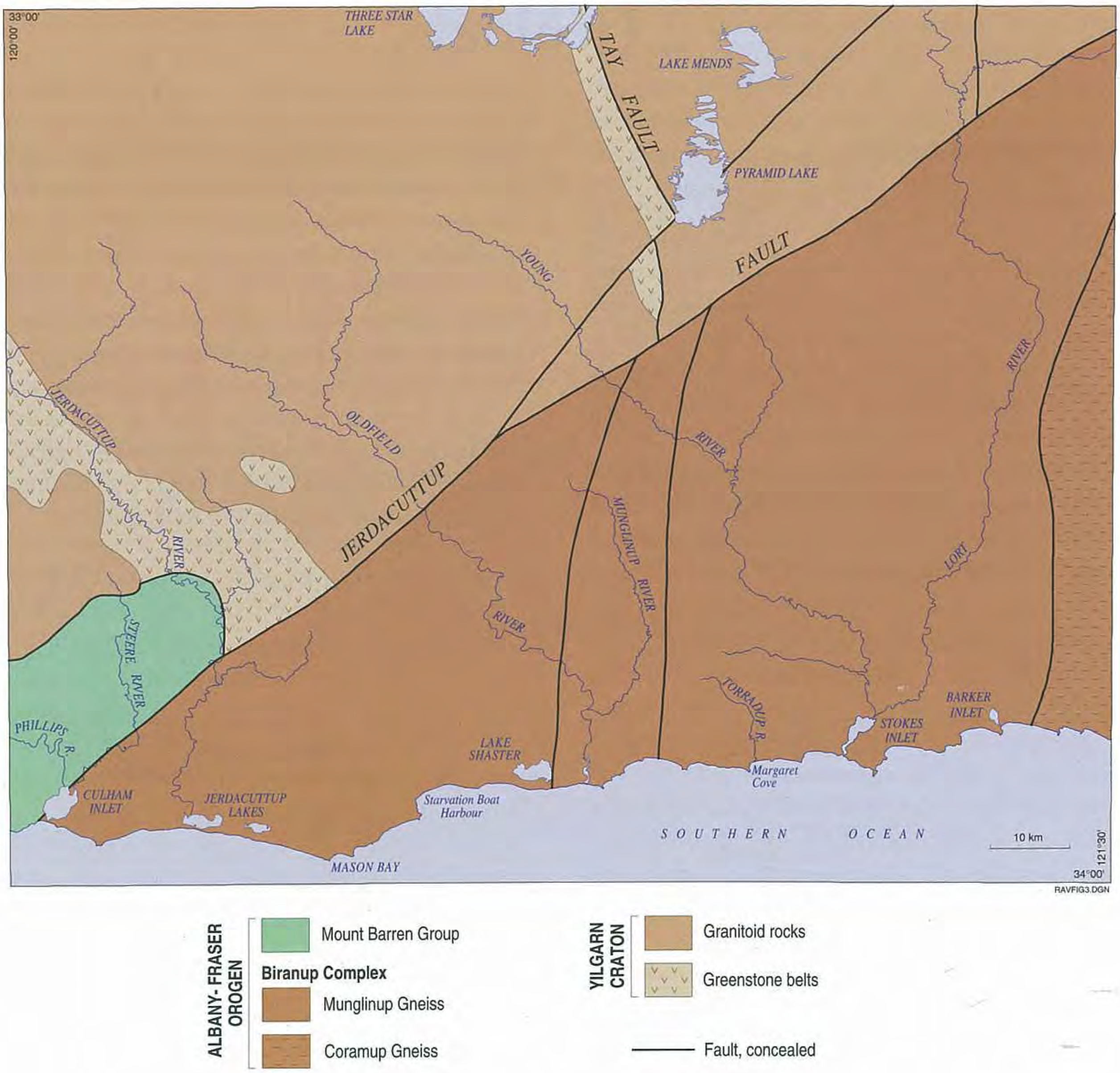


**Figure 3. Structure**

Cainozoic surficial deposits, which form a thin cover over most of the sheet, have formed through reworking of the duricrust, crystalline rocks and Tertiary sediments. The surficial sediments consist of eolian sand, alluvium, colluvium, lacustrine and estuarine deposits of clay and, near the coast, shelly sandstone and dune sand.

## 2.2 Archaean

The greenstone belt near Ravensthorpe (Witt, 1997) contains metamorphosed and deformed sequences of mafic and ultramafic volcanic rocks *(Ab)*; sedimentary and felsic volcanic rocks *(As)*; and minor chert and banded iron-formation *(Ac)*. A variety of granitoid rocks *(Ag)*, predominantly porphyritic and even grained, occupy about 40% of RAVENSTHORPE and are generally poorly exposed, except for the granite pluton located northeast of Ravensthorpe. The Munglinup Gneiss *(An)*, part of the Biranup Complex, exhibits strong foliation and is poorly exposed in the southern portion of the sheet. Most of the Archaean rocks on RAVENSTHORPE, excluding the greenstone belt, are poorly exposed due to extensive surficial cover and deep weathering. Outcrops are mainly on hills formed by basement highs and exposures within incised drainages.

The principal structure of the Archaean greenstone sequence is a south-plunging syncline with numerous northeast- and east-trending faults. The greenstone rocks are strongly deformed and recrystallised with a steeply dipping, north-northwest tectonic fabric, in contrast to most granites which are porphyritic, weakly deformed and partially recrystallised (Myers, 1995). The Munglinup Gneiss, derived from Archaean granites, exhibits a general northeast trend and large-scale sweeping fold structures resulting from Proterozoic deformation during the Albany–Fraser Orogeny.

The Jerdacuttup Fault, the dominant fault structure on RAVENSTHORPE, separates the Yilgarn Craton from the Albany–Fraser Orogen and is expressed at the surface as a quartz dyke, up to 5 m wide, south of Lee Road (Johnson and Baddock, 1995). The north-trending Tay Fault Zone contains part of the Johnston Greenstone Belt with intruded mafic and ultramafic sills overlain by mafic volcanics (Myers, 1995). The trace of a recent fault, located 15 km east of Cascade, is marked by a rounded scarp about 2 m in height (Thom *et al.*, 1977).

Most Archaean rocks on RAVENSTHORPE have been lateritised and weathered, and typically comprise a thin laterite duricrust or silcrete over a variable thickness of dense, kaolinitic clay. The weathering profiles on the greenstones and granitoids have developed through the chemical breakdown of the crystalline bedrock during Tertiary and Quaternary times. In places, a quartz-rich grit comprising partially decomposed basement, directly overlies the fresh bedrock and has been intersected in exploratory drillholes SCR-18 and SCR-27 (Panasiewicz *et al.*, 1996). The upper portion of the weathered profile in the south of RAVENSTHORPE has been largely eroded as a result of drainage rejuvenation. A deeper weathering profile occurs in the northern half of the map sheet with a thickness of 28 m intercepted in SCR-6 (Panasiewicz *et al.*, 1996) and a thickness of 40 m in mafic rocks, northwest of Cheadanup Nature Reserve.

## 2.3 Proterozoic

The Dalyup Gneiss *(Png),* which forms part of the Biranup Complex in the Albany–Fraser Orogen, is a minor unit restricted to the eastern portion of RAVENSTHORPE. These rocks are intensely deformed resulting in northeast-trending foliations, cleavages and lineations. A deep weathering profile similar to the Archaean rocks is formed above the fresh gneissic rocks; however, the grit zone is generally absent.

The Mount Barren Group was defined by Thom *et al.* (1977) as comprising three formations: the Steere Formation, the Kybulup Schist *(Pby)* and Kundip Quartzite *(PBk)*. The Steere Formation lies unconformably on the Archaean, but because it contains only a thin layer of groundwater on RAVENSTHORPE it is grouped with the Kybulup Schist. The Mount Barren metasedimentary rocks extend throughout the southwest corner of RAVENSTHORPE with the southern extent delineated by the Jerdacuttup Fault, where the Biranup Complex has been uplifted and thrust northward against the metasedimentary rocks.

The Kybulup Schist contains phyllite and quartz–mica schist derived mainly from pelitic and psammopelitic sedimentary rocks. It includes the Steere Formation, which comprises stromatolitic dolomite, minor conglomerate and the mafic to ultramafic schist of the Cowerdup Sill. Chevron folding and mylonitic zones are common within the phyllite and schist indicating mild thrusting (Thom *et al.*, 1977). The rocks are variably weathered to a micaceous clay with depths of more than 15 m (Panasiewicz *et al.*, 1996) and are poorly exposed except in incised drainages.

The Kundip Quartzite consists of variably recrystallised quartz arenite with minor, probably intraformational, deformed conglomerate and quartz breccia. The quartzite is generally massive to coarsely-bedded with dips of 10° to 70°S. Sedimentary structures including cross bedding and ripple marks are common. Thom *et al.* (1977) noted that, due to its resistance to weathering, the quartzite forms a low scarp along the northern boundary of the Mount Barren Group and makes up the prominent peaks of the Barren Ranges.

Proterozoic mafic and ultramafic dykes *(Pd)* intrude the granite–greenstone terrane throughout the northern portion of RAVENSTHORPE. They are widespread, less than 200 m thick, with southeasterly and northeasterly trends and can be traced as aeromagnetic lineaments. Dykes shown on RAVENSTHORPE have been simplified from Thom *et al.* (1977), Myers (1995) and Witt (1997), however all known dykes are contained in the digital database.

## 2.4 Cainozoic

### 2.4.1 Tertiary sedimentary rocks

The Archaean and Proterozoic rocks are unconformably overlain by the Middle to Late Eocene Plantagenet

Group of the Bremer Basin comprising the Werillup Formation and Pallinup Siltstone.

The Werillup Formation *(TPw)* consists of predominantly fluvial and lacustrine sediments deposited as basal units within pre-existing Cretaceous drainage valleys, known as palaeochannels, and broad topographic depressions in the weathered bedrock. The extent of the formation on RAVENSTHORPE is poorly understood, although exploratory drilling has intersected sediments beneath the salt lakes in the north and west of the Jerdacuttup River.

The Werillup Formation rests unconformably on the basement rocks and consists of medium- to coarse-grained basal sand, lignite and carbonaceous clay with a maximum thickness of 34 m intercepted in WJ-5 (Smith and Davidson, 1987). The basal sand was deposited in a fluvial environment and the overlying lignite and carbonaceous clay accumulated in swamp-like environments. The formation on ESPERANCE–MONDRAIN ISLAND (L. Baddock, pers. comm., 1996) includes an equivalent of the Nanarup Limestone Member (Cockbain, 1968), but this has not been identified on RAVENSTHORPE.

The Pallinup Siltstone *(TPp)* overlies either weathered basement or the Werillup Formation and was deposited in a shallow-marine environment during a major marine transgression in the late Eocene. The unit typically consists of multicoloured siltstone to fine-grained clayey sandstone with minor glauconite, spongolite and various marine fossils. The sediments are best exposed along the upper slope of dissected river valleys south of South Coast Highway. In the north the formation also includes minor plastic clay typical of the age equivalents in palaeochannels of the Kalgoorlie region (Kern and Commander, 1993).

The upper portion of the Pallinup Siltstone contains a shoreline sand/silt facies *(TPps)* and a shallow-marine spongolite facies *(TPpg)*. The shoreline facies is interpreted as a coastal littoral zone deposit, consisting of unconsolidated fine- to medium-grained quartz sand and silt. The maximum thickness intersected on RAVENSTHORPE was 16 m in SCR-35 (Panasiewicz *et al.*, 1996). The unit occurs as discontinuous deposits, up to 4 km wide, between 50 m AHD in the south to about 100 m in the north, sub-parallel to the present shoreline. The major shoreline zone extends from 5 km northwest of Stokes Inlet to the eastern sheet boundary, with minor deposits located 16 km north of Hopetoun, and was intersected in exploratory drillholes SCR-23, SCR-24 and SCR-28 between Hopetoun and Munglinup (Panasiewicz *et al.*, 1996).

The spongolite facies is a highly fossiliferous unit, including molluscs, gastropods, echinoids, bryozoans, sponge spicules and foraminifera, and a large degree of silicification and chert vugs interlayered with clay. The unit is exposed in numerous localities on RAVENSTHORPE, predominantly east of Munglinup, between the coast and South Coast Highway. The maximum thickness of the unit is uncertain, as it interfingers the shoreline facies and possibly grades into the underlying siltstone–sandstone facies. However a thickness of 9 m was intersected in SCR-16, 8 km southwest of Munglinup (Panasiewicz *et al.*, 1996).

### 2.4.2 Surficial sediments

A variety of Cainozoic surficial sediments occur on RAVENSTHORPE where they form a veneer over the Archaean, Proterozoic and Tertiary rocks (Thom *et al.*, 1977). Only those units that contain groundwater are represented on RAVENSTHORPE.

Alluvial, colluvial and minor sandplain deposits *(Cza)* occur as stream channels and outwash fans in the north, and in palaeodepressions to the northeast of Hopetoun. In the north these are unconsolidated, medium- to coarse-grained sand and gravel with minor silt and clay in the valley-flat environment, which is similar to that of BOORABBIN (Kern, 1995). The lithology is similar in the south, comprising a lower, clayey, unconsolidated limonite gravel which grades to a clayey sand with a maximum thickness of 25 m (Smith and Davidson, 1987). The unit rests unconformably on the Archaean basement rocks and the Werillup Formation, and is derived from reworking of Tertiary sediments and the underlying weathered profile.

The sediments to the northeast of Hopetoun were deposited in an intrabasinal depression and overlie a discontinuous, extensively eroded surface on the Pallinup Siltstone and Werillup Formation. The margins of the depression correspond to an easterly trending ridge which parallels the Jerdacuttup Fault (Witt, 1997) and a northerly trending ridge located 4.5 km east of the Jerdacuttup River.

Coastal and marine deposits *(Qs)* trend parallel to the coast, forming narrow and discontinuous ridges of dune sand overlying calcareous shelly sandstone. The basal unit, a shoreline deposit, consists of white, fine- to medium-grained, calcareous quartz sand with variable cementation and abundant shells at some localities. Dune sediments blanket the coastal area and consist of white to light grey, unconsolidated, very fine to fine-grained quartz sand. The coastal sediments are generally thickest towards the east with 40 m of calcareous sand near Barker Inlet (Harewood, 1994), and ridges up to 95 m AHD to the east of Stokes Inlet.

Sandplain deposits *(Qd)* on the Coastal and Esperance Sandplains consist of eolian fine-grained quartz sand and silt derived from reworked Pallinup Siltstone and coastal sediments. The sand ranges in thickness from a few centimetres deep to sand dunes several metres in height. The dunes are poorly distributed on RAVENSTHORPE, forming discontinuous ridges within 10 km of the coast.

Alluvium with minor colluvium *(Qa)* occurs within mature drainage systems, such as the Oldfield and Young Rivers, and also in the chain of lakes behind the coastal dunes and intertidal swamps associated with inlets such as Barker Inlet. The unit comprises reworked sandplain and other Cainozoic deposits, and is characterised by unconsolidated grey to brown gravel, sand and silty clay, up to 13 m thick (Johnson, 1995).

Lacustrine deposits *(Ql)* are associated with playa lakes and consist of clay and silt with minor sand, generally overlying weathered Archaean rocks or Tertiary sediments. The lake sediments in the north of the sheet are saline and gypsiferous with a thickness of 6 m encountered in Lake Tay (Magnet Metals Ltd., 1977).

# 3 Hydrogeology

## 3.1 Groundwater occurrence

Groundwater occurs in eighteen major rock units with their distribution shown on RAVENSTHORPE. The relationships between rock units are demonstrated schematically in Figure 4, and in the diagrammatic sections A–B–C and D–E on the hydrogeological map. The principal aquifers in the region are the shoreline and spongolite facies of the Pallinup Siltstone and the Werillup Formation. However, there is a large variation in both potential yield and salinity within the aquifers.

RAVENSTHORPE is almost entirely underlain by fractured and weathered Archaean and Proterozoic granite, gneiss and greenstone. Fissured and fractured metasedimentary rocks of the Mount Barren Group occur in the southwest with groundwater contained within joints of the Kundip Quartzite and fracturing in the quartz veins of the Kybulup Schist. The hydrogeology of the basement rocks is generally complex with groundwater occurrence restricted to joints, fractures and sandy sections of the weathering profile; hence, basement rocks are considered minor localised aquifers.

Major mafic and ultramafic dykes occur within the Archaean granite–greenstone terrane. These rocks are generally more resistant to weathering than granite or gneiss and when weathered they form a massive, impermeable clay which can impede groundwater flow.

The Archaean and Proterozoic basement is partially overlain by Tertiary sedimentary aquifers which are mainly characterised by low permeability due to their fine-grained and clayey nature. The Werillup Formation and the shoreline and spongolite facies of the Pallinup Siltstone, which are more permeable aquifers with intergranular and secondary porosity, contain significant volumes of groundwater but are restricted to broad, flat depressions and palaeochannels on the uneven basement palaeosurface.

Surficial sediments of Quaternary and Cainozoic age have a widespread distribution on RAVENSTHORPE, but most are unsaturated except at the coast, and within alluvium and lacustrine deposits. A perched aquifer may be present within the eolian dune deposits *(Qd)*, particularly where the sand overlies relatively impermeable Tertiary sediments and basement.

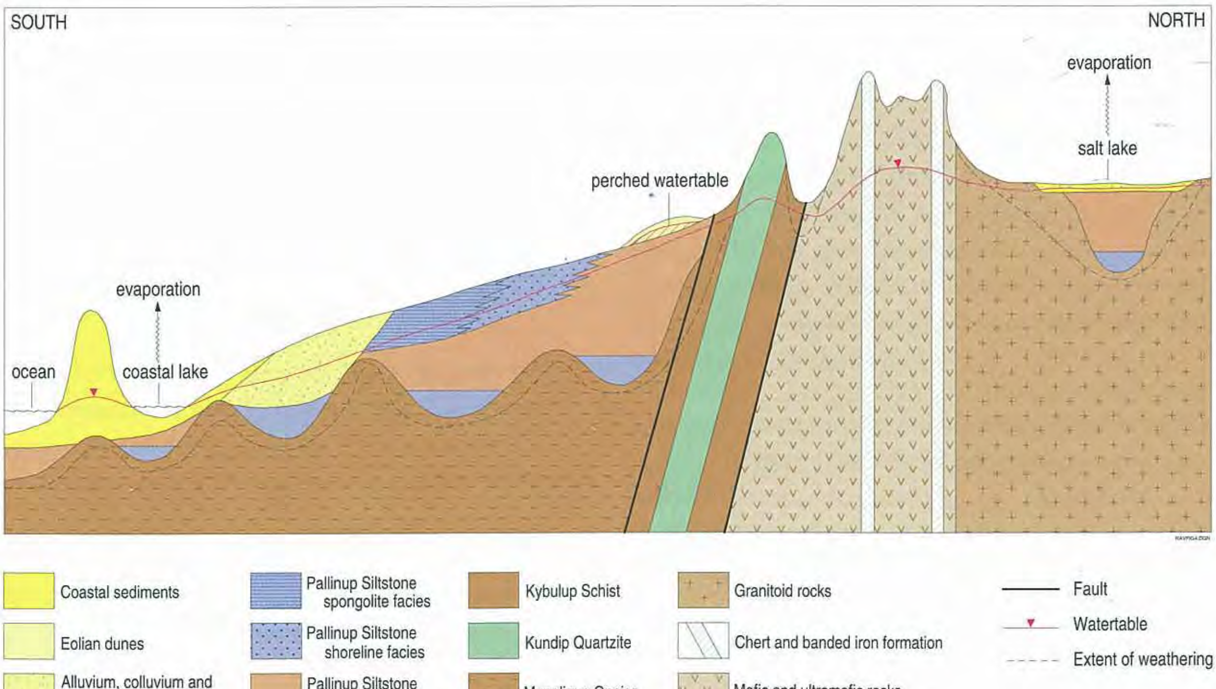


**Figure 4. Schematic section showing groundwater occurrence**

## 3.2 Regional watertable

The regional watertable forms an almost continuous surface throughout Ravensthorpe representing the level below which all pore spaces and fractures within rocks are saturated. However the watertable may be absent in elevated areas where the weathered profile and fractures are unsaturated, or where fractures are poorly developed. The depth to the watertable is dependent on rock type, topography, groundwater recharge and discharge. The regional watertable is depicted on the map sheet by groundwater contours in metres AHD, which are approximate as they are interpreted from historical and recent bore water levels in the region, where few bores have been surveyed. The groundwater contours are represented at 40 m contour intervals on the map sheet. Additional contours, south of 33°30' at 20 m intervals, are available in the graphical database.

In the north, the watertable forms a subdued reflection of the topography, particularly where basement rocks are near the surface. The depth to groundwater is generally less than 5 m below ground surface in the valleys, but may reach a depth of 30 m along topographic divides such as the Jarrahwood Axis. In the Tertiary sediments the watertable has a low gradient and the depth to the watertable is less than 10 m below ground surface. The watertable gradient becomes steeper around large hills and well incised drainage features, such as the Oldfield and Young Rivers. The depth to groundwater near the coast is generally shallow, less than 5 m below ground surface, increasing to 25 m beneath the large coastal dunes.

## 3.3 Groundwater flow and discharge

The watertable elevation falls from 360 m AHD in the northwestern part of the sheet to near sea level at the coast and is characterised by a low gradient reflecting the generally low topographical relief. The volume of groundwater throughflow is small owing to low hydraulic gradient, low hydraulic conductivity and the limited thickness of the saturated zone.

The Jarrahwood Axis is an important groundwater divide on Ravensthorpe, with groundwater flow towards the south discharging to the ocean and northward flow towards the palaeodrainages which eventually discharge in the Eucla Basin. Local groundwater flow variations occur as radial flow around bedrock highs and as discharge in incised drainages. Groundwater flow patterns can also be locally affected by groundwater barriers such as mafic dykes and bedrock highs.

Groundwater in the south of Ravensthorpe discharges at the coast and along drainage courses, whereas in the north, groundwater discharge occurs mainly by evaporation from salt lakes and throughflow along palaeochannels. Groundwater is also discharged by evapotranspiration or evaporation where the watertable intersects the surface or is cut by incised drainages, such as within the Oldfield River.

## 3.4 Aquifers

### 3.4.1 Surficial sediments (*Qs, Ql, Qa* and *Cza*)

The Quaternary coastal sediments *(Qs)* occur as a narrow discontinuous belt along most of the coast, comprising fine- to medium-grained sand which grades into shelly limestone. The sediments form an unconfined aquifer with intergranular porosity, high permeability and a maximum saturated thickness of approximately 30 m. The coastal sediments are recharged by rainfall with minimal surface runoff evident from dune sands. Enhanced recharge occurs where elevated gneiss outcrops give rise to increased runoff to surrounding sandy sediments and from minor stream flow in clayey sediments. Groundwater flow is generally localised, discharging into surface drainages, lakes and estuarine embayments such as Stokes Inlet, and at the coast possibly over a saltwater interface. A local groundwater mound occurs within the coastal sediments, north of the Hopetoun Town Borefield, with most groundwater flow towards the west discharging into Culham Inlet. Discharge is also likely through vertical leakage to the underlying Pallinup Siltstone, where the more permeable shoreline and spongolite facies are present.

Production bores in the Hopetoun Town Borefield yield up to 1500 $m^3$/day and aquifer transmissivities derived from pumping tests range from 100 to 200 $m^2$/day (Hirschberg, 1980). Groundwater near the Town Borefield is potable to marginal ranging up to 1200 mg/L Total Dissolved Solids (TDS). The sediments between Hopetoun and Stokes Inlet contain only small supplies of brackish to saline water with airlift yields up to 330 $m^3$/day (Smith and Davidson, 1987). The dunes to the east of Stokes Inlet are similar to those of the Esperance town water supply borefield but have not been explored.

Alluvium *(Qa)*, which occurs within mature drainages, interdunal depressions and intertidal swamps, consists of unconsolidated gravel, fine to coarse quartz sand and silty clay. The poorly sorted sediments form an unconfined aquifer with low permeability and a maximum saturated thickness of 8 m (Johnson, 1995). The alluvial sediments are recharged by rainfall, river flow and occasional flooding with enhanced recharge from increased surface runoff from cleared granite outcrops. Groundwater flow is localised, with discharge as springs or seepages into surface drainages, such as in the Oldfield River at Wilga Bank. The interdunal and intertidal deposits have not been explored on RAVENSTHORPE, but bore yields from the alluvium within mature drainages range from 10 to 50 $m^3$/day, dependent on sorting and clay content. Groundwater is brackish to saline ranging from 1500 mg/L at Wilga Bank to about 20 000 mg/L with the lower salinity occurring in mature drainages which receive enhanced recharge through runoff.

Lacustrine sediments *(Ql)* are intermittently saturated as the lakes are usually dry for much of the year and are replenished only after heavy rainfall. The regional watertable is close to the surface in playa lake environments whereas there may be a perched watertable in claypans and swamps (not mapped) on the Esperance Sandplain. The sediments are generally fine grained or clayey, with bore and well yields likely to be low. They are not utilised as aquifers on RAVENSTHORPE. Groundwater within the lake sediments is saline to hypersaline with a sample collected from an exploratory hole at the margin of Three Star Lake analysed at 51 000 mg/L (Magnet Metals Ltd, 1977). Playa lakes often have marginal gypsiferous sand and clay deposits which are not mapped but may contain a perched watertable.

Alluvial, colluvial and minor sandplain deposits *(Cza)* consist mainly of lower clayey gravels with an upper sand unit. The sediments form an unconfined aquifer of variable permeability and intergranular porosity with a maximum saturated thickness of 19 m in WJ5 (Smith and Davidson, 1987). In the north they are only partially saturated in low-lying areas where the thickness of sediment is greatest. The alluvial and colluvial deposits are recharged by rainfall and in the south, also through downward leakage from the overlying Quaternary coastal sediments. A groundwater mound, west of the Oldfield Borefield, exhibits a northeast–southwest groundwater divide indicating that groundwater flow is away from the mound, with discharge mainly towards the Jerdacuttup River and coastal wetlands. There is also minor groundwater discharge through vertical leakage into the underlying Werillup Formation, where present. Groundwater discharge in the north is primarily by evaporation at playa lake surfaces and intermittent discharge into surface drainages or lakes. Bore and well yields generally range from 10 to 300 $m^3$/day, with short-term yields up to 440 $m^3$/day recorded during pumping tests in the Oldfield Borefield (Smith and Davidson, 1987). Aquifer transmissivities range from 200 to 500 $m^2$/day which is equivalent to a hydraulic conductivity of approximately 10 m/day.

Groundwater salinity within the alluvial and colluvial sediments ranges from less than 1000 mg/L in the Oldfield Borefield to 14 000 mg/L in bores north of Munglinup. In addition to potable groundwater, there are large supplies of brackish to saline groundwater available from the sediments on either side of the Jerdacuttup River. While the aquifer is poorly explored in the north of the map sheet, the groundwater is likely to be saline to hypersaline and unsuitable for stock-watering purposes.

### 3.4.2 Eolian dune deposits (*Qd*)

Eolian dune deposits occur inland of the coast forming distinct dunes or broad areas of deep sand, up to several metres thick, overlying the less permeable Tertiary sediments or weathered basement. A perched watertable often forms in the fine-grained quartz sands during winter and may be permanent in the more extensive deposits. The perched groundwater system which is recharged by rainfall forms a mound above the regional watertable. Discharge is represented as soaks at the dune margins. These fresh to brackish systems have limited extent and a saturated thickness of a few metres. They may become saline or depleted if the resource is overpumped.

### 3.4.3 Tertiary sediments (*TPp, TPpg, TPps* and *TPw*)

The Middle to Late Eocene Plantagenet Group, consisting of the Pallinup Siltstone and Werillup Formation, unconformably overlies Archaean and Proterozoic bedrock. The Pallinup Siltstone forms an unconfined aquifer which predominantly consists of a moderately to well-cemented siltstone–sandstone facies *(TPp)*. The upper portion of the Pallinup Siltstone comprises two lithofacies; a shoreline facies comprising fine-grained quartz sand and silt, and a shallow marine spongolite with interlayered clay and siliceous spongolite.

The Pallinup Siltstone is recharged by rainfall and by downward leakage from overlying Quaternary sediments. The saturated thickness varies considerably, depending on the uneven palaeotopography of the basement rocks. Groundwater flow is generally to the south with some northward movement, north of the Jarrahwood Axis, but flow may be constrained by irregular bedrock topography and lateral differences in hydraulic conductivity. Groundwater discharges by evapotranspiration, slow vertical leakage to the underlying Werillup Formation and by throughflow along the incised drainages of the Steere, Jerdacuttup, Oldfield, Young and Lort Rivers, and evaporation at salt lakes surfaces in the north.

The siltstone–sandstone facies of the Pallinup Siltstone is generally of low permeability due to the fine-grained lithology and cementation of the sediments. Bore and well yields are typically very low, ranging between 2 and 20 m$^3$/day, although yields up to 108 m$^3$/day as obtained from SCR-19 (Panasiewicz *et al.*, 1996) are possible. The facies becomes progressively more impermeable towards the north as lacustrine plastic clay interfingers the Pallinup Siltstone.

The shoreline facies *(TPps)* forms an unconfined to semi-confined aquifer with intergranular porosity, high permeability and a maximum saturated thickness of 23 m. The aquifer, poorly explored on Ravensthorpe, occurs as a discontinuous unit between 50 and 100 m AHD within 25 km of the coast and its mapped extent is based on limited bore information. Pumping tests within the aquifer at SCP-2 (Koomberi, 1996) produced yields of 247 m$^3$/day with a stable drawdown of 0.68 m, although bore yields usually range between 30 and 150 m$^3$/day. Running silts can cause considerable problems with bore construction and development and can also result in the abandonment of established bores.

The spongolite aquifer *(TPpg)* is confined to semi-confined and has a karstic nature due to interconnection between extensively developed vugs and solution channels within the spongolite. The spongolite is generally unsaturated on Ravensthorpe except for the southeastern corner where the saturated thickness is about 10 m and bore yields are between 15 to 45 m$^3$/day.

Groundwater salinity within the Pallinup Siltstone is highly variable ranging from fresh to saline, with lower salinity areas located south of South Coast Highway beneath localised catchment divides and thick sandplain deposits. The salinity within the shoreline and spongolite facies ranges between 1000 and 7000 mg/L TDS with areas of lower salinity at the flanks of basement highs. The sediments are poorly explored in the north, but the groundwater is likely to be saline to hypersaline reflecting the reduced rainfall and increased evaporation northward across Ravensthorpe.

The Werillup Formation *(TPw)* comprises fluvial and lacustrine deposits with fine- to coarse-grained quartz sand overlain by clay and lignite. It has a variable thickness with a maximum saturated thickness of 34 m, but its extent is poorly understood. In the north the basal sand aquifer is semi-confined to confined beneath relatively impermeable marine sediments and interfingering lacustrine clays of the Pallinup Siltstone. In the south, however, the formation is semi-confined to unconfined, with partial or complete removal of the Pallinup Siltstone, which is often replaced by unconsolidated Cainozoic deposits, such as in Bore WJ-7 (Smith and Davidson, 1987). Where the aquifer is confined beneath the Pallinup Siltstone it is recharged by slow downward leakage. Where unconfined, it can receive recharge from direct rainfall, leakage through overlying Cainozoic sediments and possibly upward discharge from weathered basement. In the north of Ravensthorpe, groundwater is discharged from the aquifer by evaporation from salt lakes with a small amount of throughflow in the palaeochannels. Although no pumping test data are available, Bores WJ15 and WJ24 drilled during the Hopetoun Town Water Supply program were airlifted at 360 and 150 m$^3$/day respectively (Smith and Davidson, 1987) from the basal sand aquifer.

Groundwater in the Werillup Formation is commonly saline to hypersaline, although fresh to brackish groundwater has been intersected in a small area to the west of the Jerdacuttup River where the aquifer is unconfined. This lower salinity is probably due to increased local recharge through the permeable Cainozoic sediments and active groundwater throughflow towards the Jerdacuttup River. The groundwater salinity also generally increases sharply with depth in the Werillup Formation. In the north of RAVENSTHORPE the aquifer is hypersaline resulting from groundwater discharge at salt lake surfaces.

### 3.4.4 Mount Barren Group (*PBk* and *PBy*)

The Mount Barren Group lies within the southwestern corner of RAVENSTHORPE and consists of the interbedded Kundip Quartzite (*PBk*) and Kybulup Schist (*PBy*). The mapped boundaries on RAVENSTHORPE are based on the solid geology interpretation by Witt (1997). The Kundip Quartzite is a fractured and fissured aquifer comprising fine- to medium-grained, rounded quartz grains in a siliceous matrix, with well developed horizontal and vertical jointing. The Kybulup Schist, the dominant rock type in the Mount Barren Group, forms a weathered and fractured aquifer comprising phyllite and quartz-mica schist which is readily weathered to clay. These aquifers have been poorly explored and are not utilised on RAVENSTHORPE.

Groundwater occurs primarily in joints in the quartzite, with small amounts in the dolomite, conglomerate and quartz veins in the phyllite. The beds of quartzite and other potential aquifers are generally less than 100 m thick and separated by up to 500 m of low-permeability phyllite. The fractured- and fissured-rock aquifer is recharged by rainfall and runoff from ephemeral drainages. Groundwater flows radially from topographic highs, and probably discharges into overlying Tertiary sediments. Bore yields from the Kybulup Schist are small (less than 5 $m^3$/day) due to the fine-grained and clayey nature, whereas the quartzite yields between 10 and 50 $m^3$/day dependent on positioning within fold closures, fracture intensity and closure with increasing depth. Groundwater is brackish to saline in the Kundip Quartzite ranging from 2600 to 6600 mg/L TDS, and up to 15 000 mg/L in the Kybulup Schist (Baddock, 1997).

### 3.4.5 Granitoid and gneissic rocks (*Ag, An* and *Png*)

The granitoid rocks *(Ag)* occur in the northern portion of RAVENSTHORPE, while the Munglinup Gneiss *(An)* and Dalyup Gneiss *(Png)* are poorly exposed in the south and southeastern corner of the sheet respectively. The granitoid rocks consist of even-grained to porphyritic granite and adamellite that are generally foliated and metamorphosed, whereas the gneissic rocks are intensely foliated and metamorphosed granitoids which were heterogeneously deformed during the Albany–Fraser Orogeny.

In places the granitoid and gneissic rocks are deeply weathered to more than 40 m. In granitoid rocks small supplies of groundwater may be obtainable from a quartz-rich grit at the base of the weathered profile, and fractures in the uppermost 5 to 10 m of fresh rock. Bore yields from granitoid rocks typically range between 5 and 100 $m^3$/day, although an exploratory bore drilled west of Cordingup Dam produced an airlift yield of 550 $m^3$/day from fractures in the fresh rock (Baddock, 1997). Smith and Davidson (1987) observed that the joints and fractures in the gneissic rocks are very sparse or have been infilled with low-permeability clay resulting in low yields of less than 10 $m^3$/day.

Groundwater is typically saline to hypersaline, although it may be brackish in fractures near surface catchment divides in the south of RAVENSTHORPE. The groundwater salinity is generally higher in the gneissic rocks compared with granitoids due to the low permeability of the gneissic weathered profile.

Pegmatite dykes and quartz veins (not mapped) are a minor but widespread component of granitic rocks and may form small but locally important aquifers. Proterozoic mafic dykes *(Pd)* generally intrude the Archaean granitoid rocks and weather to massive, impermeable clay.

### 3.4.6 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 characterised by columnar jointing and pillowed, variolitic lavas. The rocks are variably weathered, up to a depth of 36 m in SCR-40 (Panasiewicz *et al.*, 1996), with the joints generally filled with clay.

The mafic and ultramafic rocks are poorly explored on RAVENSTHORPE, but may form local fractured aquifers. Two exploratory drillholes, 20 km east of Ravensthorpe, obtained airlift yields of up to 105 $m^3$/day from a highly fractured ultramafic rock. Groundwater is typically saline to hypersaline, with brackish groundwater being localised and restricted to catchment divides along the Ravensthorpe Range and at Bandalup Hill.

### 3.4.7 Sedimentary, felsic volcanic and volcaniclastic rocks (*As*)

A complex succession of metamorphosed sedimentary rocks with minor felsic volcanic and volcaniclastic rocks form the upper sequence of the Ravensthorpe greenstone belt. The sedimentary rocks are derived from quartz-rich siltstones, sandstones, shales and polymictic conglomerates that are metamorphosed and recrystallised, and variably weathered to a depth of 25 m. The felsic extrusive rocks, such as quartz–feldspar porphyry, dacite and rhyolitic tuffs, have a limited distribution with fine-grained weathering products and are not generally jointed.

The metasedimentary rocks are poorly explored on RAVENSTHORPE; however, they may form local fractured aquifers where recrystallised and deformed in the greenstone sequence. In general the felsic volcanic and metasedimentary rocks are poor aquifers owing to their clay-rich weathering products. Five bores drilled into highly weathered metasedimentary rock, 5 km north of Ravensthorpe, were abandoned with up to 38 m of kaolin clay and bore yields less than 5 $m^3$/day. The groundwater is generally saline to hypersaline.

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

Chert and banded iron-formation are associated with metasedimentary and ultramafic volcanic rocks in the Ravensthorpe greenstone belt and form prominent ridges within the Ravensthorpe Range. Chert and banded iron-formation commonly have well developed joint systems as a result of brittle deformation, and are not deeply weathered. They form local fractured aquifers with bore yields being variable, ranging from negligible to greater than 50 $m^3$/day depending on the presence of fractures.

The fractured-rock aquifer is recharged by rainfall. Groundwater flow is radial from topographic highs and may discharge to drainage courses. Groundwater is generally saline, increasing from 6000 to 22 000 mg/L TDS with depth (Baddock, 1997), although brackish groundwater may be intersected along the crest of the Ravensthorpe Range.

# 4 Groundwater quality

## 4.1 Regional groundwater salinity

Groundwater salinity is represented on the hydrogeological map by isohalines, in mg/L TDS, interpreted from non-synoptic water sample data collected from numerous bores and monitoring piezometers since 1950. The isohalines represent the groundwater salinity at or close to the watertable, such as would be obtainable from a shallow pumping bore, below which salinity may increase substantially with depth.

The groundwater within RAVENSTHORPE is predominantly saline, ranging from less than 1000 mg/L TDS in the Quaternary coastal sediments, to more than 35 000 mg/L TDS in the Tertiary sediments beneath the northern playa lakes. Groundwater salinity increases to the north and east across the sheet area, corresponding to lower rainfall.

Potable groundwater, less than 1000 mg/L, occurs within Quaternary coastal sediments, Cainozoic alluvial deposits and the Pallinup Siltstone in the higher rainfall, coastal areas. Eolian dune deposits may also contain seasonal, small quantities of potable groundwater, where a perched watertable forms above less permeable strata.

Because rainfall decreases to the north and east, brackish to stock-quality groundwater (1000 to 7000 mg/L) is restricted to the southern third of RAVENSTHORPE, south of South Coast Highway. Groundwater salinity in the Pallinup Siltstone and the Werillup Formation, west of the Jerdacuttup River, is generally brackish to saline with areas of lower salinity at the flanks of basement monadnocks and beneath localised catchment divides and thick sandplain deposits. Facies changes within the Pallinup Siltstone can also lead to significant variation in groundwater quality, with the more permeable shoreline and spongolite facies containing lower salinity groundwater.

Brackish groundwater from fractures in fresh granite has been reported near surface-water divides in the southwest (Baddock, 1997), where excess runoff enhances local recharge. Although salinity distribution within the Mount Barren Group is uncertain, fresh to brackish groundwater may occur in the Kundip Quartzite along catchment divides, whereas the Kybulup Schist contains small supplies of saline groundwater.

Groundwater salinity exceeding 7000 mg/L is reported over most of RAVENSTHORPE within the Tertiary sedimentary aquifers and the fractured basement aquifers. Within the Pallinup Siltstone and Cainozoic alluvial deposits, north of the South Coast Highway, groundwater is generally saline beneath localised catchment divides and becoming hypersaline (greater than 35 000 mg/L) to the north of the Jarrahwood Axis. Groundwater salinity in the Werillup Formation ranges from 8600 mg/L, south of Lee Road, to over 35 000 mg/L where associated with salt lakes. The salt lakes in the north of RAVENSTHORPE lead to increased groundwater salinity with upstream groundwater discharge from the underlying Tertiary sediments and downstream recharge of more concentrated brines to the sediments (Commander *et al.*, 1992).

Groundwater salinity within the granitoid, gneiss and greenstone rocks in the north is typically greater than 14 000 mg/L, with areas of lower salinity along major surface-water divides, including the Ravensthorpe Range and Jarrahwood Axis. Variations in salinity may also occur in fractured-rock aquifers where open fractures allow preferential groundwater flow, and where there is heterogeneity within the saprolite of weathered granitic rocks.

## 4.2 Hydrochemistry

Most waters are of sodium chloride type irrespective of the aquifer, reflecting their derivation (through precipitation) from cyclic salts (Fig. 5). The results of chemical analyses of groundwater from 28 bore and shafts are shown in Table 2. Both the Quaternary coastal sediments and two bores, EJ3 and WJ11, in Cainozoic alluvial deposits contain significant calcium and bicarbonate concentrations. This reflects groundwater recharge from the coastal sediments into the underlying Cainozoic alluvial aquifer on either side of the Jerdacuttup River.

The pH ranges from slightly alkaline to strongly acidic, although most groundwater sampled has a pH between 7-8. Lowest pHs occur in the Werillup Formation (4.5-6) and are possibly due to the presence of pyritic material in carbonaceous shale. Nitrate levels are low and generally below 10 mg/L, except for three samples containing up to 41 mg/L, which may indicate contamination. Concentrations of boron, up to 3.3 mg/L, are probably related to groundwater recharge through alkaline duplex soils (Table 2). Soluble iron is generally very low with Bore WJ24 containing up to 1 mg/L. Several bores in the Oldfield Borefield, especially bore WJ5, contain high levels of silica although these are not considered harmful.

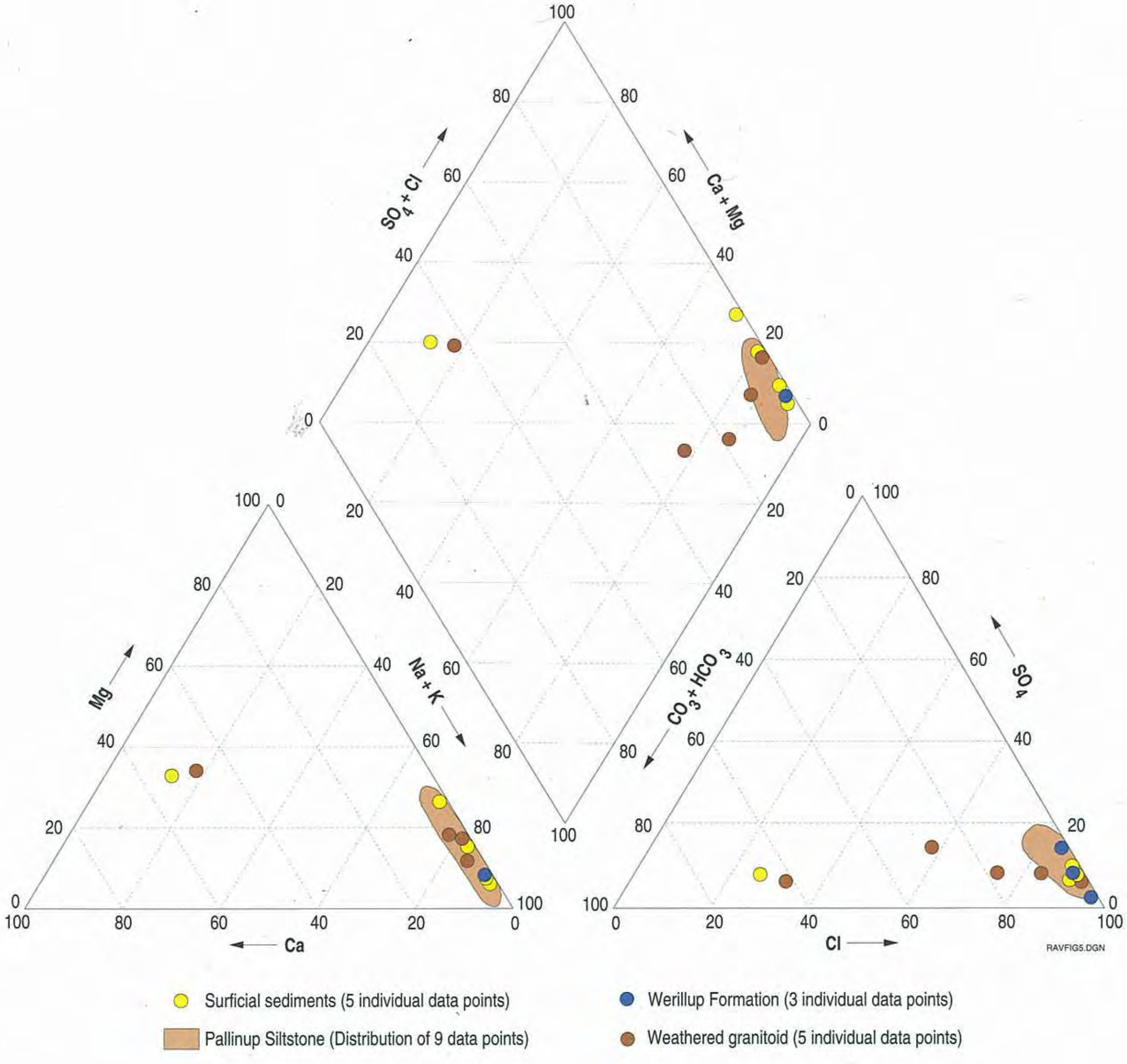


**Figure 5. Piper trilinear diagram of selected chemical analyses of groundwaters**

**Table 2. Selected chemical analyses of groundwater**

| Bore/well | pH | EC (a) (mS/m at 25°C) | TDS (b) | Total hardness (as $CaCO_3$) | Total alkalinity (as $CaCO_3$) | Ca | Mg | Na | K | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | $SiO_2$ | B | F | $Fe^+$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (mg/L) | | | | | | | | | | | | | | |
| **Surficial deposits** | | | | | | | | | | | | | | | | | |
| 2930-2-C-0019 | 6.9 | 89 | 520 | 402 | 310 | 100 | 37 | 28 | 2 | 378 | 84 | 39 | 2 | 40 | na | 0.2 | 0.05 |
| 2930-3-A-0012 (WJ17@20m) | 6.6 | 298 | 1580 | 134 | 36 | 6 | 29 | 528 | 18 | 44 | 828 | 115 | <1 | 34 | na | 0.5 | na |
| 2930-3-B-0055 (WJ5@23m) | 5.8 | 100 | 570 | 31 | 6 | 1 | 7 | 172 | 9 | 7 | 273 | 37 | <1 | 66 | na | <0.1 | 0.16 |
| 3030-1-A-0007 | 7.2 | 1280 | 7700 | 1850 | 150 | 100 | 390 | 2090 | 45 | 185 | 4450 | 645 | 6 | 36 | 1.1 | 0.6 | <0.1 |
| 3130-4-C-0004(c) | 7.2 | 760 | 4550 | 725 | 63 | 41 | 150 | 1450 | 40 | 77 | 2500 | 405 | <1 | 24 | 1.0 | 0.4 | <0.1 |
| **Pallinup Siltstone** | | | | | | | | | | | | | | | | | |
| 2930-2-D-0040 (EJ10) | 6.8 | 181 | 930 | 114 | 25 | 6 | 24 | 301 | 11 | 31 | 494 | 58 | <1 | 21 | na | 0.2 | 0.17 |
| 3030-1-B-0003 | 6.9 | 210 | 1250 | 155 | 67 | 14 | 29 | 365 | 10 | 82 | 550 | 135 | 3 | 8 | 0.2 | <0.1 | <0.1 |
| 3030-1-C-0014(d) | 7.0 | 590 | 3500 | 600 | 50 | 46 | 120 | 1100 | 27 | 61 | 1850 | 250 | 9 | 36 | 1.2 | 0.3 | <0.1 |
| 3030-1-C-0018 | 5.7 | 340 | 2050 | 220 | 6 | 15 | 45 | 600 | 19 | 8 | 1050 | 120 | 20 | 34 | 0.6 | <0.1 | <0.1 |
| 3030-2-A-0007 | 7.4 | 370 | 2200 | 320 | 68 | 26 | 62 | 645 | 15 | 83 | 1050 | 150 | <1 | 8 | 0.5 | 0.1 | <0.1 |
| 3030-3-D-0020(d) | 7.3 | 340 | 2050 | 210 | 21 | 9 | 45 | 630 | 21 | 25 | 1000 | 160 | 3 | 14 | 1.0 | 0.5 | <0.1 |
| 3030-4-C-0025 | 7.4 | 130 | 770 | 110 | 22 | 7 | 23 | 230 | 8 | 27 | 350 | 110 | 2 | 12 | 0.2 | 0.1 | <0.1 |
| 3030-4-C-0031 | 7.6 | 120 | 730 | 95 | 28 | 6 | 20 | 200 | 8 | 35 | 300 | 97 | 6 | 12 | 0.2 | 0.2 | <0.1 |
| **Werillup Formation** | | | | | | | | | | | | | | | | | |
| 2930-3-B-0051 (WJ4@30m) | 6.0 | 313 | 1730 | 105 | 14 | 6 | 22 | 570 | 24 | 17 | 827 | 196 | <1 | 77 | na | 0.1 | 0.05 |
| 2930-3-B-0054 (WJ24) | 4.5 | 229 | 1250 | 83 | 2 | 2 | 19 | 398 | 17 | 3 | 607 | 126 | <1 | 81 | na | <0.1 | 1 |
| 2930-3-B-0055 (WJ5@48m) | 5.9 | 118 | 640 | 42 | 5 | 2 | 9 | 206 | 8 | 6 | 324 | 49 | <1 | 41 | na | <0.1 | <0.05 |
| **Granitoid** | | | | | | | | | | | | | | | | | |
| 2930-4-B-0004 | 4.4 | na | 7890 | na | na | 60 | 200 | 2050 | na | na | 1250 | 2050 | na | na | na | na | 381 |
| 3030-4-C-0012 | 7.0 | 390 | 2350 | 240 | 28 | 11 | 52 | 740 | 16 | 35 | 1180 | 145 | <1 | 23 | 0.6 | 0.2 | <0.1 |
| 3131-3-B-0001 | 7.9 | 390 | 2350 | 450 | 550 | 33 | 89 | 710 | 34 | 685 | 850 | 270 | 41 | 29 | 2.2 | 1.2 | <0.1 |
| **Granite–gneiss** | | | | | | | | | | | | | | | | | |
| 2930-1-B-0018 | 7.7 | 350 | 2100 | 270 | 125 | 25 | 50 | 640 | 15 | 155 | 1000 | 145 | 23 | 9 | 0.7 | 0.1 | <0.1 |
| 2930-1-B-0030 | 8.0 | 520 | 3150 | 425 | 495 | 37 | 80 | 1000 | 50 | 605 | 1450 | 250 | 2 | 12 | 3.3 | 0.3 | <0.1 |
| 2930-3-B-0056 (WJ11) | 7.0 | 99 | 580 | 425 | 313 | 100 | 43 | 41 | 2 | 382 | 110 | 48 | <1 | 41 | na | 0.4 | 0.05 |
| 3030-4-A-0012 | 7.7 | 250 | 1500 | 85 | 110 | 5 | 18 | 480 | 8 | 135 | 650 | 125 | 7 | 37 | 0.8 | 0.8 | 0.4 |
| 3031-2-D-0003 | 3.8 | 5450 | 37300 | 5700 | <2 | 51 | 1360 | 11600 | 200 | <2 | 21200 | 2770 | 1 | 102 | na | <0.1 | na |
| **Mafic and ultramafic rocks** | | | | | | | | | | | | | | | | | |
| 2930-4-B-0001 | 7.8 | na | 15400 | na | na | 215 | 425 | 5000 | na | na | 7700 | 1780 | na | na | na | na | 0.02 |
| 2930-4-B-0002 | 7.5 | na | 18180 | na | na | 105 | 700 | 6150 | na | na | 10000 | 1725 | na | na | na | na | <0.05 |
| 2930-4-B-0003 | 8.0 | na | 28160 | na | na | 160 | 1100 | 8500 | na | na | 14000 | 2155 | na | na | na | na | <0.05 |

**Notes:**(a) EC=Electrical conductivity; (b) TDS=Total dissolved solids; (c) Quaternary alluvium; (d) Shoreline facies; na = not analysed

# 5 Land salinisation and rising watertables

The clearing of native vegetation and replacement by annual crops and pastures has led to an imbalance in the groundwater system on RAVENSTHORPE. The shallow rooted crops and pastures utilise less of the infiltrating rainfall than the deep rooted native species. This additional recharge has resulted in steadily rising watertable levels, in the order of 0.1 to 0.3 m/year (Short, 1997). Groundwater levels are rising most rapidly in areas with high rainfall and inadequate drainage, whereas rates of rise are slower in low rainfall zones of the north and east.

Land salinisation occurs where brackish to saline groundwater has risen to within one to two metres of the surface. In these areas capillary action causes upward movement of groundwater to the surface where it evaporates and salts accumulate in the soil. Groundwater salinity may increase where stored salts in the unsaturated zone are dissolved and remobilised by the rising waterlevels. The increase in soil and water salinity can lead to reduced agricultural production in mild cases and salt scalding at the ground surface in severe cases.

Most instances of salinisation within the Tertiary sediments on RAVENSTHORPE are primarily related to the low permeability of the Pallinup Siltstone where it underlies a poorly drained, flat land surface. In areas of shallow bedrock, predominantly north of the South Coast Highway, the presence of basement highs and dolerite dykes can locally influence land salinisation by impeding groundwater movement leading to upslope rising watertables and salt seeps. Inland swamps and lakes that historically contained intermittent perched fresh water have become semi-perennial and saline through rising watertables and the concentration of salts by evaporation.

Since 1991, detailed studies on salinisation, waterlogging and land degradation along the South Coast have been carried out by Agriculture Western Australia. Hearn (1991) highlighted waterlogging as an important land degradation issue in the perched aquifer systems near Cascade. McFarlane *et al.* (1994) discussed and suggested integrated solutions to land degradation issues such as wind erosion, soil erosion, soil acidity and soil structure decline on the south coast.

Detailed mapping of landform patterns on RAVENSTHORPE (Nicholas and Gee, *in prep.*) has enabled fourteen hydrological systems to be defined in the Esperance Agricultural District (Short, 1997). Each system has a particular depth to groundwater, salt storage, groundwater salinity, and soil salinity and waterlogging hazards.

# 6 Groundwater development

Groundwater resources on RAVENSTHORPE are limited by the lack of major aquifer systems and the prevalence of high groundwater salinity over most of the area. Groundwater is used south of the South Coast Highway mainly for stock watering, whereas in the north, surface dams are widely used to meet water demands. Hopetoun is the only settlement on RAVENSTHORPE which relies on groundwater supplies with Ravensthorpe and Munglinup supplied by a network of key dams.

## 6.1 Town water supplies

The Hopetoun town water supply consists of two borefields (Fig. 6): Town Borefield, the original source of reticulated water, is 3 km northwest of the townsite; and Oldfield Borefield is located 15 km northeast of the town on Oldfield Location 831. The establishment of the Oldfield Borefield increased the safe yield from 30 000 $m^3$/yr in the Town Borefield to 110 000 $m^3$/yr, which is anticipated to meet a demand of 85 000 $m^3$/yr by the year 2000 (Holmes, 1995). Groundwater from the Oldfield Borefield is pumped via a pipeline alongside Springdale Road and Hopetoun–Ravensthorpe Road to a reservoir on Table Hill, 2 km northeast of the townsite.

The Town Borefield comprises five production bores (Table 3) positioned in the Quaternary coastal sediments with a salinity range of 800 to 1200 mg/L, and total hardness of approximately 350 mg/L $CaCO_3$. The Oldfield Borefield consists of three production bores, which are positioned in the Cainozoic alluvial and colluvial deposits, with an average salinity of 690 mg/L TDS. There is potential for future development both to the north and east of the Oldfield Borefield, with additional sources of marginal water available from the Werillup Formation to the west of the Jerdacuttup River.

## 6.2 Potential groundwater resources

The potential for groundwater development is highest in the south of RAVENSTHORPE within surficial, sedimentary and fractured-rock aquifers. The Quaternary coastal sediments to the east of Stokes Inlet, although poorly explored, may yield large supplies of fresh to brackish groundwater. Small to large supplies of brackish groundwater suitable for stock watering purposes may be obtainable from the shoreline facies of the Pallinup Siltstone to the northeast of Stokes Inlet and the siltstone–sandstone facies along localised catchment divides. Significant volumes of fresh to brackish groundwater are available from the Werillup Formation and Cainozoic alluvial deposits on each side of the Jerdacuttup River, near the Oldfield Borefield.

Prospects for locating fresh to brackish groundwater near Ravensthorpe are largely restricted to fractured-rock aquifers of the Mount Barren Group and the Archaean greenstone belt. Groundwater resources in the Mount Barren Group are poorly defined; however, bore yields up to 50 $m^3$/day of fresh to brackish groundwater may be obtainable from the fractured Kundip Quartzite. In addition, moderate supplies of brackish groundwater may be obtainable from fractures within the granite southwest of Ravensthorpe, and brecciated chert and banded iron-formation along the Ravensthorpe Range.

Groundwater resources in the northern portion of RAVENSTHORPE are saline to hypersaline and limited to the Werillup Formation within palaeodrainages beneath the salt lakes. The Werillup Formation is largely confined below the Pallinup Siltstone and its distribution is poorly defined, but significant yields up to 360 $m^3$/day may be obtained. Supplies from the weathered and fractured basement rocks are generally very small and saline.

Perched groundwater within thick Quaternary eolian deposits are an important water source for stock. As the saturated thickness is generally less than a few metres, they are best utilised from soaks or wells. Such sandplain deposits are already extensively developed within 10 km of the coast.

**Table 3. Hopetoun town water supply production bore data**

| *Borefield* | *Bore name* | *Casing diameter (mm)* | *Screen interval (mbtoc)* | *Depth (mbns)* | *Pump test yield ($m^3$/day)* | *Salinity (mg/L TDS)* |
|---|---|---|---|---|---|---|
| Town | 1/66 | 200 | 18.50 - 22.25 | 22.2 | 290 | 760 |
| | 2/67 | 200 | 13.50 - 18.45 | 18.4 | 523 | 810 |
| | 1/77 | 200 | 8.60 - 17.50 | 18.8 | 1530 | 1020 |
| | 4/77 | 200 | 17.95 - 24.45 | 32.6 | 785 | 1070 |
| | 6/77 | 200 | 21.80 - 31.45 | 32.6 | 270 | 780 |
| Oldfield | 9/88 | 143 | 25.20 - 37.20 | 39.0 | 440 | 800 |
| | 14/88 | 143 | 28.90 - 34.90 | 37.5 | 350 | 600 |
| | 15/88 | 143 | 30.10 - 36.10 | 38.7 | 300 | 400 |

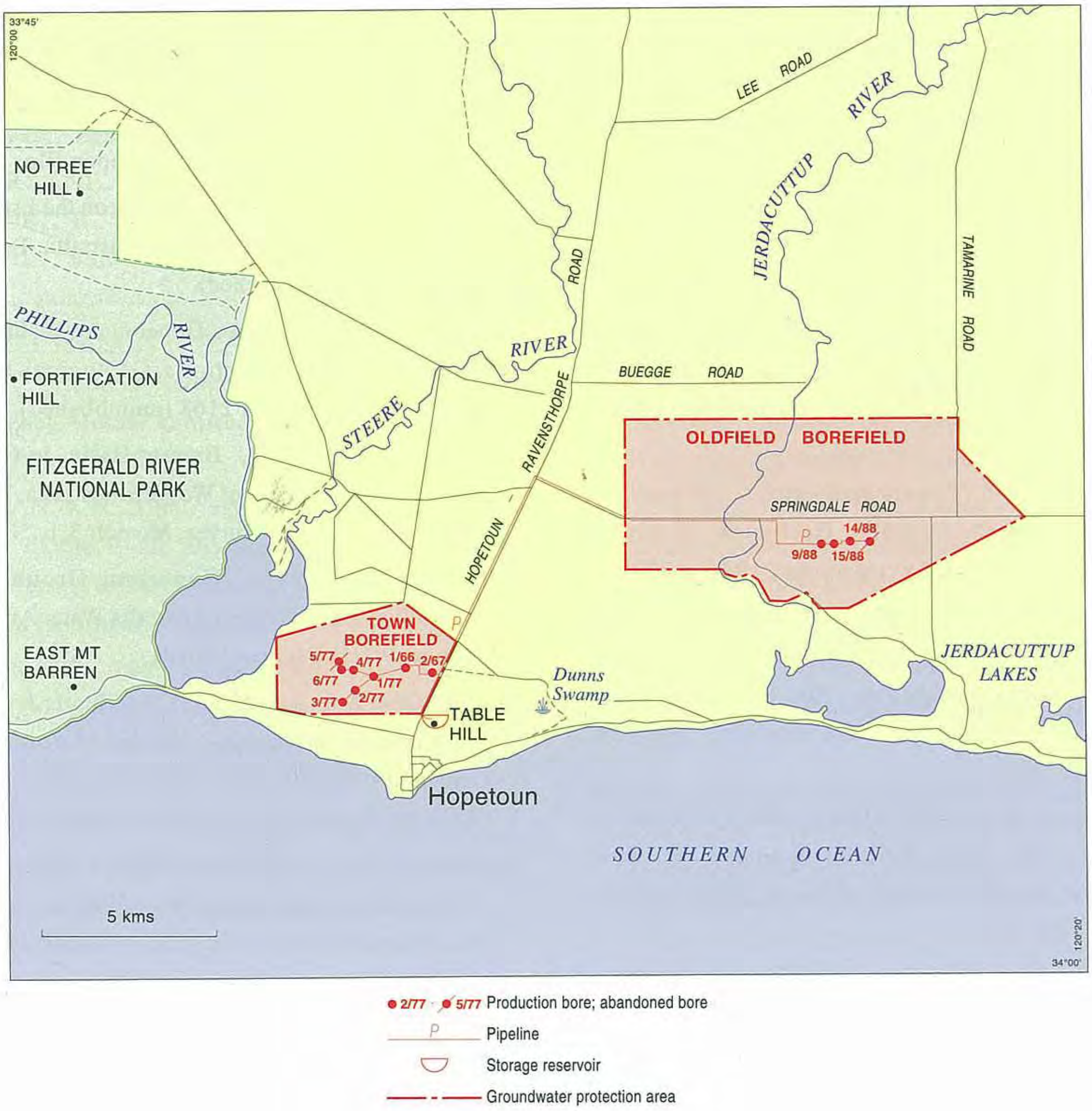


**Figure 6. Hopetoun Town Water Supply borefields**

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# Appendix 1

**Ravensthorpe 1:250 000 hydrogeological series digital data reference files and documentation**

| Design file | Levels | Description | Scale of capture (where applicable) |
|---|---|---|---|
| Ravgeo.*dgn* | L1 | Geological and map boundaries | |
| | L2 | Geological boundary, concealed | |
| | L3 | Surficial sediment boundaries and labels | |
| | L5 | Faults | 1:100 000 |
| | L15* | Air photo lineation | 1:100 000 |
| | L17 | Chert and banded iron-formation | 1:100 000 |
| | L18 | Dolerite dykes | 1:100 000 |
| | L20 | Coastline | |
| | L37 | Watertable — cross section only | |
| | L40 | Geological labels | |
| | L45 | AMG grid | |
| | L60 | Lat and long grid, grid ticks, legend | |
| Ravtopo.*dgn* | L1 | Roads, National route Nos, highway | |
| | L2 | Tracks | |
| | L4 | Railway line | |
| | L6 | Airport | |
| | L8 | Rabbit-proof fence | |
| | L11 | Pools, swamps; swamp names, rockholes | |
| | L20 | Lakes | |
| | L21 | Creeks, rivers and names | |
| | L27 | Coastline, islands | |
| | L31 | Topographic contours and values | |
| | L38 | Rocks | |
| | L41 | Destination names | |
| | L42 | Road names | |
| | L43 | Mountains, hills, ranges, trig points, rock names | |
| | L44 | Localities | |
| | L45 | National Parks, reserve boundaries, labels | |
| | L60* | Map border | |
| | L63* | Lat and long grid | |
| Ravpan.*dgn* | L1 | Black linework | |
| | L2 | PRI bar | |
| | L5 | Faults, geological structure panel | |
| | L20 | Coastline | |
| | L21 | Blue linework, text | |
| | L40 | Labels and hidden labels | |
| | L46 | Panel borders | |
| | L49* | Outermap limit | |
| | L54 | DOME and Water and Rivers Commission logo | |
| | L55 | GSWA logo | |
| | L60 | Format information and text | |

| Design file | Levels | Description | Scale of capture (where applicable) |
|---|---|---|---|
| Ravsal.*dgn* | L2 | 1000 mg/L isohalines | 1:100 000 |
| | L3 | 3000 mg/L isohalines | 1:100 000 |
| | L4 | 7000 mg/L isohalines | 1:100 000 |
| | L5 | 14000 mg/L isohalines | 1:100 000 |
| | L6 | 35000 mg/L isohalines | 1:100 000 |
| | L10 | 1000 mg/L text | |
| | L11 | 3000 mg/L text | |
| | L12 | 7000 mg/L text | |
| | L13 | 14000 mg/L text | |
| | L14 | 35000 mg/L text | |
| | L60 | Lat and long grid | |
| Ravwc.*dgn* | L1 | Map border | |
| | L2* | 20 metre AHD contour | 1:50 000 |
| | L3 | 40 metre AHD contour | 1:50 000 |
| | L4* | 50 metre AHD contour | 1:50 000 |
| | L5* | 60 metre AHD contour | 1:50 000 |
| | L6 | 80 metre AHD contour | 1:50 000 |
| | L7* | 100 metre AHD contour | 1:50 000 |
| | L8 | 120 metre AHD contour | 1:50 000 |
| | L9* | 140 metre AHD contour | 1:50 000 |
| | L10* | 150 metre AHD contour | 1:50 000 |
| | L11 | 160 metre AHD contour | 1:50 000 |
| | L12* | 180 metre AHD contour | 1:50 000 |
| | L13 | 200 metre AHD contour | 1:50 000 |
| | L14* | 220 metre AHD contour | 1:50 000 |
| | L15 | 240 metre AHD contour | 1:50 000 |
| | L16* | 250 metre AHD contour | 1:50 000 |
| | L17* | 260 metre AHD contour | 1:50 000 |
| | L18 | 280 metre AHD contour | 1:50 000 |
| | L19* | 300 metre AHD contour | 1:50 000 |
| | L20 | 320 metre AHD contour | 1:50 000 |
| | L21* | 340 metre AHD contour | 1:50 000 |
| | L22* | 350 metre AHD contour | 1:50 000 |
| | L23 | 360 metre AHD contour | 1:50 000 |
| | L24* | 380 metre AHD contour | 1:50 000 |
| | L25 | 400 metre AHD contour | 1:50 000 |
| | L26* | 20 metre AHD text | |
| | L27 | 40 metre AHD text | |
| | L28* | 50 metre AHD text | |
| | L29* | 60 metre AHD text | |
| | L30 | 80 metre AHD text | |
| | L31* | 100 metre AHD text | |
| | L32 | 120 metre AHD text | |
| | L33* | 140 metre AHD text | |
| | L34* | 150 metre AHD text | |
| | L35 | 160 metre AHD text | |
| | L36* | 180 metre AHD text | |
| | L37 | 200 metre AHD text | |
| | L38* | 220 metre AHD text | |
| | L39 | 240 metre AHD text | |
| | L40* | 250 metre AHD text | |
| | L41* | 260 metre AHD text | |

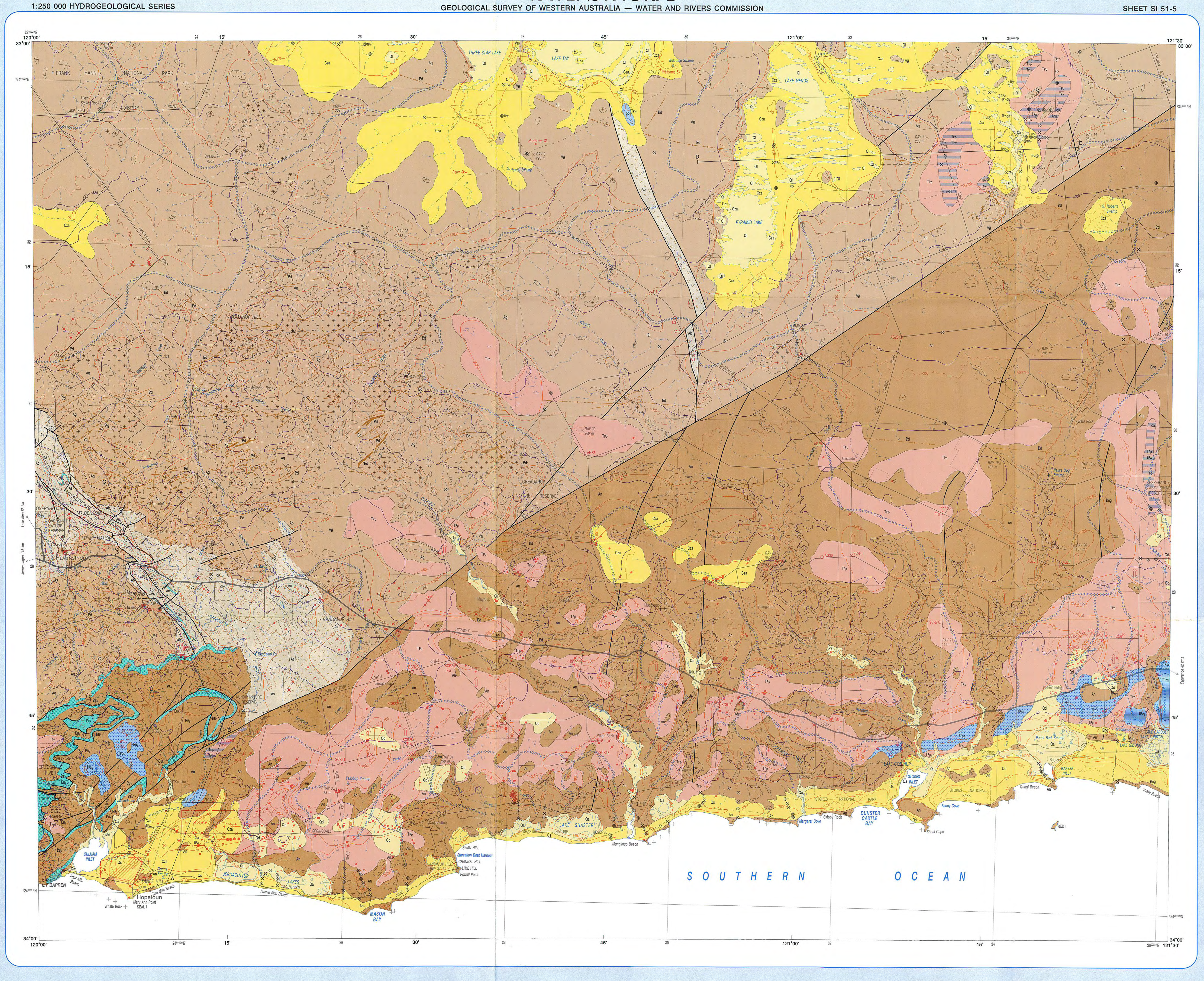
| Design file | Levels | Description | Scale of capture (where applicable) |
|---|---|---|---|
| | L42 | 280 metre AHD text | |
| | L43* | 300 metre AHD text | |
| | L44 | 320 metre AHD text | |
| | L45* | 340 metre AHD text | |
| | L46* | 350 metre AHD text | |
| | L47 | 360 metre AHD text | |
| | L48* | 380 metre AHD text | |
| | L49 | 400 metre AHD text | |
| | L50 | Water catchment divide | 1:50 000 |
| | L51 | Water catchment divide (approximate) | 1:50 000 |
| | L52* | Sub-catchment divide (minor) | 1:50 000 |
| | L60 | Lat and long grid | |
| Ravdepw.*dgn* | L1 | Map border | |
| | L2 | 0–5m below ground level | 1:100 000 |
| | L3 | 5–15m below ground level | 1:100 000 |
| | L4 | 15–25m below ground level | 1:100 000 |
| | L5 | >25m below ground level | 1:100 000 |
| | L45* | AMG grid | |
| | L60* | Lat and long grid | |
| Ravbores.*dgn* | L1 | Bore, yield >50 $m^3$/day | |
| | L2 | Abandoned bore, yield >50 $m^3$/day | |
| | L3 | Artesian | |
| | L4 | Dry bore | |
| | L5 | Mineral exploration holes | |
| | L6 | Monitoring bore (piezometer) | |
| | L7* | River | |
| | L8 | Mine shafts | |
| | L9 | Bore, yield <50 $m^3$/day | |
| | L10 | Abandoned bore, yield <50 $m^3$/day | |
| | L11 | Soaks | |
| | L12 | Springs | |
| | L13 | Wells | |
| | L14* | Lakes | |
| | L15 | Reservoir | |
| | L17 | Refuse sites | |
| | L18 | Rising watertable | |
| | L37 | Pipeline | |
| | L38 | Groundwater protection area | |
| | L45* | AMG grid | |
| | L50* | Date | |
| | L51* | TDS | |
| | L52* | TD | |
| | L53* | Supply | |
| | L54* | SWL | |
| | L55 | Lithology labels | |
| | L56 | Name labels | |
| | L60* | Lat and long grid | |

* Note: information not shown on printed map

# RAVENSTHORPE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA — WATER AND RIVERS COMMISSION





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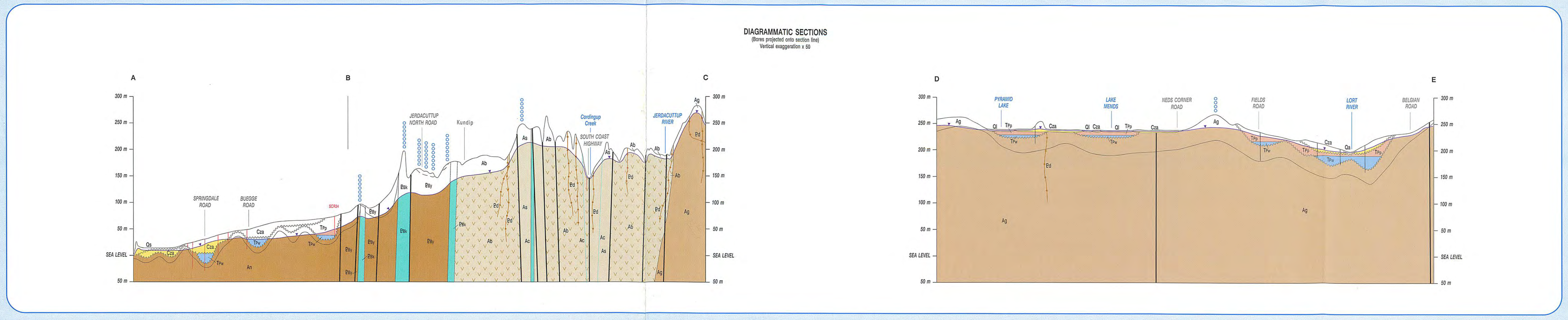


## REFERENCE

### AQUIFER CHARACTERISTICS

- Surficial aquifer—local sedimentary aquifer, minor groundwater resources
- Surficial aquifer—local sedimentary aquifer, minor to major groundwater resources
- Sedimentary aquifer—extensive aquifer, minor to major groundwater resources
- Sedimentary aquitards and local aquifers—minor groundwater resources
- Sedimentary aquifer overlain by aquitard—minor to major groundwater resources
- Fissured aquifer, locally fractured and jointed—moderate supplies from fracture zones, minor groundwater resources
- Fractured and weathered rocks—local aquifers, with large supplies from fracture zones, minor groundwater resources
- Fractured and weathered rocks—local aquifers, minor groundwater resources
- Fractured and weathered rocks—local aquifers, very minor or no groundwater resources

### HYDROGEOLOGY

| Age | | | Unit | Description | Aquifer | |
|---|---|---|---|---|---|---|
| PHANEROZOIC | CAINOZOIC | QUATERNARY | Qa | Alluvium, minor colluvium—gravel, sand, silt and clay | Minor local aquifers; fresh to saline | |
| | | | Qs | Coastal eolian and marine sediments—sand, clay, and limestone | Minor to major aquifers; fresh to saline | |
| | | | Ql | Lacustrine and estuarine sediments—mostly clay | Minor shallow aquifer; saline to hypersaline | |
| | | | Qd | Eolian dunes and sandsheet | Minor perched, discontinuous aquifer; fresh to brackish | |
| | | | Cza | Alluvium, colluvium and sandsheet—mostly sand, gravel, minor clay and silt; mainly overlying Plantagenet Group sediments | Minor to major aquifer; fresh to saline | |
| | | TERTIARY (Plantagenet Group) | TPps | PALLINUP SILTSTONE — Shoreline facies—unconsolidated fine-grained sand and silt | Minor to major aquifer; fresh to saline | BREMER BASIN |
| | | | TPpg | Spongolite facies—interlayered siliceous, vuggy spongolite and claystone | Minor to major aquifer; fresh to saline | |
| | | | TPp | Brown to grey carbonaceous siltstone, fine-grained sandstone and claystone | Minor aquifer to aquitard; fresh to saline | |
| | | | TPw | WERILLUP FORMATION—grey fine- to coarse-grained sand, carbonaceous clay and lignite, bryozoan limestone | Major aquifer; fresh to hypersaline | |
| PROTEROZOIC | | | Ed | Dolerite dyke; interpreted where dashed | Very minor local aquifers; saline | |
| | | Mount Barren Group | EBy | KYBULUP SCHIST—phyllite, schist; minor dolomite of the Steere Formation and mafic to ultramafic schist of the Cowerdup Sill: outcrop (indicated by overprint); generally weathered to clay | Minor local aquifers; fresh to saline | ALBANY–FRASER OROGEN |
| | | | EBk | KUNDIP QUARTZITE—massive orthoquartzite and micaceous quartzite: outcrop (indicated by overprint) | Minor aquifers; fresh to saline | |
| | | | Eng | Granitoid gneiss and granitoid rock: outcrop (indicated by overprint); generally weathered to clay | Very minor local aquifers; brackish to saline | |
| ARCHAEAN | | | An | Granitoid gneiss, migmatite, minor augen gneiss: outcrop (indicated by overprint); generally weathered to clay | Very minor local aquifers; brackish to saline | |
| | | | Ag | Granitoid rock, porphyritic and even-grained: outcrop (indicated by overprint); generally weathered to sandy clay | Minor local aquifers; brackish to saline | YILGARN CRATON |
| | | | Ac | Chert and banded iron-formation | Significant local aquifer; brackish to saline | |
| | | | As | Metamorphosed sedimentary and felsic volcanic rocks; sandstone, shale, siltstone, minor dacite and rhyolite | Minor local aquifers; saline | |
| | | | Ab | Mafic and ultramafic rocks, basalt, amphibolite, komatiite and minor peridotite | Minor local aquifers; saline | |

## SYMBOLS

### GEOLOGY

hydrogeological boundary; concealed
unconformity (section only)
fault
extent of weathering (section only)

### SURFACE WATER FEATURES

drainage, intermittent; pool
lake; permanent, intermittent, swamp
surface water divide
surface water pipeline
rockhole
dam; abandoned

### GROUNDWATER FEATURES

spring
watertable contour (m AHD)
watertable (section only)
isohaline TDS (mg/L)

### ARTIFICIAL FEATURES

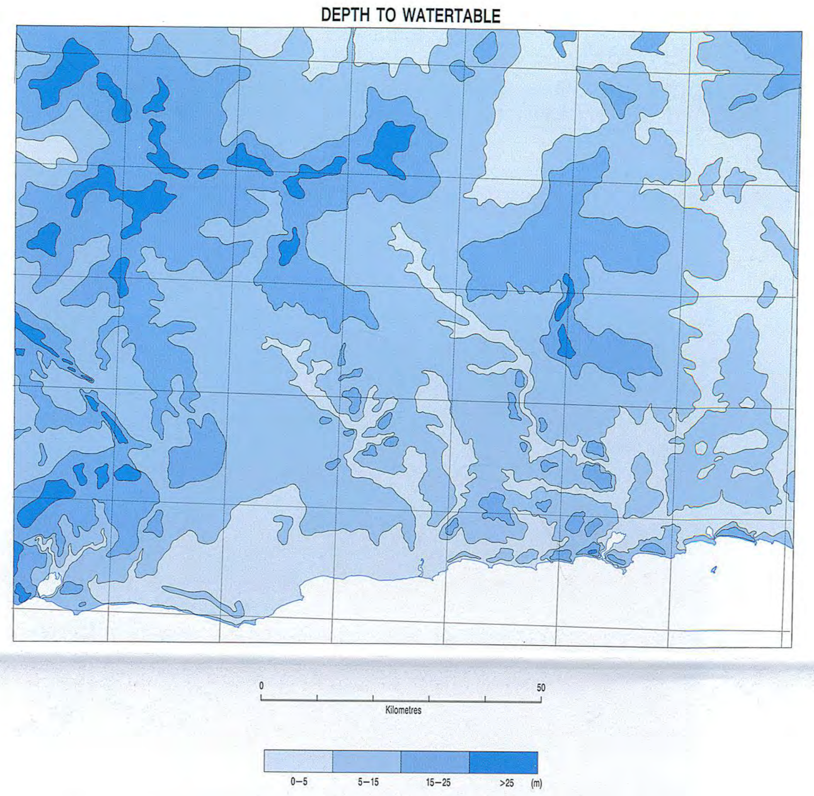
water bore; yield >50 m³/day; >50 m³/day; artesian
bore intersecting significant confined aquifer
water bore, abandoned; yield >50 m³/day; >50 m³/day; dry
excavated soak for stock watering

well; shaft
monitoring bore, piezometer
area with numerous bores, well field, town water supply
boundary of proposed groundwater control area
groundwater pipeline
storage reservoir
saline disposal site; abandoned
landing ground
rising watertable, land salinization
mineral exploration drillhole; intersecting significant confined aquifer

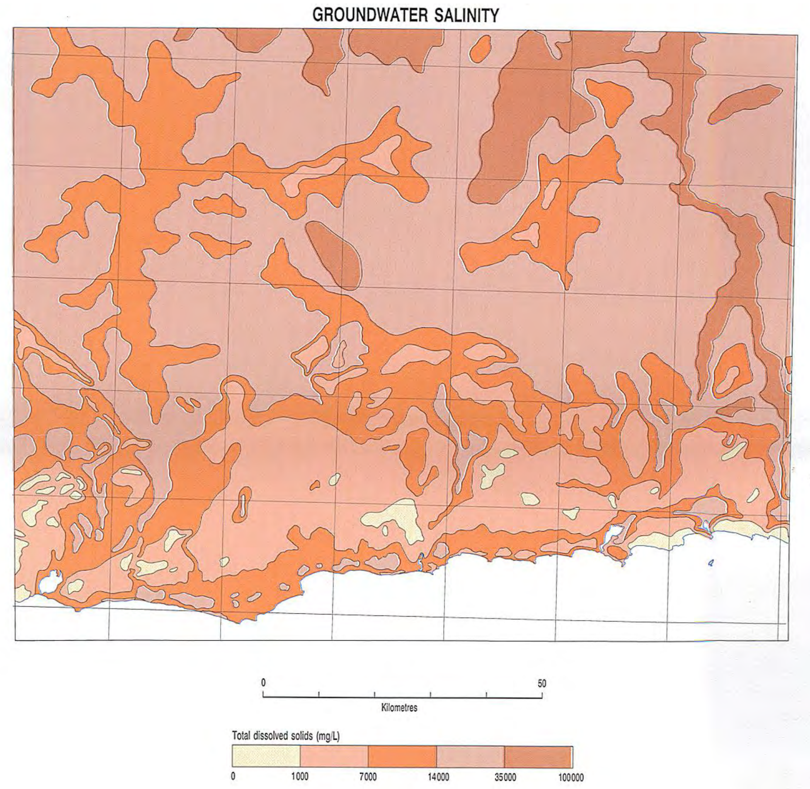
### TOPOCADASTRAL INFORMATION

highway with national route marker
formed road
track
railway; abandoned
townsite, population 100–1000
townsite, population <100
locality
coral reef or submerged rock
topographic contour line, 50 metre interval (m AHD)
horizontal control, minor (AHD)
national park, nature reserve and Aboriginal reserve boundary

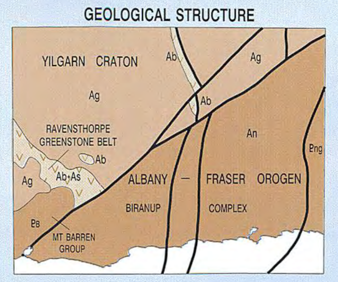
DEPTH TO WATERTABLE



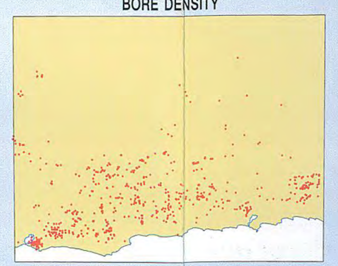
GROUNDWATER SALINITY



GEOLOGICAL STRUCTURE



BORE DENSITY



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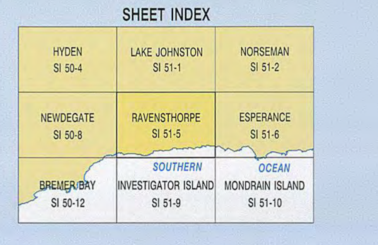
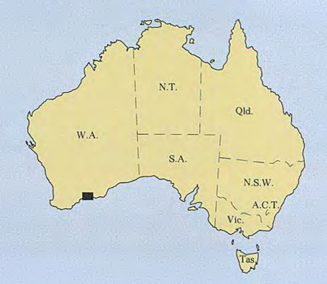
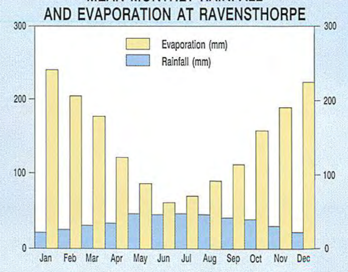
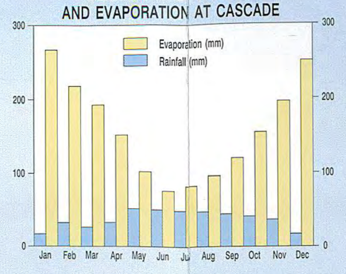




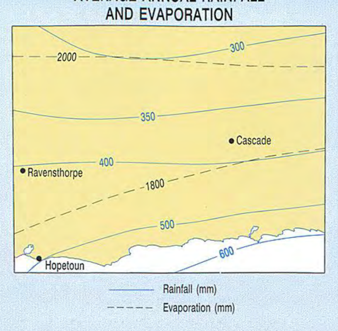
MEAN MONTHLY RAINFALL AND EVAPORATION AT RAVENSTHORPE



MEAN MONTHLY RAINFALL AND EVAPORATION AT CASCADE



AVERAGE ANNUAL RAINFALL AND EVAPORATION



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GOVERNMENT OF WESTERN AUSTRALIA
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DEPARTMENT OF MINERALS AND ENERGY
K.R. PERRY, DIRECTOR GENERAL

WATER AND RIVERS COMMISSION
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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
PIETRO GUJ, DIRECTOR

SCALE 1:250 000

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 20000 metre interval of the Australian Map Grid Zone 51

1:250 000 HYDROGEOLOGICAL SERIES

# RAVENSTHORPE

SHEET SI 51-5

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