GOVERNMENT OF
WESTERN AUSTRALIA

HYDROGEOLOGY OF THE COLLIE 1:250 000 SHEET

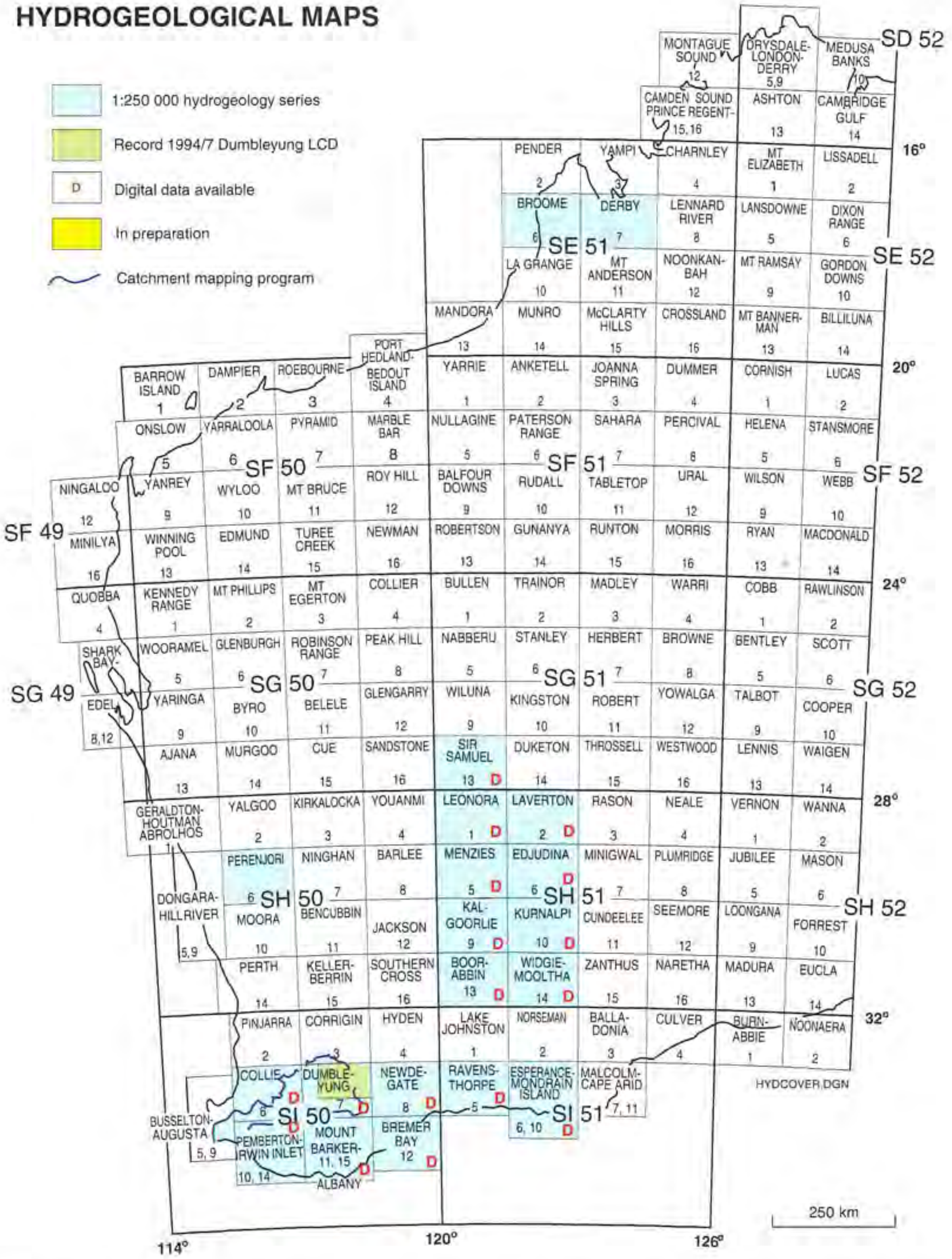
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES

WATER AND RIVERS COMMISSION REPORT HM 7

2000

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



HYDROGEOLOGICAL MAPS

Cover Photograph: Salinisation in the upper catchment has raised salt levels in the Collie River beyond the potable limit. The water however is released from Wellington Dam for irrigation and is seen here flowing over a bedrock ridge.

HYDROGEOLOGY OF THE
COLLIE
1:250 000 SHEET

by

J. L. RUTHERFORD

Water and Rivers Commission
Science and Evaluation Division

WATER AND RIVERS COMMISSION
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES
REPORT HM 7
SEPTEMBER 2000

Recommended Reference

RUTHERFORD, J. L., 2000, Hydrogeology of the Collie 1:250 000 sheet: Western Australia, Water and Rivers Commission, Hydrogeological Map Series Explanatory Notes, Report HM 7, 36p.

Copies available from:
Science and Evaluation Division
Water and Rivers Commission
3 Plain Street
EAST PERTH
WESTERN AUSTRALIA 6004
Telephone (08) 9278 0522 Facsimile (08) 9278 0586

ISBN 0-7309-7465-0
ISSN 1328-1194

Text printed on recycled stock,
Onyx 100% recycled 135gsm
Cover, Topkote Dull Recycled 256gsm
September 2000

Contents

Abstract 1

1 Introduction 3
- 1.1 Location and land use 3
- 1.2 Climate 3
- 1.3 Physiography 3
- 1.4 Vegetation 5
- 1.5 Previous investigations 5
- 1.6 Map compilation 6

2 Geology 7
- 2.1 Regional setting 7
- 2.2 Yilgarn Craton 7
  - 2.2.1 Archaean gneiss and granitoids 7
  - 2.2.2 Metasedimentary rocks 7
  - 2.2.3 Proterozoic quartz dykes and veins 8
  - 2.2.4 Proterozoic mafic dykes 8
  - 2.2.5. Donnybrook Sandstone 9
  - 2.2.6 Early Tertiary (Eocene) palaeochannel sediments 9
  - 2.2.7 Late Tertiary and Quaternary surficial formations 10
- 2.3 Collie, Wilga and Boyup Basins 10
- 2.4 Perth Basin 10

3 Hydrogeology 12
- 3.1 Groundwater occurrence 12
- 3.2 Perth Basin 13
  - 3.2.1 Quaternary superficial formations *(Qa, Qt, Qpgs, Qpy)* 13
    - 3.2.1.1 Swan Coastal Plain 13
    - 3.2.1.2 Blackwood Plateau 14
  - 3.2.2 Leederville Formation *(Kl)* 14
  - 3.2.3 Yarragadee Formation *(Jwy)* 14
  - 3.2.4 Cockleshell Gully Formation *(Jlo)* 15
- 3.3 Permian basins 15
  - 3.3.1 Collie Basin *(Ps, Pcm)* 15
  - 3.3.2 Wilga Basin *(Pcm)* 17
  - 3.3.3 Boyup Basin *(Pcm)* 17
  - 3.3.4 Donnybrook Sandstone *(Pn)* 17
- 3.4 Yilgarn–Southwest Province 18
  - 3.4.1 Surficial aquifer *(Qa, Qpgs, Cza, Czg)* 18
  - 3.4.2 Early Tertiary (Eocene) palaeochannel sediments *(Tw, Twq, Tc)* 20
  - 3.4.3 Archaean gneiss and granitoids *(An, Ag)* 21
  - 3.4.4 Archean quartzite and Proterozoic quartz dykes and veins *(Aq, Pq)* 22
  - 3.4.5 Mafic dykes and sills *(Pd)* 22

4 Groundwater quality 23
4.1 Regional groundwater salinity 23
4.2 Hydrochemistry 24
5 Rising watertable and land salinisation 25
6 Groundwater development 28
6.1 Town water supply 28
6.2 Irrigation 28
6.3 Mining and industry 28
6.4 Domestic and stock water 29
6.5 Groundwater resources 29
6.6 Groundwater development 29
7 References 30

Figures

1. Location map 2
2. Physiography 4
3. Geological structure (after Myers and Hocking, 1998) 9
4. Collie Basin diagrammatic structure and stratigraphy 16
5. Hydraulic connection in the Beaufort Palaeochannel (from section C-D-E, Prangley, 1995) 19
6. Groundwater salinity, Maringee Farm (after Martin, 1984) 23
7. Geological controls on groundwater flow and discharge in the Collie River Catchment;
(a) Salmon and Wights catchments (adapted from Peck and Williamson, 1987; Turner *et al.*, 1987)
(b) Lemon Catchment (adapted from Johnston, 1987a) 26
8. Watertable rise in Lemon catchment 1980–1996 27

Tables

1. Stratigraphy and aquifer potential on COLLIE 8
2. Stratigraphy correlations between the Collie, Wilga, and Boyup Basins 10
3. Groundwater use and resource estimates in the Perth Basin 29

Appendix

Digital data documentation 35

Map

COLLIE 1:250 000 hydrogeological sheet .... (back pocket)

HYDROGEOLOGY OF THE COLLIE 1:250 000 SHEET

by

J. L. RUTHERFORD

Abstract

The COLLIE 1:250 000 hydrogeological sheet covers part of the Yilgarn–Southwest Groundwater Province, the Collie Basin and the Perth Basin. Groundwater in the COLLIE sheet area occurs in the weathered profile of Archaean granitoid and gneissic rocks and Proterozoic mafic dykes and sills, along with joints and fractures of Archaean metasedimentary rocks and Proterozoic quartz dykes. Groundwater is also contained in Palaeozoic and Mesozoic sedimentary rocks and surficial sediments of Tertiary–Quaternary age.

Significant groundwater supplies in the weathered profile and joints and fractures of basement rocks are uncommon and difficult to locate. These rocks occupy the Yilgarn–Southwest Province which covers approximately 80% of COLLIE. Groundwater resources in sediments overlying the basement, within Permian basins, palaeochannels and localised topographic depressions, are variable in quantity and quality. Aquifers in Mesozoic sedimentary rocks of the Perth Basin contain major groundwater resources as do the overlying Quaternary Tamala Limestone and Guildford Formation (sand member).

Potable groundwater in the Yilgarn–Southwest Province is limited to grus (at the weathering front), quartz-rich zones developed within the weathering profile, joints and fractures in crystalline rocks, and sand-dominated sediments. Most other groundwater in the Yilgarn–Southwest Province is saline, with only minor resources suitable for watering stock. The lowest salinity groundwater is located in upper landscape areas, where direct infiltration first intersects the regional watertable. In

WATER AND RIVERS COMMISSION
HYDROGEOLOGICAL MAP EXPLANATORY NOTES SERIES
REPORT HM 7
2000

the Perth Basin most groundwater is fresh to brackish, apart from areas of swamp land developed over the Guildford Formation (clay member) and coastal saline lakes.

The city of Bunbury and other coastal towns use groundwater from Mesozoic aquifers in the Perth Basin. Inland towns rely on water piped from the Harris–Wellington reservoir system, or from local surface sources. On the coastal plain, mining and industry utilise groundwater from Mesozoic aquifers and in the Collie Basin groundwater is used for power generation following the mining of coal. Superficial aquifers supply groundwater for the major irrigation areas on the coastal plain. In the Yilgarn–Southwest Province, groundwater resources in palaeochannel aquifers support small-scale irrigation and soaks are commonly excavated for stock water. Scope for the potential development of groundwater resources on COLLIE is restricted to areas requiring further investigation and assessment; these areas include the Tertiary palaeochannels in the Yilgarn–Southwest Province, the Wilga Basin, and sediments in the Preston Valley and on the Collie Plains.

Keywords: hydrogeological maps, hydrogeology, aquifers, groundwater resources, Collie.

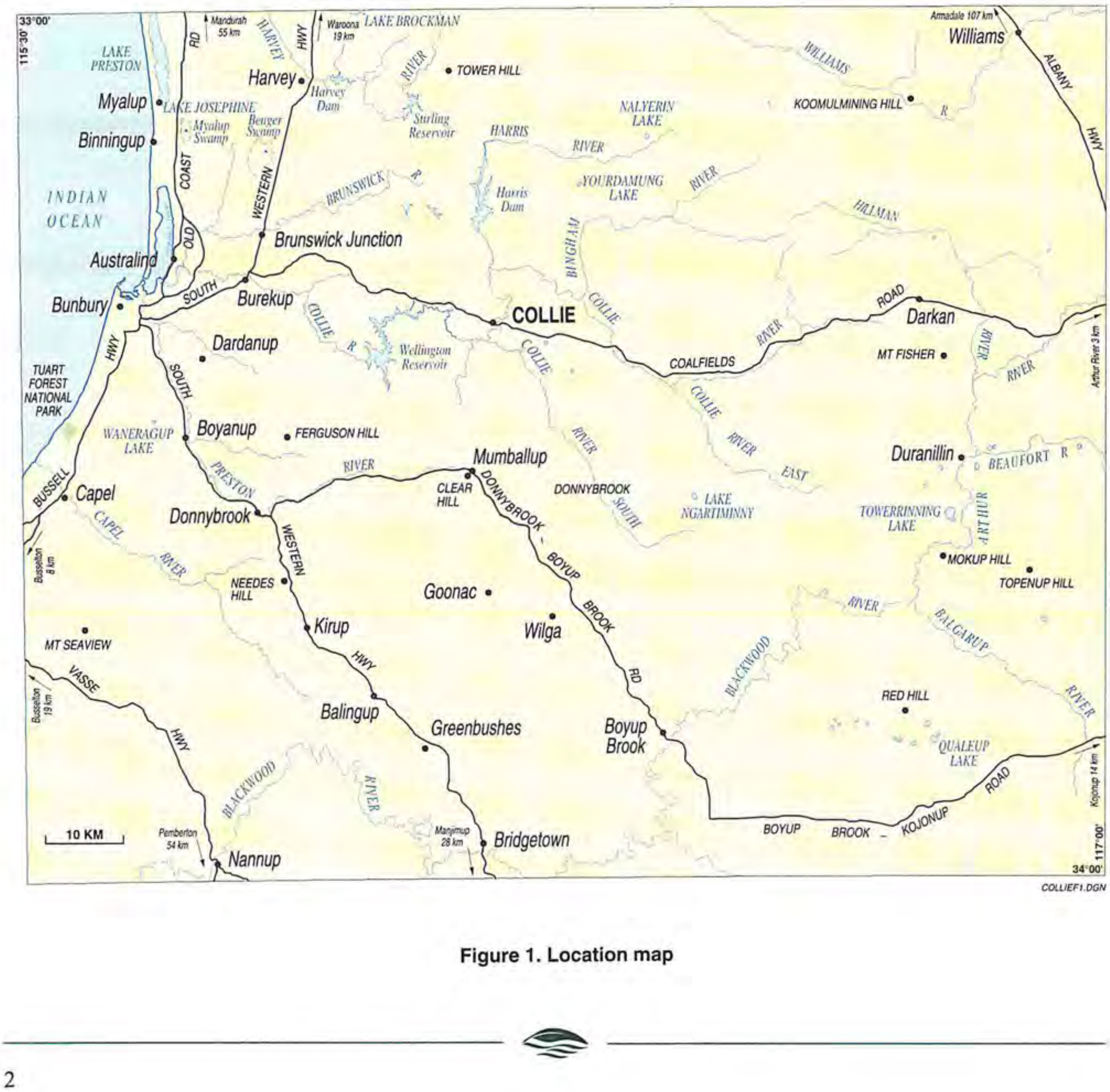


Figure 1. Location map

1 Introduction

1.1 Location and land use

The Collie[1] 1:250 000 hydrogeological sheet (SI 50-6 of the international series) is bounded by latitudes 33° S and 34° S and longitudes 115°30'E and 117°00'E (Fig. 1).

Land use in the area is primarily forestry and grazing, along with cereal grain, oil-seed and other horticultural cropping. Additional industries include viticulture and the growing of apples and stonefruit. The area supports mining operations; Western Australia's only working coal mines are located in the Collie Basin, and on the coastal plain, near Bunbury, there are several mineral sand extraction and processing industries. The coal mining town of Collie is centrally located and is the second most populous centre on Collie. The largest urban centre is the coastal city of Bunbury; other significant towns include Australind, Bridgetown, Donnybrook, Harvey and Boyanup.

A comprehensive network of roads provides access to the area covered by the sheet (Fig. 1). Major roads are the South Western Highway, which extends south from Perth through Bunbury and Bridgetown linking with the Bussell Highway to Busselton, the Coast Road to Mandurah, and the Coalfields Road which extends east through Collie and Darkan to join a section of the Albany Highway in the northeast corner of the sheet. Access to the forested areas is generally via gravel roads and dirt tracks.

1.2 Climate

The area has a Mediterranean-type climate, with warm to hot, dry summers and cool, wet winters. The temperatures for the town of Collie range from 5° to 16°C during winter months and from 13° to 30°C during summer months.

The average annual rainfall ranges from 991 mm at Donnybrook to 544 mm at Williams, indicating a substantial decrease in rainfall from the western, coastal and escarpment areas towards the gently undulating areas 100 km inland. Rainfall occurs primarily in the winter months, May to September. The wettest month is June; the driest month is January.

Mean annual pan evaporation increases from the southwest to northeast across Collie. Average annual pan evaporation is 1400 mm for Donnybrook and 1830 mm for Duranillin (Fig. 1).

1.3 Physiography

There are three main physiographic areas on Collie: the Darling Plateau, Blackwood Plateau and the Swan Coastal Plain. The Darling Scarp separates the Darling Plateau from the Blackwood Plateau to the west; the Whicher Scarp forms the divide between the Blackwood Plateau and the Swan Coastal Plain (Fig. 2).

The Darling Scarp is the surface expression of the Darling Fault, which is located between 1–3 km west of the Darling Scarp (Wilde and Walker, 1982). The Darling Plateau is the major physiographic feature on Collie, and constitutes approximately 80% of the map sheet area. The plateau has an undulating surface, with elevation ranging between 250 and 370 m AHD (Australian Height Datum).

Perennial and seasonal drainage systems on the Darling Plateau exhibit major westerly to southwesterly trends directed towards the Indian Ocean. However, in the eastern section of the plateau, gradients decrease and depressions are common features, often occupied by swamps and small seasonal lakes. These areas coincide with modern and ancient drainage lines and are in, or proximal to, the Beaufort and Arthur Rivers. The main catchments comprise the Collie, Blackwood and Preston Rivers catchments. The southern section of the Murray (Williams) River catchment is located in the northern quadrant of the map sheet.

The Blackwood Plateau is located west of the Darling Scarp, in the south-western quadrant of Collie. The surface is gently undulating and ranges in elevation from 80 to 180 m AHD (Wilde and Walker, 1982). At elevations between 120 and 180 m remnants of an earlier drainage system are preserved. Coastal processes have modified these sediments, as indicated by the formation of a bench along major valleys and the Whicher Scarp, itself formed through marine erosion. This bench is lateritized and is considered to represent the southern continuation of the Ridge Hill

---

[1] *Capitalised names refer to the standard map sheets*

Shelf (Wilde and Walker, 1982). The current drainage system on the Blackwood Plateau is predominantly dendritic, the valleys are filled with Quaternary colluvium and appear to have been formed in a earlier pluvial period (Wilde and Walker, 1982). The main rivers drain the plateau in a northwesterly direction across the Whicher Scarp and onto the Swan Coastal Plain.

The Swan Coastal Plain is a curvilinear belt of superficial sediments (Fig. 2). This region is approximately 17–20 km wide and attains a maximum elevation of 60 m. The Darling and Whicher Scarps mark the eastern margin and the plain terminates in the west at the Indian Ocean. The variability in the sediments deposited on the plain correlates with subtle changes in the physiography.

The eastern margin of the Swan Coastal Plain, near Harvey, is the site of a narrow piedmont zone characterised by colluvial fans. The colluvial fans grade to the west into a 10 km-wide alluvial tract known as the Pinjarra Plain. The plain ranges in elevation from 10 to 30 m AHD and correlates with the distribution of the Guildford Formation, which consists of sands and clays with minor shallow-marine and estuarine lenses (Wilde and Walker 1982). West of the Pinjarra Plain lies a series of dune systems. The Bassendean Sand is the oldest of three major dune systems; the Tamala Limestone and the Quindalup Dune System are deposited in succession to the west (Playford *et al.*, 1976). Modern drainage lines dissect the Swan Coastal Plain, and swamps and small lakes are prevalent due to the subdued topography.

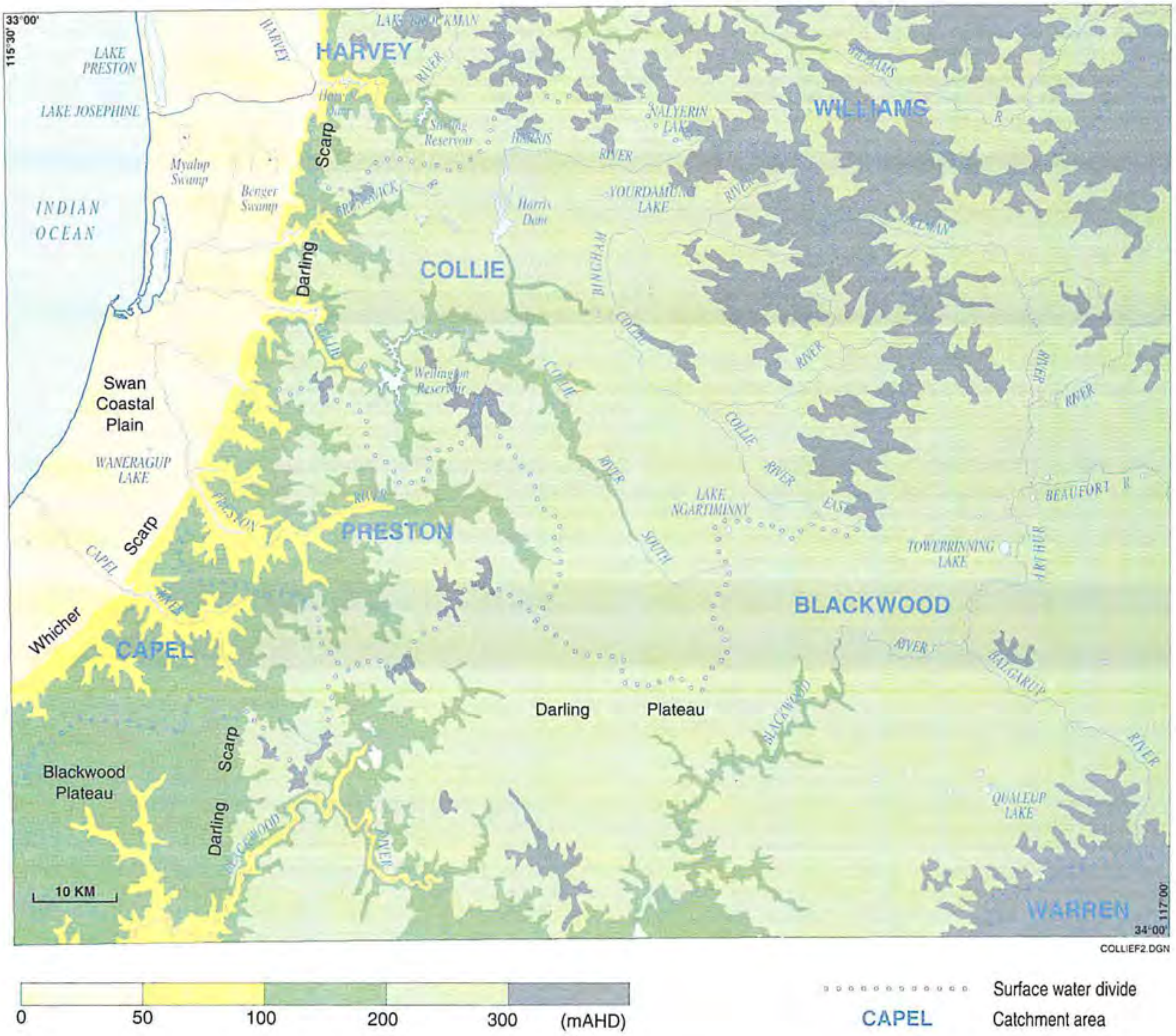


Figure 2. Physiography

1.4 Vegetation

There are nine major vegetation systems on COLLIE (Smith, 1974). The Darling, Beaufort, Williams and Bannister systems on the Darling Plateau; the Chapman system on the Blackwood Plateau and the Pinjarra, Bassendean, Spearwood and Rockingham systems on the Swan Coastal Plain. The variation in vegetation corresponds to changes in soils, climate and physiography.

The Darling system occupies the western margin of the Darling Plateau, where major areas of native vegetation are constrained to State Forests. In these areas jarrah (*Eucalyptus marginata*) is prevalent on areas of laterite whilst sandy areas comprise mixed jarrah–marri (*Corymbia calophylla*) open forest and blackbutt (*E. patens*). The Beaufort system, located on the drier, eastern section of COLLIE, is dominated by jarrah and wandoo (*E. redunca*) in the remnant woodland, and swamp yate (*E. occidentalis*) with an understorey of *Melaleuca* spp. in and around small lakes and swamps. Open heath (*Myrtaceae*) and high, closed forests frequently vegetate drainage lines. The area surrounding the Williams River is host to the Williams system of wandoo and jarrah woodland with occasional stands of York gum (*E. loxophleba*), brown mallet (*E. astringens*) and flooded gum (*E. rudis*) forming patches of low, open forest.

The Chapman system on the Blackwood Plateau is largely uncleared and consists of jarrah–marri open forest with blackbutt in the valleys. Mountain marri (*Corymbia haematoxylon*), jarrah and *Banksia* spp. grow in the sandier soils along the Whicher Scarp.

The systems occupying the Swan Coastal Plain form curvilinear 'belts' of vegetation which parallel the coastline. The area is predominantly cleared, and the remnant vegetation grades from jarrah, marri and wandoo on the Pinjarra Plain (Pinjarra system) through to jarrah, *Banksia* spp. and *Melaleuca* spp. on the Bassendean Dunes (Bassendean system). The Spearwood and Rockingham systems are developed over coastal dunes of limestone and sand and support jarrah, marri and tuart (*E. gomphocephala*) on sandy areas whereas paperbarks (*Melaleuca*) are common around swamps, lakes and estuaries. Peppermint (*Agonis flexuosa*) form an understorey near the coast and open heath grows on limestone ridges and recent dunes adjacent the to coast.

1.5 Previous investigations

The majority of early geological investigations on COLLIE focused on mineral exploration. On the Yilgarn Craton, this work centred primarily on gold prospecting in the Donnybrook, Nannup and Preston Valley areas, and on coal mining in the Collie Basin (Hardman, 1884; Lord, 1952). The search for petroleum in the Perth Basin by West Australia Petroleum Pty Ltd (Wapet) provided information on the stratigraphy and structure of deep sections of the basin (Playford and Willmott, 1958). The surface geology of the Perth Basin has been mapped by the Geological Survey of Western Australia (GSWA) and is detailed in Playford *et al.* (1976), and the geology of COLLIE was mapped by Wilde and Walker (1982).

Major hydrogeological investigations on COLLIE have concentrated on the location of water supplies for townships and various industries, particularly on the Swan Coastal Plain in the Perth Basin. This is in response to the demand from a growing population base, and burgeoning horticultural and mineral processing industries. Early investigations in the Perth Basin centred on artesian water resources (Maitland, 1913) and water supplies for rural townships (Campbell, 1909). Exploratory drilling in the Busselton area reported by Probert (1968) marked the beginning of systematic deep-drilling programs in the Perth Basin. This was prompted through concerns expressed by the Public Works Department (PWD) in the late 1960s and 1970s on the resource potential of the aquifers in the Bunbury region (Commander, 1982). A network of monitoring bores was installed during the 1970s and late 1980s by GSWA to assess both deep and shallow groundwater resources in the basin. Deep-drilling programs jointly funded by the Commonwealth and State Governments were reported in Wharton (1980, 1981a,b, 1982), Smith (1984), Commander (1989), Deeney (1989b,c), Appleyard (1991) and Koomberi (1996). Commander (1984, 1988), Deeney (1989b) and Hirschberg (1989) discussed the hydrogeology of shallow-drilling investigations in the Perth Basin.

In the Yilgarn–Southwest Groundwater Province, exploration for groundwater in the Archaean basement and the overlying regolith continues to be problematic. Locating resources that provide required yields of acceptable quality is difficult. As a consequence, water supplies for many of the larger townships are provided by surface water piped from the Harris–Wellington reservoir system (Karafilis and Ruprecht, 1993). Detailed hydrogeological investigations have been generally restricted to the Permian basins on the Yilgarn Craton (Collie, Wilga and Boyup). However, locating and monitoring groundwater resources within these basins was initially an issue secondary to that of coal exploration. The impact of dewatering, as a consequence of coal mining in the Collie Basin, was reported by Hirschberg (1976), Moncrieff (1993) and Mohsenzadeh (1998a,b). The compilation of the available data in the Wilga and Boyup Basins was outlined by Laws (1992) along with recommendations to implement a groundwater-assessment drilling program. This forms the basis of the current hydrogeological work in these basins (Yesertener, 1997).

Other less extensive groundwater prospects in the Yilgarn–Southwest Province include sequences of 'sandy' Cainozoic sediments preserved in localised topographic depressions and palaeochannels, and fractured or weathered-zone aquifers at the contact between the granitoid basement and the overlying saprolite (George *et al*., 1997; Clarke *et al*., 2000). Drilling programs targeting specific areas were recommended in Moncrieff (1988) after preliminary drilling investigations, and proposed in Laws (1992) after the interpretation of geophysical anomalies. These programs were implemented and the drilling results confirmed prospective groundwater resources in the Boscabel–Towerrinning (Beaufort) Palaeochannel (Commander *et al*., 1996; Perry, 1994; George *et al*., 1994; Prangley, 1994a,b; Waterhouse *et al*., 1995), the Darkan palaeochannel (Prangley, 1995) and the Qualeup palaeochannel (Panasiewicz *et al*., 1997).

Comprehensive small-scale studies were carried out in five experimental catchments in the Collie River Catchment (Martin, 1982; Johnston, 1987a,b; Peck and Williamson, 1987; Turner *et al*., 1987; Williamson *et al*., 1987; Ruprecht and Schofield, 1991; Bari, 1992). The aims of these studies were to attain a better understanding of the hydrogeological setting and the occurrence of dryland salinity, and to further develop management strategies regarding groundwater discharge and recharge in the southwest of Western Australia.

1.6 Map compilation

The hydrogeological map of COLLIE depicts aquifer distribution and type, topographic contours in metres AHD (Perth Basin: Blackwood Plateau only), groundwater salinity (isohalines), groundwater point-data distribution, and cadastral data. Data used in the compilation and interpretation of this map include: topocadastral data from AUSLIG; geology from GSWA (Wilde and Walker, 1982); bore data from the Water and Rivers Commission (WRC) water point databases (AQWABase and SWRIS database); experimental catchment, irrigation and waste-disposal areas from the WRC; bore and piezometer data from Agriculture Western Australia, Bunbury Office (AgBores database); surface water pipeline digital data from the Water Corporation; and WAMEX mineral exploration and drilling data from the Department of Minerals and Energy.

Interpretation of aquifer boundaries, watertable contours and groundwater isohalines was carried out by plotting information obtained from groundwater point data including depth of penetration, screen interval, aquifer type, waterlevel and salinity measurements on a base map of geology and topography. Hydrogeological boundaries were derived primarily from the interpolation of water point data at scales of 1:100 000 or, where bore data were intensive, at 1:25 000 scale. These boundaries are interpretative and depend on variable density of groundwater point data that have been collected over a period of decades. These factors should be considered when using this information at larger scales.

The COLLIE hydrogeological map sheet is at the 1:250 000 scale. A simplification of the data which have been entered into the COLLIE digital database and stored as graphical layers of information are documented in the Appendix.

2 Geology

2.1 Regional setting

Archaean basement of the Yilgarn Craton underlies approximately 80% of the Collie map sheet area (Table 1). The basement rocks are divided into two main regions based primarily on lithological variation: the granitic rocks of the Darling Range Batholith, and the metamorphosed rocks of the Balingup Metamorphic Belt (Fig. 3). The Balingup Metamorphic Belt is aligned with the western margin of the Yilgarn Craton and forms a wedge-shaped area in the western section of Collie. A number of suites of Proterozoic dykes and veins have intruded the Archaean basement and possess dominant east, northwest and northeast orientations.

Rock outcrop or subcrop occurs primarily along the Darling Scarp and the northeastern and southeastern corners of the Collie map sheet. Permian and Cretaceous sedimentary rocks are preserved in localised, graben-style structural depressions within the basement (Fig. 3). Basement rocks are commonly covered by a thick regolith produced from *in situ* weathering and a veneer of Cainozoic sediments, where the latter have been preserved. Intensive weathering in the Late Cretaceous to Early Tertiary has resulted in the widespread lateritization of many of these sediments and of the weathered profile of the basement rocks. Quaternary alluvium and colluvium occupy modern drainage lines of the Yilgarn Craton.

The western section of Collie also covers part of the southern Perth Basin (Playford *et al.*, 1976). The basin is a large sedimentary trough, which extends between 80 and 100 km westwards from the Darling Scarp to the edge of the continental shelf (Wilde and Walker, 1982). The basin contains up to eight kilometres of Permian, Triassic, Jurassic and Cretaceous sedimentary and minor Cretaceous volcanic rocks. Quaternary alluvial sands are deposited along the drainage lines that dissect the Blackwood Plateau, and on the Swan Coastal Plain, the Yoganup Formation shoreline deposit is preserved discontinuously on the eastern boundary at the Whicher and Darling Scarps (Fig. 2). This deposit is bordered in succession to the west by alluvial clays and sands of the Guildford Formation, the Tamala Limestone eolian calcarenite, and Recent (Holocene) dune systems that fringe the present coastline (Wilde and Walker, 1982).

2.2 Yilgarn Craton

2.2.1 Archaean gneiss and granitoids

The crystalline basement of the Yilgarn Craton extends over 80% of the Collie map sheet. Gneissic rocks (*An*) are located predominantly within the Balingup Metamorphic Belt and localised areas of the Darling Range Batholith (Fig. 3). The major rock type in the Balingup Metamorphic Belt is a fine to medium-grained layered gneiss which has been produced through the emplacement of orthogneiss into a previously deformed layered sequence of paragneiss and metasedimentary rocks (Wilde and Walker, 1982). Orthogneiss is less prevalent south of the belt, corresponding to an increase in quartzite, schist and ultramafic rock within the paragneiss (Wilde and Walker, 1982). Other gneissic rocks are associated primarily with the deformation of granitoids with the exception of gneiss in the central northern section of Collie. Migmatite, developed through the intrusion of granitic material, is common in the gneissic terrains and is grouped with the various categories of gneiss, and with minor schist.

Granitoid rocks (*Ag*) are the major lithology on Collie with rocks in the granodiorite adamellite granite range covering approximately half of the map sheet. These rocks are constrained to the Darling Range Batholith. They are predominantly post-tectonic and possess variable textures ranging from porphyritic to fine- to coarse-grained and even-grained granites (Wilde and Walker, 1982). Regional, southeast-trending faults cut the Archaean basement (Fig. 3) (Myers and Hocking, 1998).

2.2.2 Metasedimentary rocks

Quartzite (*Aq*) is the most abundant metasedimentary unit, and is restricted to areas within the Balingup Metamorphic Belt, where it forms irregular boudins or continuous bands, commonly associated with mafic and ultramafic dykes and sills. The two distinct variants of quartzite on Collie are a hornblende-bearing category with scattered clinopyroxene and an epidote-bearing quartzite, both likely to be derived from the

Table 1. Stratigraphy and aquifer potential on COLLIE

Age	*Formation*	*Lithology*	*Aquifer potential*
Cainozoic Tertiary–Quaternary	Alluvium (*Qa*)	Sand, silt and clays	Minor local — fresh to saline
	Tamala Limestone (*Qt*)	Eolian calcarenite	Major — generally fresh
	Guildford Formation		
	Sand member (*Qpgs*)	Sand, minor clay and gravel	Minor local — fresh to brackish
	Clay member (*Qpgc*)	Clay, minor sand and gravel	Very minor — brackish to saline
	Yoganup Formation (*Qpy*)	Sand and conglomerate	Minor — fresh to brackish
	Alluvium and Colluvium (*Cza*)	Sand, silt, clay, gravel and minor laterite	Minor local — brackish to hypersaline
	Conglomerate (*Czc*)	Quartzite / sandstone conglomerate	Minor — brackish
	Alluvium (*Czg*)	Sand, clay, silt and gravel	Minor — fresh to brackish
	Lacustrine sediment (*Tc*)	Clay	Aquitard
	Fluvial sediment (*Tw*)	Sand	Minor to major — fresh to hypersaline
	Fluvial sediments (*Twq*)	Sands and clays	Minor — fresh to brackish
Mesozoic Jurassic– Cretaceous	Nakina Formation (*Kn*)	Sandstone, mudstone, claystone and conglomerate	Minor local — brackish to saline
	Warnbro Group (*Kl*); including Leederville Formation	Sandstone, siltstone and shale	Minor – fresh to brackish
	Bunbury Basalt (*Kb*)	Basalt	Aquiclude
	Yarragadee Formation (*Juy*)	Sandstone, siltstone and shale	Major — mainly fresh
	Cockleshell Gully Formation (*Jlo*)	Sandstone, siltstone, shale and coal	Major — mainly brackish to saline
Palaeozoic Permian	Donnybrook Sandstone (*Pn*)	Sandstone, shale and grit	Minor — fresh
	Collie Group (*Pcm*); including coal measures	Coal, sandstone and shale and mudstone	Major — fresh to brackish
	Stockton Formation (*Ps*); including Shotts Formation	Siltstone, claystone	Minor aquifer/aquitard — fresh to brackish
Proterozoic	Mafic dyke and sill (*Pd*)	Dolerite and gabbro	Aquiclude
	Quartz dyke (*Pq*)	Quartz	Minor local — fresh to saline
Archaean	Darling Range Batholith (*Ag*)	Granitoid basement rocks	Minor local — fresh to saline
	Balingup Metamorphic Belt (*An*)	Granitoid gneiss, migmatite and schist	Very minor local — fresh to saline
	Quartzite (*Aq*)	Quartzite	Minor local — fresh to brackish

metamorphism of calcareous sandstone (Wilde and Walker, 1982).

2.2.3 Proterozoic quartz dykes and veins

Quartz veins (*Pq*) are prolific within the basement rocks on COLLIE, although they are generally of an insufficient size to be shown at a scale of 1:250 000 (Wilde and Walker, 1982). Mapped quartz dykes and veins in the northeastern area of the COLLIE map sheet correlate with the southern extension of the Saddleback Group and have a easterly or northeasterly orientation. Quartz dykes are also common in the area adjacent the Darling Scarp near Nannup, and exhibit dominant northeasterly and northwesterly trends.

2.2.4 Proterozoic mafic dykes

Mafic dykes and sills (*Pd*), of a tholeiitic quartz dolerite lithology, are mapped on COLLIE primarily through the evidence of outcrop and inference of subcrop. This constrains the length of the dykes mapped to range from 100 to 2500 m, with an average around 1000 m (Wilde and Walker, 1982). Dolerite dykes in the northeastern quadrant of COLLIE, near Williams, are more extensive with one dyke mapped for several hundred kilometres (Sofoulis, 1966). These dykes are up to 700 m wide and contain quartzo-feldspathic xenoliths (Wilde and Walker, 1982). These dykes and sills exhibit dominant east to northeast and northwest orientations.

Metamorphism has altered the mineral assemblages and textures of many of these dykes.

2.2.5 Donnybrook Sandstone

The Donnybrook Sandstone (*Pn*), previously mapped as Cretaceous but now believed to be Permian, comprises a well-sorted, pale yellow, fine- to medium-grained feldspathic sandstone with shale and minor grit interbeds (Wilde and Walker, 1982). It is an elongate unit bounded by the Darling Fault and Archaean basement on its respective western and eastern boundaries. The Donnybrook Sandstone extends approximately 15 km south and 7 km north of the Donnybrook township. The unit overlies Permian shales that rest unconformably on Archaean Basement (Backhouse and Wilson, 1989; Backhouse, 1995).

2.2.6 Early Tertiary (Eocene) palaeochannel sediments

Tertiary palaeovalley deposits that have been mapped on the Yilgarn Craton extend to the Collie sheet. Arenaceous Eocene sediments have been mapped as isolated deposits located on or near drainage divides on the western area of the craton (Wilde and Backhouse, 1977). Recent investigations on Collie have identified these sediments in topographical depressions in swamp and estuarine environments, and more extensively within palaeochannels along part of the upper Blackwood River drainage system incorporating the Beaufort, Hillman and Arthur River drainage lines (Hawkes, 1993; George *et al.*, 1994; Waterhouse *et al.*, 1995).

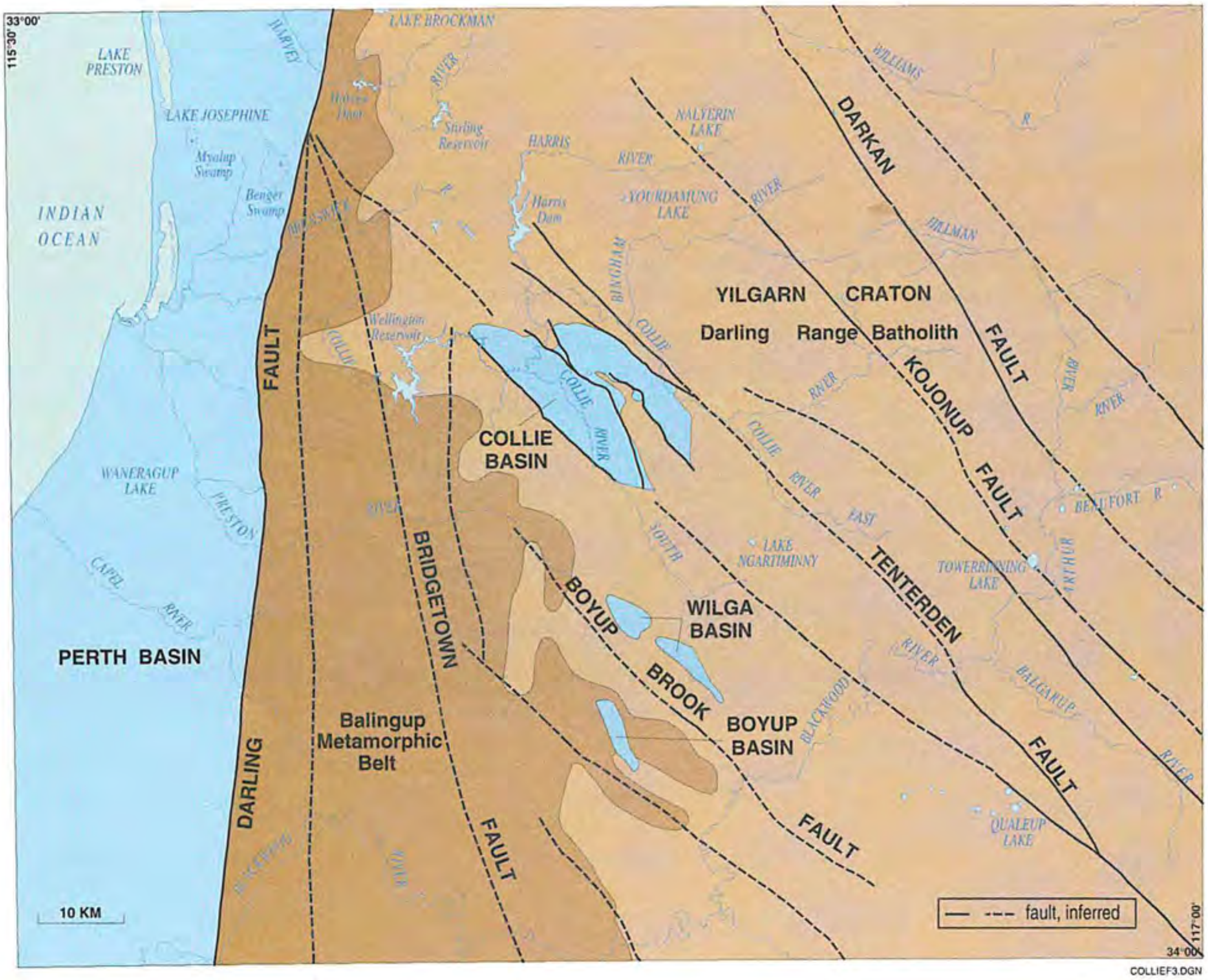


Figure 3. Geological structure (after Myers and Hocking, 1998)

These deposits unconformably overlie the Archaean basement and comprise sands, clayey sands, clays and carbonaceous sediments of a fluvial origin (*Twq, Tw*) and are commonly overlain respectively by alluvial clay, deposited under lacustrine conditions (*Tc*), and Late Tertiary alluvium and colluvium (*Cza*).

2.2.7 Late Tertiary and Quaternary surficial formations

Late Tertiary alluvial deposits (*Czg*) consist of sand, clay, silt and gravel. These sediments have infilled depressions and palaeovalleys (not channels) and are preserved on the topographically low-lying areas typified by the Collie Plains, located north-northeast of Collie township, and the surrounds of the Wilga Basin and the Qualeup Palaeochannel (Laws, 1992; Hawkes, 1993). Outcrop of Late Tertiary conglomerate (*Czc*) is generally localised, the most extensive deposit is the Kirup Conglomerate, which is up to 2.5 km wide and extends for approximately 60 km, in the southwestern quadrant of COLLIE. This conglomerate unconformably overlies Archaean basement and has a consistent matrix of poorly sorted clayey sand (Wilde and Walker, 1982).

Tracts of Tertiary alluvium and colluvium (*Cza*) generally occupy broad but irregular valleys along the Hillman, Beaufort and Arthur Rivers on the Darling Plateau (Wilde and Walker, 1982). These deposits are variable and comprise up to 20 m of sand, silt, clay, gravel with minor laterite.

Quaternary deposits on the Yilgarn Craton are localised on COLLIE and lie along the Williams River and Darling Scarp (*Qa*), and the upper reaches of the Preston River (*Qpgs*) (Fig. 1).

2.3 Collie, Wilga and Boyup Basins

The Collie, Wilga and Boyup Basins (Fig. 3) are remnants of a much wider distribution of Permian sediments that covered the Yilgarn Craton (Wilson, 1989). Permian sedimentary rocks (*Ps, Pcm*) are preserved on COLLIE in these fault-bounded, graben-like structural depressions within the Archaean basement. Stratigraphic correlations are possible between the basins despite the faulted nature of the strata (Table 2). The Stockton Group or equivalent, inclusive of the Shotts Formation, unconformably overlies Archaean Basement and generally comprises a glacial base of tillite, claystone, siltstone and sandstone (Wilson, 1990; Laws, 1992; Le Blanc Smith, 1993; Moncrieff, 1993; Mohsenzadeh, 1998a,b). The Collie Group (originally referred to as the Collie Coal Measures) conformably overlies the Stockton Group and consists of sandstone, siltstone, claystone and coal (Wilson, 1990). The Cretaceous Nakina Formation (*Kn*) or equivalent, unconformably overlies the Collie Group and comprises up to 30 m of poorly lithified sands, clays and silty clays.

2.4 Perth Basin

On the COLLIE sheet, the Perth Basin is represented by one major structural unit, the Bunbury Trough (Fig. 3). The stratigraphy and structure of deep sections of the basin are based on information obtained from deep drilling programs and the interpretation of geophysical data (Playford and Willmott, 1958; Wilde and Walker, 1982).

Table 2. Stratigraphic correlations between the Collie, Wilga and Boyup Basins

Basin	*Collie*	*Wilga**	*Boyup**
Nakina Formation	0–30 m	0–20 m	20–50 m (Boonarie Claystone)
Collie Group	960–1120 m	Up to 20 m	30–130 m (Boyup Coal Measures and Barrons Sandstone)
Stockton Group	?0–330 m	0–124 m	0–60 m (Greenfield Formation)
Archaean basement			

**from Laws (1992)*

The Permian Sue Coal Measures, the equivalent of the Collie Group, unconformably overlie the Archaean basement and consist of up to 2500 m of interbedded sandstone, siltstone and coal (Le Blanc Smith, 1993). The coal measures are overlain in turn by the Sabina and Lesueur Sandstones (approximately 1500 m of fine- to very coarse-grained quartz sandstone) and by Jurassic sediments.

The Cockleshell Gully and Yarragadee Formations (*Jlo*) and (*Juy*), represent over 2000 m of Jurassic sediments and consist of moderately consolidated sandstone with interbeds of well-lithified grey, silty shale and coal, and weakly to moderately cemented, fine- to very coarse-grained quartz sandstone with siltstone and shale interbeds. The Yarragadee Formation is extensively eroded and thins to the northeast of COLLIE to the extent that the formation is absent north of the Myalup Swamp and Brunswick River (Fig. 1).

Valleys eroded into the Yarragadee Formation to the south have assisted in the localised preservation of the Early Cretaceous Bunbury Basalt (*Kb*), predominantly in the subsurface and as outcrop at numerous localities in the Bunbury area. The Cretaceous Warnbro Group (*Kl*), inclusive of the Leederville Formation, or Cainozoic sediments unconformably overlie the Yarragadee Formation (where the Bunbury Basalt is not present). The Warnbro Group consists of interbedded clay, clayey sand and sand with minor coal and overlies the eroded surfaces of older formations, or Archaean basement where it onlaps the Yilgarn Craton (Thorpe and Baddock, 1994).

The Quaternary sediments of the Swan Coastal Plain extend eastwards from the coast to the Darling and Whicher Scarps and up into the main valleys of the Blackwood Plateau (Commander, 1984). These superficial formations unconformably overlie a gently west-sloping unconformity on Mesozoic sedimentary rocks of the Perth Basin (Commander, 1984, 1988; Deeney, 1989a; Hirschberg, 1989).

The shoreline deposits of the Yoganup Formation (*Qpy*) are considered to be Early Pleistocene in age and thus are the oldest Quaternary sediments on COLLIE. This formation is preserved on the margin of the Darling and Whicher Scarps and consists of leached and ferruginised beach sand and conglomerate containing mineral sands (Baxter, 1977; Wilde and Walker, 1982). These sediments range from 1 to 25 m thick and they are unconformably overlain, or are bordered to the west by, the Guildford Formation (Wilde and Walker, 1982).

The Guildford Formation is a Middle Pleistocene alluvial deposit, which covers a large area of the coastal plain, generally unconformably overlying the Leederville Formation. Similar alluvium occurs in the valley of the Preston River within the Yilgarn Craton and unconformably overlies Archaean basement (Commander, 1984). The formation can be subdivided into two laterally equivalent members inclusive of a clay member (*Qpgc*) in the east, comprising clay and sandy clay with occasional discontinuous sand layers. To the west, a sand member (*Qpgs*) outcrops that consists primarily of a poorly sorted, fine- to very coarse-grained quartz sand with minor beds of clay, and clayey sand with traces of heavy minerals (Deeney, 1989a; Hirschberg, 1989). The clay and sand members range in thickness from 2 to 27 m and 4 to 30 m respectively, with the vertical extent of the clay member decreasing towards the middle of the coastal plain where it interfingers with the sand member (Deeney, 1989a).

The Late Pleistocene Tamala Limestone (*Qt*) (Playford *et al.*, 1976) unconformably overlies Cretaceous sediments in the west, and probably the Guildford Formation on its eastern margin (Deeney, 1989a; Hirschberg, 1989). The limestone is predominantly eolian, comprises limestone, calcarenite and sand with minor clay and shell beds, and attains a maximum thickness of 90 m (Deeney, 1989a). The most recent sediments on COLLIE are alluvium deposits along the Williams and Capel Rivers.

3 Hydrogeology

3.1 Groundwater occurrence

There are two major hydrogeological units on Collie: sediments and crystalline basement. The most substantial supplies of groundwater occur in sedimentary rocks within the Perth and Collie Basins (Fig. 3). The weathered profile of the basement rocks in the Yilgarn–Southwest Province predominantly exhibits low porosities and low hydraulic conductivities and contains only localised groundwater (George, 1992; George *et al.*, 1994; Clarke *et al.*, 2000). The surficial aquifer on Collie comprises a number of hydrogeological units with generally minor supplies of groundwater. A conceptual model of the hydrogeology of these units is illustrated schematically in Map sections A–B, C–D–E and F–G–H and in Figures 4 to 8, in this text.

Major groundwater resources are contained in sedimentary rocks in the Perth Basin. The Jurassic Cockleshell Gully and Yarragadee Formations, together with the Cretaceous Leederville Formation, form the principal aquifers. The sedimentary rocks within these formations form multi-layered aquifer systems ranging in thickness from hundreds of metres to several kilometres. These aquifers contain fresh to saline groundwater located at various depths throughout the basin (Wharton, 1980, 1981b; Commander, 1984; Smith, 1984; Deeney, 1989b; Hirschberg, 1989).

The second largest groundwater resource on Collie exists within the Collie Basin. Permian coal measures form aquifers in all three Permian basins, the Collie, Wilga and Boyup Basins (Fig. 3). These sequences also form multi-layered aquifer systems with variable groundwater quality and with the thicknesses of the coal measures ranging from tens to hundreds of metres (Table 2) (Laws, 1992; Yesertener, 1997; Mohsenzadeh, 1989a,b). Groundwater also occurs within the Permian Donnybrook Sandstone, where sands rather than shales and clays dominate the composition. Variation in the quantity of shale and clay is quite pronounced thereby restricting groundwater occurrence.

Groundwater occurs in surficial aquifers in the Yilgarn–Southwest Province, and particularly within Quaternary alluvium in modern drainage lines, in Cainozoic sediments where thick sequences of sands are preserved, and in Early Tertiary (Eocene) alluvial sands and clays which commonly occupy palaeochannels and topographical depressions. The quality of the groundwater is variable with resources typically localised; major groundwater resources are restricted to those aquifers within palaeochannels (George *et al.*, 1994; Waterhouse *et al.*, 1995).

The Perth Basin superficial aquifer contains substantial groundwater resources on the Swan Coastal Plain and localised resources on the Blackwood Plateau (Fig. 2). Quaternary sediments on the Swan Coastal Plain are hydraulically connected to form a relatively thin unconfined aquifer with a saturated thickness of some 20 to 30 m (Commander, 1984; Deeney, 1989a). These sediments consist of predominantly clay and sand in the east, and sand and limestone in the west. Groundwater resources are commonly restricted to areas containing minimal amounts of clay sediments. Groundwater in Quaternary sediments on the Blackwood Plateau is associated with modern drainage line deposits. These form minor local aquifers.

Groundwater in the Archaean granitoid and gneissic basement exists in faults, fractures and joints in the unweathered rocks, and in the pore spaces of the overlying weathered profile. In granitoid basement, aquifers possessing higher hydraulic conductivities commonly develop at the contact between the unweathered rock and the overlying saprolite (George *et al.*, 1997). Here, fragmental disintegration produces a friable zone with high intergranular porosities, often referred to as grus (Nahon and Tardy, 1992; Dobereiner and Porto, 1993) and known colloquially as saprolite grit. In rocks containing low quartz, saprock develops, which is generally compact and has lower hydraulic conductivities. Above the grus and saprock, primary minerals weather to secondary clays forming the actual saprolite. That the saprolite contains variable quantities of groundwater is due to the mineralogical heterogeneity of the granitoid and gneissic basement rocks. Rocks with higher amounts of quartz and feldspar in the lower saprolite develop more macropores during weathering (Anand and Gilkes, 1984, 1987; Anand *et al.*, 1985; McCrea *et al.*, 1990).

As a result, these rocks commonly contain more groundwater, but more importantly, tend to have higher hydraulic conductivities and are therefore associated with increased bore yields.

Other basement rocks prospective for groundwater in the Yilgarn–Southwest Province include Archaean quartzite and Proterozoic quartz dykes and veins. These rocks are sporadic and limited in their dimensions and contain localised groundwater in well developed joint and fracture systems. In contrast, the general absence of fracturing in Proterozoic mafic dykes and sills, combined with low hydraulic conductivities, restricts groundwater to areas immediately up gradient from their occurrence.

3.2 Perth Basin

3.2.1 Quaternary superficial formations (*Qa, Qt, Qpgs, Qpgc, Qpy*)

3.2.1.1 Swan Coastal Plain

On the Swan Coastal Plain, Quaternary sediments form a variety of aquifers (Commander, 1982, 1984, 1988; Deeney, 1989a; Hirschberg, 1989). Of these, the Yoganup Formation (*Qpy*) outcrops on the eastern margin of the Swan Coastal Plain, and the Tamala Limestone (*Qt*) fringes the coastline (Deeney, 1989a). Between these units are the Guildford Formation (clay member) (*Qpgc*) in the east and the Guildford Formation (sand member) (*Qpgs*) in the west (Map section A–B).

Groundwater recharge in the superficial[2] formations is received directly from rainfall in addition to upward leakage from the underlying Leederville Formation near the coast (Commander, 1984; Smith, 1984; Hirschberg, 1989). Higher rates of recharge occur in the central coastal plain where the watertable is shallow and topographic gradients and the clay content of sediments are low (Deeney, 1989a). The direction of groundwater flow is to the northwest, where discharge takes place at the seawater interface. Discharge also takes place along watercourses, coastal lakes and drains, through evapotranspiration where watertables are shallow, and by localised downward leakage into Mesozoic sediments (Deeney, 1989a).

At the eastern margin, recharge to the Yoganup Formation (*Qpy*) takes place at the base of the Darling Scarp, near Harvey. Downward leakage from this formation to the confined Mesozoic aquifers occurs where the formation extends below the Guildford Formation (clay member) (*Qpgc*) (Map section A–B). The salinity of groundwater in the Yoganup Formation is low, compared with high salinities in the Guildford Formation (clay member) and the Mesozoic sediments beneath. The salinity of groundwater in the clay member is highest in the Harvey, Benger and Dardanup areas. Salinities commonly exceed 7000 mg/L TDS (total dissolved solids) around the Benger Swamp and may increase to 14 000 mg/L TDS in the near surface, at depths less than 5 m. Salinity decreases to the south towards Capel, and to the west where the clay member interfingers with the sandy member of the Guildford Formation (*Qpgs*). Groundwater in the sand member (*Qpgs*) is characteristically less saline. The lowest salinities, (<250 mg/L), are recorded on the crest of the Mialla and Yanget Mounds, which are discussed in Deeney (1989a). These mounds are located south and north of the Harvey Diversion Drain which discharges major surface water and some groundwater westwards into the Indian Ocean.

West of the Guildford Formation, the Tamala Limestone (*Qt*) aquifer receives high recharge from rainfall and supplies generally fresh groundwater from bores and shallow excavations (Deeney, 1989a). The Lake Preston area is an exception, where salinities are high both within the lake, and at the base of the aquifer at the interface with the Leederville Formation (Commander, 1988). The lake is a sink for groundwater with recharge received from rainfall together with inflow from the Lake Preston flow system (primarily to the east of the lake). Discharge is mainly through evaporation, which increases the salinity of the lake water to between 8000 and 90 000 mg/L. The salinity of groundwater underlying the lake is between 48 000 and 64 000 mg/L, and increases to the south (Commander, 1988). This hypersaline groundwater extends approximately half a kilometre east of the lake, inside the South West Coastal Groundwater Area, where the watertable is generally less than 5 m below the land surface. However, there is a fresh-water flow system above the hypersaline groundwater, with the two zones separated by a zone of mixing where salinity increases from 10 000 to 50 000 mg/L within a metre (Commander, 1988).

---

[2] *On the Swan Coastal Plain the surficial sediments are referred to as the superficial formations (Allen, 1976)*

3.2.1.2 Blackwood Plateau

On the Blackwood Plateau, Quaternary alluvial sands, silts and clays (*Qa*) and the equivalent of the Guildford Formation (sand member) (*Qpgs*) are deposited along the modern drainage lines of the Capel and Preston Rivers respectively. In the Preston River valley, Cainozoic alluvial and colluvial deposits are inferred to be preserved below the Quaternary sediments. These sediments may form a significant aquifer but require further investigation and are not shown on COLLIE.

Recharge to Quaternary sediments is primarily through the infiltration of rainfall. Additional recharge may be derived from groundwater discharging from the Leederville Formation into the valleys of the Blackwood Plateau. This occurs in response to local flow systems producing upward hydraulic gradients, generally within the argillaceous sequences of the Leederville Formation aquifer (Thorpe and Baddock, 1994). Groundwater discharge is primarily through evapotranspiration, direct flow into streams where there are localised upward hydraulic gradients, or downward leakage into the deeper formations, possibly Cainozoic sediments along the Preston River, but more commonly the Leederville Formation.

The quantity and quality of groundwater within these sediments is variable; areas where clays predominate are likely to correspond with lower bore yields and brackish to saline groundwater. Potable supplies of groundwater may be obtained from the Quaternary sediments in the Preston River valley, where salinities are commonly less than 1000 mg/L.

3.2.2 Leederville Formation (*Kl*)

The Leederville Formation (*Kl*) is a multi-layered confined aquifer consisting primarily of interbedded sand and shale and ranging in thickness from 150 to 200 m (Hirschberg, 1989). The formation extends throughout the Perth Basin on COLLIE, except over the Capel Anticline (near Capel, Commander, 1984), where the formation thins, becomes absent and inliers of Yarragadee Formation (*Juy*) or Bunbury Basalt (*Kb*) are exposed (Map panel). Groundwater resources are smallest near the Capel Anticline and largest in the Dardanup Syncline (near Dardanup, Commander, 1984), where the formation is thickest, up to approximately 300 m. These thick sequences of sands have been developed for groundwater resources (Commander, 1984; Smith, 1984; Hirschberg, 1989).

The major recharge to the Leederville Formation occurs on the Blackwood Plateau through direct infiltration of rainfall. Additional recharge is by downward leakage through the superficial formations on the Swan Coastal Plain, principally the Yoganup Formation to the east and Guildford Formation (sand member) to the west, together with upward leakage from the Yarragadee Formation near the coastline. Groundwater flow is northwest from the Blackwood Plateau with the potentiometric head declining from 125 m AHD northwest of Nannup, to approximately 2 m near the coast (Map panel) (Commander, 1984). Inland, a significant proportion of groundwater recharged to the aquifer is subsequently discharged through downward leakage into the Yarragadee Formation (Hirschberg, 1989; Thorpe and Baddock, 1994). Further discharge occurs offshore above the seawater interface, and inland there is upward leakage through the superficial formations in a northwesterly trending zone, from Rush Swamp (near North Boyanup) to the Leschenault Estuary (Commander, 1984; Hirschberg, 1989).

Groundwater salinity in the Leederville Formation ranges from less than 1000 mg/L on the Blackwood Plateau, to less than 800 mg/L on the Swan Coastal Plain with the higher salinities generally attributed to the restriction of groundwater movement by shale beds (Wharton, 1981b; Commander, 1984; Hirschberg, 1989; Appleyard, 1991).

3.2.3 Yarragadee Formation (*Juy*)

The Yarragadee Formation (*Juy*) is a major confined aquifer consisting mainly of sandstone, with minor shale interbeds. The percentage of sandstone decreases to approximately 25% in the upper part of the formation near the Darling and Whicher Scarps, as evident in Quindalup and Picton Line boreholes Q9, PL4 and Q6 (Map section) (Wharton, 1980, 1981b). The formation thins northwards, and is intersected beneath the Leederville Formation at approximately 1000 m depth in the Quindalup Line Bores and at depths of approximately 600 to 200 m below the Leederville Formation in the Picton Line Bores (Map panel). North of the Picton Line bores near Burekup the Yarragadee Formation is absent. Here, the Leederville Formation lies directly on the Cockleshell Gully Formation (*Jlo*). The stratigraphic thickness of the Yarragadee Formation ranges from 600 to 1600 m, with a maximum of 1300 m inferred in the axis of the Bunbury Trough, south of Bunbury (Commander, 1984).

Recharge to the Yarragadee Formation occurs through the direct infiltration of rainfall in outcrop areas on the Blackwood Plateau and downward leakage of groundwater through the Leederville Formation where the Bunbury Basalt (*Kb*) is absent. Local recharge also occurs via the superficial formations south of Bunbury where both the Leederville Formation and Bunbury Basalt are absent. Near the coast, additional recharge takes place from the upward leakage from the Cockleshell Gully Formation (*Jlo*) (Smith, 1984). South of Nannup, the direction of groundwater flow is northwards with discharge into the ocean at the seawater interface near Bunbury, by upward leakage into the Leederville Formation near the coast, and by downward leakage into the Cockleshell Gully Formation away from coastal areas (Wharton, 1981b; Smith, 1984).

Groundwater salinity is generally less than 500 mg/L, but may range from about 200 to 800 mg/L. Salinity increases northwards from the Quindalup Borehole Line to the Picton Line of bores (Wharton, 1980, 1981b; Commander, 1984; Smith, 1984; Hirschberg, 1989). The fresh water flow system is bounded by shales at the Yarragadee/Cockleshell Gully Formations contact, below which groundwater rapidly increases in salinity.

3.2.4 Cockleshell Gully Formation (*Jlo*)

The Cockleshell Gully Formation (*Jlo*) is a confined multilayered aquifer composed of siltstone and shale with sandstone interbeds (Deeney, 1989b). The formation is overlain by the Leederville Formation north of the Kemerton area and by the Yarragadee Formation to the south.

Minor recharge may occur through the downward leakage of groundwater from the Yarragadee and Leederville Formations apart from coastal areas, where the Cockleshell Gully Formation discharges groundwater into the overlying formations (Deeney, 1989b; Smith, 1984). Throughflow in this aquifer is limited as a result of the formation not being actively recharged (Thorpe and Baddock, 1994).

Groundwater salinity ranges from 200 mg/L to greater than 50 000 mg/L, but is generally less than 1000 mg/L to depths of about –700 m AHD, except in the Binningup and Harvey Lines (Wharton, 1980; Deeney, 1989b).

3.3 Permian basins

3.3.1 Collie Basin (*Ps, Pcm, Kn*)

The most significant fresh groundwater resource located east of the Darling Fault on COLLIE is in the Collie Basin. This sedimentary basin, located in the Collie River Catchment, is the largest of the Permian basins on COLLIE and covers a surface area of approximately 225 km^2. The basin is structurally controlled and has an elongate bilobate shape. The Cardiff Sub-basin and Premier Sub-basin form the respective western and the eastern lobes and are separated by a basement high named the Stockton Ridge. The basin extends in length approximately 5 km northwest and 22 km southeast of the Collie township. The maximum width of the basin is roughly 13 km and the maximum thickness of sediments is approximately 1050 m (Le Blanc Smith, 1993; Moncrieff, 1993). The stratigraphy of the Collie Basin is detailed in Table 2.

Groundwater exists in the Permian Stockton Group, inclusive of the Shotts Formation (*Ps*), in the Collie Group (*Pcm*) and in the Cretaceous Nakina Formation (*Kn*). The Collie Group is the major aquifer in the basin. The Shotts Formation may form either an aquitard, or a minor aquifer where groundwater is generally confined, apart from areas where it outcrops on the southern and northern margins of the Collie Basin near the Stockton Ridge. Groundwater in the Nakina Formation is poorly known, probably localised and restricted to topographically low-lying areas within the basin, such as discharge areas in close proximity to the Collie River (Fig. 4). Groundwater recharge to the Collie Basin is mainly derived from the direct infiltration of rainfall. Recharge may occur in the southern part of the Cardiff Sub-basin through the downward leakage of surface water from the Collie River South Branch, where the river elevation exceeds that of the watertable (as a consequence of dewatering). Additional recharge may also occur by inflow and in response to lowering the watertable during coal mining. Annual recharge to the Collie Basin is estimated as 14–16 x 10^6 m^3 (Dames and Moore Pty Ltd, 1998), although conventional wisdom suggests the true figure may be as much as 50% higher.

Shallow groundwater flow in the Collie Basin is largely topographically controlled, moving down gradient and discharging along drainage lines. Significant

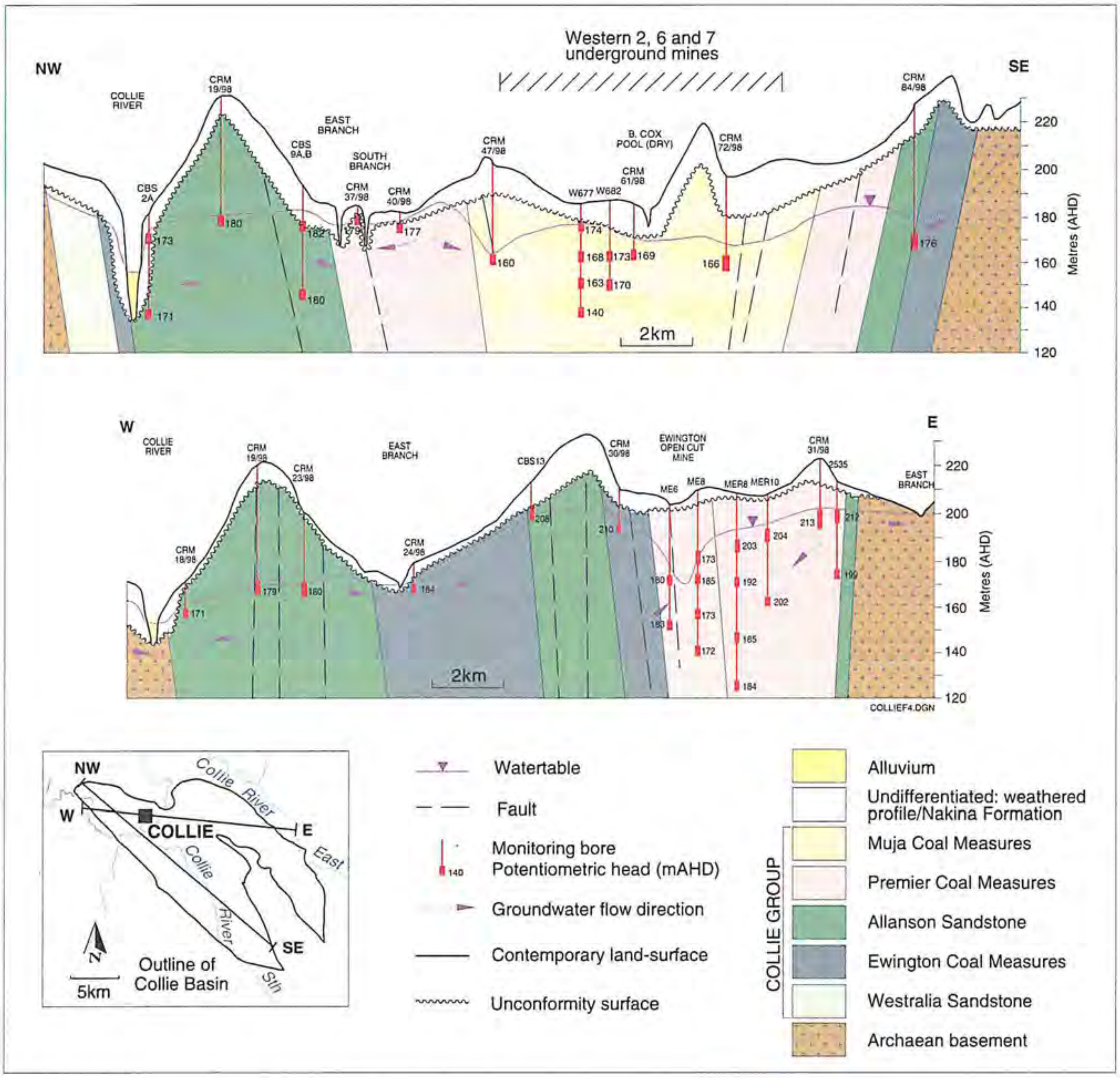


Figure 4. Collie Basin diagrammatic structure and stratigraphy

disturbance to the regional groundwater flow patterns in the Collie Basin has been attributed to large-scale mine dewatering (Map section A–B). Groundwater flow in the Premier Sub-basin is essentially internal and towards the opencut mines and wetlands, whereas in the northern section of the sub-basin, the presence and location of a groundwater mound results in groundwater discharging into the Collie River East Branch. In the Cardiff Sub-basin groundwater flow and resultant discharge is generally directed towards the Collie River and Collie River South Branch (Figs 1 and 4). There is hydraulic connection between the two sub-basins, as indicated by groundwater flow from the Premier Sub-basin into the Cardiff Sub-basin in the Stockton Lake area (Mohsenzadeh, 1989a,b). Groundwater flow deeper in the Collie Basin is complex and not well understood. The hydraulic connection of these aquifers is complex, controlled by a number of factors including coal seams, basin structure, faults and the heterogeneity of the aquifer.

Groundwater in the Permian aquifers of the Collie Basin is generally fresh with salinity typically less than 500 mg/L. However, the groundwater is acidic with pH readings as low as 3 recorded in many parts of the basin, particularly on contact with sulphides within the coal measures.

3.3.2 Wilga Basin (*Pcm*)

The Wilga Basin is located approximately 30 km southeast of the Collie township, near the southern divide of the Collie River Catchment and consists of a pair of north-northwesterly trending basins; the Wilga West and Wilga East Basins. These basins are approximately 6 and 10 km long respectively and range in width from 3.5 to 1 km.

The hydrogeology of the Wilga Basin is not well understood, although correlations in stratigraphy indicate that it is likely to be similar to that of the Collie Basin (Table 2). Sandstones within the Collie Group (*Pcm*) form the major aquifers and are estimated to constitute approximately 50% of the total thickness of the group. An interpretation of the limited hydrogeological data on groundwater levels within the basin suggests that the position of the watertable is topographically controlled. The depth to groundwater ranges from less than 6 m to approximately 28 m, the latter in areas of higher elevation (Laws, 1992).

Recharge to the Wilga Basin is through direct infiltration of rainfall. Groundwater flow regimes have yet to be established but are expected to be complex with aquicludes such as coal seams, shales, heterogeneous sandstone beds and faults constraining groundwater movement. Groundwater discharges from the sediments of the Wilga Basin through evapotranspiration and baseflow to the Collie River South Branch. The sediments of the Wilga Basin may contain a reasonable resource of fresh groundwater; salinity ranges from approximately 700 to 5000 mg/L, but is generally less than 1500 mg/L (Laws, 1992).

3.3.3 Boyup Basin (*Pcm*)

The Boyup Basin is located approximately 42 km south of the Collie township and 8 km southwest of the Wilga Basin, in the Blackwood River Catchment. The Boyup Basin is elongate with a general north-northwesterly trend (Yesertener, 1997). The basin is fault bounded to the west, is around 9 km in length, between 2 and 0.5 km wide with an approximate surface area of 15 km^2 (Yesertener, 1997). The stratigraphy of the Boyup Basin is detailed in Table 2.

The Permian Boyup Coal Measures (*Pcm*) and Barrons Sandstone are the main aquifers in the Boyup Basin, forming upper and lower aquifer systems respectively. The hydraulic connection between the the two aquifers is restricted to localised faults and fractures (Yesertener, 1997). The basin receives only limited recharge, and the annual recharge of the upper and lower aquifers has been calculated as 16 950 and 21 500 m^3 respectively (Yesertener, 1997). Recharge through the direct infiltration of rainfall occurs in the northwest of the basin where the aquifers outcrop. Additional recharge takes place where the overlying Cretaceous Boonarie Claystone thins to approximately 8 to 20 m along the eastern and southeastern section of the basin and along a fault zone in the western part of the basin (Yesertener, 1997). Insufficient information is available to establish groundwater flow patterns throughout the basin. However, in the northern half of the basin, groundwater appears to flow in a northwesterly direction with discharge occurring at Wilgee Spring (Yesertener, 1997).

Groundwater salinities, from limited borehole data, suggest the resource is saline with measurements of 3830 and 5280 mg/L obtained for the upper and lower aquifers respectively (Yesertener, 1997).

3.3.4 Donnybrook Sandstone (*Pn*)

The Donnybrook Sandstone (*Pn*), a predominantly feldspathic sandstone with a high intergranular porosity, forms a small unconfined aquifer in the Preston River catchment, on the eastern margin of the Darling Scarp. The aquifer is an elongate structure extending approximately 22 km in a north–south direction with a maximum width of approximately 5 km. Joshua Brook and Capel River South mark the northern and southern extent of the sandstone. The sandstone overlies Permian claystone/shales and is overlain by up to 18 m of generally unsaturated, Cainozoic, alluvial clays, and sands.

Groundwater is recharged through direct infiltration of rainfall where the sandstone outcrops, although more commonly through overlying alluvial sediments. Additional recharge is received from the Preston River in areas where there is a downward hydraulic gradient. Groundwater within the sandstone is unconfined with the watertable at depths of between 10 and 30 m, except along its western margins of the unit where this depth may be up to 50 m. Groundwater flow appears to be topographically controlled, and westwards towards the Perth Basin. Discharge occurs laterally into the Leederville Formation aquifer. Additional discharge takes place via groundwater flow into the Preston and

Capel North Rivers where there is an upward hydraulic gradient. Evapotranspiration becomes a factor in areas where groundwater levels are close to the surface.

Groundwater within the Donnybrook Sandstone is generally fresh with the majority of bores accessing groundwater of salinities less than 600 mg/L. However, groundwater from bores located on the eastern margin of the sandstone may have salinities around 900 mg/L. Bores are lower yielding as the sandstone thins to the east and shales and clays predominate. Groundwater resource prospects increase towards the west, and deep bores on the western margin yield up to 500 m^3/d.

3.4 Yilgarn–Southwest Province

In the Yilgarn–Southwest Province on COLLIE, the tectonic evolution of the landscape in conjunction with the chemical and physical properties of the basement rocks, has shaped the contemporary topography. Surficial sediments accumulate where lessening topographic gradients have decreased the ability of the river systems to remove weathered and transported material. Groundwater may reside in these surficial sediments where they are preserved in topographic lows above the weathered granitic basement rocks.

The hydrogeology of the granitic rocks of the Yilgarn–Southwest Province is complex. A significant quantity of groundwater discharges into the river systems. Locally, however, the topography of the basement, and the presence of geological barriers such as faults, quartz and mafic dykes, and aquitards within the regolith affect groundwater flow, which results in groundwater discharging at seeps on valley flanks.

3.4.1 Surficial aquifer (*Qa, Qpgs, Cza, Czc, Czg*)

On COLLIE, the surficial aquifer in the Yilgarn–Southwest Province consists of Late Tertiary to Quaternary sediments of varying character and extent. Predominantly this aquifer is unconfined and comprises heterogeneous fluvial sediments. Groundwater processes such as recharge, groundwater flow and discharge are similar in these aquifers. Recharge takes place either through the direct infiltration of rainfall or indirectly through surface runoff (derived upstream, or from granitic outcrop, or from localised aquicludes formed by clay layers), in addition to throughflow received from the weathering profile of the adjacent granitic basement rocks (Fig. 5). Groundwater flow is largely topographically controlled with discharge occurring mainly through evapotranspiration and direct flow into streams, lakes and swamps.

Quaternary fluvial sediments deposited along modern drainage lines of the Williams and Preston Rivers comprise clay with sand lenses (*Qa*) and sands and clays and gravels (*Qpgs*) respectively. These sediments may attain a local thickness of 20 m and are categorised on COLLIE as forming potential aquifers where the saturated thickness exceeds five metres. High proportions of clays in the aquifers generally correlate with brackish to saline groundwater. Salinity is also influenced by the principal source of recharge, where higher salinities relate to the dominant recharge being derived from the weathering profile of the neighbouring granitic rocks. Low bore yields tend to be associated with localised aquifers that may contain high quantities of clays.

Cainozoic alluvial and colluvial deposits (*Cza*) consisting of sands, gravels and clays are widespread in the eastern areas of COLLIE, occupying broad river valleys and relict fluvial systems of the Hillman, Arthur and Beaufort Rivers (Map section C–D–E). Cainozoic deposits (*Cza*), overlie either weathered granitic basement or Early Tertiary (Eocene) sediments, with the latter occupying palaeochannels (Fig. 5) (Hawkes, 1993; George *et al.*, 1994; Perry, 1994; Prangley, 1994a,b, 1995; Waterhouse *et al.*, 1995; Commander *et al.*, 1996; Clarke, 2000). The aquifer they form is generally unconfined, except in the Preston River valley where a major groundwater resource in Cainozoic sediments is confined beneath Quaternary cover (*Qpgs*). Owing to the heterogeneity of the sediments, areas of high hydraulic conductivity are localised and bore yields and groundwater quality show a wide variation with yields ranging from less than 5 m^3/d to 300 m^3/d. Bores producing high yields are limited to zones of high hydraulic conductivity and hence minimal quantities of clay. As with the Quaternary aquifers, lower yields correlate with high salinities and high amounts of clay, with groundwater quality ranging from brackish (1000–3000 mg/L) to highly saline (7000–14 000 mg/L). Lower salinities are restricted to the sediments in the Preston River valley, where high rainfall favours high recharge through the overlying Quaternary sediments and overshadows saline throughflow from the neighbouring weathered profile of the granitic basement rocks (Fig. 5). Likewise, fresher groundwater (brackish

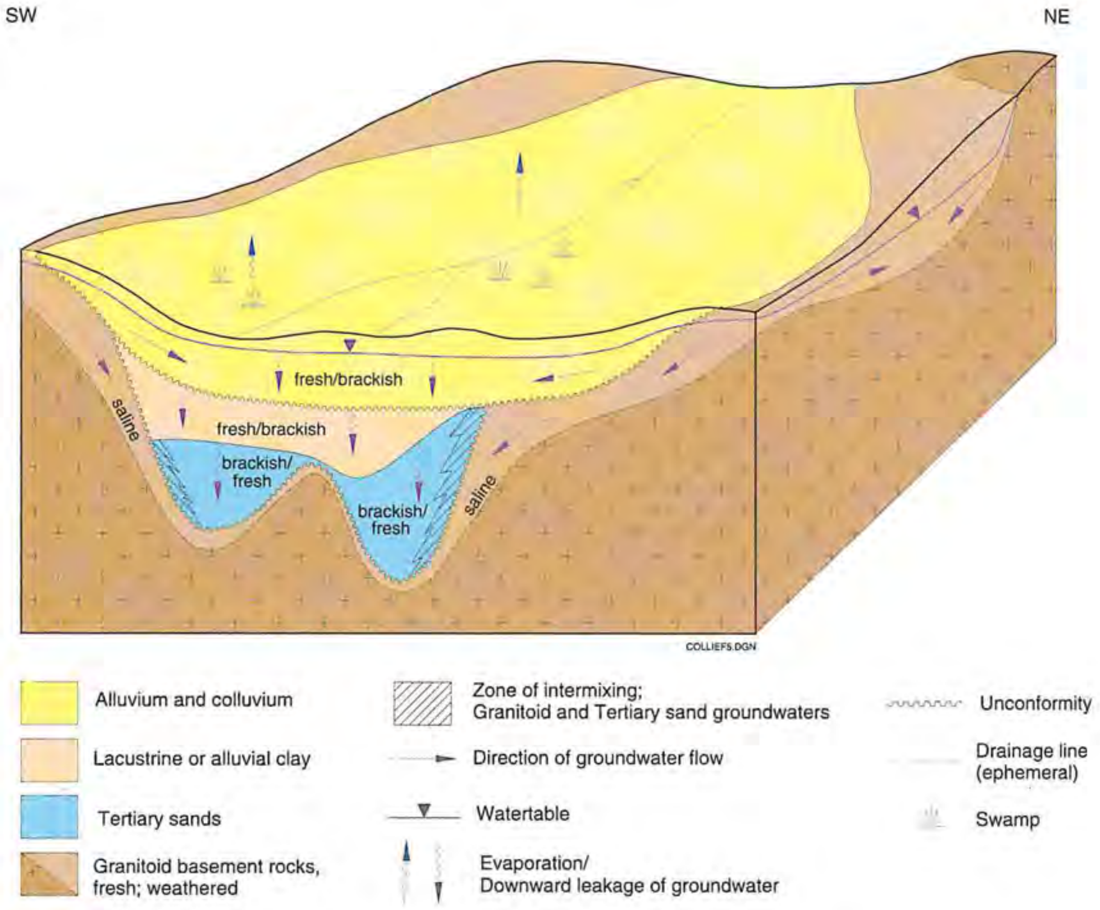


Figure 5. Hydraulic connection in the Beaufort Palaeochannel (from section C-D-E, Prangley, 1995)

instead of saline) may be obtained in the eastern area of COLLIE near the Dardadine palaeochannel, where Cainozoic sediments (*Cza*) located in upper landscape positions, receive a higher proportion of recharge directly from rainfall.

Cainozoic Kirup Conglomerate (*Czc*) comprises rounded cobble clasts with a matrix of clayey sand and forms a local unconfined aquifer in the southwestern corner of the map sheet. These materials have been deposited in a palaeovalley, are up to 2.5 km wide, extend for approximately 60 km, and have a maximum thickness of 15 m. The maximum saturated thickness of these sediments is variable but more likely to occur in lower landscape positions. So whilst the salinity is typically fresh to brackish (1000–3000 mg/L), bore yields are likely to show a wide degree of variation.

Extensive, 'sheet like' Cainozoic alluvial deposits (*Czg*) are identified in three main locations (Laws, 1992; Tille and Percy, 1995). The major deposit is situated in the Collie Plains, a topographically low-lying area located approximately five kilometres north of the Collie Basin. Further deposits include a locality which straddles the divide of the Collie River and Blackwood River catchments, immediately west of the Wilga Basin, and an area of internal drainage occupied by swamps near Kulikup (near C on Map section C–D). These sediments consist of alluvial silt, clay, sand and gravel, and form minor unconfined aquifers with variable intergranular porosities and hydraulic conductivities.

Groundwater quality in the *Czg* aquifer varies from fresh to brackish, reflecting both the proportion of sand versus silt and clay within the sediments and the source of groundwater recharge. Salinities are dependent on the quantity and quality of recharge received from both sediments and weathering profiles of granitic basement rocks. In the Wilga Basin area, *Czg* sediments contain generally fresh groundwater (200–600 mg/L) in the upper landscape areas where sediments receive most of their recharge from rainfall. In the north, however, as groundwater moves down gradient through the *Czg* aquifer to lower landscape positions, groundwater becomes brackish. In the Kulikup area, groundwater quality ranges from very saline (13 800 mg/L) to brackish (2600 mg/L), as the *Czg* sediments are located in an area of internal drainage. Here the sediments receive most of the recharge from the surrounding weathered profile of the granitic basement rocks.

Substantial groundwater resources correlate with thick sequences of sediments containing limited amounts of silt and clay. The range in thickness of these sediments (*Czg*), and hence aquifer potential, is not known. Records in the Collie Plains area contain only information from shallow bores, those less than 5 m in depth, which confirm yields of less than 50 m^3/d, whereas shallow bore holes in the *Czg* aquifer near the Wilga Basin produce generally smaller yields, (<5–16 m^3/d). Yields up to 160 m^3/d have been recorded from a smaller *Czg* aquifer to the northeast of the Wilga Basin where the sediments are known to be up to 30 m in thickness. Bores in *Czg* sediments to the southeast of the palaeochannel (*Twq*), near Qualeup Lake, in the Kulikup area, produce bore yields up to 218 m^3/d. Bore yields to the northwest of Kulikup are expected to be substantially lower because the thickness of the sediments decreases to generally less than 15 m.

3.4.2 Early Tertiary (Eocene) palaeochannel sediments (*Tw, Twq, Tc*)

Three major palaeochannels are located on the eastern section of COLLIE, namely the Dardadine, Beaufort and Qualeup Palaeochannels. All three palaeochannels follow westerly trends in broad valleys and are concealed beneath varying thicknesses of Cainozoic sediments (*Cza*). On COLLIE, the average width of these channels is approximately one kilometre and their mapped lengths range from approximately 8 to over 50 kilometres. Sediments within the palaeochannels comprise Eocene alluvial sands (*Tw*) and alluvial sands and clays (*Twq*), commonly overlain by lacustrine clays and silts (*Tc*) (Fig. 5) (Map section C–D–E). The thickness and lateral extent of the Eocene sediments preserved in the palaeochannels depends upon the depth of incision within the palaeovalleys. The sediments are estimated to attain a maximum thickness in the Beaufort Palaeochannel of over 70 m by George *et al.* (1994) and around 50 m by Waterhouse *et al.* (1995).

Palaeochannel sediments (*Tw*) and (*Twq*) form minor to major unconfined to semi-confined aquifers, generally characterised by high intergranular porosities where clay sediments are minimal. Groundwaters within the Beaufort Palaeochannel have been determined through carbon-14 dates as being relatively young (1000–1600 years), with the age increasing down flow lines from Cordering to Darlingup (George *et al.*, 1994).

Recharge to the palaeochannels occurs directly by infiltration of rainfall and indirectly through downward leakage from surficial sediments, runoff from outcrop, and throughflow received from either or both hydraulically connected upslope sections of the palaeochannel and the weathering profile of adjacent granitic basement rocks (Fig. 5). Groundwater within the palaeochannels flows down gradient towards the modern water courses and discharge takes place through direct flow into small swamps and lakes and along intersecting drainage lines (Hawkes, 1993; George *et al.*, 1994).

Surface water divides within the Boscabel and Towerrinning Palaeochannels (Prangley, 1994a,b), part of the Beaufort Palaeochannel, produce both 'upstream' and 'downstream' flow systems. In the Boscabel Palaeochannel this results in groundwater discharging to the east of the divide in the Beaufort Flats, and to the west into the Beaufort River. Similarly, in the Towerrinning Palaeochannel discharge occurs east of the divide at Darlingup Springs and to the west at Dingo Swamp and Haddleton Springs. Groundwater quality varies along these flow paths, generally deteriorating with distance from the divide but, more importantly, with distance from the source of fresh recharge. These factors are influenced by groundwater flow rates and the amount of saline recharge received from the Cainozoic (*Cza*) aquifer and the weathering profile of the granitic basement rocks (Fig. 5). Important constraints on the movement of groundwater in the palaeochannel include the hydraulic gradient, the permeability of the aquifer materials, and the degree of hydraulic interconnection within the aquifer.

Fresh to brackish groundwater (<1000–3000 mg/L) is more common near surface water divides where there is high rainfall infiltration, or fresh recharge obtained from overlying Cainozoic sediments. Conversely, groundwater with high salinities (>14 000 mg/L) occurs where fresh recharge is reduced. This is illustrated in a section across the Beaufort Palaeochannel in Figure 5, where saline groundwater is more prevalent at palaeochannel margins with salinity decreasing towards the centre of the channel (Clarke, 1998; Prangley, 1994a,b, 1995).

Factors which influence groundwater salinity also affect bore yields. Increased yields are anticipated where there is a high degree of hydraulic connection between aquifer materials with high hydraulic conductivities. That these factors vary is reflected in the range of bore yields. In the Dardadine and Beaufort Palaeochannels, yields range from 15 to 400 m^3/d, with the highest figure having been obtained at Towerrinning by GSWA (Prangley, 1994a,b, 1995). Bore yields of up to 200 m^3/d have been recorded in the Qualeup Palaeochannel. Groundwater resources are unlikely to be substantial in this area owing to the Eocene sediments (*Twq*) possessing higher volumes of lacustrine/fluvial clays. However, locally the groundwater resource is being developed to support small-scale irrigation for viticulture, the growing of lucerne and horticultural crops such as potatoes.

3.4.3 Archaean gneiss and granitoids (*An, Ag*)

These rocks comprise the fine- to medium-grained layered gneiss of the Balingup Metamorphic Belt (*An*) and the variably textured granodiorite–adamellite–granites (*Ag*) of the Darling Range Batholith (Wilde and Walker, 1982). Granitic outcrop is most prolific on the western margin of the Yilgarn–Southwest Province and the northeast area of Collie near the Williams River (Fig. 3). Outcrop represents areas of high surface runoff and retains little to no groundwater in joints and fractures. However, outcrop covers only approximately 20% of the Yilgarn–Southwest Province, the remaining area is deeply weathered and contains groundwater in pore spaces within the weathered profile and the fractures and joints in the bedrock.

The weathering profile shows marked variations in thickness. These variations are unrelated to landscape position, and thicknesses may exceed 40 m. The profile is often typified by a complex vertical zonation with fractured material termed grus developing at the weathering front of granitoid rocks. Grus is described by various authors, (e.g. Johnston et al., 1983; Johnston, 1987a,b; George, 1992; George *et al.*, 1997; Clarke *et al.*, 2000) as saprolite 'grit' or saprolite, and is ascribed saturated hydraulic conductivities approximating 0.5 m/d. Saprolite clays develop over the grus in granitoids and commonly over the saprock in gneissic rocks (Nahon and Tardy, 1992, Dobereiner and Porto, 1993). Saprolite commonly grades upwards into mottled and ferruginised zones (Bettenay *et al.*, 1980). Low hydraulic conductivities recorded at less than 0.05 m/d correlate with clay-rich sections within the saprolite which frequently occur at the top of the profile forming an aquitard (George *et al.*, 1997; Clarke *et al.*, 2000).

Groundwater recharge is through direct infiltration of rainfall, surface runoff from outcrop and throughflow derived from upslope sections of the weathering profile. Topography of the basement exerts the dominant control over groundwater flow and major discharge takes place in drainage lines and in areas where the watertable intersects the land surface. Additional discharge occurs through evapotranspiration and throughflow into Permian Basin sediments and Eocene, Cainozoic and Quaternary surficial deposits. Groundwater discharge resulting in the formation of springs and soaks is widespread on Collie and is likely to increase as watertables continue to rise. Yields from springs and soaks are variable. On the western margin yields tend to be higher, as this area receives increased recharge from rainfall.

The groundwater held in the weathered profile of granitic basement rocks is typically brackish to highly saline. Groundwater salinity gradually increases on Collie from west to east, with fresh to brackish groundwater generally restricted to the western margin of the Yilgarn–Southwest Province. Here, higher rainfall, undulating topography and perennial watercourses increase recharge and effectively flush salts from the catchments. Low rainfall in the eastern areas of Collie, combined with a poorly drained landscape of low relief, has resulted in the storage of salts and poor groundwater quality. Within catchments and sub-catchments there is a general topographic control on salinity, so that lower landscape areas contain groundwater with higher salinities.

Major and minor faults in the Archaean basement rocks exert control on the movement of groundwater. Faults align with preferential weaknesses in the basement, a number of which coincide with the margins of previously injected intrusives such as Proterozoic mafic and quartz dykes and sills. These fractures may contain groundwater depending on the interplay of groundwater processes, basement topography and the ability of the faults, dykes or sills and regolith to form effective barriers to groundwater flow (George *et al.*, 1997;

Sutton, 1999). Good yields have been found in fractured zone aquifers at depths of 5–10 m below the weathering profile. These zones form a potential groundwater resource as their hydraulic conductivities are commonly high (Clarke, 1998). Yields up to and greater than 500 m^3/d have been obtained where fracture zones from faulting are intercepted. However, areas with high yields are limited in their extent and bore yields from the granitic basement are typically small (<10 – 50 m^3/d).

3.4.4 Archaean quartzite and Proterozoic quartz dykes and veins (*Aq, Pq*)

On COLLIE, Archaean quartzite (*Aq*) outcrops as irregular boudins or continuous bands within the Balingup Metamorphic Belt (Fig. 3). Proterozoic quartz dykes and veins (*Pq*) are more widely distributed, with high concentrations occurring in the northeastern section of COLLIE and in the area adjacent the Darling Scarp, near Nannup. These rocks consist almost entirely of quartz and may hold substantial groundwater in joint and fracture systems.

Groundwater recharge to these aquifers takes place via direct infiltration of rainfall, surface runoff and throughflow from either or both surficial aquifers and the weathered profile of nearby granitic basement rocks. Topography and the degree of fracturing of the aquifer form major controls on groundwater flow while discharge occurs along drainage lines and seeps. The quality of the groundwater is likely to be fresh to brackish depending on the quality of the recharge.

Owing to the limited dimensions and sporadic occurrence of these aquifers, they represent only a minor groundwater resource on COLLIE. Bore yields are dependent on the amount of recharge and the size and hydraulic conductivity of the aquifer. Yields up to 498 m^3/d have been recorded from the quartzites near Manjimup, on PEMBERTON to the south (Prangley, 1994c).

3.4.5 Mafic dykes and sills (*Pd*)

Mafic dykes and sills (*Pd*), described as tholeiitic quartz dolerites, are mapped throughout the Archaean basement on COLLIE (Wilde and Walker, 1982). As with areas of the granitoid gneiss and migmatitic rocks (*An*), these elongate Proterozoic intrusives contain only minor quartz and produce high volumes of clay minerals during weathering. Recent work by Clarke *et al.* (2000) suggests that the hydraulic conductivity of aquifers in the weathered profile of mafic dykes are similar to, or greater than, that of granitic rocks. However, these results contradict Johnston *et al.* (1983), Engel *et al.* (1987) and McCrea *et al.* (1990), who found that these dykes possess low hydraulic conductivities and were likely to form barriers to groundwater travelling down gradient through weathered granitoid and gneissic basement.

The salinity of the groundwater in aquifers located behind dykes is dependent on the quality of the water received up gradient via throughflow. Water quality is influenced by distance from fresh recharge and landscape position. Salinities, minor fresh but predominantly saline, have been recorded from soaks and bores in close proximity to *Pd* on COLLIE. Groundwater resources are localised, and yields vary according to the position of the dyke in relation to the local groundwater flow regime.

4 Groundwater quality

4.1 Regional groundwater salinity

The salinity of groundwater across COLLIE varies widely, both within and between the hydrogeological units, ranging from less than 1000 mg/L in the Perth, Collie and Wilga Basins, to more than 30 000 mg/L in the weathered and fractured basement aquifers of the Yilgarn–Southwest Province. Isohalines (in mg/L), representing groundwater salinity, have been interpreted from bore water samples collected over a period of 50 years. Only bores of depth 5 m or more have been used in the interpretation to avoid confusion with the salinity of perched aquifer systems. The isohalines depict the salinity of the groundwater close to the watertable and indicate the salinity expected from a shallow pumping bore. However, groundwater salinity may increase substantially with depth in the Yilgarn–Southwest Province, as shown in the Maringee farm study (Fig. 6) (Martin, 1984).

The major sources of potable groundwater on COLLIE are the Perth and Collie Basins. The Leederville, Yarragadee and Cockleshell Gully aquifer systems all contain groundwater of salinity less than 1000 mg/L. In the Leederville aquifer salinity is generally less than 800 mg/L on the Swan Coastal Plain and less than 1000 mg/L on the Blackwood Plateau. Salinity is commonly less than 500 mg/L in the Yarragadee aquifer, and less than 1000 mg/L in the Cockleshell Gully aquifer system to depths of about −700 m AHD. Superficial aquifers on the other hand contain water of salinities less than 1000 mg/L to over 7000 mg/L. Saltwater intrudes the superficial aquifers (Tamala Limestone) in the northern coastal area around Lake Preston. Toxic effluent was discharged into lagoon systems in the superficial aquifers on the Leschenault Peninsula by SCM Chemicals in the 1980s (Kern, 1985). These abandoned sites are discussed together with other contamination sites on COLLIE by Appleyard (1993).

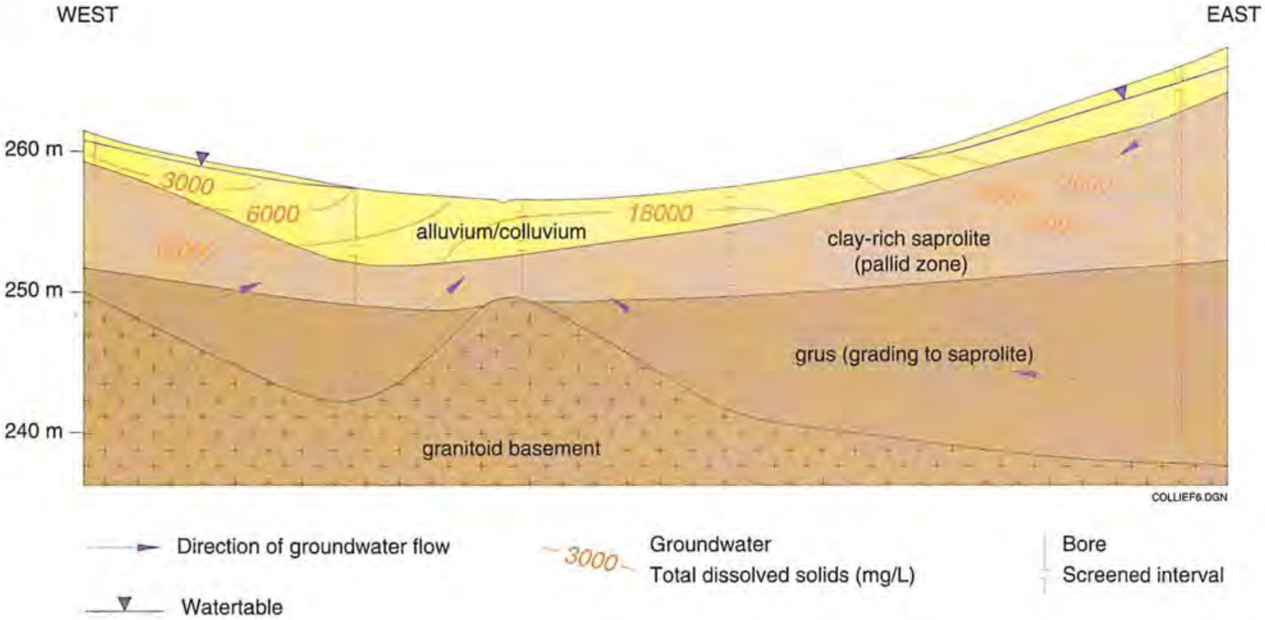


Figure 6. Groundwater salinity, Maringee Farm (after Martin, 1984)

In the Collie and Wilga Basins, confined and unconfined aquifer systems contain groundwater with less than 1000 mg/L. Groundwater in the Wilga Basin is generally less than 1500 mg/L but ranges from around 700 to 5000 mg/L (higher salinities in the western basin). Aquifers in the Boyup Basin yield groundwater with up to 5300 mg/L.

Groundwater salinity is variable within palaeochannel sediments. Sections situated within poorly drained broad valleys are generally highly saline (>7000 mg/L); however, sections situated upslope and across surface water divides tend to contain brackish to fresh groundwater. This is a reflection of the combination of effective drainage and higher rainfall infiltration compared with the adjacent weathered profile. In some cases this has led to a central core of fresh groundwater within the palaeochannel, which becomes brackish towards the edges as in the eastern Beaufort Palaeochannel (Fig. 5) (Clarke, 1998; Prangley, 1994a,b, 1995).

Salinity in the Yilgarn–Southwest Province aquifers commonly increases from west to east (Map panel). In the western part of the Yilgarn area, adjacent to the Darling Fault, groundwater is fresh to brackish, reflecting the high rainfall and the high proportion of outcrop (leading to high runoff). Most supplies in these areas are from shallow bores and springs. They therefore may not be an indication of groundwater salinity at greater depths. Farther east, groundwater salinity increases significantly with decreasing rainfall, larger areas of weathered bedrock aquifers and poorer drainage. In particular, groundwater in swamps and playa lakes, formed in depressions in the landscape and drainage lines, has become particularly saline through evaporation and the leaching of salts from higher areas. In most eastern areas, groundwater salinity around drainage lines exceeds 7000 mg/L and in some areas exceeds 14 000 mg/L. Groundwater within weathered and fractured basement and surficial sediments is brackish (1000–3000 mg/L) along major surface water divides, becoming saline down slope.

4.2 Hydrochemistry

Chemical analyses of groundwater samples from WRC monitoring bores in the Perth Basin show sodium and chloride to be the dominant ions, reflecting atmospheric saltfall. There is vertical and lateral variability within the Mesozoic and superficial aquifers; work by Commander (1984), Smith (1984), Hirschberg (1989) and Appleyard (1991) describe the chemistry in detail.

The groundwater in the weathered basement aquifers and overlying Permian and surficial sediments in the Yilgarn–Southwest Province is sodium chloride type, described in Martin (1982, 1984), Prangley (1994a,b) and Panasiewicz *et al.* (1997), and similar to those discussed in Dodson (1999). The chemistry of the Permian Collie Basin groundwaters is discussed in detail in Dames and Moore Pty Ltd (1996, 1998), and Mohsenzadeh (1998a,b). Further work is required on the other Permian Basins (Boyup and Wilga), although the Boyup Basin is mentioned briefly in Yesertener (1997).

5 Rising watertable and land salinisation

In the granitic terrains of southwestern Australia, major changes in the water balance have arisen from large-scale land clearing. The replacement of deep-rooted, perennial species of native vegetation with shallow-rooted annual species has lowered transpiration and rainfall interception rates (Wood, 1924). The lower water usage of annual crops and pastures has led to increased recharge, resulting in rises in the watertable. When groundwater nears the land surface, capillary action concentrates the salts in the root zone (Nulsen, 1981; George *et al.*, 1997). Salinisation of the near-surface soils seriously affects the productivity of many plants and may render the land infertile.

Salts are stored in regolith, which on COLLIE constitutes surficial sediments along with the weathering profiles of sediments, granitoid and gneissic basement rocks. The volume of total soluble salts stored in these materials ranges from 100 to 10 000 tons per hectare (George *et al.*, 1997). These salts, of which sodium chloride is the major constituent, are derived from rainfall (Hingston and Gailitis, 1976; McArthur *et al.*, 1989). Coastal areas receive higher rainfall and therefore more salt. However, as they are generally well drained, the unsaturated zone is regularly flushed by rainfall, thus limiting the quantity of salts retained within the regolith. Conversely, areas farther inland receive less rainfall and hence saltfall, but retain more salt owing to a subdued topography and higher rates of evaporation.

At regional scales in the Yilgarn–Southwest Province, the concentration of salt correlates with topographic position; salt stores generally increase with regolith thickness, which commonly increases from upper to lower landscape areas (Salama *et al.*, 1994). This association is exacerbated by groundwater throughflow, which follows the bedrock topography, and as a consequence transfers salt into the lower landscape (Fig. 6) (Martin, 1984).

At smaller or local scales there is a more complex pattern of salt storage across the landscape. Relationships that explain this distribution require an understanding of the local variation in groundwater recharge and flow through a variable regolith and a knowledge of biological processes. Geology, landform and vegetation are the major controls on groundwater recharge (Salama *et al.*, 1994). The movement and concentration of salt by groundwater is influenced by bedrock topography and variations in hydraulic conductivity, the latter determined primarily by variations in the fabric, texture and mineralogy of the parent lithology (Johnston, 1987a,b).

On COLLIE, the granitoid and gneissic basement includes a high percentage of primary minerals which weather to clays (Anand and Gilkes, 1984 and 1987; Anand *et al.*, 1985). As a result a 'clay-rich' saprolite often develops, which effectively stores salts because of very slow rates of groundwater movement (George, 1992; Clarke *et al.*, 2000). Groundwater flow rates are higher through the grus, faults, fractures and joints, higher hydraulic conductivity zones within the regolith such as quartz 'rich' bands or veins, and vegetation root structures and channels (Johnston, 1987a).

The increased recharge as a consequence of land clearing increases flow rates in zones of higher hydraulic conductivity. This often results in the saturation of the saprolite in lower landscape areas and the mobilisation of salt from previously unsaturated zones. Mobilisation of salt may also take place in mid- to upper landscape positions as watertables continue to rise. Groundwater seepage may occur in these areas, commonly where regolith materials, down gradient from groundwater flow, show a significant decrease in hydraulic conductivity (Engel *et al.*, 1987; McCrea *et al.*, 1990).

In order to better understand processes that cause salinisation in response to land clearing in the Collie River Catchment, a series of five experimental catchments (Salmon, Wights, Lemon, Ernies and Dons) (refer to Map) were established in the 1970s (Williamson *et al.*, 1987). These were followed during the late 1970s and early 1980s with the establishment of a number of additional experimental sites; namely Batalling Creek (Maxon Farm) and Maringee Farms (Fig. 6) (Martin, 1984). The latter studies examined the time relationships of watertable rises and salinisation in locations dissimilar in their geology, hydrogeology and climate (Bettenay *et al.*, 1980).

These studies showed that land clearing history and rainfall were the most important regional controls on watertable rises and salinisation (Williamson *et al.*, 1987). Catchments with higher rainfall, approximately 1200 mm/a (Salmon and Wights), were predicted to reach an equilibrium more rapidly than those with lower rainfall, approximately 800 mm/a (Lemon, Ernies and Dons) (Williamson *et al.*, 1987). The water balance equilibrium in Wights and Lemon catchments was calculated to be reached approximately twenty and thirty years after clearing respectively (Hookey, 1987). This difference was attributed to the efficiency with which the catchments discharged the increased groundwater recharge. This efficiency was found to be constrained by geomorphological features and regolith characteristics, such as bedrock slope, depth to bedrock, and the hydraulic conductivity of aquifers within the regolith (Hookey, 1987; Sharma *et al.*; 1987).

Outcrop or the presence of thin regolith in mid to lower landscape areas in Salmon and Wights catchments influenced a more rapid attainment of a water-balance equilibrium, with mid-slope seepage areas becoming more prominent with rises in the watertable of 0.9 m/a (Fig. 7a) (Williamson *et al.*, 1987). In contrast, catchments receiving less rainfall (Lemon, Ernies and Dons) are characterised by thick regolith in the lower landscape and low hydraulic gradients (Fig. 7b). This resulted in the saturation of the regolith as watertable rose, at rates of 2.6 m/a, with groundwater discharging in valley floors in 1989, 13 years after clearing (Fig. 8) (Williamson *et al.*, 1987).

The catchment water-balance equilibrium was calculated to precede that of the new salt balance, by approximately fifty years (Peck and Williamson, 1987; Williamson *et al.*, 1987; Turner *et al.*, 1987). Delays in attaining salt balance following land clearance are due to the immobility of salt stored in low hydraulic conductivity zones of the regolith. The leaching of salt from these zones, most typically the saprolite, requires a major influx of groundwater, which is only achieved when groundwater levels saturate the regolith (Johnston, 1987b). However, salt is released from the saprolite at the same rate at which groundwater moves through this zone (10^{-9} to 10^{-8} m/s), which is very slow compared with recorded watertable rises of 0.9 to 2.6 m/a (Johnston, 1987b; Williamson *et al.*, 1987). The rates of rise are ~1000 times the rate of movement. The initial increases in the salinity of groundwater in the experimental catchments were revealed to be the result of groundwater saturating more saline parts of the profile (Johnston *et al.*, 1987b). The salt balance in these catchments is yet to be attained.

Research is continuing in a number of these experimental catchments in order to gain a better understanding of groundwater dynamics and to determine the long term, major controls on salinisation (Mauger, 1994).

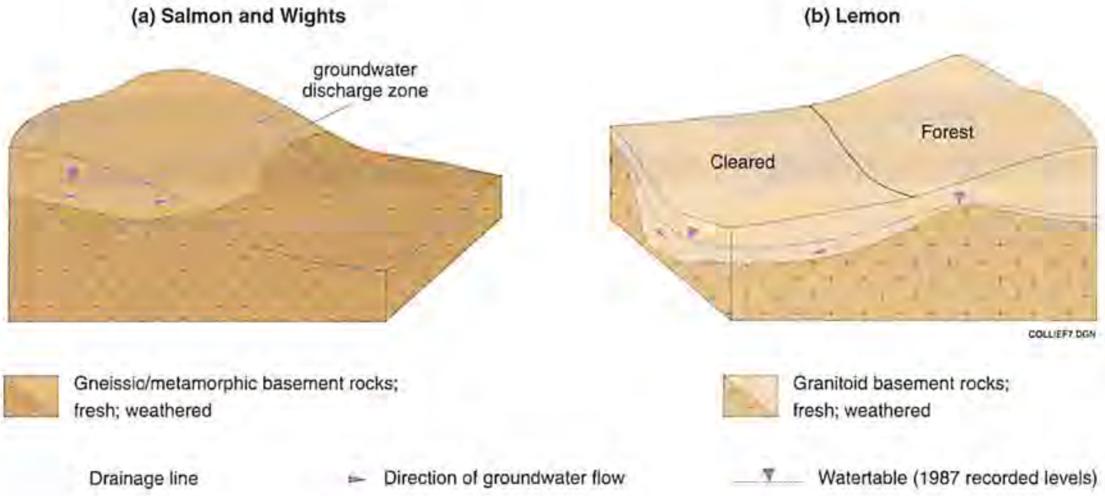


Figure 7. Geological controls on groundwater flow and discharge in the Collie Catchment;
(a) Salmon and Wights Catchments (adapted from Peck and Williamson, 1987; Turner et al., 1987)
(b) Lemon Catchment (adapted from Johnston, 1987a)

Watertable rises and salinisation may also occur in association with increased recharge to groundwater within Tertiary and Cainozoic sediments that occupy lower to mid landscape areas in the Yilgarn–Southwest Province. These sediments commonly have higher hydraulic conductivities than the weathered profile of adjacent granitoid and gneissic basement and therefore form zones of preferential recharge (Clarke *et al.*, 2000). Depending on hydraulic gradients, the thickness of the sediments and the hydraulic conductivity of overlying sediments (where they are present), groundwater may discharge at the land surface (George *et al.*, 1994; Clarke, 1998).

In the Perth Basin, the areas vulnerable to salinisation are largely restricted to specific lithologic and geomorphic zones within the Swan Coastal Plain. Natural groundwater salinity is associated with the coastal lakes in the Tamala Limestone (*Qt*) and areas within the Guildford Formation (clay member) (*Qpgc*), near the Benger Swamp (refer to Map). In the coastal lakes, hypersaline water is located at the base of the superficial aquifer and is generally not disturbed by agricultural practices. Farther inland, swamps are associated with poorly drained areas where rainfall, and therefore salt, slowly enters the 'clay-rich' sediments and is stored in shallow watertables. At times of high rainfall, lakes form, with ensuing evaporation concentrating the salt within the groundwater and increasing the salinity at the watertable (Deeney, 1989a).

Salinisation in the Tamala Limestone (*Qt*) and Guildford Formation (sand member) (*Qpgs*), is negligible owing to high rainfall and effective drainage. Increased recharge from clearing and irrigation in the South West Irrigation Area near Myalup, in conjunction with the evaporation of applied water, has increased salinities (George *et al.*, 1997).

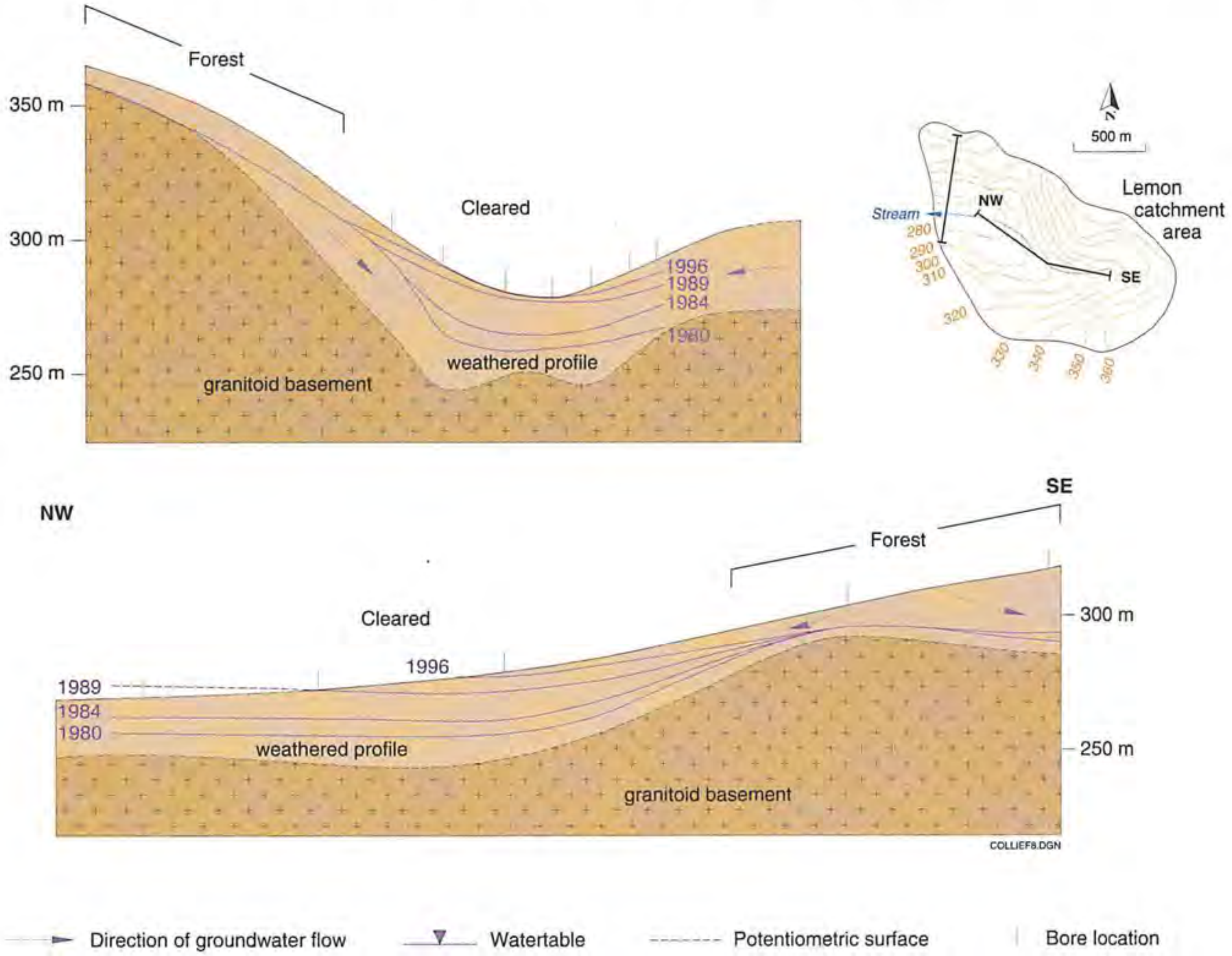


Figure 8. Watertable rise in Lemon Catchment 1980 - 1996

6 Groundwater development

6.1 Town water supplies

Groundwater is the main source for public water supplies in the Perth Basin, whereas inland towns rely on water piped from the Harris–Wellington reservoir system, or from local surface sources. Town water supplies in the Perth Basin are drawn from the Leederville Formation and the Yarragadee Formation. As these aquifers are laterally extensive, bores are placed where convenient for the distribution system, within or immediately adjacent to the townsites. The groundwater in the confined aquifers is inferred to be thousands of years old and therefore is not readily subject to contamination; nor are there environmental implications involved in pumping the water. Careful management of abstraction is required for bores near the ocean at Bunbury, Binningup and Myalup, due to the proximity to sea water interfaces.

Groundwater for Bunbury is drawn from the Yarragadee Formation, by bores to depths of 60 m. These are distributed through the city (Commander, 1982) and feed a number of local treatment plants. The total abstraction is currently about 6 GL/a. Groundwater salinity is generally 300 to 500 mg/L, except near the coast where bores have encountered higher salinity, due to the proximity of the seawater interface. The seawater interface has been penetrated in the Symmonds Street bore in the extreme northwest (Commander, 1982). The groundwater contains varying amounts of iron and minor manganese, which have to be removed by aeration and filtration. Groundwater from the Yarragadee Formation in the east of the city, drawn from bores below the Bunbury Basalt, generally has a lower iron content.

Capel and Boyanup water supplies are also from the Yarragadee Formation, and the towns of Australind and Eaton draw groundwater from both the Yarragadee and Leederville Formations. Dardanup, Donnybrook, Binningup and Myalup town supplies are all from the Leederville Formation.

6.2 Irrigation

The main area irrigated from groundwater is on the coastal plain in the vicinity of Lake Preston. Groundwater is drawn from the unconfined aquifer in the Tamala Limestone at depths of between 3 and 25 m mainly for vegetables, lucerne and citrus crops. Natural groundwater salinity ranges up to about 1500 mg/L, especially downstream of the swamps, and salinity has also risen due to recirculation of salts. Groundwater abstraction for irrigation is mainly within the South West Coastal Groundwater Area, in which all abstraction is licensed.

Irrigation in the eastern part of the coastal plain, mainly for pasture, is carried out using surface water channelled from the Harvey and Wellington Dams.

Irrigation in the lower Preston River valley west of Donnybrook utilises groundwater from the Leederville Formation at depths of as much as 200 m (Koomberi, 1996). The main crops are apples and stone fruit, with some turf. In the Preston Valley east of Donnybrook, as far upstream as Mumballup, crops are mainly stone fruit and nuts which, dependent on the salinity, use minor groundwater for irrigation from alluvium in the Preston River valley (Commander, 1993).

6.3 Mining and industry

The major groundwater abstraction associated with mining on COLLIE is from the Collie Basin. Groundwater is pumped from borefields and from opencut and underground coal mines. Total groundwater abstraction for all purposes is about 25 GL/a, of which about 6 GL/a are supplied to the Muja Power Station (Dames and Moore Pty Ltd, 1998). The groundwater is fresh to marginally saline (<1000 mg/L), with pH generally less than 6 and high concentrations of suspended sediment (Dames and Moore Pty Ltd, 1996). The quality of abstracted minewater is dependent on location, runoff and groundwater volumes and residence time in swamps and holding ponds (Dames and Moore Pty Ltd, 1996).

Dewatering and its consequent disposal has substantially altered the groundwater regime. Water in the Collie River South has leaked into underground mines, resulting in lowered pool levels, and disposal has created perennial pools where the river was otherwise at a seasonally low level.

The mineral sand industry on COLLIE, centred around Capel and Boyanup in the Perth Basin, is an important groundwater user with an abstraction of about 17 GL/a for mineral sand separation and processing. The processing plants at Capel, and mining areas along the Whicher Scarp between Yoganup and Boyanup, utilise groundwater from the Yarragadee Formation.

Groundwater was drawn from five bores in the Leederville and Yarragadee Formation for the former titania plant at Australind. The industrial park at Kemerton is supplied from the superficial formations (~1 GL/a), and the Leederville and Cockleshell Gully Formations (~4 GL/a).

A number of industrial users abstract smaller amounts of groundwater from the Leederville Formation in the Picton area east of Bunbury.

The Dardadine tannery, 15 km northeast of Darkan, is the only significant groundwater user within the Yilgarn–Southwest Province on COLLIE. Groundwater is abstracted from the Dardadine Palaeochannel from a bore yielding up to 350 kL/d.

6.4 Domestic and stock water

Groundwater is used widely on the coastal plain, although in the Guildford Formation (clay member) in the east the salinity is too high for drinking. Bores have been drilled for stock water throughout the Yilgarn–Southwest Province, but few are currently in use due to generally high salinities and low yields. Stock water is commonly supplied from excavated soaks throughout the eastern and southern part of COLLIE.

6.5 Groundwater resources

The Mesozoic (Yarragadee and Leederville Formations) and superficial aquifers in the Perth Basin are the most significant groundwater resources on COLLIE (Table 3). Archaean and Proterozoic basement rocks do not provide significant groundwater supplies, and groundwater in the Permian Wilga and Boyup Basins, Tertiary palaeochannels and Cainozoic sediments in the Yilgarn–Southwest Province are yet to be fully assessed.

6.6 Groundwater development

Groundwater abstraction is managed according to the Management Plans for the Bunbury Groundwater Area, the Busselton–Capel Groundwater Area, and the South West Coastal Groundwater Area (Hammond, 1989). Allocation limits have been reached in the South West Coastal Groundwater Area, and for the Leederville Formation in the Donnybrook Sub-area of the Busselton Capel Groundwater Area, but there is scope for significant further development in the Leederville and Yarragadee Formations to the south of Kemerton. North of Kemerton, the groundwater in the Leederville and Cockleshell Gully Formations is mainly brackish to saline.

The groundwater resources in the Collie Basin are being progressively depleted on a local scale around the mines. Groundwater resources in the Wilga and Boyup Basins are not currently utilised. There is potential for supplies from the Wilga Basin of fresh to marginal water (<1500 mg/L), whereas in the Boyup Basin the groundwater is brackish to saline.

There is some potential for development of groundwater supplies from the palaeochannels for small-scale supply to rural industry or irrigation, of marginal to brackish water. Groundwater resources in the Preston River valley have not been assessed and may have potential for further horticultural development.

The area of Tertiary sediments north of the Collie Basin in the catchments of the Harris and Bingham Rivers may contain relatively thin (tens of metres) aquifers, but has not been investigated.

Table 3. Groundwater use and resource estimates in the Perth Basin

Aquifer	*Licensed*		*Unlicensed stock and domestic*	*Total use (GL/a)*	*Sustainable yield*	
	Urban/industrial	*Irrigation*			*(GL/a)*	*(% Use)*
Leederville Formation	13 564	15 269	852	29 685	65 807	45
Yarragadee Formation	31 823	4 647	105	36 575	100 000	37
Superficial Formations	5 770	25 583	4 716	36 069	115 500	31

Note: includes part of Busselton Capel Groundwater Area on the BUSSELTON sheet

7 References

ALLEN, A.D., 1976, Outline of the hydrogeology of the superficial formations of the Swan Coastal Plain: Western Australia Geological Survey, Annual Report for 1975, p. 31–42.

GILKES, R. J., 1984, Weathering of hornblende, plagioclase and chlorite in meta-dolerite, Australia: Geoderma, v. 34, p. 261–280.

ANAND, R. R., and GILKES, R. J., 1987, Muscovite in Darling Range bauxitic laterite: Australian Journal of Soil Research, v. 25, p. 445–450.

ANAND, R. R., GILKES, R. J., ARMITAGE, T. M., and HILLYER, J.W., 1985, Feldspar weathering in lateritic saprolite: Clays and Clay Minerals, v. 33, no. 1, p. 31–43.

APPLEYARD, S. J., 1991, The geology and hydrogeology of the Cowaramup borehole line, Perth Basin, Western Australia: Western Australia Geological Survey, Professional Papers, Report 30, p. 1–12.

APPLEYARD, S. J., 1993, Explanatory notes for the groundwater vulnerability to contamination maps of the Perth Basin: Western Australia Geological Survey, Record 1993/6, 28p.

BACKHOUSE, J., 1995, Donnybrook DNB 1, 2, 3, 4, 5 palynology: Western Australia Geological Survey, Palaeontology Report 1995/2 (unpublished).

BACKHOUSE, J., and WILSON, A. C., 1989, New records of Permian and Cretaceous sediments from the southwestern part of the Yilgarn Block: Western Australia Geological Survey, Professional Papers, Report 25, p.1–5.

BARI, M. A., 1992, Early streamflow and salinity response to partial reforestation at Batalling Creek catchment in the south-west of Western Australia: Water Authority of Western Australia, Water Resources Directorate, Surface Water Branch, Report No. WS 107, 82p.

BAXTER, J. L., 1977, Heavy mineral sand deposits of Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 10, p. 148.

BETTENAY, E., RUSSELL, W. G. R., HUDSON, D. R., GILKES, R. J., and EDMISTON, R. J., 1980, A description of experimental catchments in the Collie area, Western Australia: Commonwealth Scientific and Industrial Research Organisation, Australian Division Land Resources Management, Technical Paper no. 7, 36p.

CAMPBELL, W. D., 1909, Capel water supply: Western Australia Geological Survey, Annual Report for 1908, p. 15.

CLARKE, C. J., 1998, The impact of geology on dryland salinity, and the development of revegetation strategies, in the western wheatbelt of Western Australia: Murdoch University, Western Australia, PhD thesis (unpublished).

CLARKE, C. J., GEORGE, R.J., BENNETT, D.L., and BELL, R.W., 2000, Geologically related variations in saturated hydraulic conductivity in the regolith of the western wheatbelt of Western Australia and its implications for the development of dryland salinity: Australian Journal of Soil Research, v. 38: p. 555–567.

COMMANDER, D. P., 1982, The geology and hydrogeology of Bunbury: Western Australia Geological Survey, Hydrogeology Report 2327.

COMMANDER, D. P., 1984, The Bunbury shallow drilling groundwater investigation: Western Australia Geological Survey, Professional Papers for 1982, Report 12, p. 32–52.

COMMANDER, D. P., 1988, Geology and hydrogeology of the superficial formations and coastal lakes between Harvey and Leschenault Inlets (Lake Clifton Project): Western Australia Geological Survey, Professional Papers, Report 23, p. 37–50.

COMMANDER, D. P., 1989, Results of exploratory drilling in the Kemerton area: Western Australia Geological Survey, Hydrogeology Report 1989/39.

COMMANDER, D. P., 1993, Groundwater prospects — Mumballup, Upper Preston valley: Western Australia Geological Survey, Hydrogeology Report No 1993/27

COMMANDER, D. P., SMITH, R. A., BADDOCK, L. J., PRANGLEY, C. J., and PERRY, A., 1996, Transient electromagnetic surveys for groundwater exploration in Tertiary sediments: Western Australia Geological Survey, Annual Review 1995–96, p. 111–117.

DAMES and MOORE PTY LTD, 1996, Report: Collie Basin groundwater resource and aquifer review to June 1996, for Western Power Corporation.

DAMES and MOORE PTY LTD, 1998, Report: Collie Basin production/monitoring summary (July 1997 to June 1998), for Western Power Corporation.

DEENEY, A. C., 1989a, Geology and groundwater resources of the superficial formations between Pinjarra and Bunbury, Perth Basin: Western Australia Geological Survey, Professional Papers, Report 26, p. 31–57.

DEENEY, A. C., 1989b, Hydrogeology of the Binningup borehole line, Perth Basin: Western Australia Geological Survey, Professional Papers, Report 25, p. 7–16.

DEENEY, A. C., 1989c, Hydrogeology of the Harvey borehole line, Perth Basin: Western Australia Geological Survey, Professional Papers, Report 26, p. 59–68.

DOBEREINER, L., and PORTO, C.G., 1993, Considerations on the weathering of gneissic rocks, *in* The engineering geology of weak rocks, *edited by* CRIPPS and others, p. 193–205.

DODSON, W. J., 1999, Hydrogeology of the Newdegate 1:250 000 Sheet; Hydrogeological Map Explanatory Notes Series: Water and Rivers Commission Report, HM5, 27p.

ENGEL, R., McFARLANE, D. J., and STREET, G., 1987, The influence of dolerite dykes on saline seeps in south-western Australia: Australian Journal of Soil Research, v 25, p. 125–136.

GEORGE, R. J., 1992, Hydraulic properties of groundwater systems in the saprolite and sediments of the wheatbelt, Western Australia: Journal of Hydrology, v. 130, p. 251–278.

GEORGE, R. J., COCHRANE, D. L., and BENNETT, D. L., 1994, Groundwater systems responsible for dryland salinity in the Lake Towerrinning catchment, Western Australia, *in* Water Down Under '94, v. 2A, Groundwater Papers: Combined 25th Congress of the International Association of Hydrogeologists with the 22nd International Hydrology and Water Resources Symposium of The Institution of Engineers, Adelaide November 1994, p. 355–360.

GEORGE, R. J., McFARLANE, D., and NULSEN, B., 1997, Salinity threatens the viability of agriculture and ecosystems in Western Australia: Journal of Hydrogeology, v. 5, p. 6–21.

HAMMOND, R., 1989, South West Coastal Groundwater Area — groundwater management plan review: Water Authority of Western Australia, Water Resources Directorate, Groundwater Branch, Report WG 84.

HARDMAN, E. T., 1884, Report on the geology and supposed gold-bearing rocks in the neighbourhood of Bunbury, the Blackwood, etc.: Western Australia Parlimentary Paper No. 19 of 1884.

HAWKES, G. E., 1993, A review of available groundwater data in the Boscabel and Kybellup Plain areas: Western Australia Geological Survey, Hydrogeology Report 1993/24 (unpublished).

HINGSTON, F. J., and GAILITIS, V., 1976, The geographic variation of salt precipitated over Western Australia: Australian Journal of Soil Research, v. 14, p. 319–335.

HIRSCHBERG, K-J. B., 1976, Collie Basin groundwater resources: Western Australia Geological Survey, Hydrogeology Report 1457 (unpublished).

HIRSCHBERG, K-J. B., 1989, Busselton shallow-drilling groundwater investigation: Western Australia Geological Survey, Professional Papers, Report 25, p. 17–37.

HOOKEY, G. R., 1987, Prediction of delays in groundwater response to catchment clearing, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special Issue, no. 1/2, p. 181–198.

JOHNSTON, C. D., 1987a, Distribution of environmental chloride in relation to subsurface hydrology, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 67–88.

JOHNSTON, C. D., 1987b, Preferred water flow and localised recharge in a variable regolith, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 129–142.

JOHNSTON, C. D., HURLE, D. H., HUDSON, D. R., and HEIGHT, M. I., 1983, Water movement through preferred paths in lateritic profiles of the Darling Plateau, Western Australia: Commonwealth Scientific and Industrial Research Organisation, Division of Groundwater Resources, Technical Paper No. 1.

KARAFILIS, D. W., and RUPRECHT, J. K., 1993, Harris–Wellington Reservoir system yield and salinity study: Water Authority of Western Australia, Water Resources Directorate, Report No. WS 130, 44p.

KERN, A. M., 1985, SCM Chemicals factory effluent disposal scheme; performance of effluent disposal areas on the Leschenault Peninsula September 1985: Western Australia Geological Survey, Hydrogeology Report 2712.

KOOMBERI, H. A., 1996, Hydrogeology of the Leederville Formation in the Donnybrook horticultural area: Western Australia Water and Rivers Commission, Hydrogeology Report HR 22 (unpublished).

LAWS, A. T., 1992, Review of available data on the Wilga, Boyup, and minor basins in southwest Western Australia, and a proposed assessment program: Western Australia Geological Survey, Hydrogeology Report 1992/12 (unpublished).

LE BLANC SMITH, G., 1993, Geology and Permian coal resources of the Collie Basin, Western Australia: Western Australia Geological Survey, Report No. 38, 86p.

LORD, J. H., 1952, Collie Mineral Field: Western Australia Geological Survey, Bulletin 105, Part 1, 247p.

MacPHERSON, D. K., and PECK, A. J., 1987, Models of the effect of clearing on salt and water export from a small catchment, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 163–179.

McARTHUR, J. M., TURNER, J. V., LYONS, W. B., and THIRLWALL, M. F., 1989, Salt sources and water-rock interaction on the Yilgarn Block, Australia—isotopic and major element tracers: Applied Geochemistry, v. 4, p. 79–92.

McCREA, A. F., ANAND, R. R., and GILKES, R. J., 1990, Mineralogical and physical properties of lateritic pallid zone materials developed from granite and dolerite: Geoderma, v. 47, p. 33–57.

MAITLAND, A. G., 1913, The artesian water resources of Western Australia, *in* Report of the Interstate Conference on Artesian Water, Brisbane, 1912 *compiled by* J. E. SLADE: New South Wales, Government Printer, Appendix M, p. 115–129.

MARTIN, M. W., 1982, Maringee farm salinity study — Hydrogeology: Western Australia Geological Survey, Hydrogeology Report No. 2589 (unpublished).

MARTIN, M. W., 1984, Maringee Farm salinity study — Hydrogeology: Western Australia Geological Survey, Hydrogeology Report 2589 (unpublished).

MAUGER, G., 1994, Trees on farms to reduce salinity in the clearing control catchments — volume 2: Wellington catchment: Water Authority of Western Australia, Report WS 148.

MOHSENZADEH, H., 1998a, Collie Basin watertable monitoring bores drilling project — bore completion reports: Western Australia Water and Rivers Commission, Hydrogeology Report HR 118 (unpublished).

MOHSENZADEH, H., 1998b, Collie Basin watertable monitoring bores drilling results: Western Australia Water and Rivers Commission, Hydrogeology Report HR 119 (unpublished).

MONCRIEFF, J. S., 1988, Groundwater prospects Towerrinning, West Arthur: Western Australia Geological Survey, Hydrogeology Report 1988/R7 (unpublished).

MONCRIEFF, J. S., 1993, Hydrogeology of the Collie Basin, Western Australia: Western Australia Geological Survey, Professional Papers, Report 34, p. 129–153.

MYERS, J. S., and HOCKING, R. M., 1998, Geological map of Western Australia, 1:2 500 000 (13th edition): Western Australia Geological Survey.

NAHON, D., and TARDY, Y., 1992, The ferruginous laterites, *in* Regolith exploration geochemistry in tropical and subtropical terrains *edited by* C.R.M., BUTT and H, ZEEGERS: Handbook of Exploration Geochemistry, 4, Elsevier, Amsterdam, 42pp and 537pp.

NULSEN, R. A., 1981, Critical depth to saline groundwater in non-irrigated situations: Australian Journal of Soil Research, v. 19, p. 83-86.

PANASIEWICZ, R., De SILVA, J., and McGANN, M. P., 1997, Pemberton and Blackwood drilling programs — Completion report: Western Australia Water and Rivers Commission, Hydrogeology Report HR 86 (unpublished).

PECK, A. J., and WILLIAMSON, D. R., 1987, Effects of forest clearing on groundwater, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 47–66.

PERRY, A., 1994, Geophysical surveys for fresh water mapping Beaufort Palaeochannel Volume 1: World Geoscience Corporation Limited, Job No. 3010.

PLAYFORD, P. E., COCKBAIN, A. E., and LOW, G. H., 1976, Geology of the Perth Basin, Western Australia: Western Australia Geological Survey, Bulletin 124, 311p.

PLAYFORD, P. E., and WILMOTT, S. P., 1958, Stratigraphy and structure of the Perth Basin, Western Australia: West Australian Petroleum Pty Ltd Report (unpublished).

PRANGLEY, C. J., 1994a, Boscabel Palaeochannel project bore completion report: Western Australia Geological Survey, Hydrogeology Report 1994/11 (unpublished).

PRANGLEY, C. J., 1994b, Towerrinning palaeochannel project bore completion report: Western Australia Geological Survey, Hydrogeology Report 1994/12 (unpublished).

PRANGLEY, C. J., 1994c, Manjimup fractured rock drilling project bore completion report: Western Australia Geological Survey, Hydrogeology Report 1994/21 (unpublished).

PRANGLEY, C. J., 1995, Darkan palaeochannel drilling bore completion report TOW 41–TOW 44: Western Australia Geological Survey, Hydrogeology Report 1995/51 (unpublished).

PROBERT, D. H., 1968, Groundwater in the Busselton area — progress report on exploratory drilling: Western Australia Geological Survey, Annual Report for 1967, p. 12–17.

RUPRECHT, J. K., and SCHOFIELD, N. J., 1991, The effect of partial clearing on the hydrology and salinity of the Lemon catchment: Water Authority of Western Australia, Surface Water Branch, Report no. WS 74, 25p.

SALAMA, R. B., BARTLE, G., FARRINGTON, P., and WILSON, V., 1994, Basin geomorphological controls on the mechanism of recharge and discharge and its effect of salt storage and mobilisation — comparative study using geophysical surveys: Journal of Hydrology, v. 155, p. 1–26.

SHARMA, M. L., BARRON, R. J. W., and WILLIAMSON, D. R., 1987, Soil water dynamics of lateritic catchments as affected by forest clearing for pasture, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 29–46.

SMITH, F. G., 1974, Vegetation map of Collie Sheet SI 50-6 International Index: Western Australia Department of Agriculture.

SMITH, R. A., 1984, Geology and hydrogeology of the Boyanup Bore Line, Perth Basin: Western Australia Geological Survey, Professional Papers for 1982, Report 12, p. 72–81.

SOFOULIS, J., 1966, Widgiemooltha, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 25p.

SUTTON, J. L., 1999, The mineralogical and petrophysical properties of the regolith at Broomehill, southwestern Australia: Curtin University of Technology, Western Australia, BSc Honours thesis (unpublished)

THORPE, P. M., and BADDOCK, L. J., 1994, Groundwater resources of the Busselton–Walpole Region. Western Australia Geological Survey, Hydrogeology Report 1994/29 (unpublished).

TILLE, P. J., and PERCY, H. M., 1995, Land Resources *in* Remnant Vegetation and Natural Resources of the Blackwood River Catchment: An Atlas *compiled by* S.B. GREIN: Spatial Resources Information Group, Agriculture Western Australia Miscellaneous Publication 9/95.

TURNER, J. V., ARAD, A., and JOHNSTON, C. D., 1987, Environmental isotope hydrology of salinised experimental catchments, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 89–107.

WATERHOUSE, J. D., COMMANDER, D. P., PRANGLEY, C., and BACKHOUSE, J., 1995, Newly recognised Eocene sediments in the Beaufort Palaeochannel: Western Australia Geological Survey, Annual Review 1993–94, p. 82–85.

WHARTON, P. H., 1980, The geology and hydrogeology of the Picton borehole line: Western Australia Geological Survey, Annual Report for 1979, p. 14–20.

WHARTON, P. H., 1981a, Geology and hydrogeology of the Picton line of bores, Perth Basin: Western Australia Geological Survey, Record 1981/2, 34p.

WHARTON, P. H., 1981b, The geology and hydrogeology of the Quindalup borehole line: Western Australia Geological Survey, Annual Report for 1980, p. 27–34.

WHARTON, P. H., 1982, The geology and hydrogeology of the Quindalup borehole line in southern Perth Basin, Western Australia: Western Australia Geological Survey, Record 1982/2, 35p.

WILDE, S. A., and BACKHOUSE, J., 1977, Fossiliferous Tertiary deposits on the Darling Plateau: Western Australia Geological Survey, Annual Report for 1976, p. 49–52.

WILDE, S. A., and WALKER, I. W., 1982, Collie, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

WILLIAMSON, D. R., STOKES, R. A., and RUPRECHT, J. K., 1987, Response of input and output of water and chloride to clearing for agriculture, *in* Hydrology and salinity in the Collie River Basin, Western Australia *edited by* A. J. PECK and D. R. WILLIAMSON: Journal of Hydrology, v. 94, Special; Issue, no. 1/2, p. 1–29.

WILSON, A. C., 1989, Palaeocurrent patterns in the Collie coal measures — the implication for sedimentation and basin models: Western Australia Geological Survey, Professional Papers for 1989, Report 25, p. 85–91.

WILSON, A. C., 1990, Collie Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 525–531.

WOOD, W. E., 1924, Increase of salt in soil and streams following the destruction of the native vegetation: Journal of the Royal Society, Western Australia, v. 10, p. 35–47.

YESERTENER, C., 1997, Boyup Basin drilling project: Western Australia Water and Rivers Commission, Hydrogeology Report HR 54 (unpublished).

Appendix

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

Design file	Level	Description
Collietopo.*dgn*	1	Highways
	2	Tracks
	4	Railway, railway abandoned, railway siding symbol
	6	Pipeline, pipeline text
	15	Indian Ocean
	19	Permanent lakes
	26	Saline lakes
	20	Drainage permanent
	21	Drainage intermittent, flow arrow
	22	Lakes permanent, names
	23	DL stream
	24	Rivers, creeks, names
	25	Reservoirs
	27	Swamp symbols, swamp outline, swamp names
	31	Underground mine dewatered
	32	Open cut mine dewatered
	35	Topographic contours, values
	36	National parks, nature reserves
	41	Arrow heads, text
	42	Road names, highway names, siding names
	43	Peaks/mountains/hills, rocks, ranges
	44	Control points: major, minor, control point names
	45	Localities
	46	Towns: Population <1000, 1000–10 000, >10 000
Colliegeo.*dgn*	1	Geological boundaries
	2*	Outcrop boundaries
	3*	Ql boundaries
	4*	Hidden polygon boundaries
	5	Faults concealed, faults inferred, Darling Fault
	8	Outline of Collie Basin
	17	Dolerite dykes
	18	Quartz veins
	19*	Dykes not shown on map
	40	Geological labels and lead lines
	41	X-section lines and labels
	45	AMG grid
	53*	GIS, polygon labels
	60	Ticks, text for latitude and longitude grid
	61*	Latitude and longitude grid
	62	Map border
	63*	Level structure
Colliesal.*dgn*	1	Isohalines
	5	Area of saltwater intrusion
	6*	Fault line
	8*	Outline of Collie Basin
	45*	AMG grid
	61*	Latitude and longitude grid
Colliegwc.*dgn*	1	10 m contours and values
	2	20 m contours and values
	3	30 m contours and values
	4	40 m contours and values
	5*	Faultline
	8*	Outline of ocean
	9*	Outline of Collie Basin
	15*	170 m contours and values
	16*	180 m contours and values
	17*	190 m contours and values
	18*	200 m contours and values
	19*	210 m contours and values
	20*	220 m contours and values
	21	Major surface water divides
	22*	Major Surface Water Divides
	23*	Digitize line for Major Surface Divide
	24	Groundwater contamination
	45*	AMG grid
	60*	Latitude and Longitude grid
Colliebore.*dgn*	1	Water bore, abandoned, <50 m^3/d
	2	Water bore, yield >50 m^3/d
	3	Water bore, yield <50 m^3/d
	4	Monitoring bores
	5	Soaks, seepage areas
	6	Well abandoned
	7	Well, yield >50 m^3/d
	8	Well, yield <50 m^3/d
	9	Cluster of monitoring bores
	10	Experimental catchment with numerous bores
	11	Exploratory drilling line
	12	Monitoring production bores >500 m^3/d
	60*	Latitude and longitude grid
Collieply.*dgn*	1	Qa
	2	Qt
	3	Qpgs
	4	Qpgc
	5	Qpy
	6	Cza
	7	Czc
	8	Czg
	9	Tw

Design file	Level	Description
	10	Twq
	11	Kn
	12	Kl
	13	Kb
	14	Pn
	15	Pcm
	16	Ps
	17	Pd
	18	Aq
	19	Ago
	20	Ag
	21	Ano
	22	An
	23	Dam
	24	Water
	62*	Clean linework
	63*	GIS text labels
Colliepan.*dgn*	1	Linework for polygonisation Printing boundary
	2*	Linework for polygonisation (hidden)
	3	Extent of weathering, section and legend only
	4	Groundwater features – legend and section
	5	Faults, faults inferred
	6	Bore distribution (ref scale colliebore, replace cell moc); bores legend; bores section, text for bores
	7	Isohalines – legend and section
	8	Topographic contour – legend
	9	Grey linear features, legend and section
	10	Area of saltwater intrusion
	11*	Offset for position of trim marks, maximum printing area
	20	Outline of Collie basins
	21	Coastline, surface waterfeatures, blue linear features
	27	Dots for subsurface extent of Bunbury Basalt
	31	Underground mine dewatered
	32	Open cut mine dewatered
	40	Geological labels and lead lines
	41	Quartz vein dyke – legend and section

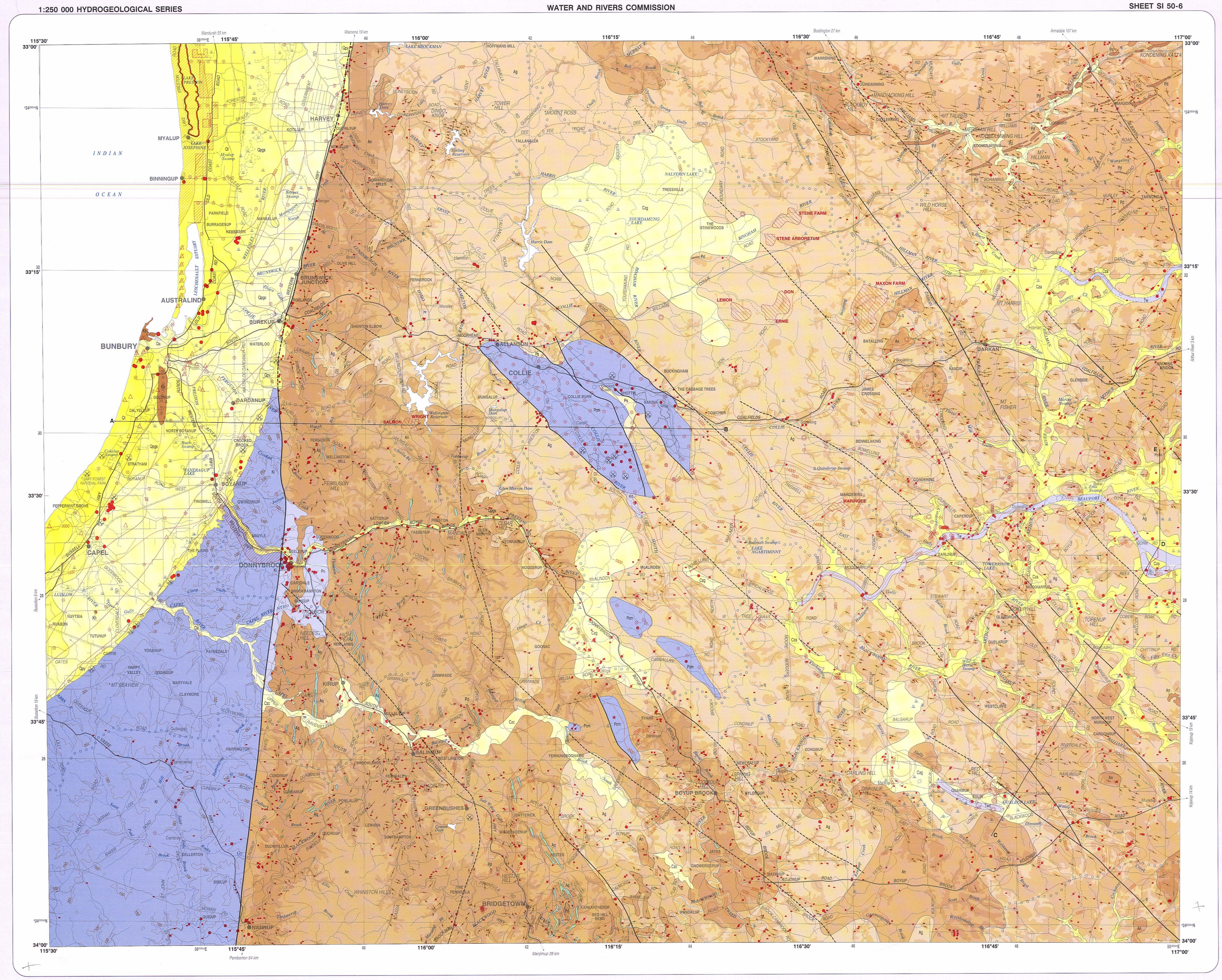
Design file	Level	Description
	42	Dolerite dyke – legend and section
	45	AMG grid
	46	Map border, WRC logo – water only
	47	WRC logo – leaves only (green*)*
	50	Gov logo – black outline
	53	Gov logo – white
	54	Gov logo – BLK 30%
	58	Gov logo – BLK
	59	Gov logo – BLK 80%
	60	Black text, labels
	61	Registration marks for colour separates
	62*	Level structure
	63*	GIS labels, text IDs for polygons
Panply.*dgn*	1	Qa
	2	Qt
	3	Qpgs
	4	Qpgc
	5	Qpy
	6	Cza
	7	Czc
	8	Czg
	9	Tc
	10	Tw
	11	Twq
	12	Kn
	13	Kl
	14	Kb
	15	Juy
	16	Jlo
	17	Pn
	18	Pcm
	19	Ps
	20	Pd
	21	Aq
	22	Ago
	23	Ag
	24	Ano
	25	An
	26	Dam
	27	Evaporation – graph only
	28	Rain – graph only
	29	Landmass, yellow
	30	Location area
	31	Map border
	32	Salinity <1000 mg/L
	33	Salinity 1000–3000 mg/L
	34	Salinity 3000–7000 mg/L
	35	Salinity 7000–14 000 mg/L
	36	Salinity >14 000 mg/L

* Note information not shown on printed map

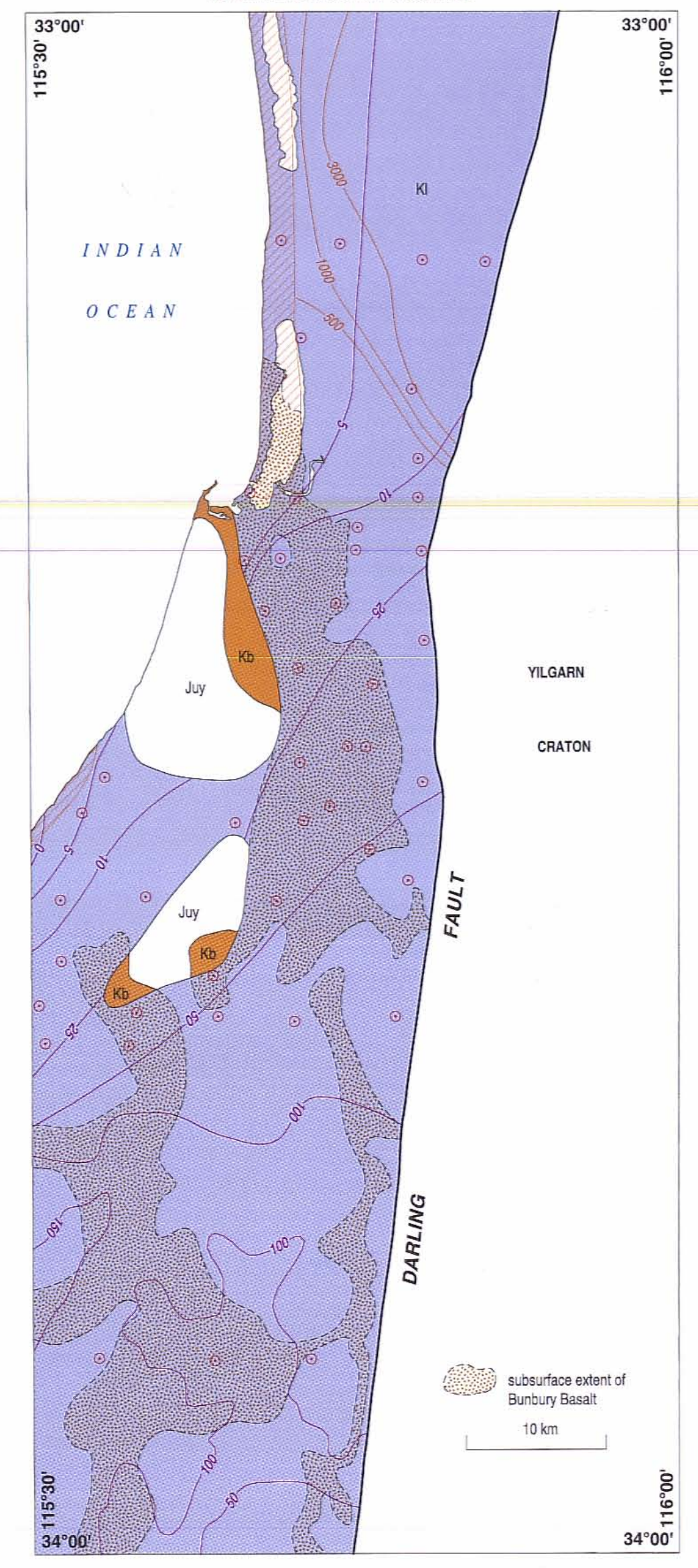
HYDROGEOLOGY: COLLIE 1:250,000

COLLIE

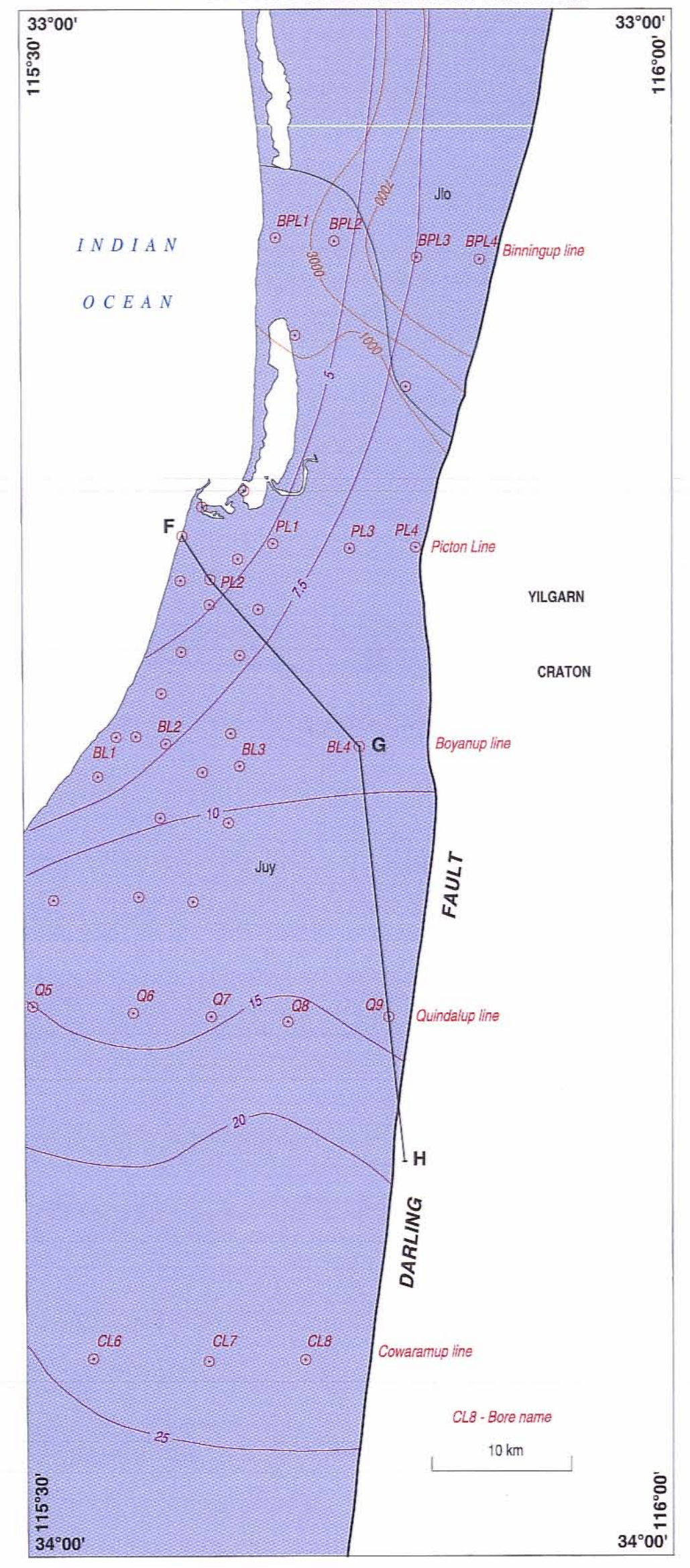
WATER AND RIVERS COMMISSION



SALINITY AND POTENTIOMETRIC HEAD IN THE LEEDERVILLE FORMATION

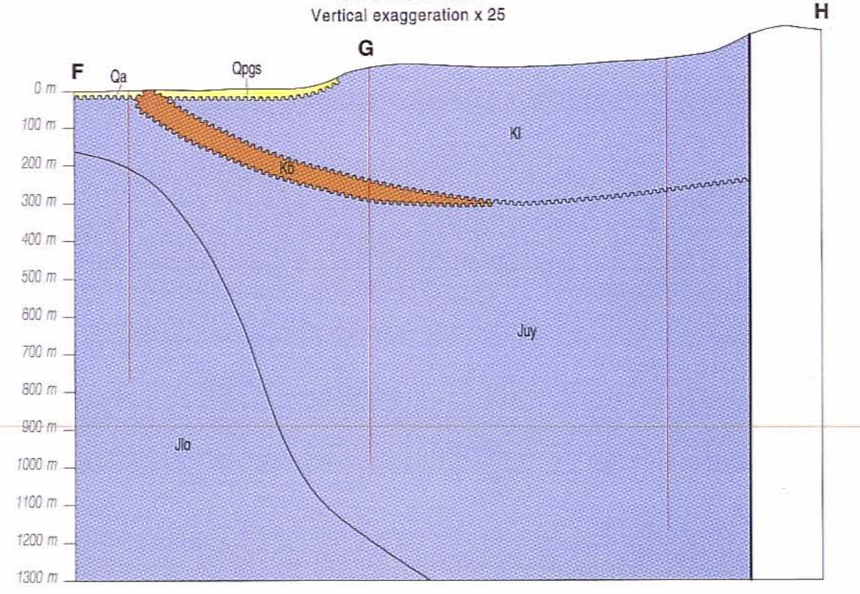


SALINITY AND POTENTIOMETRIC HEAD IN THE YARRAGADEE AND COCKLESHELL GULLY FORMATIONS



SECTION FGH

Vertical exaggeration x 25



REFERENCE

AQUIFER CHARACTERISTICS

Surficial aquifer – karstic or unconsolidated, extensive or local major to minor groundwater resources

Sedimentary aquiclude minor or no groundwater resources

Sedimentary aquifer – major to minor groundwater resources, extensive to local unconfined and confined aquifers with intergranular porosity, minor local unconfined and confined aquifers; inclusive of palaeochannels

Aquiclude – no groundwater resources

Fractured rock aquifer – locally fractured and jointed, minor groundwater resources

Fractured and weathered rocks – local aquifer, minor or no groundwater resources

Fractured and weathered rocks – local aquifer, minor or no groundwater resource

HYDROGEOLOGY

PHANEROZOIC – CAINOZOIC	QUATERNARY	Qa	Alluvium; sands, silts and clays deposited by modern drainage	Minor local aquifer; fresh to saline	
		Qt	**TAMALA LIMESTONE** – eolian calcarenite, calcretized and leached to quartz sand	Major unconsolidated or karstic aquifer, generally fresh; saltwater intrusion near coast	
		Qpgs	**GUILDFORD FORMATION** – alluvial sand, clay and gravel with minor estuarine and shallow marine lenses Sand member	Minor local aquifer; fresh to brackish	
		Qpgc	Clay member	Very minor aquifer; brackish to saline	
		Qpy	**YOGANUP FORMATION** – leached or ferruginized beach sand and basal conglomerate	Minor aquifer; fresh to brackish	
		Cza	Alluvium and colluvium; sand, silt, clay, gravel and minor laterite; conceals palaeochannels or overlies weathered basement	Minor local aquifer; brackish to hypersaline	
		Czc	Conglomerate; quartzite or sandstone cobbles in a sand/clay matrix – variably lateritized	Minor aquifer; brackish	
		Czg	Alluvial deposits; broad tracts of sand, clay, silt and gravel; locally lateritized	Minor aquifer; fresh to brackish	
	TERTIARY	Tc	Lacustrine or alluvial clay; restricted to palaeochannels (section only)	Aquitard	
		Tw	Sand – restricted to palaeochannels; concealed by palaeochannel clay and overlain by alluvium and colluvium	Minor to major aquifer ; fresh to hypersaline	
		Twq	Sands and clays within the Qualeup palaeochannel	Minor aquifer; fresh to brackish	
PHANEROZOIC – MESOZOIC	CRETACEOUS	Kn	**NAKINA FORMATION** – fluvio-lacustrine sediments; weakly lithified sandstone, mudstone, claystone and conglomerate	Minor local aquifer; brackish to saline	PERTH BASIN
		Kl	**WARNBRO GROUP** (including the **LEEDERVILLE FORMATION**) – interbedded sandstone, siltstone and shale	Major aquifer; fresh to brackish	
		Kb	**BUNBURY BASALT** – porphyritic basalt; locally weathered to clay in subsurface	Aquiclude	
	JURASSIC	Juy	**YARRAGADEE FORMATION** – interbedded sandstone, siltstone and shale	Major aquifer; mainly fresh	
		Jlo	**COCKLESHELL GULLY FORMATION** – interbedded sandstone, siltstone, shale and coal	Major aquifer; mainly brackish to saline	
PHANEROZOIC – PALAEOZOIC	PERMIAN	Pn	**DONNYBROOK SANDSTONE** – interbedded feldspathic sandstone and shale with minor grit	Minor aquifer; fresh	
		Pcm	Coal measures – interbedded coal seams, sandstone and shale	Major aquifer fresh to brackish	COLLIE BASIN
		Ps	**SHOTTS FORMATION** – siltstone, claystone and mudstone with granitoid clasts overlying crystalline basement	Minor aquifer/aquitard; fresh to brackish	
PROTEROZOIC		Pd	Mafic dyke and sill – fine to coarse-grained, doleritic and gabbroic dykes; some xenolithic	Aquiclude	YILGARN CRATON
		q	Quartz dyke	Minor local aquifer; fresh to saline	
ARCHAEAN		Ag	Granitoid rock, porphyritic and even-grained: outcrop (indicated by darker colour); subsurface generally weathered to clayey sand (indicated by lighter colour)	Minor local aquifer; fresh to saline	
		An	Granitoid gneiss, migmatite and minor schist: outcrop (indicated by darker colour); subsurface generally weathered to clay (indicated by lighter colour)	Very minor local aquifer; fresh to saline	
		Aq	Quartzite – metamorphosed, locally fractured and jointed	Minor local aquifer; fresh to brackish	

SYMBOLS

GEOLOGY

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

SURFACE WATER FEATURES

drainage; permanent, intermittent
lake; permanent, intermittent; reservoir, saline lake; swamp
surface water divide
surface water pipeline

GROUNDWATER FEATURES

40 potentiometric head contour (m AHD)
watertable; position uncertain (section only)
3000 isohaline (mg/L TDS)
area of saltwater intrusion

MINING FEATURES

mine; major opencut, extensive opencut (Collie Basin only)

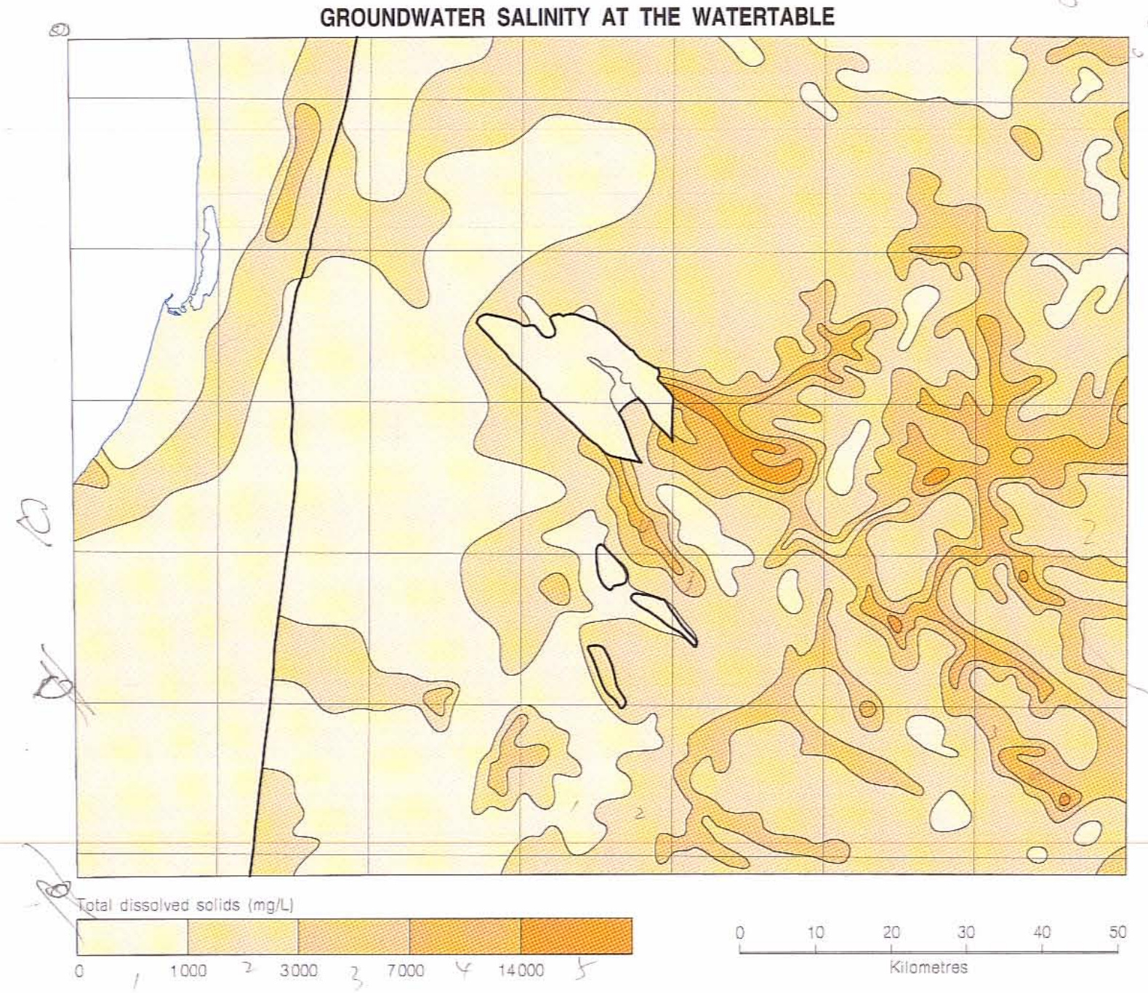
ARTIFICIAL FEATURES

water bore: yield < 50m³/day; > 50m³/day; monitoring; > 500m³/day
water bore abandoned: yield < 50m³/day; > 50m³/day
well: yield < 50m³/day; > 50m³/day; abandoned
excavated soak and seepage areas
cluster of monitoring bores; experimental catchment with numerous bores
area of irrigation using groundwater
Geological Survey Western Australia exploratory drilling line
waste disposal site; abandoned

TOPOCADASTRAL INFORMATION

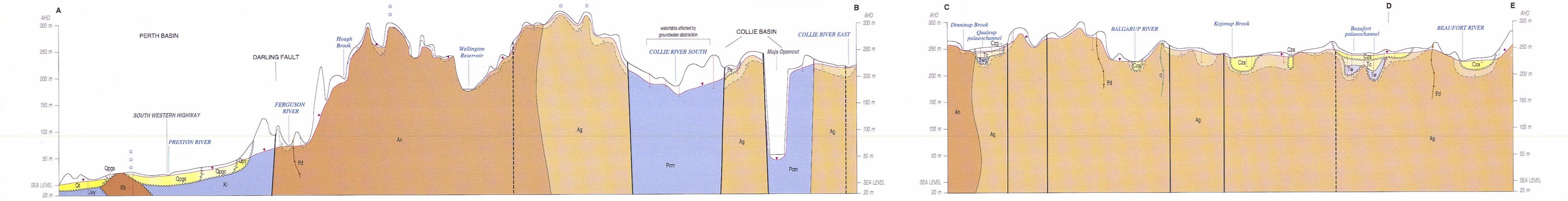
major road with national route marker
minor road
track
Picton railway with siding
GREENBUSHES townsite, population < 1000
BRIDGETOWN townsite, population 1000 – 10000
BUNBURY townsite, population > 10000
FERNBROOK locality
100 topographic contour, 50 metre interval (AHD) (Perth Basin only)
COL 84 horizontal control; major, minor (AHD)
national park boundary

GROUNDWATER SALINITY AT THE WATERTABLE

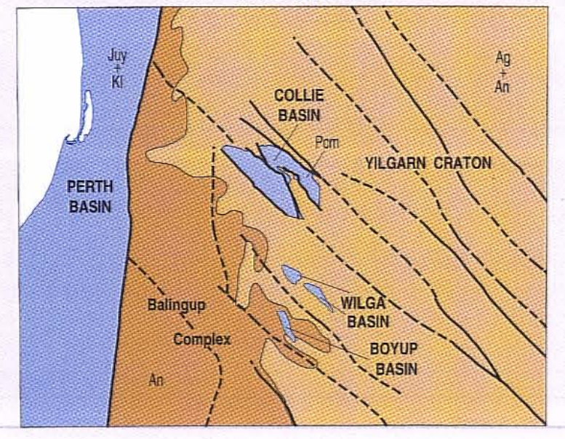


DIAGRAMMATIC SECTIONS

(Bores projected onto section line)
Vertical exaggeration x 50

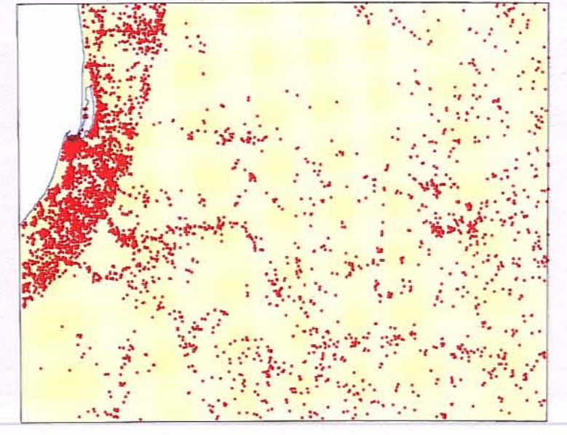


GEOLOGICAL STRUCTURE

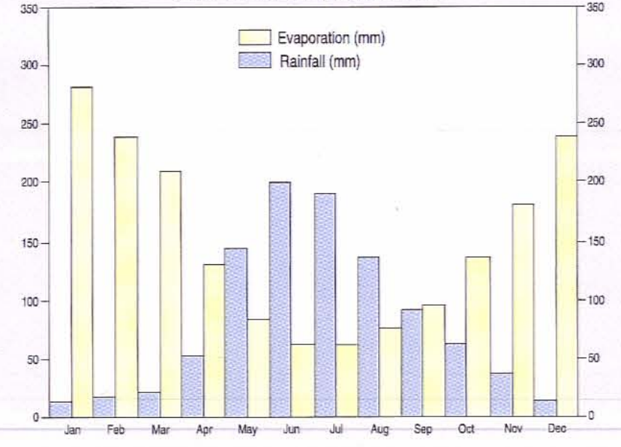


BORE DENSITY

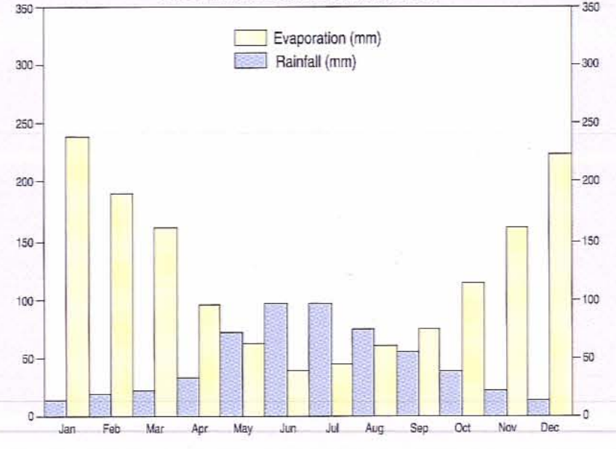
(includes bore categories within 20km of coastline (not shown on main map); > 500m³/day, < 500m³/day, abandoned bores and wells)



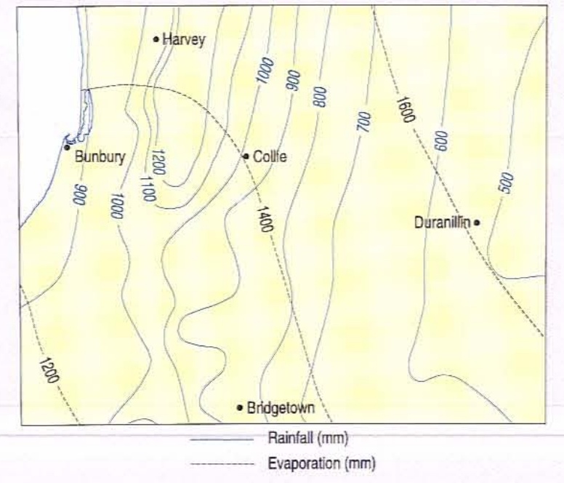
MEAN MONTHLY RAINFALL AND EVAPORATION AT HARVEY



MEAN MONTHLY RAINFALL AT DURANILLIN AND EVAPORATION AT KOJONUP



AVERAGE ANNUAL RAINFALL AND EVAPORATION



SHEET INDEX

FREMANTLE SI 50-1	PINJARRA SI 50-2	CORRIGIN SI 50-3
BUSSELTON SI 50-5	COLLIE SI 50-6	DUMBLEYUNG SI 50-7
AUGUSTA SI 50-9	PEMBERTON SI 50-10	MT BARKER SI 50-11

Hydrogeology by C.J. McCombe, 1999
Geology by S.A. Wilde and I.W.Walker, 1984
J.S. Myers, 1989

Edited by R. Duberal and J. Rutherford

Cartography by D. Donoghue and S. Mulligan Water and Rivers Commission

Topography from the Department of Land Administration Sheet SI 50-6, with modifications from geological field survey

Published by the Water and Rivers Commission.
Copies available from the Water and Rivers Commission,
The Hyatt Centre, 3 Plain Street, East Perth, WA, 6004,
Phone (08) 9278 0300, Fax (08) 9278 0301

This map is also available in digital form

The WRC recommended reference for this map is: McCOMBE C.J., 1999, Collie, W.A. Sheet SI 50-6: Western Australia, Water and Rivers Commission, 1:250 000 Hydrogeological Series

GOVERNMENT OF WESTERN AUSTRALIA
Dr KIM HAMES
MINISTER FOR WATER RESOURCES

WATER AND RIVERS COMMISSION
R. PAYNE
CHIEF EXECUTIVE OFFICER

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 50

1:250 000 HYDROGEOLOGICAL SERIES

COLLIE

SHEET SI 50-6