GROUNDWATER IN THE BUSSELTON AREA, PROGRESS REPORT ON EXPLORATORY DRILLING

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INTRODUCTION

Between September 1966 and August 1967 an east-west line of exploratory groundwater bores was drilled in the Busselton area in the southern part of the Perth Basin. The bores were drilled to investigate groundwater occurrence in the rapidly developing coastal areas between Busselton and Dunsborough and also as part of the general investigation of the Perth Basin. Five bores ranging from 1,485 feet to 2,010 feet deep were drilled at locations shown on Plate 1.

The drilling confirmed the presence west of Busselton of major faulting beneath a strong unconformity seperating underlying older sediments of Permian and Lower Jurassic ages from an overlying blanket of South Perth Formation and Quaternary sediments. The faulting divides the western section of the basin into fault blocks of different ages. Groundwaters in the sediments west of Quindalup bore 1 are generally of poor quality and supply, and unsuitable for domestic use or irrigation. In Quindalup bores 1, 4, and 5 promising supplies of low salinity groundwater were encountered in Lower Jurassic to Lower Cretaceous sediments. This water is suitable for domestic use, but because of high bicarbonate content, some may have to be treated before being acceptable for irrigation use on clayey soils.

The bores were drilled using the Mines Department Mayhew 2000 rotary rig, with sludge samples collected every 10 feet and cores taken wherever practicable. Water samples were collected by means of Halliburton and Johnson Formation Testers and samples sent for analysis at the Government Chemical Laboratories. The bores were geophysically logged by the Geological Survey and routine palynology was carried out on selected samples. The results of chemical analyses and palynological determinations are shown in Appendices 2 and 3.

PHYSIOGRAPHY

The southern part of the Perth Basin has been divided (Lowry, 1965) into four broad physiographic regions.

The *Swan coastal plain* is a flat dune, soil, and alluvium covered plain extending northwards along the coast of Geographe Bay, bounded in the south by the Whicher scarp, and in the east by the Darling fault scarp. The plain has an average width of about 12 miles.

The *Blackwood area* is in the central section of the basin, and has a maximum elevation of about 500 feet, capped by sand and laterite and underlain by Mesozoic sediments.

The *Leeuwin—Naturaliste ridge*, which marks the western margin of the basin, has a maximum elevation of about 700 feet and is a north-south trending ridge of Precambrian crystalline rocks capped by laterite and Coastal Limestone. The ridge is bounded on the east by the Dunsborough fault.

The *Scott coastal plain* is a low lying swampy flat plain marked by scattered dune ridges.

GENERAL GEOLOGY

The southern part of the Perth Basin consists of a deep trough of sediments flanked on the east and west by Precambrian crystalline rocks of the Western Australian Shield and the Leeuwin-Naturaliste ridge. The trough continues to the north and south beneath the Indian Ocean, forming a graben between the Dunsborough and Darling faults.

Geophysical evidence suggests that a maximum thickness of 15,000 to 20,000 feet of easterly dipping sediments is present in the central and eastern sections of the basin, and that this is intersected by four major, branching, north-south trending, faults having throws of up to 8,000 feet.

Lowry has described in detail the surface geology, which consists of a few scattered outcrops of Mesozoic sediments mainly masked by Quaternary deposits including alluvium, dune sands, and Coastal Limestone in the coastal plains, and sand and laterite in the Blackwood area.

Bores have intersected the sediments underlying the Quaternary sequence but mostly they are shallow and have been confined to the Lower Cretaceous—Upper Jurassic South Perth Formation, which probably blankets older sediments over a large proportion of the basin. However Sue No. 1, Alexandra Bridge No. 1 petroleum exploration wells and several coal bores in the southwest encountered Lower Permian sediments beneath the South Perth Formation, and the Abba River and Western Titanium bores encountered the Upper Jurassic Yarragadee Formation.

Quindalup bores 1 to 5

Drilling in the present part of the programme was confined to the Swan coastal plain. Bores 1 to 3 were located on the fringes of Geographe Bay 2½, 6½ and 10 miles west of Busselton respectively, and bores 4 and 5 at Wonnerup and Ruabon, 8 and 12 miles east of Busselton (Plate 1).

The bores intersected a thin veneer of Quaternary sediments overlying South Perth Formation, which in turn is separated from underlying older sediments by a strong unconformity. These sediments include those of Permian, Lower Jurassic, and Upper Jurassic ages.

The stratigraphic relationship between the bores is shown in Table 1.

Quaternary

The Quaternary sediments vary from 20 to 35 feet in thickness, forming a veneer above the South Perth Formation. In bores 1 to 3 they consist of well-sorted, fine-grained sand, marly clay, and shelly limestone of the Quindalup Dune System. In bores 4 and 5 farther inland, the sediments are poorly sorted, iron-stained sand and shelly limestone which possibly belong to the older Bassendean Dune System.

Lower Cretaceous to Upper Jurassic

Current thought on the South Perth Formation includes sediments described by previous workers as belonging to the Capel River Group and Yarragadee Formation.

In the Quindalup bores the thickness ranges from 270 feet in bore 4 to 1,180 feet in bore 5. The sediments are dominantly of continental type but rare microplankton indicate some marine influence during deposition. They are typically poorly consolidated, finely current-bedded, and lenticular. Correlation between bores is difficult and suspect, but the general dip is very gentle from east to west.

The sequence consists mainly of silt, siltstone, clay, poorly-sorted sand and sandstone containing abundant carbonaceous material, pyrite, and mica, and thin bands of lignite.

The arenaceous sediments are feldspathic, and are more consolidated with depth, making up 60 to 75 per cent of the total section.

The South Perth Formation unconformably overlies older sediments in each of the Quindalup bores.

Upper Jurassic

The Upper Jurassic Yarragadee Formation was encountered in Quindalup bores 4 and 5 and in nearby bores in the Abba River and Capel areas where it underlies the South Perth Formation.

e section is dominantly an arenaceous conti-
al deltaic deposit containing less than 20 per
clay and silt. The sandstone and sand differ
from those of the overlying South Perth For-
on but are typically garnetiferous and slightly
consolidated. They are generally moderately
oorly sorted, medium to very coarse in grain,
slightly feldspathic. Interbedded siltstone, clay,
stone, and rare lignite make up the remainder.

r Jurassic

wer Jurassic sediments of continental type are
nt between 630 and 1,930 feet in Quindalup
1. They consist of cross-bedded, poorly-sorted,
to coarse-grained sand and poorly consolidated
stone interbedded with mottled grey to red
tone, grey to green pyritic shale and siltstone.
claystone shows slickensiding and slumping.

erlain unconformably by the South Perth For-
on, the Lower Jurassic material in Quindalup
1 is the first observed occurrence of sediments
is age in the southern part of the Perth Basin,
s equated to the Cockleshell Gully Formation.

ian

mian sediments, also overlain unconformably
e South Perth Formation, occurred in Quinda-
ores 2 and 3, the westernmost bores of the

Quindalup bore 2 they are present between
nd 1,807 feet, and consist of well consolidated
to coarse-grained, slightly argillaceous sand-
containing abundant garnet, finely current-
d, grey siltstone, 17 seams of carbonaceous
, and poor quality dull coal ranging from 7 to
et in thickness. The sandstone contains rare
eous material.

Quindalup bore 3 the sequence is lithologically
ar except that only one 8-feet thick dull coal
was encountered, although carbonaceous
rial commonly occurred as partings on bed-
planes.

e Permian sequences are of different ages, that
indalup bore 3 being the younger of the two.

STRATIGRAPHY AND STRUCTURE

e stratigraphic relationships are shown in
2, and in Table 1.

e Quaternary material forms a thin veneer
the South Perth Formation, and the maximum
ved thickness of 35 feet is probably exceeded
n the Wonnerup area where gamma-ray log-
of existing bores indicates a thickness of
50 to 120 feet near the Wonnerup Estuary.

South Perth Formation is present through-
e drilling area and ranges widely in thickness
345 to 668 feet west of Busselton, thickening
r 1,000 feet in the Milne Street, Abba River
d Quindalup 5 bores. It thins again to 180
0 feet in the Wonnerup-Capel area. The
section between Abba River 1 bore and Capel
e 2) shows this variation, which may either
e to deposition over a deeply dissected Upper
sic surface or to post-Yarragadee Formation
ng. There is little concrete evidence to sup-
he latter supposition, but differences in levels
of basalt flows encountered in Quindalup bore 5 and Abba River bore 3 may either be due to depositional dip or to minor faulting. If a deep trough of South Perth sediments exists it probably is an old erosional channel which may extend as far east as the Whicher scarp, and possibly be related to basalt occurrences in the area.

The variation in thickness of the South Perth Formation illustrates the strong unconformity which separates these beds from the underlying strata. Below the unconformity three major north-south trending faults with throws of several thousand feet have been proved by the drilling. These include the Wirring and Busselton faults inferred from previous gravity and seismic surveys, and a fault postulated by Lodwick from seismic data. The faults divide the area beneath the unconformity west of Busselton into four blocks containing Upper to Lower Permian, Lower Permian, Lower Jurassic, and Upper Jurassic sediments. The block between the Wirring and Busselton faults is uplifted with respect to the others, which are normal east block down.

The Yarragadee Formation is present east of Busselton in Quindalup bores 4 and 5, Abba River bores 1 and 3, and in bores at the Western Titanium mining pit at Capel. No bores have penetrated the full succession of the Jurassic sediments which reach a maximum observed thickness of 1,615 feet in Quindalup bore 4.

Lower Jurassic sediments in Quindalup bore 1 are of similar lithology and age to the Cockleshell Gully Formation in the Hill River area, but the arenaceous sediments appear to be generally coarser in grain. The Lower Jurassic sediments are restricted in occurrence to the fault block immediately west of Busselton and nothing is yet known of their extension to the south.

Lower Permian coal-bearing sediments in Quindalup bore 2 are probably Upper to Lower Artinskian in age. The lower part of the section contains similar spore assemblages to the lower Artinskian coals of the Collie and Irwin River areas and to those encountered at 8,866 feet in WAPET's Sue No. 1 well. In this part of the basin these sediments are confined to the wedge-shaped block between the Wirring and Busselton faults.

The Permian sediments in Quindalup bore 3 appear younger than those in bore 2 and have been tentatively dated as early Upper Permian to Upper Artinskian. They lie between the Dunsborough and Wirring faults and their southward extent is not known.

OCCURRENCE OF GROUNDWATER

Groundwater was present in sediments of all ages and was sampled wherever possible by formation testers. The water samples were used by D. L. Rowston as controls for the estimation of salinities from resistivity logging. These results are shown on bore completion reports and on Plate 1.

Quaternary aquifers

Small supplies of groundwater are available from the thin veneer of Quaternary sediments. The water varies from stock to domestic quality and

TABLE 1

STRATIGRAPHIC SUCCESSION IN QUINDALUP BORES (EAST TO WEST)

Age	Formation	Bore 3 (feet)	Bore 2 (feet)	Bore 1 (feet)	Bore 4 (feet)	Bore 5 (feet)
ary	Recent sediments and Quindalup and Bassendean Dune Systems	0–32	0–20	0–22	0–35	0–22
Cretaceous to Upper ic	South Perth Formation	32–700	20–365	22–630	35–305	22–1180
urassic	Yarragadee Formation	Not present	Not present	Not present	305–1920	1180–2010
urassic	Cockleshell Gully Sandstone equivalent	Not present	Not present	630–1930	....	....
pper Permian	....	700 to 1485	Not present			
n	....		865–1807			

Correlation based on lithology, palynology, and geophysical data.

usually contains high H_2S and bicarbonate. Bores near the coast and tidal drainage channels are subject to saline intrusion. The sediments form a useful source of domestic and garden water in coastal cottages in and around Busselton.

South Perth Formation aquifers

The aquifers of the South Perth Formation are lenticular and contain groundwater of variable quality and supply. Lowry (1965) has summarised bore census data for the Busselton area and gives the following relationship between bore depth and frequency:

Table 2

Bore depth (feet) (average 60)	No. of bores
31–50	123
51–70	123
71–100	66
101–150	37
>150	10

These sediments are the most important source of groundwater for farmers, particularly the shallow glauconitic sands near Quindalup. Generally bores are sited for convenience, and as the beds are very lenticular the landholder continues drilling until he obtains water. Most supplies are sub-artesian, yielding 200 to 1,000 gallons per hour, and range from good stock to domestic quality, although saline groundwater has been encountered in some areas west of Busselton.

West of Busselton on the fringes of Geographe Bay, groundwater in the South Perth Formation of Quindalup bores 1 to 3 is generally of poor quality. In bore 1 thin layers of stock quality groundwater are intercalated with layers ranging in salinity from 8,000 to 20,000 ppm TDS. In bore 2 the quality is uniformly poor, avering about 14,000 ppm TDS. Farther west the quality improves to 450 to 1,500 ppm TDS.

Between Quindalup bore 1 and Capel, domestic quality groundwater is obtained at depths of 50 to 1,000 feet from the South Perth Formation. A little saline groundwater has been met near the coast at shallow depths but generally the supply and quality improves with depth. Supplies are generally good ranging from 200 gph in shallow bores to over 30,000 gph in bores 500 to 1,000 feet deep. Near the coast the bores flow.

Yarragadee Formation aquifer

Sediments of the Yarragadee Formation were encountered 305 and 1,920 feet in Quindalup bore 4, and between 1,180 and 2,010 feet in Quindalup bore 5. They have also been encountered in the Abba River bores 1 and 3 and in the Western Titanium works at Capel. In the Wonnerup area the sequence is dominantly arenaceous and formation testing suggests that large quantities of domestic quality groundwater (200 to 400 ppm TDS) are available. In the Capel area, bores produce 20,000 to 25,000 gallons per hour from similar but more argillaceous beds. In the Abba River area, poor results obtained in drilling the three Abba River bores probably reflect bad drilling techniques.

Cockleshell Gully Formation (?) aquifers

The Lower Jurassic sand and sandstone in Quindalup bore 1 contain domestic quality groundwater between 670 and 720 feet and between 952 and 1,520 feet. Between 720 and 950 feet and below 1,520 feet the salinity increases to about 2,000 ppm TDS.

Formation testing of these sands indicates that they contain good supplies which are possibly artesian.

Permian aquifers

The well consolidated Upper and Lower Permian sandstones in Quindalup bores 2 and 3 vary greatly in porosity and permeability. They contain groundwater ranging from good to poor stock quality (1,300 to 8,800 ppm TDS) and are probably of poor supply.

CHEMICAL CHARACTERISTICS OF THE GROUNDWATER

Standard chemical analyses were obtained for most of the deeper bore samples in the Busselton-Capel area, and the results are shown in Appendix 3. Appendix 4 shows calculated sodium adsorption ratios, calcium—magnesium ratios, and residual sodium bicarbonate.

In the Busselton—Capel area most groundwater has a salinity of less than 600 ppm TDS and only west of Busselton, in the South Perth, Lower Jurassic, and Permian formations, do some salinities exceed this figure.

The two main groundwater sources, the South Perth and Yarragadee Formations, contain low salinity water of very similar characteristics. They have a pH ranging from 6.3 to 7.6, contain high concentrations of dissolved iron, and are typically low in calcium, magnesium, and fluoride ions. Variation lies mainly in the bicarbonate—chloride ion content of the South Perth Formation aquifers. These show a decrease in the bicarbonate—chloride ratio from east to west, which appears to be related to the incidence of old calcareous dune systems on the Swan coastal plain. The calcium—magnesium ratio shows little variation although there is a general trend of increase from east to west, indicating westerly groundwater movement.

The Yarragadee Formation aquifers show primary salinity, and both calcium-magnesium and bicarbonate-chloride ratios increase from east to west across the basin, indicating groundwater movement to the west. The bicarbonate ion content also decreases with depth and is possibly related to intake from overlying dune areas. The bicarbonate content is, with one possible exception, marginal to high, and untreated groundwater is generally unsuited for use in the irrigation of clayey soils. The exceptional groundwater, which probably belongs to the Yarragadee aquifer system, was in Yoganup bore 1 in the eastern section of the Swan coastal plain at the base of the Whicher scarp. This water has a low pH and very low bicarbonate content and suggests that groundwaters at the eastern margin of the coastal plain near the Whicher scarp may be more suitable for irrigation use.

RECHARGE

Only limited data are yet available on static water levels. Between Busselton and Yoganup two distinct water levels are present in the Yoganup bores and Quindalup bores 4 and 5, suggesting different potentiometric surfaces for the South Perth and Yarragadee aquifer systems. These have average downward gradients from east to west of 4 and 2½ feet per mile respectively over most of the plain, but rise towards the Whicher scarp.

Data from levels, lithology, and chemical analyses suggest that recharge of the South Perth aquifers is mainly by direct infiltration of rainfall and river water from the Swan coastal plain. The recharge is selectively governed by topography and the lenticular nature of the sediments, particularly in the areas west of Busselton where saline groundwater is present in both the South Perth Formation and Permian strata.

The Yarragadee Formation probably receives groundwater from the elevated areas between the Darling fault and the Swan coastal plain, although some direct recharge may occur if areas of shallow Upper Jurassic sediments are present in the eastern sections of the plain.

AVAILABILITY AND USE OF GROUNDWATER

At present a maximum of about 10 million gallons per day of groundwater is extracted from the Yarragadee and South Perth aquifer systems for stock, domestic, town supply, and industrial purposes in the Busselton-Capel areas. It is not possible to estimate the total amount of groundwater available in this area but probably 20 million gallons could be extracted safely without depleting supplies.

All low salinity waters are suitable for domestic use, but the waters of the Jurassic and deeper South Perth aquifers contain moderate concentrations of bicarbonate ions which would make them unsuitable for the irrigation of heavy clay soils and use in some industries without treatment. Appendix 4 shows the relationship of sodium adsorption ratios and residual bicarbonate (Eaton, 1950). Calculations based on Handa (1964) indicate that the groundwater could be made suitable for irrigation by the application of between 0.2 and 0.6 tons of gypsum per acre foot of water used.

CONCLUSIONS AND RECOMMENDATIONS

The drilling has shown that large supplies of low salinity groundwater are available from Lower Cretaceous and Upper Jurassic sediments east and north of Busselton. This groundwater is suitable for domestic and some industrial use, but as usual in groundwaters from this area, has a high iron content. Some of the groundwaters also contain moderate concentrations of bicarbonate ions which make them unsuitable for use in irrigation without treatment. This should be no great problem.

West of Busselton the groundwater in sediments underlying the near coastal strip is of marginal to very poor quality, and between Busselton and the Busselton fault, moderate to low salinity groundwater suitable for domestic use was encountered only in the Lower Jurassic sediments. Small quantities of domestic to stock quality groundwater are present in shallow Quaternary sands or in low lying areas underlain by Lower Cretaceous sediments east of Geographe Bay. These supplies are too small and irregular to be of great value other than for farming purposes.

Plate 1 shows the location of five drill-holes proposed for the second stage of the programme. Four bores continue in a line between Ruabon and Donnybrook and will investigate the stratigraphy and hydrological potential of the eastern section of the Swan coastal plain and the elevated area of Mesozoic sediments between Yoganup and Donnybrook. A further bore is proposed to investigate the presence of groundwater between the Sabina and Vasse Rivers, 5 miles southeast of Busselton, where poor and conflicting results were obtained during the drilling of the Abba River bores in 1958.

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Appendix 1

LIST OF DEEP BORES IN THE BUSSELTON—CAPEL AREA

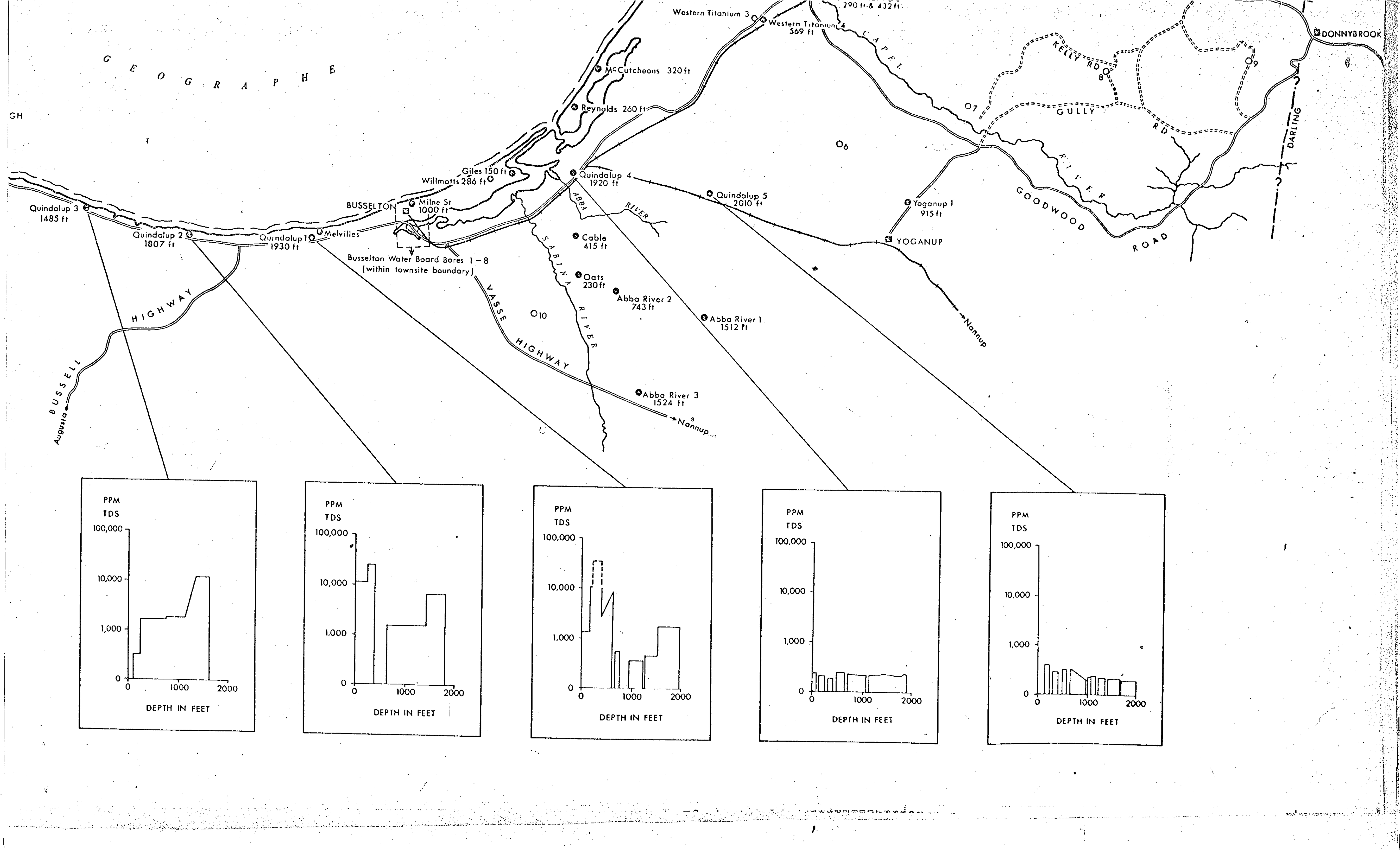
Bore	Depth (feet)	Remarks
G.S.W.A. Quindalup 1	1930	8 in. casing to 504 feet
2	1807	Plugged, capped and abandoned
3	1485	Plugged, capped and abandoned
4	1910	10 in. standpipe to 80 ft.; bore capped
5	2010	Plugged, capped and abandoned
G.S.W.A. Abba River 1	1712	Abandoned
2	743	Abandoned
3	1524	Abandoned
Busselton Water Board 1	470	Drilled 1908, abandoned 1960
2	480	Abandoned 1938
3	560(?)	Abandoned
4	163	Bore in use
5	495	Bore in use
6	363	Bore in use
7	555(?)	Bore in use
8	490(?)	Bore in use
Milne Street	1000	Bore in use
Western Titanium 1	351	Bore in use
2	572	Bore in use
3	632	Bore in use
No bore 4 drilled		
5	569	Bore in use
Westralian Oil Capel 1	193	Bore in use
Westralian Oil Yoganup 1	915	Bore abandoned
2	361	Bore abandoned
Western Mineral Sands Capel 1	495	Bore in use
2	498	Bore equipped
Capel town water supply 1	290	
2	432	
Oats bore	320	Wonnerup-Ruabon area
Cable (1956) Ruabon	450	
Cable (1956) Stratham	450	
McCutcheon's bore	320	Wonnerup area
Vasse coal bore 1	159	Drilled 1892-1900
2	143	
3	269	
4	476	
5	656	
6	330	
Blums bore	297	Bore in use
Reynolds bore	200	Bore in use
Wilmotts bore	286	Bore in use

Appendix 2

PALAEONTOLOGICAL DETERMINATIONS IN THE BUSSELTON—CAPEL AREA

Quindalup Bore 1

feet	
22	Quaternary—Recent
110	Lower Cretaceous: South Perth Formation
140	Lower Cretaceous: South Perth Formation (?)
270	Lower Cretaceous—Upper Jurassic: South Perth Formation
507	Barren
620-650	Lower Jurassic: Cockleshell Gully Formation equivalent (?)
926-934	Barren
1266	Lower Jurassic: Cockleshell Gully Formation equivalent (?)
1580	
1680	
1690	
1820	
1900	


GEOGRAPHE
GH
290 ft & 432 ft
Western Titanium 3
Western Titanium 4
569 ft
DONNYBROOK
KELLY RD
GULLY RD
CAPEL RIVER
GOODWOOD ROAD
DARLING
McCutcheons 320 ft
Reynolds 260 ft
Giles 150 ft
Willmotts 286 ft
Quindalup 4
1920 ft
Quindalup 5
2010 ft
Yoganup 1
915 ft
YOGANUP
BUSSELTON
Milne St
1000 ft
Quindalup 3
1485 ft
Quindalup 2
1807 ft
Quindalup 1
1930 ft
Melvilles
Busselton Water Board Bores 1 - 8
(within townsite boundary)
ABBA RIVER
SABINA RIVER
Cable
415 ft
Oats
230 ft
Abba River 2
743 ft
Abba River 1
1512 ft
Abba River 3
1524 ft
VASSE HIGHWAY
Nannup
BUSSELL HIGHWAY
Augusta
6
7
8
9
10
PPM
TDS
100,000
10,000
1,000
0
1000
2000
DEPTH IN FEET

Quindalup Bore 2

feet	
110	
170	Lower Cretaceous (possibly Uppermost Jurassic ?): South Perth Formation
310	
380	
500	
630	Lower Permian—Upper Artinskian (?)
820	
960	
1190	
1300	Lower Permian—Lower Artinskian
1450	
1730	
1800	

Quindalup Bore 3

feet	
75	
315	Lower Cretaceous (Aptian—Neocomian): South Perth Formation
400	
505	
640	
840	
1140	
1165–1170	Early Upper Permian to Lower Permian (Upper Artinskian ?)
1282	
1289	
1484	

Quindalup Bore 4

feet	
60	Lower Cretaceous—Uppermost Jurassic: South Perth Formation
310–316	Upper Jurassic: Yarragadee Formation
405	Barren
1098	Upper Jurassic: Yarragadee Formation
1240–1250	Upper Jurassic: Yarragadee Formation
1620–1627	Barren

Quindalup Bore 5

feet	
88	Lower Cretaceous: South Perth Formation
90	
202	
343	Barren
484	
556	Lower Cretaceous: South Perth Formation
585	
620	Aptian—marine (?): South Perth Formation
1051	Lower Cretaceous: South Perth Formation
1055	Barren
Sludge	
1190	Lower Cretaceous: South Perth Formation
1337	Upper Jurassic: Yarragadee Formation
1340	

Western Titanium Capel Bore C3

feet	
195	
210	
244	Upper Jurassic: Yarragadee Formation
260	
309	

Western Titanium Capel Mining Pit

feet	
	Sample taken from mining area 30 feet below ground level
30	Lower Cretaceous—Upper Neocomian to Lower Aptian—marginal marine

Milne Street Bore (Busselton)

feet	
150	
160	Lower Cretaceous—Neocomian to Aptian
300	
550	
690	Lower Cretaceous, probably samples poor
946	
970	

Capel Town Bore 1

feet	
30	Quaternary, probably Pleistocene
70	Lower Cretaceous—Aptian to Neocomian marine
270	Lower Cretaceous—Neocomian

Appendix 3

CHEMICAL ANALYSES—BUSSELTON-CAPEL AREA

Bore	Depth (feet)	pH	ppm TDS Evap.	ppm TDS Cond.	NaCl	Hardness $CaCO_3$	Alkalinity	Ca	Mg	Na	K	Fe	HCO_3	CO_2	SO_4	Cl	NO_3	Fl	SiO_2 ppm
Melville	15	....	1330	1440	764	579	403	143	54	248	6	0·1	491	....	88	464	<1	ND	6
Quindalup 1	460–510	6·9	....	17,000	11,000	....	....	....	....	....	....	....	....	....	....	....	....		....
	935–1025	8·3	640	730	274	76	225	24	4	202	6	?	274	....	61	166	1	ND	5
	1180–1250	7·5	1450	1700	1110	176	205	31	24	484	18	0·4	250	....	90	675	....	ND	8
	1455–1580	8·1	....	19,700	18,100	....	....	CONTAMINATED SAMPLE											
	1680–1770	7·3	2720	3010	2160	216	233	39	29	933	24	<0·1	284	....	185	1310	3	ND	6
Quindalup 2	238–310	....	....	42,000+	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	834–884	12·0	....	3680	1710			CONTAMINATED SAMPLE											
	1670–1700	7·3	....	8930	7650	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	1670–1700	7·1	....	8930	7650	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Quindalup 3	275–315	7·9	1270	1470	941	171	90	60	5	404	18	<0·1	110	....	168	571	1	ND	9
	1050–1080	8·3	1280	1440	913	93	155	34	2	442	10	<0·1	189	....	124	554	ND	ND	18
	1390–1485	7·5	8850	8850	7840	1980	65	721	43	2840	53	<0·1	79	....	634	4760	<1	ND	9
Quindalup 4	326	6·3	200	220	120	41	50	5	7	53	11	<0·1	61	....	14	73	3	ND	16
	530–560	7·1	330	340	120	66	158	20	4	96	10	<0·1	192	....	25	73	1	ND	12
	1370–1400	7·6	420	420	166	83	181	20	8	109	20	<0·1	220	....	21	101	<1	ND	13
Quindalup 5	695–763	7·3	520	540	194	43	210	11	4	174	12	<0·1	256	....	59	118	1	ND	16
	1057–1105	6·7	310	340	140	74	122	15	9	75	18	<0·1	149	....	18	85	<1	ND	15
	1338–1392	6·7	330	370	178	87	112	17	11	79	16	<0·1	137	....	15	108	<1	ND	17
	1926–1955	6·5	270	310	152	71	85	12	10	63	17	<0·1	104	....	14	92	<1	0·2	15
	1929–2000	6·8	310	350	163	65	105	13	8	84	16	<0·1	128	....	23	99	<1	0·2	15
Busselton Water B.5	585		240		....	....	....	12	9	49	14	8	54	....	10	95	3	0·25	19
Milne Street	350–620	6·6	190	218	....	....	....	9	7	39	15	0·1	82	....	11	55	<1	ND	ND
	750–1000	7·6	272	361	....	....	....	44	7	37	14	0·1	181	....	12	54	0·2	ND	12
Giles (Wonnerup)	150*	6·5	250	260	148	64	48	14	7	52	9	0·1	58	....	4	90	<1	0·3	24
Willmott (Wonnerup)	286*	6·3	380	400	270	77	43	13	11	94	9	0·1	52	....	19	164	<1	0·4	23
Reynolds (Wonnerup)	200*	6·3	200	230	124	49	48	5	9	44	14	0·1	58	....	10	75	<1	0·4	19
McCutcheon (Wonnerup)	320	7·3	220	250	124	64	67	6	12	53	6	0·1	82	....	14	75	<1	0·3	21
Oats (Ruabon)	320*	5·9	530	630	428	103	40	10	19	145	9	0·1	49	....	22	260	<1	0·4	26
Cable(1956)(Ruabon)	450*	6·2	220	240	135	41	48	5	7	55	12	0·1	58	....	13	82	<1	0·4	17
Western Titanium Capel 3	622*	6·7	220	240	92	56	90	11	7	48	20	(13) 0·1	110	....	16	56	<1	0·3	14
Western Titanium Capel 4	569*	6·6	220	240	92	52	90	11	6	49	21	0·1	110	....	16	56	<1	0·3	19
Capel Town Bore 1	289½*	6·1	380	380	....	83	35	11	13	83	15	16	43	....	17	166	ND	ND	17
Westralian Oil (Capel)	193*	6·1	280	340	206	73	48	13	10	67	15	0·1	58	....	14	125	<1	0·2	14
Western Mineral Sands	495*	7·2	210	230	101	65	72	0	8	42	19	0·1	83	....	13	61	<1	0·3	16
Cable (Stratham)	379*	7·0	230	250	110	54	76	10	7	50	18	1	92	....	15	67	<1	0·4	15
Westralian Oil	915*	4·6	420	400	331	64	5	4	13	102	15	0·9	6	....	16	201	<1	0·1	37

* Total depth of bore.

Appendix 4

CHEMICAL CHARACTERISTICS OF GROUNDWATER

No.	Bore	Depth (feet)	Calcium magnesium ratio rCa/rMg	Sodium adsorption $\frac{Na^+}{\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}}}$	Residual sodium bicarbonate
1	Melville	10	1·6	4·5	
2	Quindalup 1	935–1025	4·0	10·1	6
3	Quindalup 1	1180–1250	0·8	16·3	1·1
4	Quindalup 1	1680–1770	0·4	27·5	0·6
5	Quindalup 3	275–315	7·5	13·5	....
6	Quindalup 3	1050–1080	8·0	20·0	3·0
7	Quindalup 3	1390–1495	10	27	....
8	Quindalup 4	326	0·4	3·5	0·3
9	Quindalup 4	530–560	3·3	4·0	3·8
10	Quindalup 4	1370–1400	1.5	5·1	3·0
11	Quindalup 5	695–763	1·7	11·0	6·6
12	Milne Street	550–620	0·8	2·4	....
13	Milne Street	750–1000	3·8	0·8	0·4
14	Busselton 5	407–495	0·8	2·6	....
15	Quindalup 5	1057–1105	0·9	2·9	0·9
16	Quindalup 5	1926–1955	0·7	3·2	0·6
17	Quindalup 5	1929–2000	1·0	3·3	1·6
18	Yoganup 1	915	0·2	5·6	....
19	McCutcheon's	320	0·3	2·9	0·1
20	Western Titanium 3	622	1·0	2·8	1·3
21	Western Titanium 4	569	1·1	2·9	1·5
22	Cable Ruabon	415	0·7	2·6	0·2
23	Oats	230	0·3	6·2	....
24	Giles	150	1·2	2·8	....
25	Western Mineral Sands, Capel	495	0·7	2·4	....
26	Willmotts	157–286	0·7	4·6	....
27	Reynolds	154–174	0·3	2·7	0·1
28	Cable Stratham	379	0·9	8·6	0·9
29	Westralian Oil Capel	192	0·8	3·4	....
30	Capel Town water supply 1	289	0·5	4·0	....

PROSPECTS FOR UNDERGROUND WATER SUPPLIES FOR CARNAMAH TOWNSHIP

by P. Whincup

ABSTRACT.

In the Carnamah district, groundwater suitable for the town supply is available only from Quaternary sand overlying chert of the Proterozoic Moora Group. Groundwater in the chert is too brackish to be of use.

Exploratory drilling of an area of Quaternary sand adjacent to the present pumping field is recommended.

INTRODUCTION

Carnamah is a northern wheatbelt town on the Geraldton Highway, 188 miles north of Perth. It has a population of about 370.

Water is supplied to the town from a catchment which yields an average 3 million gallons per annum, and from shallow sands at Winchester, 7 miles south of the town. Overabstraction from these sands has resulted in a marked increase in groundwater salinity and it has become necessary to locate additional supplies. The Moora Group, a sequence composed mainly of chert and orthoquartzite which provides water for several towns about 50 to 75 miles south of Carnamah, crops out near Winchester. Accordingly a hydrogeological investigation has been made of these rocks in the Carnamah area at the request of the Public Works Department, the primary object being to delineate their extent and assess the groundwater potential. Geological mapping with an associated groundwater census was done between 4th and 13th April, 1967.

A more detailed geological investigation of the Moora Group has been completed recently by G. H. Low and L. N. Wall and some of their results are incorporated.

TOPOGRAPHY

The major control on the topography is geological. The Mt. Scratch Siltstone and the Permian Nangetty Formation form the flat, low-lying saline areas on the west and probably underlie the Yarra Yarra salt lakes. These flats are succeeded to the east by a narrow zone of low, rounded hills and ridges of the Moora Group, succeeded in turn by gently undulating granite hills. In general the natural surface rises from west to east. Intermittent saline creeks drain westerly towards the large Yarra Yarra saline system. The average annual rainfall is about 15 inches, and ranges between 4 inches and 29 inches.

GEOLOGY

Rocks exposed are of Archaean, Proterozoic, and Permian age with overlying Quaternary alluvium.

Archaean

The Archaean is represented by a massive, medium-grained, porphyritic granite often well-jointed and intruded by dolerite dykes. Generally it either crops out or occurs at shallow depth and weathers to a coarse feldspathic sand with the typical kaolinitic weathering profile often being absent.

Proterozoic

The *Moora Group* type section near Coomberdale is subdivided by Logan and Chase into four formations. Near Carnamah no subdivision is possible as only the Coomberdale Chert appears to be present. This is a sequence of chert, chert breccia, and orthoquartzite, often well-bedded and dipping at about 30 degrees to the west. Occasional interbedded siltstone appears towards the west.

The chert contains colonial organisms resembling stromatolites (*Collenia*) which reflect the original calcareous nature of the sediments. Several caves have also been preserved, one directly south of points 4 and 5, while there are several sink holes in the yellow sand area which trends eastwards from points 15 and 79. (See Plate 3.)

The contact between the Archaean and the overlying Moora Group is either faulted or, less commonly, unconformable. The Moora Group is intruded by dolerite dykes and its structure is complicated by the north-south faulting shown on Plate 3. Farther south Low and Wall (pers. comm.) have found evidence of northeast-trending shear zones with associated minor multi-directional faults and shear zones. They are postulating similar faulting near Winchester but this has not been shown on either of the accompanying plates.

The chert is white, yellowish and reddish and weathers to yellow clay and sand. Extensive tracts of yellow sand, such as immediately south and east of Winchester, overlie clay and chert. The sand varies in thickness from a few inches to perhaps 20 feet and may have been derived from the chert by illuviation of the clay fraction.

The *Mt. Scratch Siltstone* is a purple-reddish, well-bedded siltstone which dips very steeply to the west. It may be in faulted contact with the Moora Group. Only one very thin dolerite dyke was seen to intrude it.