Hydrogeology of the Esperance–Mondrain Island 1:250 000 Sheet

GOVERNMENT OF WESTERN AUSTRALIA

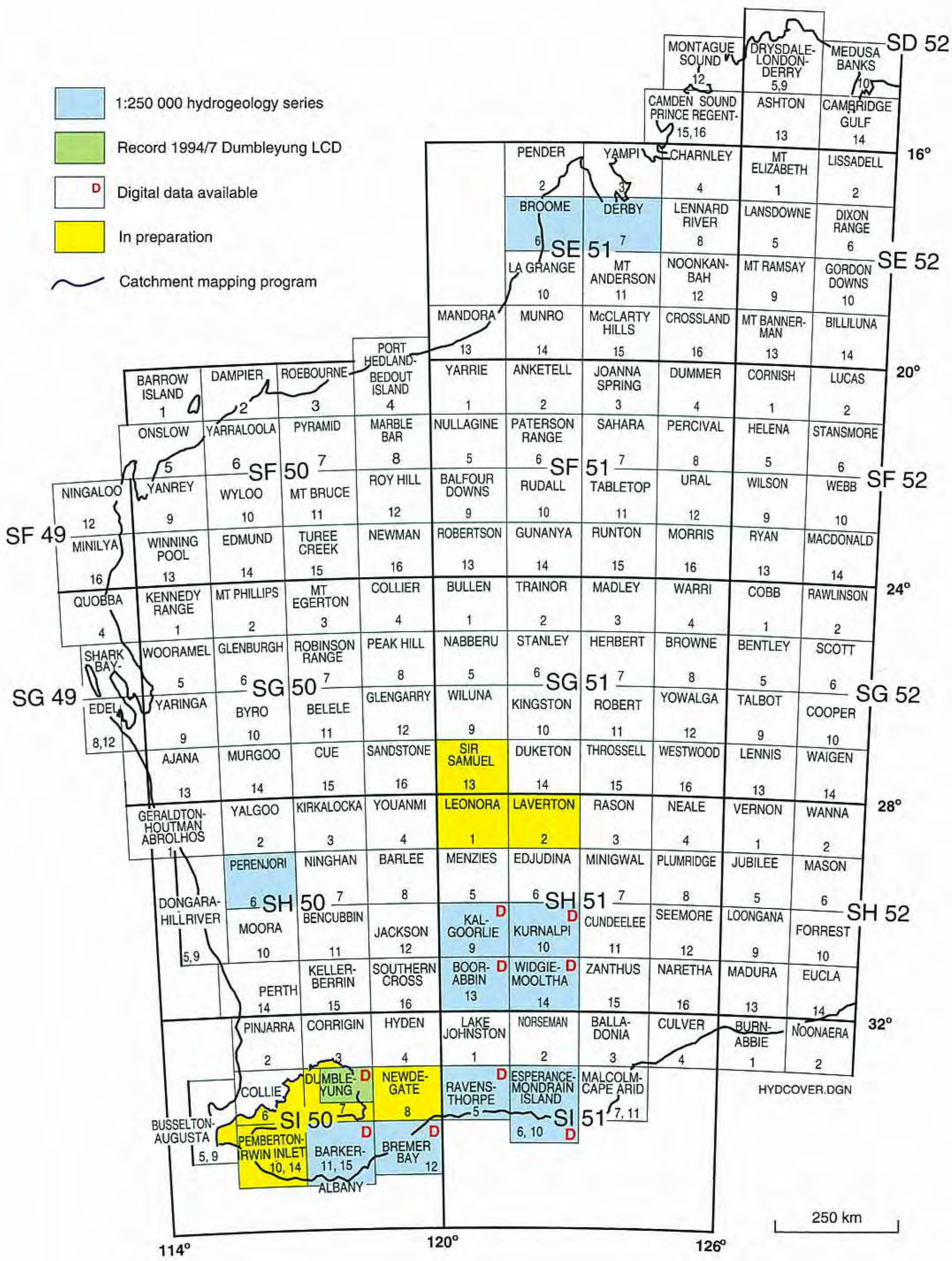
Hydrogeological Map Explanatory Notes Series

Water and Rivers Commission Report HM 2

1998

WATER AND RIVERS COMMISSION

Water and Rivers Commission
Hyatt Centre
3 Plain Street
East Perth
Western Australia 6004
Telephone (08) 9278 0300
Facsimile (08) 9278 0301



Cover Photograph: Pink Lake, viewed from a heavily vegetated coastal dune, with the Esperance Sandplain in the background to the north.

Hydrogeology of the Esperance–Mondrain Island 1:250 000 sheet

by

S.L. Johnson and L.J. Baddock

Water and Rivers Commission
Resource Investigation Division

Water and Rivers Commission
Hydrogeological Map Explanatory Notes Series
Report HM 2
1998

Acknowledgments

The authors gratefully acknowledge the assistance of staff at the Esperance Regional Office of Agriculture Western Australia who collected and compiled the bore data, and in particular, the valuable discussions with *R. Short* and *G. Skinner*.

Recommended Reference

JOHNSON, S.L. and BADDOCK, L.J., 1998, Hydrogeology of the Esperance–Mondrain Island 1:250 000 sheet: Western Australia, Water and Rivers Commission, Hydrogeological Map Explanatory Notes Series, Report HM 2, 24 p.

Copies available from:

Resource Investigation Division
Water and Rivers Commission
3 Plain Street
EAST PERTH
WESTERN AUSTRALIA 6004
Telephone (08) 9278 0522 Facsimile (08) 9278 0586

ISBN 0-7309-7297-6
ISSN 1328-1194

Text printed on recycled stock,
Onyx 100% recycled 135gsm
Cover, Topkote Dull Recycled 256gsm
July 1998

Contents

Figures

Tables

Appendix

Map

Hydrogeology of the Esperance–Mondrain Island 1:250 000 sheet

by

S.L. Johnson and L.J. Baddock

Abstract

The Esperance–Mondrain Island 1:250 000 Hydrogeological Sheet covers the eastern portion of the Albany-Fraser Orogen, part of the Yilgarn Craton and the Bremer Basin. The area comprises weathered and fractured gneiss and granitoid bedrock with Tertiary sedimentary rocks of the Bremer Basin onlapping from the south. Thick Quaternary coastal deposits form prominent sand ridges to the west of Esperance.

The siltstone facies of the Pallinup Siltstone, and fractured-rock aquifers occupy the greatest part of Esperance–Mondrain Island, but contain only minor groundwater supplies. The Quaternary coastal sediments and Tertiary sedimentary aquifers, in particular the shoreline and spongolite facies of the Pallinup Siltstone, are considered to be the most prospective regional aquifers, although they are restricted to the south of Esperance–Mondrain Island. In addition, the Tertiary sands of the Werillup Formation are an important aquifer, but generally contain saline groundwater.

Most of the groundwater on Esperance–Mondrain Island is saline, but in specific areas is fresh to brackish and suitable for town water supplies and watering stock. Fresh groundwater is restricted to the coastal areas with significant potable resources within the Quaternary coastal sediments. There are large brackish to saline groundwater resources within the Tertiary sedimentary aquifers, suitable for stock watering, with the least saline groundwater present in the higher rainfall areas of the south and localised beneath 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, aquifers, salinity, Esperance, Bremer Basin

Water and Rivers Commission
Hydrogeological Map Explanatory Notes Series
Report HM 2
1998

Figure 1. Location map

1 Introduction

1.1 Location

The ESPERANCE–MONDRAIN ISLAND[1] Hydrogeological Sheet (SI 51-6 and part of SI 51-10 of the International Series), which is bounded by latitudes 33° 00' and 34° 15' S and longitudes 121° 30' and 123° 00' 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, southern areas. The map sheet takes its name from the coastal town of Esperance and Mondrain Island, a small granitic island, positioned 10 km south of Cape Le Grand (Fig. 1). Esperance, located approximately 600 km southeast of Perth, is a major port and service centre for the surrounding agricultural and inland mining areas. Esperance is the most populated centre on ESPERANCE–MONDRAIN ISLAND with a population of 12 000, which significantly increases during the summer months owing to the influx of tourists and recreational fisherman. There are also small communities at Gibson, Condingup, Scaddan and Grass Patch but the remainder of the map sheet area is sparsely populated.

The Coolgardie–Esperance Highway and South Coast Highway are two major arterial routes which connect Esperance with other population centres to the north and west respectively (Fig. 1). Fisheries Road is a sealed road linking Esperance with Condingup and the eastern farming areas, and a network of predominantly gravel roads service farms throughout the area.

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 Esperance range from 16° to 26°C during summer months and from 8° to 17°C during winter months.

The average annual rainfall is 623 mm at Esperance, 413 mm at Scaddan and 343 mm at Salmon Gums, 3 km north of ESPERANCE–MONDRAIN ISLAND. This highlights the sharp decrease in rainfall from south to north across the map sheet (Fig. 2). Most rainfall occurs in winter and is associated with a series of low-pressure systems in the Southern Ocean. Periodic summer rainfall occurs as a result of thunderstorm activity or rain-bearing depressions formed from tropical cyclones.

Average annual potential evaporation increases from about 1600 mm at the coast to 2000 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

The physiography of ESPERANCE–MONDRAIN ISLAND is characterised by flat to gently undulating sandplain which rises gradually from sea level through a series of poorly defined benches to 260 m Australian Height Datum (AHD). Monadnocks, isolated steep rounded hills of granite or gneiss, often protrude slightly above the land surface and represent island peaks of a buried archipelago. The coastline is dominated by rocky headlands with intervening stretches of sandy beaches and bays. Cape Le Grand, being the most prominent coastal feature, comprises numerous peaks rising above 200 m, including Mount Le Grand (345 m) which is the highest peak on the map sheet.

Morgan and Peers (1973) recognised four physiographic divisions within ESPERANCE–MONDRAIN ISLAND: Coastal Plain, Lower Sandplain, Esperance Sandplain and Red Inland Sandplain (Fig. 2). The coastal plain extends up to 10 km inland and includes a large number of saline lakes, such as Pink Lake and Lake Gore, situated behind eolian sand dunes up to 150 m high. The inland extent of the coastal plain is marked by an escarpment, up to 40 m high, where the coastal plain merges with the Esperance Sandplain.

The Esperance Sandplain extends approximately 30 to 40 km inland from the coastal plain and is characterised by gently undulating topography which is incised by poorly developed drainage systems. The Lower

[1] *Sheet names are printed in capitals to distinguish them from identical place names*

Figure 2. Physiography and rainfall

Sandplain forms a step-like feature between about 45 and 75 m (Morgan and Peers, 1973) and merges with the Esperance Sandplain in the southeast of ESPERANCE–MONDRAIN ISLAND (Fig. 2). The numerous claypan depressions on the Lower Sandplain and Esperance Sandplain are believed to have been formed by ground subsidence due to leaching out of carbonate sections in the underlying Tertiary sediments (Morgan, 1969), and give rise to semi-permanent fresh-water swamps and larger salt lakes, such as Benje Benjenup Lake. Inland of the Esperance Sandplain is the Red Inland Sandplain, also referred to as the Mallee District (Beard, 1973), comprising red loam over calcareous loess and characterised by broad valleys and playa lakes.

River courses and drainage systems are well developed only along the coast, where steep gorges and river terraces show signs of rejuvenation. The drainages in the western half of ESPERANCE–MONDRAIN ISLAND extend farther inland as a chain of small interconnected salt lakes, whereas drainages to the east of Esperance often terminate abruptly at the southern edge of the Esperance Sandplain (Fig. 2). The northern half of the map sheet, previously part of the north-flowing Tay–Cowan Palaeodrainage (Morgan, 1969), is characterised by internal drainage occupied by salt lakes.

1.4 Vegetation

The natural vegetation of ESPERANCE–MONDRAIN ISLAND is predominantly scrubland heath with local woodlands of small eucalypts (Beard, 1973). Since the 1950s, much of the native vegetation of the southern and western portions of the sheet has been cleared for agriculture.

The Coastal Plain and Lower Sandplain comprise coastal dune scrub of *Eucalyptus angulosa* and *Acacia cyclopis*, and mixed Proteaceae–Myrtaceae scrub heath; swamps are colonised by *Nuytsia* and sedge heath. 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 depressions where paperbark (*Melaleuca preissiana*) or patches of yate (*E. occidentalis*) flourish.

In the north of the sheet, the Red Inland Sandplain is typically covered with mallee and woodland of *E. redunca* in the south, and *E. eremophila* and *E. oleosa* towards the north. Depressions that are frequently inundated in winter support stands of yate, whereas the playa lakes are bordered by saltbush and numerous varieties of samphire.

1.5 Previous investigations

The sheet area has been geologically mapped at 1:250 000 scale by Morgan and Peers (1973) who incorporated a comprehensive description of the hydrogeology and groundwater prospects throughout the region. Myers (1990, 1995) provided a regional account of the structural geology in the Albany–Fraser Orogen based on the synthesis of published works, geophysical data and field work. An overview of the Plantagenet Group stratigraphy and evolution of the Bremer Basin is described by Hocking (1990).

Mineral exploration has provided the most comprehensive insight into the geology of ESPERANCE–MONDRAIN ISLAND. Most mineral exploration has focused on the Tertiary sedimentary rocks in the northern portion of the map sheet, where various mining companies have explored for lignite (Chapman, 1989). The area south of Fisheries Road, between Condingup Peak and Alexander Hill, was explored for heavy-mineral sands and drilled extensively by Placer Exploration Ltd (Hall, 1989).

The first exploratory drilling for water on ESPERANCE–MONDRAIN ISLAND was carried out by Berliat (1952) to assess hydrogeological conditions on the Esperance Sandplain, prior to agricultural development. A bore census and regional mapping were conducted by Sanders (1968) to provide an assessment of groundwater resources in the southwestern corner of the map sheet. This information was incorporated in the first hydrogeological map of the Esperance and Ravensthorpe region (Morgan, 1969) which showed the generalised relationship between rainfall, topography, geology and regional groundwater salinity.

Drilling for groundwater has slowed considerably since the initial rapid farm development work that took place in the mid-1950s and 1960s. Recent groundwater investigations in the Esperance region have focused on further development of the Esperance town water supply (Baddock, 1994a), drought relief drilling (Baddock, 1995a) and the evaluation of groundwater resources in the Coramup–Bandy Creek area (Baddock, 1995b). Additional exploratory drilling was carried out in conjunction with Agriculture Western Australia (AgWA) by establishing 31 piezometers in areas deficient in hydrogeological data and contributing to the mapping of ESPERANCE–MONDRAIN ISLAND (Baddock, 1994b).

Unpublished Geological Survey of Western Australia (GSWA) hydrogeological reports describe groundwater prospects for stock supplies on approximately 100 private farms throughout the area and town water supplies at Esperance, Gibson and Condingup. There have also been several site-specific investigations to evaluate potential groundwater contamination, including CSBP–Esperance and a proposed refuse disposal site at Condingup.

There have been numerous investigations into salinity and waterlogging problems throughout the Esperance region conducted by AgWA (George and Bull, 1979; Hearn, 1991; McFarlane *et al.*, 1994; Short *et al.*, 1994). In conjunction with landform systems mapping (Overheu *et al.*, 1993), catchment management strategies were developed by Platt *et al.* (1996) to assist farm and catchment planning within the Esperance Land Conservation District.

1.6 Map compilation

The hydrogeological map of ESPERANCE–MONDRAIN ISLAND depicts aquifer distribution, watertable level and topographic contours in metres AHD, groundwater salinity (isohalines), groundwater point-data distribution and cadastral data. Data used in the compilation of the map include: topocadastral data from Department of Land Administration; geology from GSWA (Morgan and Peers, 1973; Myers, 1995); bore data from the Water and Rivers Commission water point database (AQWABase); AgWA–Esperance Branch bore and piezometer data, and landform systems mapping (Overheu *et al.*, 1993); Australian Geological Survey Organisation aeromagnetic and radiometric data; and WAMEX mineral exploration drilling data and reports from the Department of Minerals and Energy.

The ESPERANCE–MONDRAIN ISLAND 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 and, owing to poor data distribution, at the smaller 1:100 000 scale in the northern half. This difference should be considered when working with larger scales. The hydrogeological boundaries, watertable-level contours, and groundwater isohalines are interpretative and must be taken as approximate. The accuracy of the interpretation can be gauged from the density of bores and mineral exploration holes (shown on the hydrogeological map) which provided useful geological information.

2 Geology

2.1 Regional setting

ESPERANCE–MONDRAIN ISLAND is underlain by Proterozoic granite and gneiss of the Albany–Fraser Orogen and Archaean granite of the Yilgarn Craton. Tertiary sedimentary rocks of the Bremer Basin (Hocking, 1990) form a discontinuous cover over the Precambrian basement and comprise two distinct lithofacies: the basal Werillup Formation and the overlying Pallinup Siltstone (Table 1). The Werillup Formation infilled pre-existing Cretaceous to Early Tertiary palaeodrainages and broad drainage depressions formed during the continental breakup of Australia from Antarctica.

Extensive weathering of the basement rocks and Tertiary sediments during the Caïnozoic has resulted in the formation of a duricrust and weathering profile. Quaternary surficial sediments, which form a thin veneer over most of the sheet, have formed in an erosive landscape associated with reworking of the duricrust, crystalline rocks and Tertiary sedimentary rocks. The thickest Quaternary deposits are shelly limestone and sand ridges developed along the coast. There are also widespread eolian dunes which are best developed on the Lower Sandplain and minor alluvial deposits associated with saline wetlands, such as Pink Lake and Lake Warden.

2.2 Archaean and Proterozoic

Archaean rocks are present only in the northwestern corner and northeastern part of ESPERANCE–MONDRAIN ISLAND and comprise even-grained to porphyritic granite. Proterozoic granite and gneiss of the Albany–Fraser Orogen, which underlies most of the sheet area, is divided into the early to mid-Proterozoic Biranup Complex and the mid-Proterozoic Nornalup Complex. Both complexes consist of banded gneiss that exhibits polyphase deformation and are thrust northwards in steeply dipping tectonic slices up to 15 km thick (Myers, 1995). These basement rocks are poorly exposed due to extensive surficial cover and deep weathering. Outcrops are mainly on hills formed by basement highs and exposures within incised drainage.

The structure within the Archaean and Proterozoic bedrock on ESPERANCE–MONDRAIN ISLAND is poorly understood owing to limited outcrop. Morgan and Peers (1973) noted that the basement rocks are folded in a series of parallel overturned anticlines and synclines, with a dominant northeast trend in the south becoming north-northeast in the north. Myers (1995) concluded that the northeast trend, best observed north of Esperance as linear ridges and hills of granite gneiss, reflects mid-Proterozoic deformation. The faults formed mainly during a mid-Proterozoic tectonic plate

Table 1. Stratigraphy

Age	*Formation*	*Maximum thickness intersected (m)*	*Lithology*
Quaternary	Alluvium *(Qa)*	8	Silt, sand and gravel
	Coastal sand *(Qs)*	59	Sand, limestone
	Eolian dune *(Qd)*	15	Fine sand
	~~*unconformity*~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Tertiary— Eocene	Plantagenet Group		
	Pallinup Siltstone		
	Shoreline facies *(TPps)*	34	Fine sand, silt, clay
	Spongolite facies *(TPpg)*	33	Spongolite, clay
	Siltstone facies *(TPp)*	65	Siltstone, sandstone, claystone
	Werillup Formation *(TPw)*	33	Sand, gravel, lignite and carbonaceous clay
	~~*unconformity*~~~~~~	~~~~~~~~~~~~	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Proterozoic	Albany–Fraser Orogen *(Png)*	-	Gneiss, granite, sandy clay
Archaean	Yilgarn Craton *(Ag)*	-	Granite, sandy clay

collision where continental crust was thrust toward the west over the Yilgarn Craton (Myers, 1995). No dolerite dykes have been mapped, although interpretation of the aeromagnetic data (BMR, 1982) indicates that there are several dykes trending southeast across the sheet.

Most basement rocks on ESPERANCE–MONDRAIN ISLAND have been deeply weathered and typically comprise a thin laterite duricrust developed over a variable thickness of dense, kaolinitic clay. The weathering profile on the granitoid and gneissic rocks has developed through the chemical breakdown of the crystalline bedrock during Tertiary and Quaternary times. The upper portion of the weathered profile in the south of the sheet area has been largely eroded as a result of drainage rejuvenation. The weathering profile in the northern half of the map sheet is deeper, with a maximum thickness of 30 m intercepted in mineral exploration drilling northeast of Scaddan (Chapman, 1989).

2.3 Cainozoic

2.3.1 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 valleys, known as palaeochannels, and broad topographic depressions in the weathered bedrock. The extent of the formation on ESPERANCE–MONDRAIN ISLAND is poorly understood, although it may be quite extensive in the south of the sheet. The Werillup Formation rests unconformably on the basement rocks and consists of fine- to coarse-grained basal sand, lignite, and carbonaceous clay with a maximum thickness of 33 m intercepted in Neridup Bore No. 21 (Morgan and Peers, 1973). A ferruginous sandstone conglomerate with pebble-rich zones commonly occurs along the unconformity with the underlying bedrock. The basal sand and conglomerate were deposited in a fluvial environment, whereas the overlying lignite and carbonaceous clay accumulated in swamp-like environments.

In several localities throughout the sheet, marine sediments comprising limestone and fossiliferous sand have been identified within the Werillup Formation. In the upper part of the formation, lignite or carbonaceous clay has also been observed grading into a dark-green clay containing glauconite and marine fossils (Chapman, 1989). Cockbain (1968) suggested that these interfingering marine units were deposited in a series of marine transgressions from the south and may be equivalent to the Nanarup Limestone Member observed in the western portion of the Bremer Basin.

The Pallinup Siltstone (*TPp*) is an extensive unit overlying 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 to the south of Fisheries Road and the South Coast Highway. Figure 3 shows the extent and distribution of the Pallinup Siltstone throughout ESPERANCE–MONDRAIN ISLAND.

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 littoral-zone deposit, consisting of unconsolidated very fine to fine-grained quartz sand and silt. In the southern half of the sheet the shoreline deposits occur in narrow, marginal zones at the base of monadnocks, while their distribution in the north is poorly understood. The maximum thickness intersected on ESPERANCE–MONDRAIN ISLAND was 34 m (CBC-3) in the Coramup–Bandy Creek area (Baddock, 1995b). The unit occurs as discontinuous deposits, up to 5 km wide, typically along the 120 m AHD surface-elevation contour, although minor deposits have been intersected between 25 m AHD in the south and 150 m AHD in the north (Fig. 3). The major shoreline zones extend west from Lake Warden, east towards Condingup and northeast of Howick Hill.

The shoreline facies was initially identified within the upper portion of the Pallinup Siltstone by mineral exploratory drilling (Hall, 1989) and in subsequent groundwater drilling in the Coramup–Bandy Creek area (Baddock, 1995b). The airborne geophysical system,

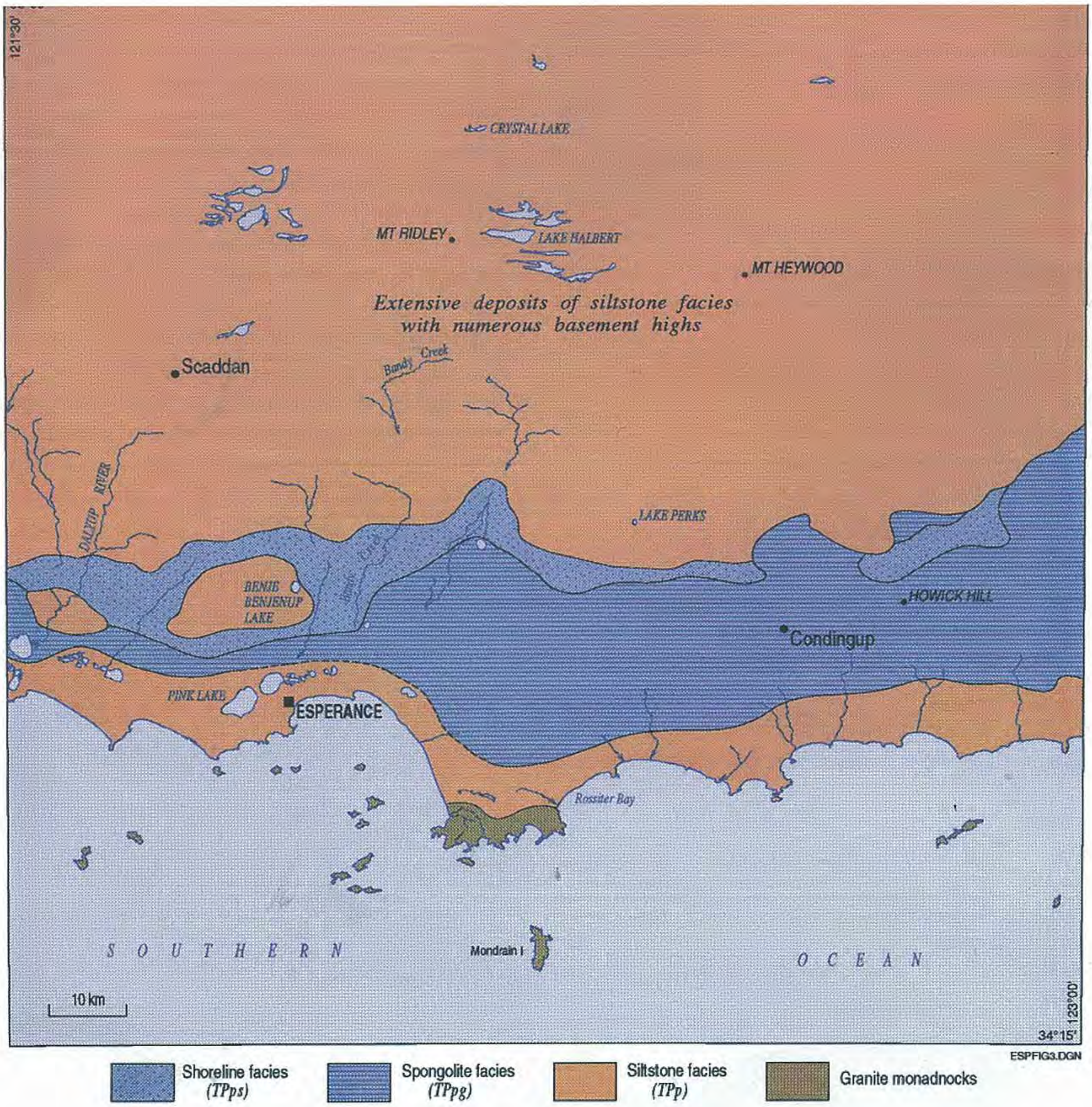


Figure 3. Extent and distribution of Pallinup Siltstone

Questem, flown in the Neridup catchment by World Geoscience in 1994 identified a boundary interpreted to be buried headlands. This boundary, located about 14 km north of Fisheries Road, appears to form the northern margin of the shoreline facies.

The spongolite facies is a highly fossiliferous unit including gastropods, bryozoans, sponge spicules, echinoids and foraminifera, with a large degree of silicification, and chert vugs interlayered with clay. The unit is exposed in numerous localities on ESPERANCE–MONDRAIN ISLAND, predominantly east of Mount Merivale, between the coast and Fisheries Road (Fig. 3). The maximum thickness of the unit is uncertain, as it interfingers the shoreline facies and possibly grades into the underlying siltstone facies. A thickness of 33 m (CBC-5) was intersected in the Coramup–Bandy Creek area (Baddock, 1995b).

2.3.2 Quaternary surficial sediments

Quaternary surficial sediments form a veneer over the Archaean, Proterozoic and Tertiary rocks. The thickest of these sediments are coastal deposits which form prominent sand dunes in the southwest of the sheet. There are widespread sandplain deposits on ESPERANCE–MONDRAIN ISLAND with the most extensive of these forming eolian dune systems. Thin alluvial deposits are present within the Dalyup River and saline lakes on the coastal plain.

Coastal deposits (*Qs*) trend parallel to the coast, forming large ridges of dune sand overlying calcareous shelly limestone. The shelly limestone comprises white, fine- to coarse-grained, calcareous quartz sand with variable cementation and abundant shells at some localities. Dune sediments blanket the coastal area and consist of white to cream, unconsolidated, very fine to fine-grained quartz sand. The coastal sediments are best developed between Lake Gore and Mount Le Grand with the thickest sequences to the west of Esperance where the ridges are up to 160 m high.

Sandplain deposits (*Qd*) occur on the Lower, Esperance and Red Inland Sandplains and comprise eolian, fine-grained quartz sand and silt which have derived from reworking of coastal sediments and the Pallinup Siltstone. The sand ranges in thickness from a few centimetres to sand dunes several metres in height. The dunes have an irregular distribution with the most extensive deposits on the Lower Sandplain, inland from Cape Le Grand.

Alluvium (*Qa*) is present within lower parts of mature drainage systems, such as Dalyup River, and in the chain of lakes behind the coastal dunes. The alluvial deposits, which consist of grey to brown silt and clay, are up to 8 m thick northeast of Lake Warden.

3 Hydrogeology

3.1 Groundwater occurrence

Groundwater occurs in the seven major rock units which are shown on ESPERANCE–MONDRAIN ISLAND. The relationships between rock units are illustrated schematically in Figure 4 and in the diagrammatic sections A–B, C–D and E–F on the hydrogeological map. The Quaternary coastal sediments and Tertiary sedimentary aquifers, including the shoreline and spongolite facies of the Pallinup Siltstone and the Werillup Formation, are the most prospective aquifers in the region. However, there is a large variation in both potential yield and salinity within the aquifers.

ESPERANCE–MONDRAIN ISLAND is underlain by weathered and fractured Archaean and Proterozoic bedrock. The hydrogeology of these granitoid and gneissic rocks is complex with groundwater occurrence restricted to joints, fractures and permeable features within the weathering profile. Hence, the basement aquifers are considered minor localised aquifers.

The Tertiary sedimentary rocks, which extensively overlie the Archaean and Proterozoic basement, are characterised by low permeability due to their fine-grained and clayey nature. However, the shoreline and spongolite facies of the Pallinup Siltstone, and the Werillup Formation, are highly permeable, generally saturated, and contain significant volumes of groundwater. These Tertiary sedimentary aquifers form the largest source of brackish to saline groundwater on the sheet.

Quaternary surficial sediments have a widespread distribution on ESPERANCE–MONDRAIN ISLAND, but most are unsaturated except at the coast and within alluvial deposits. The coastal dunes are best developed to the west of Esperance and contain significant fresh groundwater resources. A perched aquifer may be present locally within thick, eolian sandplain deposits (*Qd*), particularly where the sand overlies relatively impermeable Tertiary sedimentary rocks and basement.

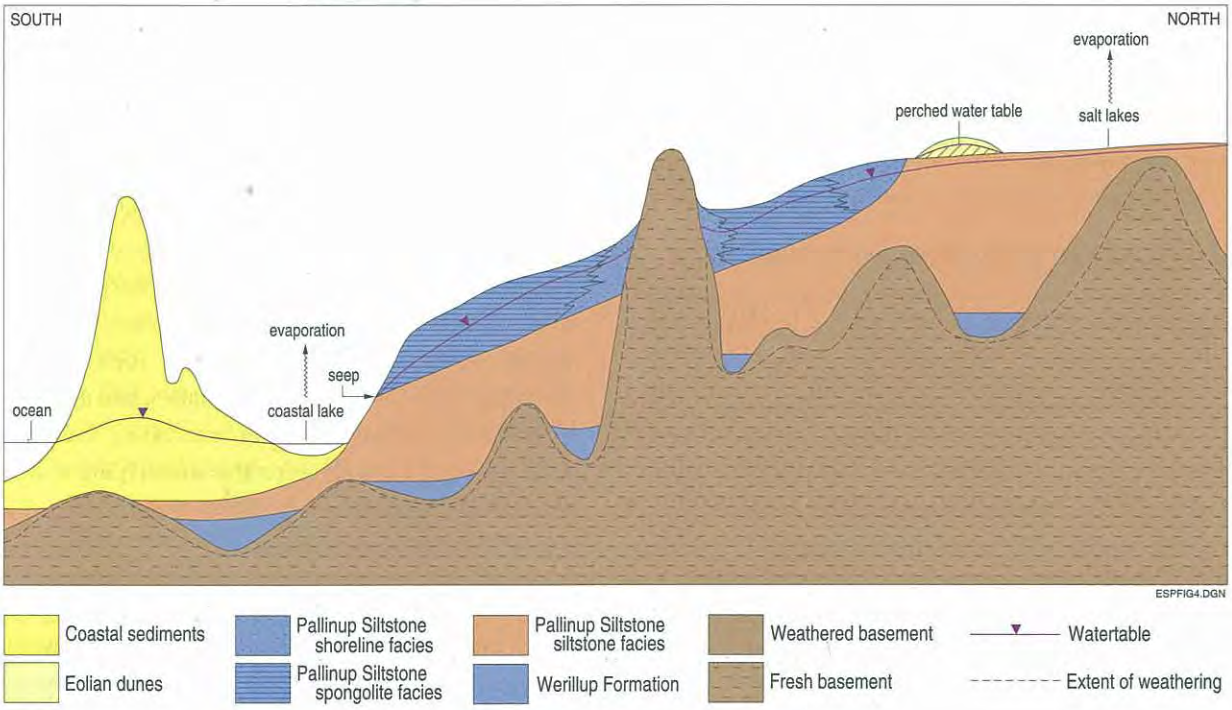


Figure 4. Schematic section showing groundwater occurrence

3.2 Regional watertable

The regional watertable forms a continuous surface throughout ESPERANCE–MONDRAIN ISLAND representing the level below which all pore spaces and fractures within rocks are saturated. However, the watertable may be absent in elevated areas either where the weathered profile and fractures are unsaturated or where fractures are poorly developed. The regional watertable is depicted on the map sheet by groundwater contours, in metres AHD, which are approximate as they are often interpreted from historical bore water levels.

In the north, the watertable is 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 on the Red Inland Sandplain, but may reach a depth of 20 m along catchment divides. Beneath the salt lakes in the north, the watertable is often less than 2 m below the lake floor, resulting in groundwater discharge. Along the coast, the depth to groundwater in the coastal sediments generally exceeds 20 m below ground surface, with increasing depth toward the west (Baddock, 1994b).

West of Esperance, a groundwater mound is developed within the Quaternary coastal sediments between the coastline and Pink Lake. The existence of this mound is the result of increased recharge due to higher rainfall and limited surface runoff over coastal dunes. The watertable elevation near the crest of the mound rises from about 3 m AHD near Esperance to over 30 m AHD west of Pink Lake.

3.3 Groundwater flow and discharge

The watertable elevation falls from 265 m AHD in the northern part of the sheet to near sea level at the coast and is characterised by a low hydraulic gradient reflecting the flat topography. Groundwater throughflow is inferred to be small to negligible owing to the low hydraulic gradient (<0.003), low hydraulic conductivity, and the limited thickness of the saturated zone. Although the regional hydraulic gradient is low, there may be local variations in throughflow as a result of enhanced recharge or variations in topographic relief.

West of Esperance, groundwater flow in the Quaternary coastal deposits is dominated by radial flow away from the crest of the mound towards the ocean and coastal lake discharge boundaries. Baddock (1994a) noted that these radial groundwater flow patterns have been locally modified by pumping from the Esperance town water supply borefield. Groundwater flow patterns can also be locally affected by groundwater barriers such as basement highs, and discharge towards incised drainages.

In the north of ESPERANCE–MONDRAIN ISLAND groundwater discharge evaporates from salt lake floors. Groundwater discharge is also being removed by evapotranspiration and by evaporation where the watertable intersects the surface or is cut by incised drainages. In the Coramup–Bandy Creek area, groundwater discharges from the shoreline facies and spongolite facies of the Pallinup Siltstone via seeps and springs (Fig. 4), which are developed on the flanks of the creeks and along the scarp between the Lower and Esperance Sandplains (Baddock, 1995b).

3.4 Aquifers

3.4.1 Quaternary surficial sediments (*Qs*, *Qa* and *Qd*)

The Quaternary coastal sediments (*Qs*) form an unconfined aquifer along the coast from Lake Gore eastward to Mount Le Grand, and by inference in the discontinuous dunes to the east of Cheyne Point. The sediments, which comprise fine- to medium-grained sand grading into shelly limestone, have intergranular porosity, high permeability and a maximum saturated thickness of up to 30 m. Groundwater within these coastal sediments is recharged primarily by rainfall, with minimal surface runoff evident from dune sands. Baddock (1994a) estimated groundwater recharge at 10% and 30% of rainfall in the coastal Quaternary dunes within areas of native scrub cover and bare dune sands respectively. Groundwater flow associated with the groundwater mound is generally localised with discharge into surface drainages, lakes, and at the coast over the presumed saltwater interface. Downward leakage is also likely into the underlying Pallinup Siltstone, particularly where the shoreline and spongolite facies are present.

Production bores in the Esperance town water supply borefield yield up to 800 m^3/day and aquifer transmissivities derived from pumping tests range up to 1500 m^2/day (Haydon, 1990). Baddock (1994a) suggested that an aquifer transmissivity of 200 m^2/day and hydraulic conductivity of 10 m/day are representative of the coastal sediments in the vicinity of the Esperance borefield. Because the lower salinity groundwater in the aquifer occurs as a lens overlying saline water, some bores in the coastal sediments are pumped at low rates to prevent upconing of the saline groundwater.

Groundwater in the coastal sediments between Lake Gore and Mount Le Grand is potable to marginal with groundwater salinity in the Esperance Borefield ranging between 500 and 800 mg/L Total Dissolved Solids (TDS). In contrast, the dunes to the east of Cheyne Point contain brackish groundwater owing to lower recharge caused by extensive dune vegetation and less permeable coastal sediments.

Alluvium (*Qa*) is restricted to the southern portion of Esperance–Mondrain Island and is found in the lower parts of mature drainages and in the chain of lakes behind the coastal dunes. The fine-grained sediments form an unconfined aquifer with low permeability and a maximum saturated thickness of several metres. The regional watertable is typically close to the surface resulting in groundwater discharge which is associated primarily with evaporation from lake floors. Recharge to the alluvial sediments occurs where the regional watertable is more than 2 m below the coastal lake bed, by direct infiltration of rainfall and seepage from rivers, and impounded surface water. The alluvial sediments are not used for groundwater supply on this sheet because of their clayey nature, poor water quality and limited saturated thickness. Groundwater is generally saline (<16 000 mg/L TDS), although small areas of brackish groundwater exist in the alluvial sediments of the Dalyup River.

Eolian sandplain deposits (*Qd*) exist inland of the coast forming distinct dunes or broad areas of deep sand, up to several metres thick, typically overlying the less permeable Tertiary sediments or weathered basement. A perched watertable often forms in these fine-grained quartz sandplain deposits during winter and may be permanent in the more extensive deposits, such as north of Condingup Peak. The perched groundwater system is recharged by rainfall and forms mounds above the regional watertable level. Discharge is represented by soaks at the dune margins. The perched systems are fresh to brackish and have limited extent with a saturated thickness of a few metres. They may quickly become depleted if the resource is overpumped.

3.4.2 Tertiary sedimentary rocks (*TPp*, *TPpg*, *TPps* and *TPw*)

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

The siltstone facies of the Pallinup Siltstone, which dominates the central and northern portions of Esperance–Mondrain Island, is characterised by low permeability due to its fine-grained lithology and cementation. Bore yields are typically very low, ranging from 2 to 20 m³/day. However, yields up to 133 m³/day are obtainable (Baddock, 1995a).

The shoreline facies (*TPps*) forms an unconfined to semi-confined aquifer with intergranular porosity and high permeability. The saturated thickness is variable, ranging from 8 to 20 m in the Coramup–Bandy Creek area (Baddock, 1995b). The aquifer persists as a discontinuous unit across the centre of the sheet within 20 km of the coast, typically between 100 and 150 m AHD with the mapped extent based on limited bore information. Bore yields usually range between 30 and 150 m³/day, although yields up to 250 m³/day have been obtained from the same aquifer on Ravensthorpe (Johnson, 1998). Running silts can cause considerable problems with bore construction and development, and can lead to 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 aquifer is an extensive unit which dominates the southern portion of Esperance–Mondrain Island. Bore yields typically range between 20 and 150 m³/day, although pumping tests of EWD-2 produced yields of 300 m³/day with a stable drawdown of 3.65 m (Baddock, 1995a). Bore yields from the spongolite aquifer are highly variable and dependent on the proportion of spongolite and the development of solution cavities (Baddock, 1995b).

The Pallinup Siltstone is recharged by rainfall and leakage from overlying Quaternary sediments.

Enhanced groundwater recharge may occur around the flanks of granitic hills, owing to the concentration of rainfall runoff, and in more-permeable zones such as the shoreline facies of the Pallinup Siltstone. Groundwater recharge rates of about 10% of rainfall have been estimated for the shoreline facies in the Coramup–Bandy Creek area (Baddock, 1995b). Groundwater flow, which is generally towards the south, may be constrained by irregular bedrock topography and lateral differences in the hydraulic conductivity. Groundwater discharge from the Pallinup Siltstone is primarily by evapotranspiration, slow vertical leakage to the underlying Werillup Formation, throughflow to the Southern Ocean, and evaporation at salt lake surfaces in the north. Baddock (1995b) also noted that groundwater within the shoreline and spongolite facies discharges via seeps, which are developed on the flanks of the creeks and along the escarpment (Fig. 4) where the coastal plain merges with the Esperance Sandplain.

Groundwater salinity in the Pallinup Siltstone is highly variable, ranging from brackish to hypersaline with localised lower salinity areas beneath catchment divides and thick sandplain deposits. The salinity within the shoreline and spongolite facies ranges from less than 1000 to 7000 mg/L TDS, with areas of lower salinity in the vicinity of the Coramup–Bandy Creek area and at the flanks of basement highs. The salinity within the Pallinup Siltstone increases rapidly towards the north reflecting the reduced rainfall and increased evaporation in this direction.

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 up to 35 m, but its extent is poorly understood. The basal sand aquifer is semi-confined beneath the relatively impermeable siltstone facies of the overlying Pallinup Siltstone. Groundwater recharge occurs primarily by slow downward leakage from the Pallinup Siltstone and possibly by lateral groundwater inflow from weathered and fractured basement. In the north of ESPERANCE–MONDRAIN ISLAND, groundwater is discharged from the aquifer and evaporates from salt lakes with a small amount of throughflow in the palaeochannels. Pumping tests in the aquifer at Coramup–Bandy Creek (EWD 1) produced yields up to 150 m^3/day with a stable drawdown of 1.9 m (Baddock, 1995a). Bore yields from the Werillup Formation typically range from 50 to 200 m^3/day, although yields of up to 300 m^3/day are possible.

The salinity distribution within the Werillup Formation is poorly understood. Groundwater in the Werillup Formation is commonly saline (<14 000 mg/L TDS), although fresh to brackish groundwater has been intersected in areas of enhanced recharge about the flanks of large granitic hills, such as at Condingup Peak and Howick Hill. In the north of the sheet, groundwater in the Werillup Formation is hypersaline as a result of internal drainage towards salt lakes and salt concentration by evaporation.

3.4.3 Granitoid and gneissic rocks (*Png* and *Ag*)

Proterozoic granitoid and gneiss (*Png*) of the Albany–Fraser Orogen occur throughout ESPERANCE–MONDRAIN ISLAND, with small areas of Archaean granite (*Ag*) poorly exposed in the north of the sheet. In places the granitoid and gneiss rocks are deeply weathered to more than 30 m. Baddock (1995a) observed that the joints and fractures in the gneissic rocks are very sparse or have been infilled with low-permeability clay resulting in low bore yields of generally less than 10 m^3/day, although moderate yields over 50 m^3/day have been obtained. Consequently, windmills and low-yielding pumps are the only suitable installations for these weathered and fractured (basement) aquifers.

Groundwater in the basement rocks is generally saline, up to 36 000 mg/L TDS in MB2D (Hirschberg, 1984), although brackish groundwater may occur within fractures near surface catchment divides in the south of the sheet. The groundwater salinity is generally higher in gneissic rocks than in granitoids due to lower permeability and the consequent increased groundwater residence times of the gneissic weathered profile.

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 since 1952 from numerous bores and monitoring piezometers. 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 ESPERANCE–MONDRAIN ISLAND is predominantly saline with low salinity groundwater restricted to the coastal area. Groundwater salinity increases to the north and east across the sheet area, corresponding to lower rainfall.

Potable groundwater (<1000 mg/L) occurs within Quaternary sediments beneath the coastal dunes in the southwest of the map sheet. The most extensive area of fresh groundwater is between Esperance and Lake Gore, where up to 30 m of fresh groundwater is present within Quaternary coastal sediments (Baddock, 1994a). Localised areas of potable groundwater occur throughout the shoreline and spongolite facies of the Pallinup Siltstone, particularly on the interfluve of Coramup and Bandy Creeks (Baddock, 1995b). There are also small potable supplies available from the Pallinup Siltstone and Werillup Formation about the flanks of basement highs, such as Howick Hill (Baddock, 1995a). Eolian dune deposits may also contain small quantities of potable groundwater where a perched watertable forms above less permeable strata during the wet winter months and dissipates during the dry summer.

Brackish to stock-quality groundwater (1000–7000 mg/L) is restricted to the southern third of the sheet, south of 30°S and west of Condingup, as rainfall decreases to the north and east. Groundwater salinity in the shoreline and spongolite facies of the Pallinup Siltstone is generally suitable for stock-watering with areas of lower salinity at the flanks of the basement highs, beneath the localised catchment divides and thick sandplain deposits. There are also small supplies of brackish groundwater in the Pallinup Siltstone and basement aquifers along catchment divides and in the higher rainfall coastal areas.

Groundwater salinity exceeding 7000 mg/L is reported within the Tertiary sedimentary rocks and basement aquifers over most of ESPERANCE–MONDRAIN ISLAND. Groundwater salinity within the Pallinup Siltstone and Werillup Formation, north of 33° 30'S, is generally hypersaline (greater than 35 000 mg/L) where associated with salt lakes. Salinity increases downstream of salt lakes are related to concentration of salts by evaporation. Groundwater salinity within the gneissic and granitoid rocks in the north is typically greater than 14 000 mg/L, with areas of lower salinity along localised catchment divides, such as at Mount Ney and Mount Ridley.

4.2 Hydrochemistry

Most waters are of the sodium chloride type irrespective of the aquifer, reflecting their derivation (through precipitation) from cyclic salts (Fig. 5). The results of the chemical analyses of groundwater from 15 bores are shown in Table 2. In both the coastal sediments and the Werillup Formation a proportion of the analyses with low-salinity groundwater also contain significant calcium and bicarbonate concentrations (Fig. 5). These concentrations are caused by dissolution of calcium carbonate either in the Quaternary coastal sediments (TWS-6 and TWS-16) or Tertiary limestone within the Werillup Formation (EWD-1). Consequently, groundwater from the coastal sediments is often very hard.

Most groundwater sampled has a pH between 6.5 to 8, but a pH as low as 3.6 has been recorded in granitoid rocks (Hirschberg, 1984). Nitrate levels are generally low (<10 mg/L) throughout ESPERANCE–MONDRAIN ISLAND, although some elevated nitrate values have been identified within the Esperance town site and are due mainly to low levels of contamination from septic tanks (Hughes-Owen, 1992a). High levels of sulphate in some areas, particularly in the Tertiary sedimentary rocks and eolian deposits on the Esperance Sandplain, suggest possible contamination from the use of fertilisers. The few analyses for soluble iron are typically very low, although values up to 0.8 mg/L have been recorded in the Gibson town water supply. Several bores in granitoid areas contain high levels of silica although these are not considered harmful.

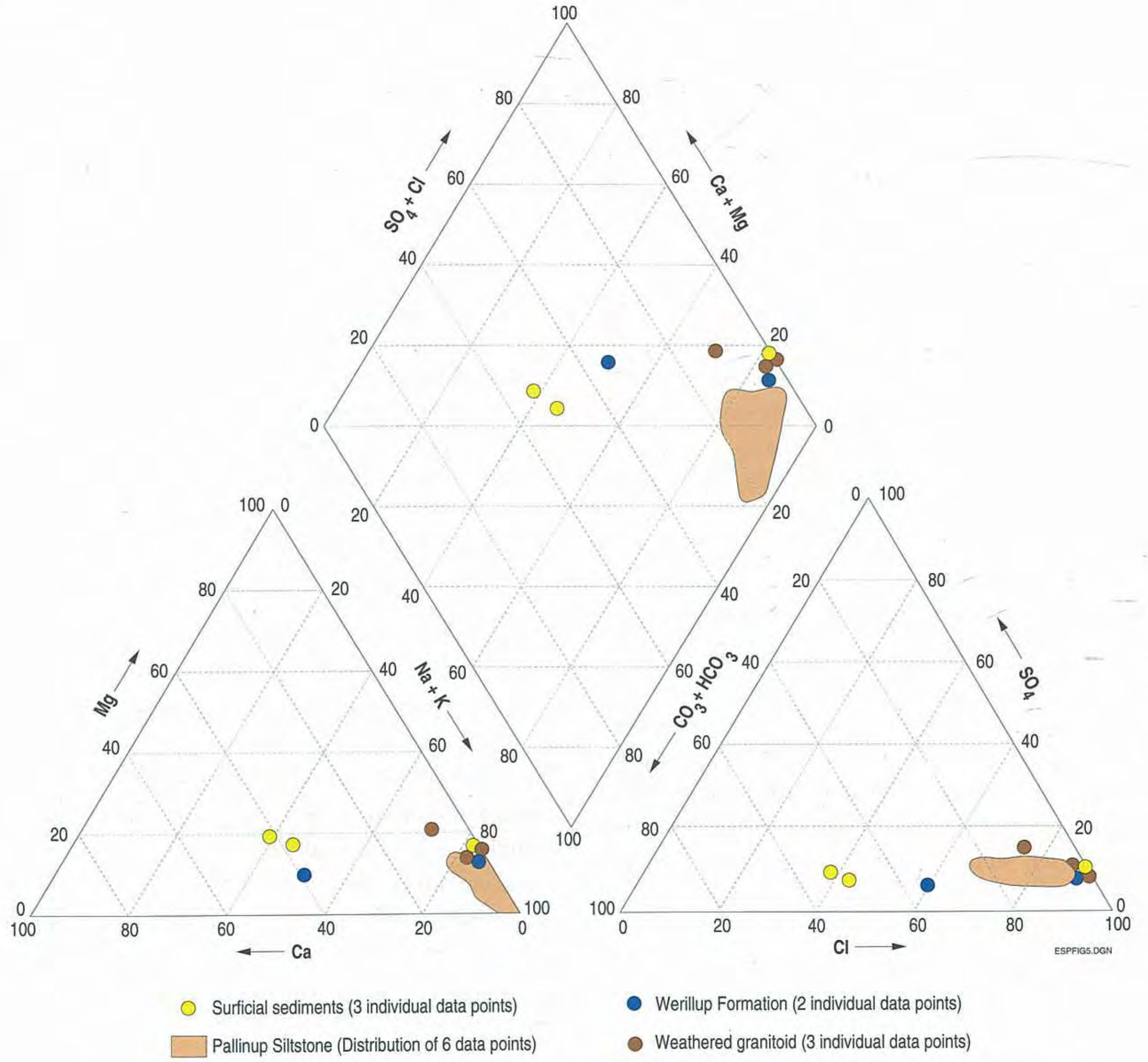


Figure 5. Piper trilinear diagram of selected chemical analyses of groundwaters

Table 2. Selected chemical analyses of groundwaters

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*	*F*
									(mg/L)						
Surficial deposits															
TWS-6	7.6	126	689	321	278	89	24	122	3	339	167	38	9	12	na
TWS-16	7.5	114	622	319	272	85	26	95	3	332	141	49	2	12	na
MB-1I (c)	5.0	12200	105000	16000	5	309	3600	33600	536	6	57300	9290	1	36	<0.1
Pallinup Siltstone															
Shoreline facies															
EWD-4A	6.6	180	1080	94	170	18	12	385	5.3	205	480	90	<1	15	0.2
CBC-2	7.8	60	370	16	64	1	3	115	3.5	78	135	30	1	10	0.7
CBC-3	7.5	145	880	145	91	19	24	270	8.1	110	370	82	7	8	0.4
Spongolite facies															
EWD-2	6.7	630	3790	445	145	52	76	1350	36	175	1950	335	<1	22	0.3
CBC-5	7.6	90	530	20	86	3	3	165	5.2	105	205	390	2	25	0.6
Siltstone facies															
CBC-1D	7.6	550	3310	475	305	65	76	1200	31	375	1600	270	<1	8	1.2
Werillup Formation															
EWD-1	7.4	160	1020	380	285	120	19	175	4.8	350	355	52	<1	9	<0.1
EWD-4	7.7	162	9720	1490	350	100	300	3750	85	430	5440	860	<1	12	1.4
Granitoid rocks															
MB2	3.6	5270	35900	4800	<2	28	1160	11500	195	<2	19800	3100	<1	96	<0.1
MB3	3.6	6450	44700	6200	<2	35	1490	14300	401	<2	24600	3720	<1	106	<0.1
406815mE 6273360mN	6.4	340	190	45	17	5	8	49	3	21	81	23	1	6	<0.1
495108mE 6257129mN	8.0	3880	25600	3909	575	320	755	8190	225	700	13100	2240	<1	21	1.6

Notes: (a) EC=Electrical conductivity; (b) TDS=Total dissolved solids; (c) Quaternary eolian dunes; na = not analysed

5 Land salinisation

Land salinisation is particularly severe in the agricultural areas of ESPERANCE–MONDRAIN ISLAND, with most instances related to the low permeability of the Pallinup Siltstone and the flat, poorly drained terrain. Other contributing factors include high salt storage, high groundwater salinity, and the presence of shallow bedrock that acts as a barrier to groundwater flow.

The clearing of native vegetation and replacement by annual crops and pastures has led to a substantial increase in recharge to the groundwater systems. George and Bull (1979) considered that the groundwater recharge under native vegetation is about 1.5% of rainfall compared to 7% under cleared land on the Esperance Downs Research Station. As a result of the increased recharge, watertable levels have been steadily rising in the order of 0.1 to 0.3 m/year throughout the Esperance Agricultural District (McFarlane *et al.*, 1994; Short, 1997). Groundwater levels are rising most rapidly in the south where the rainfall is higher and where there is inadequate drainage, whereas rates of rise are slower in the lower rainfall zones of the north and east. These rising water levels, combined with shallow saline watertables and high salt stores in the soil profile, have led to the development of secondary salinity, manifested in reduced crop yields and salt scalds. Waterlogging is also a severe problem in the area with similar effects (Short, 1997).

Although the Australian Bureau of Statistics estimated that only 1.78% of cleared land in the Esperance Agricultural District was affected by secondary salinity, McFarlane *et al.* (1994) considered that this was an underestimate and that the actual area could be up to five times greater. However, the severity of the salinisation problem is most evident at farm and paddock scale, as observed on the Esperance Downs Research Station. Short *et al.* (1994) noted that by 1988 about 39% of Esperance Downs was affected by salinity and waterlogging. Most of these problems can be attributed to the relatively flat topography, poor drainage and localised flooding in wet years (George and Bull, 1979).

Most of the soils on ESPERANCE–MONDRAIN ISLAND are alkaline with high salt storage, particularly in the Mallee district, north of Esperance (McFarlane *et al.*, 1994). Salt storages in the top 6 m of the regolith range up to 854 t/ha in the Mallee and up to 124 t/ha in the Esperance Sandplain (Short, 1996). As watertables rise in these areas, the large salt storages are being remobilised along drainage lines, commonly resulting in salt scalds (Short, 1996).

Another important factor that promotes secondary salinity throughout the Esperance region is the presence of shallow basement. Short (1996) noted that a number of salt-affected areas in the central part of the Esperance Agricultural District appear where watertables are shallow (<2 m below surface) and associated with bedrock highs which form barriers to groundwater flow.

Waterlogging is an important land degradation issue in the perched aquifer systems in the Esperance region. Overheu *et al.* (1993) identified that the soils of the Esperance Sandplain were highly susceptible to waterlogging. Further investigations by Short *et al.* (1994) concluded that poor drainage and seasonal inundation combined with the development of a perched aquifer in duplex soils are responsible for waterlogging.

Rising saline groundwater is causing increasing contamination of farm dams, and leading to increased discharge of saline groundwater into streams and lakes. Inland lakes that formerly contained intermittent fresh water have become semi-perennial and saline.

In a study to manage the effects of land salinisation and waterlogging, Short (1996) recognised fourteen hydrogeological zones in the Esperance Agricultural District based on differences in geology and geomorphology. The seven zones which fall within ESPERANCE–MONDRAIN ISLAND comprise the lower sandplain (*Qs*, *Qa* and *Qd*), the shoreline and spongolite facies of the Pallinup Siltstone (*TPps*, *TPpg*), areas of Pallinup Siltstone (*TPp*) and four zones underlain by gneissic bedrock (*Png*) which differ largely in rainfall and landforms.

6 Groundwater development

Groundwater resources on ESPERANCE–MONDRAIN ISLAND are limited by the lack of major aquifer systems and the prevalence of high groundwater salinity over most of the area. Groundwater is used in the southern third of the map sheet mainly for stock watering, whereas in the north, surface dams are widely used to meet water demands. The towns of Esperance, Condingup and Gibson are reliant on groundwater supplies with Scadden supplied by rainwater tanks.

6.1 Town water supplies

The towns of Esperance, Gibson and Condingup rely on groundwater supplies provided by Water Corporation borefields. Esperance has the largest groundwater development on ESPERANCE–MONDRAIN ISLAND with 35 bores providing 1.7 x 10^6 m^3/yr in 1994/95 from the Quaternary coastal sediments (Fig. 6). Demand for water is expected to rise to 2.5 x 10^6 m^3/a in 2001 (Haydon, 1990; Hughes-Owen, 1992a). The borefield has a salinity of less than 800 mg/L TDS and a total hardness of up to 400 mg/L $CaCO_3$, due to the dissolution of limestone in the aquifer. The groundwater salinity in several bores in the west of the borefield rises rapidly during pumping owing to upconing of saline water. There is potential for future westward extension of the borefield within the Quaternary coastal sediments to meet an increased future demand of up to 6 x 10^6 m^3/a (Baddock, 1994a).

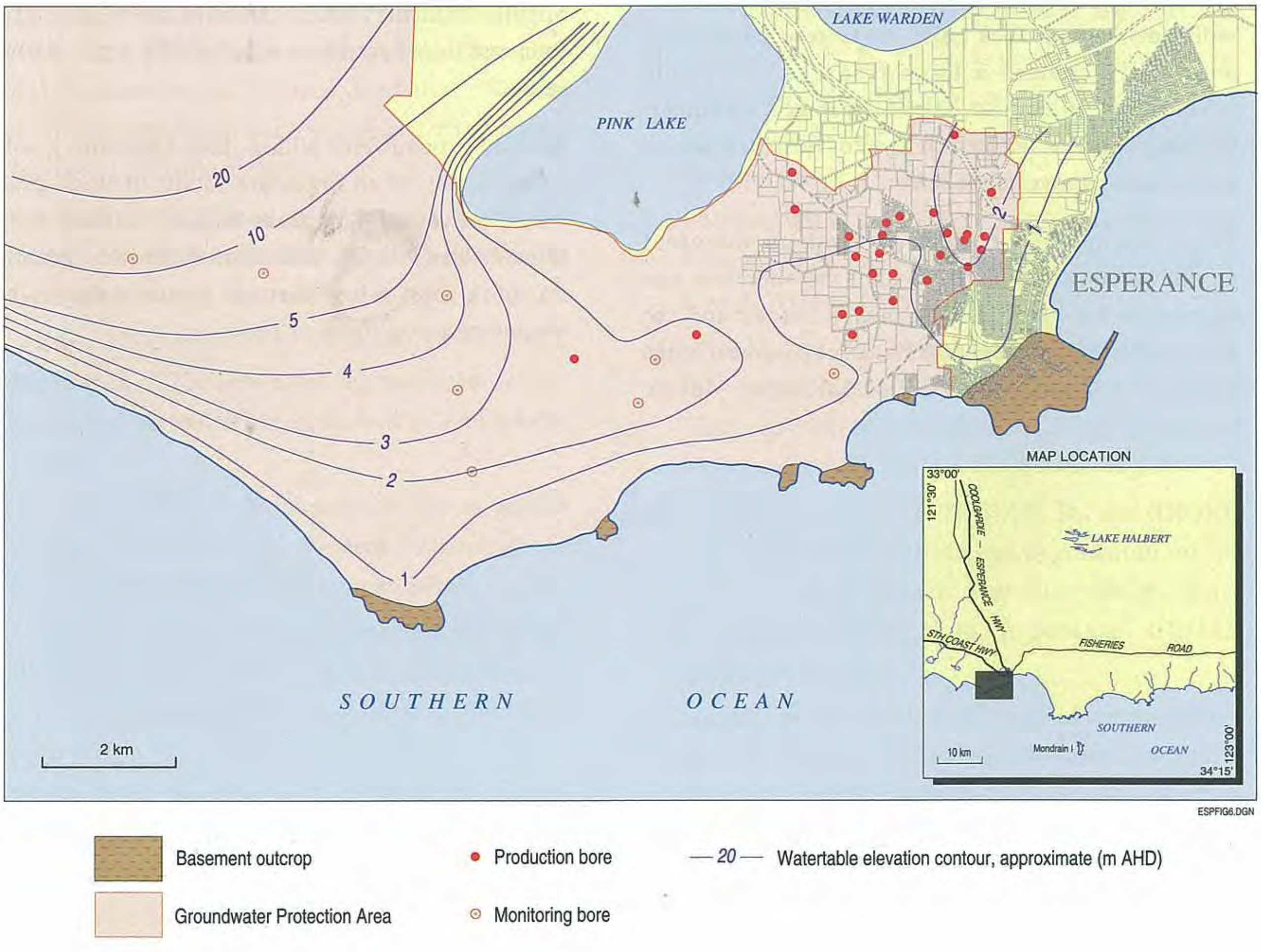


Figure 6. Esperance town water supply borefields

The town water supplies for Gibson and Condingup are located in Tertiary sedimentary aquifers. Gibson was supplied with 16 250 m^3/yr in 1994/95 from two bores positioned in the shoreline facies of the Pallinup Siltstone. Condingup is supplied by one production bore located in the Werillup Formation that drew 5950 m^3/yr for 1994/95 with an average salinity of 700 mg/L TDS (Hughes-Owen, 1992b). There is significant use of private bores in Condingup which reduces the demand on the scheme supply, although future subdivision in the town could see a large increase in scheme consumption.

6.2 Potential groundwater resources

The potential for groundwater development is highest in the south of ESPERANCE–MONDRAIN ISLAND within Quaternary coastal sediments, and the shoreline and spongolite facies of the Pallinup Siltstone. The Quaternary coastal sediments between Lake Gore and Lake Bannitup form a significant aquifer that is extensively utilised only near Esperance. The sediments, west of Pink Lake, are largely untested but potentially contain a large resource of potable groundwater. In contrast, east of Esperance, the aquifer probably contains only a thin layer of fresh to brackish groundwater above saline water.

There are localised areas of fresh to marginal groundwater (<1500 mg/L) within the shoreline and spongolite facies of the Pallinup Siltstone and the Werillup Formation about the flanks of basement highs and in the higher rainfall, coastal areas. In the Coramup–Bandy Creek area, Baddock (1995b) estimated 105 x 10^6 m^3 of stored groundwater of a salinity less than 1000 mg/L within the shoreline and spongolite facies. This may be a suitable water supply for small-scale irrigation.

Moderate to large supplies of brackish groundwater, suitable for stock-watering purposes, are readily available from the shoreline and spongolite aquifers throughout the southern third of the map sheet. There may also be small supplies of brackish to saline groundwater available from the Pallinup Siltstone and localised lower salinity groundwater in the weathered and fractured-rock aquifers along catchment divides.

Groundwater resources in the northern portion of ESPERANCE–MONDRAIN ISLAND are saline to hypersaline and limited to the Werillup Formation. The Werillup Formation is largely confined below the Pallinup Siltstone and its distribution within the concealed palaeochannels is poorly understood. However, significant yields up to 300 m^3/day may be obtained. Supplies from the Pallinup Siltstone and weathered and fractured basement rocks are generally very small and saline.

Perched groundwater within thick Quaternary eolian deposits may be an important source of stock-quality water, particularly in areas lacking suitable deeper groundwater. As the saturated thickness is generally no more than a few metres, groundwater is best abstracted using soaks or wells.

7 References

BADDOCK, L. J., 1994a, Esperance town water supply drilling investigation 1993: Western Australia Geological Survey, Hydrogeology Report 1994/4 (unpublished).

BADDOCK, L. J., 1994b, Esperance hydrogeological mapping drilling program bore completion reports: Western Australia Geological Survey, Hydrogeology Report 1994/43 (unpublished).

BADDOCK, L. J., 1995a, Bore completion reports, Esperance water deficiency area, 1995: Western Australia Geological Survey, Hydrogeology Report 1995/9 (unpublished).

BADDOCK, L. J., 1995b, Coramup–Bandy Creek, Esperance groundwater investigation program: Western Australia Geological Survey, Hydrogeology Report 1995/13 (unpublished).

BEARD, J. S., 1973, The vegetation of the Esperance and Malcolm areas, Western Australia: Western Australia Vegetation Survey Map and Explanatory Memoir 1:250 000 series.

BERLIAT, K., 1952, Report on exploratory drilling for water, Esperance Plain: Western Australia Geological Survey, Annual Report 1952, p. 21–26.

BUREAU OF MINERAL RESOURCES, 1982, Esperance 1:250 000 total magnetic intensity: Australia Bureau of Mineral Resources, Preliminary edition.

CHAPMAN, D. G., 1989, Esperance lignite project progress report for 1988: Western Collieries Ltd / Mokey Pty Ltd, Report 119 (unpublished).

COCKBAIN, A. E., 1968, The stratigraphy of the Plantagenet Group, Western Australia: Western Australia Geological Survey, Annual Report 1967, p. 61–63.

GEORGE, P. R., and BULL, S. C., 1979, The causes of saltland—a case study of Esperance: Western Australia Department of Agriculture, Journal of Agriculture No. 3, 1979, p. 74–77.

HALL, G. C., 1989, First annual report on exploration to 31st December 1989—E 63/247, E 63/248, E 69/275, Esperance project, W.A.: Placer Exploration Ltd. Report No. WA1/90 (unpublished).

HAYDON, D., 1990, Esperance groundwater scheme review: Western Australia Water Authority, Report WG106 (unpublished).

HEARN, S. J., 1991, Tackling salinity on the Esperance Sandplain: Western Australia Department of Agriculture, Technical Report 121 (unpublished).

HIRSCHBERG, K. J., 1984, Esperance new land areas: Western Australia Geological Survey, Hydrogeology Report 2613 (unpublished).

HOCKING, R. M., 1990, Bremer Basin *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 561–563.

HUGHES-OWEN, D., 1992a, Esperance water reserve; protection of groundwater quality: Western Australia Water Authority, Report WG140 (unpublished).

HUGHES-OWEN, D., 1992b, Condingup groundwater scheme review: Western Australia Water Authority, Report WG152 (unpublished).

JOHNSON, S. L., 1998, Hydrogeology of the Ravensthorpe 1:250 000 sheet: Western Australia, Water and Rivers Commission, Hydrogeological Map Explanatory Notes Series, Report HM4.

McFARLANE, D., FERDOWSIAN, R., and SHORT, R., 1994, The extent of land degradation on the South Coast of Western Australia: GRDC Water Management Workshop, Esperance, CLIMA Technical Report 4.

MORGAN, K. H., 1969, Hydrology of the southwest part of the Eucla Division, Western Australia: Western Australia Geological Survey, Record 1969/10 (unpublished).

MORGAN, K. H., and PEERS, R., 1973, Explanatory notes on the Esperance–Mondrain Island geological sheet, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

MYERS, J. S., 1990, Albany–Fraser Orogen *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 255–263.

MYERS, J. S, 1995, Geology of the Esperance 1:1 000 000 sheet: Western Australia Geological Survey, 1:1 000 000 Geological Series Explanatory Notes.

OVERHEU, T. D., MULLER, P. G., GEE, S. T., and MOORE, G. A., 1993, Esperance land resource survey: Western Australia Department of Agriculture, Land Resources Series No. 8.

PLATT, J., NICHOLAS, B., SHORT, R., and GEE, S.T., 1996, Esperance Region Catchment Planning Strategy: Agriculture Western Australia, Miscellaneous Publication 10.

SANDERS, C. C., 1968, Hydrogeology of the eastern part of the Ravensthorpe 1:250 000 geological sheet, Western Australia: Western Australia Geological Survey, Annual Report 1967, p. 19–21.

SHORT, R. J., 1996, Geology, drainage and hydrogeology, *in* Esperance Region Catchment Planning Strategy *edited by* J. Platt *et al*: Agriculture Western Australia, Miscellaneous Publication 10.

SHORT, R. J., 1997, Increasing plant water use to reduce salinity: Agriculture Western Australia, Resource Management Technical Report No. 169.

SHORT, R. J., SKINNER, G., FERDOWSIAN, R., and McFARLANE, D. J., 1994, Hydrology and geology in relation to salinity and waterlogging on the South Coast of Western Australia: GRDC Water Management Workshop, Esperance, CLIMA Technical Report 4.

Appendix 1

Digital data design files and documentation

Design file	Levels	Description	Scale of capture (where applicable)
Esptopo.*dgn*	L1	Roads, National route Nos, highway	
	L2	Tracks	
	L4	Railway line	
	L6	Airport	
	L8	Rabbit-proof fence	
	L20	Lakes, swamps, coastline	
	L21	Creeks, rivers and names	
	L26	Bathymetric contours and heights	
	L29	Sand dunes	
	L30	Topographic contours	
	L31	Topographic contour heights	
	L34	Microwave towers	
	L37	Lighthouse	
	L38	Rocks	
	L41	Destination names	
	L42	Road names	
	L43	Mountains, hills, ranges, trig points, rock names	
	L44	Localities	
	L45	National Parks, reserve boundaries, labels	
	L50*	Physiography	
Esphydro.*dgn*	L1	Hydrogeological boundaries and cross-sections	
	L2	Hydrogeological boundaries – inferred	
	L3	Surficial sediment boundaries (*Qd*) and labels	
	L4	Werillup Formation (*Tpp/Tpw*) and labels	
	L5	Faults	
	L6	Inland extent of Tertiary shoreline facies (*TPps*)	
	L31	Mines	
	L37	Watertable – section only	
	L39*	Hidden labels under surficial sediments	
	L40	Geological labels	
	L41	Cross-section lines and labels	
	L45	AMG grid – map and side panels	
	L59	Latitude and longitude grid	
	L60	Legend, latitude and longitude text, cross-section depth labels	
Esppan.*dgn*	L1	Black linework	
	L5	Faults, geological structure panel	
	L8*	PRI bar	
	L10*	PMS 140 – registration point	
	L11*	Yellow – registration point	
	L12*	PMS 139 – registration point	
	L14*	PMS 151 – registration point	
	L15*	PMS 159 – registration point	
	L37*	PMS 266 – registration point	
	L38*	PMS 192 – registration point, bore density	
	L40	Structural geology labels and hidden labels	
	L45	AMG grid	
	L46	Panel border	
	L47*	Trim marks	
	L48	Coastline	
	L49*	Average rainfall contours	

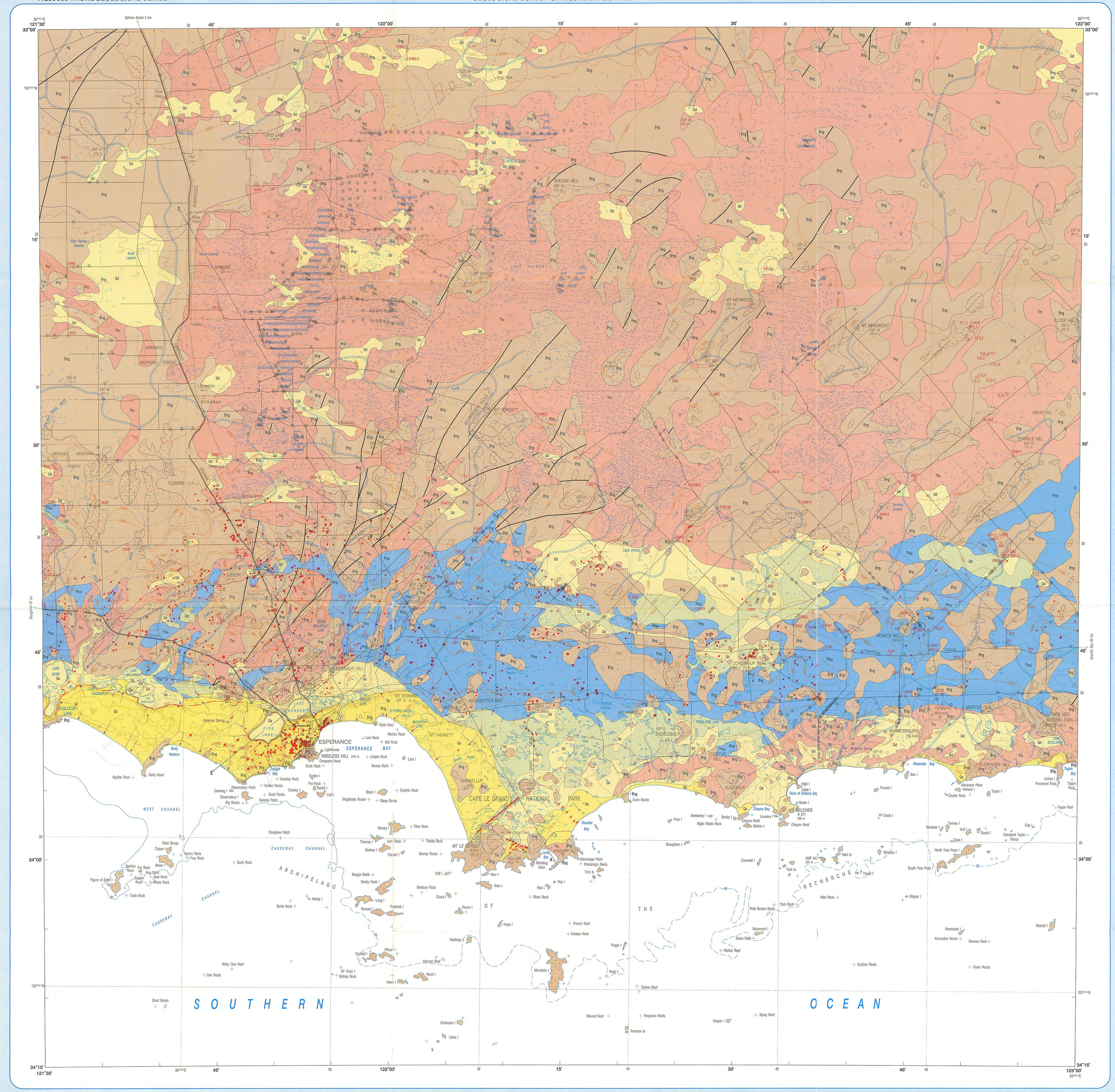
Design file	Levels	Description	Scale of capture (where applicable)
	L50*	Average potential evaporation contours	
	L54	DOME and Water and Rivers Commission logo	
	L55	GSWA logo	
	L60	Format information and text	
Esp2dsal.*dgn*	L1	1000 mg/L isohalines	1:100 000
	L2	3000 mg/L isohalines	1:100 000
	L3	7000 mg/L isohalines	1:100 000
	L4	14 000 mg/L isohalines	1:100 000
	L5	35 000 mg/L isohalines	1:100 000
	L10	1000 mg/L text	
	L11	3000 mg/L text	
	L12	7000 mg/L text	
	L13	14 000 mg/L text	
	L14	35 000 mg/L text	
	L20	Coastline	
	L25	Area underlain by saltwater	
	L59	Map border	
Esp2dgwc.*dgn*	L2	Watertable contour labels	
	L3	Watertable contours	1:100 000
	L7	Spring and spring names	
	L20	0–2 m below ground level	1:100 000
	L21	2–5 m below ground level	1:100 000
	L22	5–10 m below ground level	1:100 000
	L23	10–15 m below ground level	1:100 000
	L24	15–20 m below ground level	1:100 000
	L42	Water catchment divide	1:50 000
	L43	Sub-catchment divide (minor)	1:50 000
	L45	AMG grid	
	L50	Direction of groundwater flow	
	L59	Lat and long grid	
Espbores.*dgn*	L1	Abandoned bore, yield >50 m^3/day	
	L2	Abandoned bore, yield <50 m^3/day	
	L3	Dry bore	
	L4	Artesian	
	L5	Bore, yield <50 m^3/day	
	L6	Bore, yield >50 m^3/day	
	L7	Groundwater exploration holes; yield <50 m^3/day	
	L8	Groundwater exploration holes; yield >50 m^3/day	
	L9	Mineral exploration holes	
	L10	Monitoring bore (piezometer)	
	L11	Soaks	
	L12	Refuse sites	
	L13	Refuse sites; abandoned	
	L14	Bores intersecting significant aquifer	
	L20	Groundwater protection area	
	L40	Bore names	
	L43	Piezometer bore names	
	L44*	Mineral exploration hole names	
	L50	Hydrogeological labels	
	L51*	Salinity labels	
	L52*	Static water levels	
	L53*	Yield labels	
	L59	Map border	

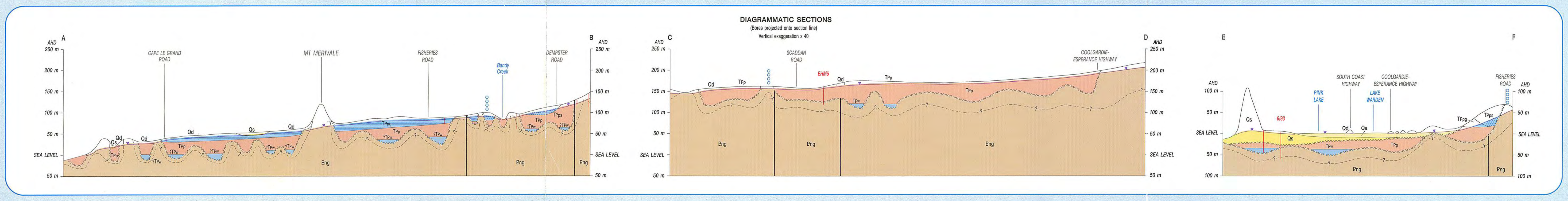
* Note: information not shown on printed map

ESPERANCE - MONDRAIN ISLAND

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SI 51-6 AND PART OF SHEET SI 51-10





REFERENCE

AQUIFER CHARACTERISTICS

- Surficial aquifer—local sedimentary aquifer, minor groundwater resources
- Surficial aquifer—local sedimentary aquifer, major groundwater resources
- Sedimentary aquifer—extensive aquifer, minor to major groundwater resources
- Sedimentary aquifer overlain by aquitard, minor to major groundwater resources
- Sedimentary aquitards and local aquifers, minor groundwater resources
- Fractured and weathered rocks—local aquifers, minor or no groundwater resources

HYDROGEOLOGY

CAINOZOIC	QUATERNARY		Qa	Alluvial sand, silt and clay	Minor aquifer; saline	
			Qs	Coastal eolian and marine sand and limestone	Minor to major aquifers; fresh, commonly saline at depth	
			Qd	Eolian sandsheets (blue overprint indicates thin superficial sediments directly overlying Tertiary aquifer)	Minor perched, discontinuous aquifer; brackish	
	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 (section only)	Major aquifer; saline	
PROTEROZOIC			Png	Granitoid gneiss and granitoid rock: outcrop (indicated by overprint); weathered to clay	Minor local aquifers; brackish to saline	ALBANY – FRASER OROGEN
ARCHAEAN			Ag	Granitoid rock, even-grained: outcrop (indicated by overprint); weathered to sandy clay	Minor local aquifers; saline	YILGARN CRATON

SYMBOLS

GEOLOGY

- hydrogeological boundary; concealed
- hydrogeological boundary, position uncertain
- unconformity (section only)
- fault
- extent of weathering (section only)

SURFACE WATER FEATURES

- drainage, intermittent
- lake; perennial, intermittent
- surface water divide

GROUNDWATER FEATURES

- spring
- 250 watertable contour (m AHD)
- watertable (section only)
- direction of groundwater flow
- 3000 isohaline (mg/L TDS)
- area underlain by salt water

ARTIFICIAL FEATURES

- water bore: yield <50 m³/day; ≥50 m³/day; artesian
- TPw bore intersecting significant confined aquifer
- water bore abandoned: yield <50 m³/day; ≥50 m³/day; dry
- excavated soak for stock watering
- TL5 monitoring bore, piezometer
- boundary of groundwater control area
- waste disposal site; operating, abandoned

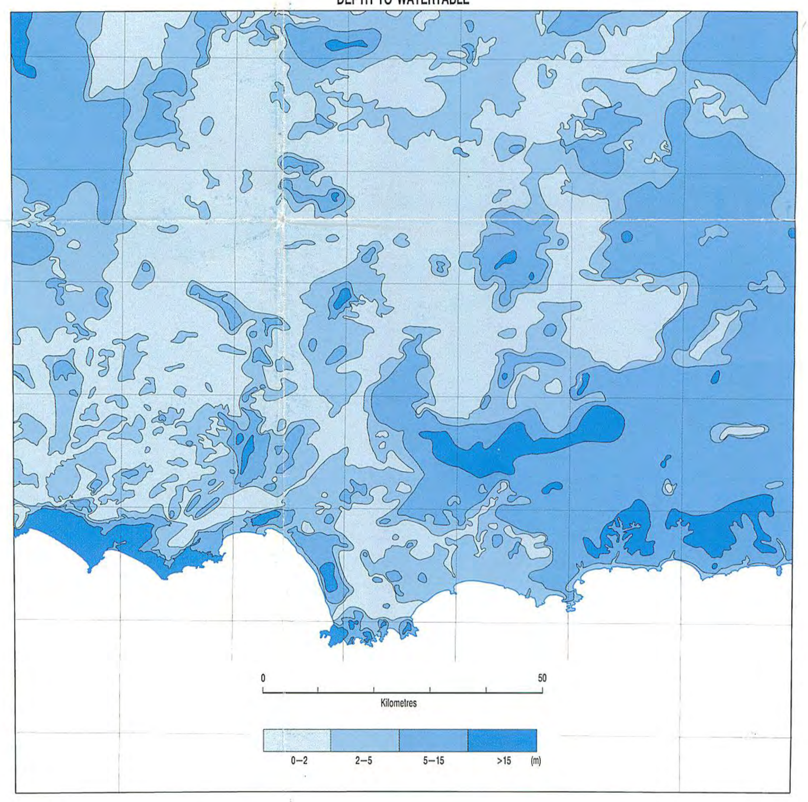
MINING FEATURES

- mineral or coal exploration drillhole
- quarry

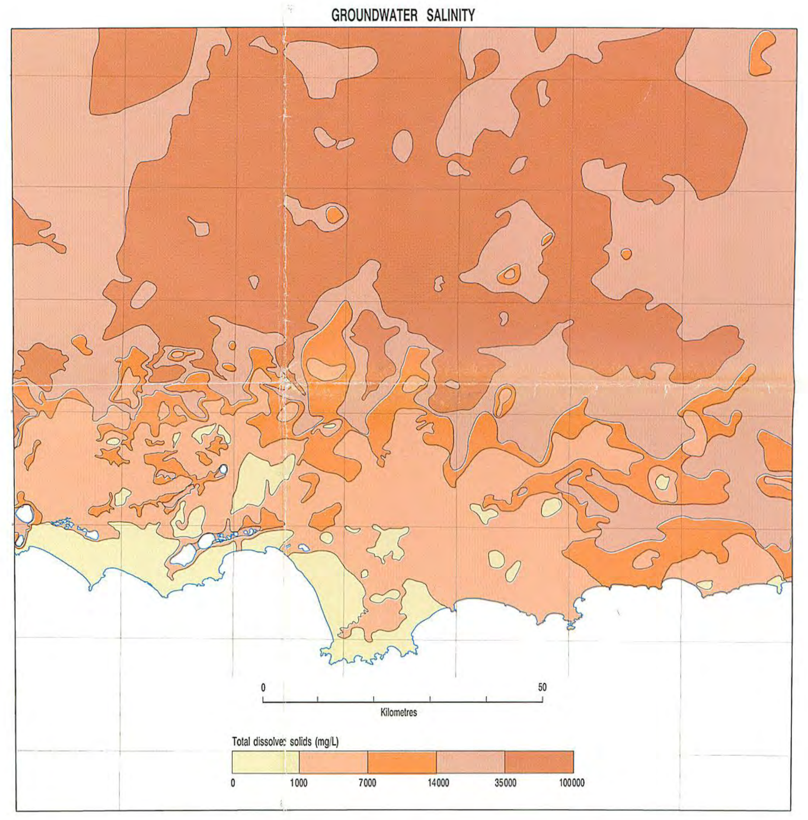
TOPOCADASTRAL INFORMATION

- highway with national route marker
- formed road
- track
- railway
- airfield; landing ground
- ESPERANCE townsite, population 1000–10000
- Scaddan townsite, population <100
- Truslove locality
- coral reef or submerged rock
- 150 topographic contour line, 50 metre interval (AHD)
- sand dune
- transmitter or microwave repeater site
- ESP 27 210 m horizontal control; minor (AHD)
- national park, nature reserve and Aboriginal reserve boundary
- 50 bathymetric contour (m); accurate, inferred

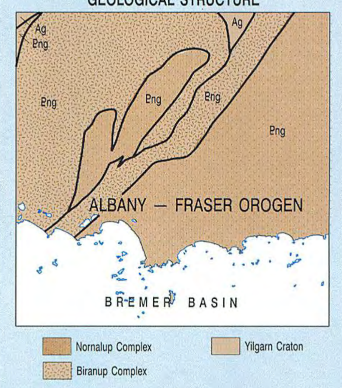
DEPTH TO WATERTABLE



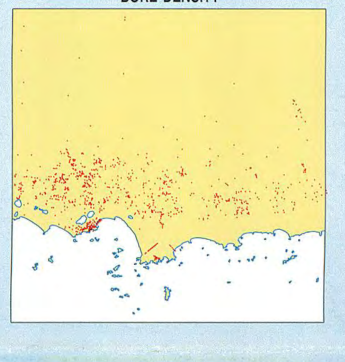
GROUNDWATER SALINITY



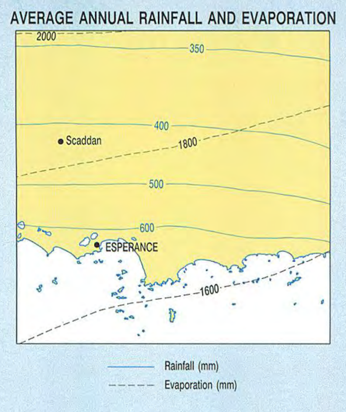
GEOLOGICAL STRUCTURE



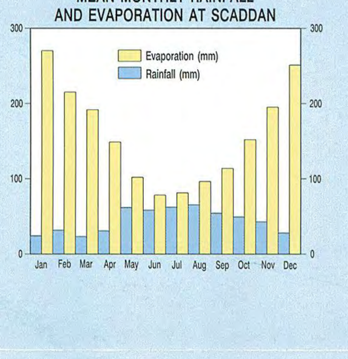
BORE DENSITY



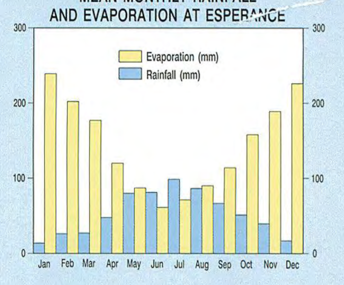
AVERAGE ANNUAL RAINFALL AND EVAPORATION



MEAN MONTHLY RAINFALL AND EVAPORATION AT SCADDAN



MEAN MONTHLY RAINFALL AND EVAPORATION AT ESPERANCE



SHEET INDEX

LAKE JOHNSTON SI 51-1	NORSEMAN SI 51-2	BALLADONIA SI 51-3
RAVENSTHORPE SI 51-5	ESPERANCE SI 51-6	MALCOLM SI 51-7
INVESTIGATOR ISLAND SI 51-9	MONDRAIN ISLAND SI 51-10	SOUTHERN OCEAN CAPE ARID SI 51-11

DEPARTMENT OF MINERALS AND ENERGY
HON. GEORGE CASH, J.P., M.L.C.
MINISTER FOR MINES
K.R. PERRY, DIRECTOR GENERAL

WATER AND RIVERS COMMISSION
HON. PETER FOSS, Q.C., M.L.C.
MINISTER FOR THE ENVIRONMENT
R. PAYNE, CHIEF EXECUTIVE OFFICER

PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Hydrogeology by L.J. Baddock 1993-1995

Geology compiled by K.H. Morgan, 1967, and J.S. Myers, 1995

Edited by C. Strong, J. Mikucki, and G. Loan

Cartography by N. Gasmier, M. Prause, D. Vann, and B. Williams

Topography from the Department of Land Administration Sheet SI 51-6, SI 51-10 with modifications from geological field survey

Catchment boundaries supplied by Agriculture Western Australia, Esperance, 1995

Bathymetric data (1991) supplied by Department of Marine and Harbours, and is not to be used for navigation purposes

Published by the Geological Survey of Western Australia. Copies available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (09) 222 3459, Fax (09) 222 3444

This map is also available in digital form

Printed by Allwest Print, Western Australia

The recommended reference for this map is: BADDOCK, L. J., 1996, Esperance—Mondrain Island, W.A. Sheet SI 51-6 and part of SI 51-10: Western Australia Geological Survey, 1:250 000 Hydrogeological Series

SCALE 1:250 000

5000 Metres 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION

Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 51

1:250 000 HYDROGEOLOGICAL SERIES

ESPERANCE - MONDRAIN ISLAND

SHEET SI 51-6 AND PART OF SHEET SI 51-10