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THE GEOLOGY AND GROUND WATER RESOURCES OF THE COAL RIVER BASIN

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PREFACE

This publication is a product of the expanded programme of investigations into the assessment of the groundwater resources of the State. The programme is being conducted by the Department of Mines assisted by grants from the Australian Water Resources Council under the Commonwealth States Grants (Water Resources Measurement) Act.

A further series of publications describing similar studies in other parts of the State will be issued in the future.

This study has indicated that the groundwater resources of the Coal River Basin may form an important increment to the total water available for agricultural purposes in that district. Much of this water is as yet undeveloped but with increasing development of this important agricultural area it will doubtless be of considerable value in the future. Little of the water is of suitable quality for domestic supplies but some could be used for irrigation and all of it is suitable for stock watering. Since the volume of underground water extracted at present is less than one per cent of the calculated annual recharge, much greater use could be made of this resource.

J.G. SYMONS, Director of Mines

Frontispiece. *Aerial view of the Coal River basin, looking north from Pitt Water.* *[Photo: Vern Reid]*

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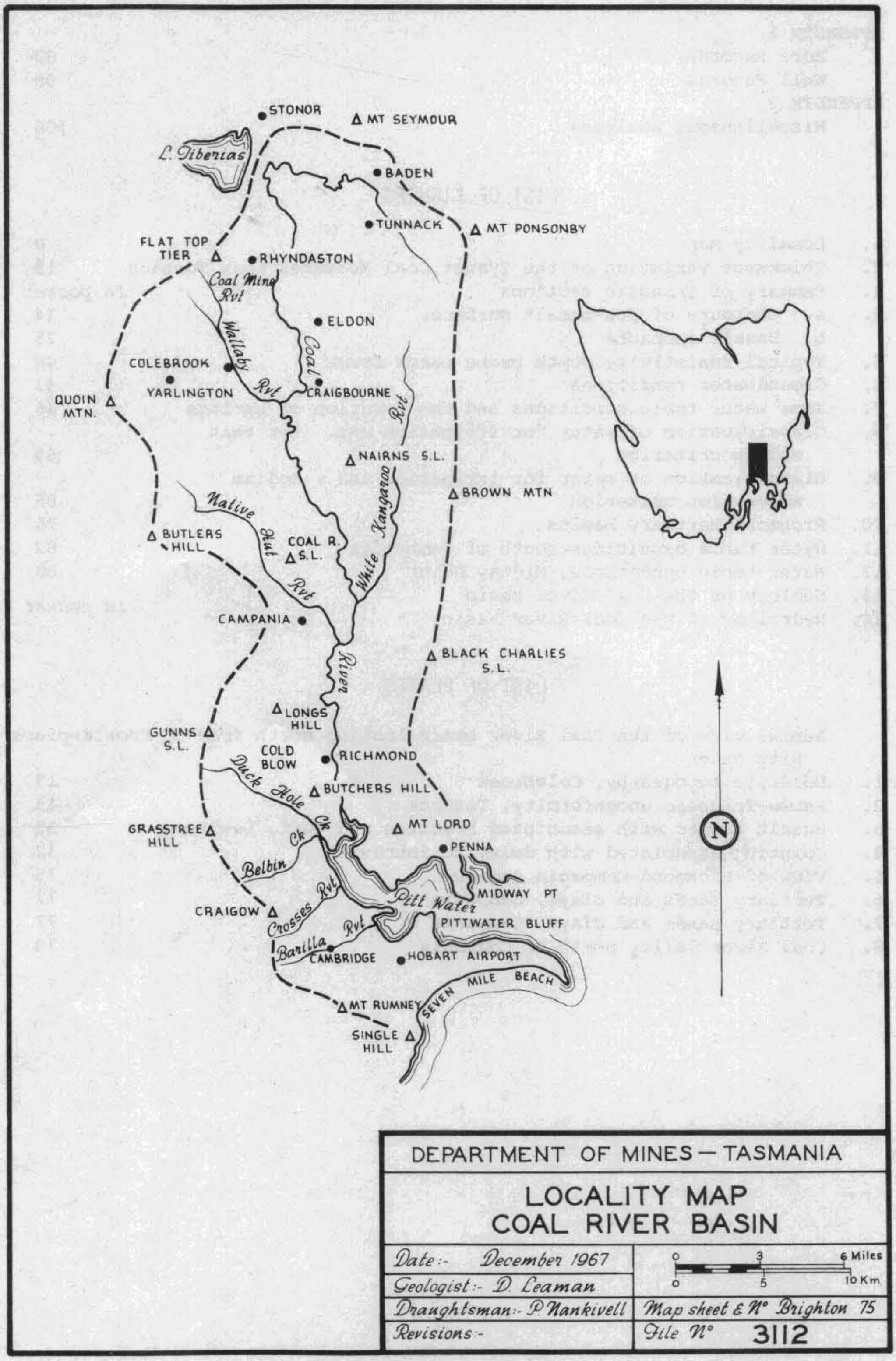
STONOR
MT SEYMOUR
L. Tiberias
BADEN
TUNNACK
MT PONSONBY
FLAT TOP TIER
RHYNDASTON
Coal Mine Rvt
ELDON
Wallaby Rvt
Coal
COLEBROOK
YARLINGTON
CRAIGBOURNE
QUOIN MTN.
Kangaroo Rvt
NAIRNS S.L.
BROWN MTN
Native Hut Rvt
White
BUTLERS HILL
COAL R. S.L.
CAMPANIA
BLACK CHARLIES S.L.
River
LONGS HILL
GUNNS S.L.
COLD BLOW
RICHMOND
Duck Hole Ck
BUTCHERS HILL
GRASSTREE HILL
MT LORD
PENNA
Belbin Ck
MIDWAY PT
Pitt Water
CRAIGOW
Crosses Rvt
PITTWATER BLUFF
Barilla Rvt
CAMBRIDGE
HOBART AIRPORT
SEVEN MILE BEACH
MT RUMNEY
SINGLE HILL
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DEPARTMENT OF MINES — TASMANIA
LOCALITY MAP
COAL RIVER BASIN
Date:- December 1967
Geologist:- D. Leaman
Draughtsman:- P. Nankivell
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0 3 6 Miles
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Figure 1.

ABSTRACT

The groundwater resources of the Coal River Basin are estimated at 8,200,000 Ml (1,800,000 million gallons). Most water is stored within secondary openings in Permian mudstone and Triassic sandstone. Igneous rocks of Jurassic and Tertiary age, while providing 20 per cent of the total storage, at present provide only one per cent of the output. Tertiary sediments have been test drilled and have proved to be good aquifers when thick sands are present, as in the Duck Hole Creek region.

The quality of the water is variable but that from each formation is quite distinct. All water may be used for stock, but only rarely is it suitable for domestic or irrigation use. The most saline water is recovered from the Tertiary deposits in the south of the basin.

The groundwater is unconfined and there is a virtually continuous water table.

INTRODUCTION

LOCATION AND ACCESS

The Coal River drainage basin, SE Tasmania, has an area of approximately 780 km^2 (300 square miles); a N-S length of some 56 km (35 miles) and an average width of 14.5 km (9 miles). The Coal River runs between two N-S ridges with heights of up to 915 m (3,000 ft) (fig. 1). The 'basin' includes the low-lying area at Penna which drains into Pitt Water, with Midway Point as the eastern margin.

The area includes the municipality of Richmond and parts of the municipalities of Brighton, Sorell, Oatlands and Clarence. The principal towns are Cambridge, Seven Mile Beach, Richmond, Campania, Colebrook and Tunnack. The total population is about 2,000 most of whom reside south of Campania.

Access to most parts of the region is good, since there is an adequate network of roads and tracks. There is limited access to the principal watersheds.

IMPORTANCE OF GROUNDWATER IN THE DISTRICT

In normal years the basin is noteworthy for the relative lack of perennial streams or springs which contain sufficient water for the agricultural needs of the area. In dry years there may be no flowing streams during the summer period. Water from ponds in stream beds or from dams is at present the main supply during the period from November to April. As such supply is often inadequate or subject to the vagaries of surface water a supplementary supply would be useful. Even though a bore supply may be less than 45,500 l/day (10,000 gal/day), it could make a considerable difference to stock raising and dairying which are the principal agricultural pursuits.

PURPOSE, SCOPE AND PERIOD OF THE INVESTIGATION

With increasing demand for water, the groundwater reserve has been tapped. As a result, it is necessary to develop a better understanding of the processes by which rocks store and transmit water and the effects rocks have on any water they may contain.

The principal objects of the study were:

(1) to provide detailed information on groundwater occurrence,

particularly with reference to various scales of rock structure and topography;

(2) to evaluate the relationship between climate, rock type and groundwater quality;

(3) to examine the groundwater potential of the unconsolidated sedimentary rocks in the southern part of the area.

Fieldwork was undertaken during 1966 and 1967. The methods used and the time of particular aspects of the study, are given where appropriate in the respective chapters.

PREVIOUS INVESTIGATIONS

SUMMARY OF PREVIOUS LITERATURE

Author	Scope of Work
Johnston (1888)	Mention of some rock units.
Nye (1921)	Geological reconnaissance of the Stonor region.
Nye (1922)	Geological reconnaissance of the basin north of Richmond.
Hills *et al* (1922)	Coal resources of the basin, particularly the Richmond and Colebrook coalfields.
Nye (1924)	Geological reconnaissance of the area south pf Richmond.
Lewis (1946)	Geological mapping of the Basin south of Campania.
Gatehouse (1967)	Geological mapping of 10-kiloyard squares adjacent to Richmond.

The publications of Nye (1921, 1922, 1924) while published as Underground Water Supply Papers are primarily geological in content as little hydrological data was available at that time.

ACKNOWLEDGMENTS

The author would like to acknowledge the assistance of K. Williams and J. Pitcher in the collection of field hydrologic data and also of the Commonwealth Bureau of Meteorology. The author is also grateful for the co-operation and assistance given by property and bore owners, who have provided a considerable amount of information on all aspects of the study, and who allowed their wells to be used for hydrological observations.

BORE NUMBERING SYSTEM

In order to provide a systematic means of reference to the bores the following nomenclature has been used throughout the text. All details concerning bores and wells are given in Appendix 1. Each bore and well is numbered serially within the drainage region in which it is situated. The basin is divided into nine such regions. The letter or letters which precede the bore number is the abbreviation for the name of the region. For example the eighth bore drilled in the Stonor Region is ST 8. A W preceding the number signifies a well as distinct from a bore.

The letter prefixes are:

Cambridge - Seven Mile Beach	C	Richmond - Campania - Cold Blow	RC
Colebrook	CO	Stonor	ST
Duck Hole Creek	DH	Tunnack	T
Native Hut Rivulet	N	White Kangaroo Rivulet	WK
Penna	P		

TERMINOLOGY

The following terms are defined below, in order that their use in the text may be fully understood. Unless otherwise stated, the definitions are based on those of Jones (1965).

POROSITY relates the total volume of voids a rock contains, and hence the total possible volume of water it may contain, to the total volume of the rock, *i.e.* P = volume voids/volume rock. It is normally expressed as a percentage (American Geological Institute, 1962).

The *PERMEABILITY* of a rock is its capacity for transmitting a fluid. A permeable rock is one having a texture that permits water to move through it perceptibly under the pressure ordinarily found in subsurface water. (Meinzer, 1923).

The *SPECIFIC YIELD* is the volume of water that a saturated stratum will yield by gravity compared to the volume of the stratum, and is expressed as a percentage. (Bateman, 1959, p. 867).

An *AQUICLUDE* is a permeable saturated rock which will not yield groundwater at a sufficient rate to be of local consequence as a source of supply. An *AQUIFER* is a permeable saturated rock which will yield groundwater at an economic rate. An *AQUIFUGE* is an impermeable rock.

The *PIEZOMETRIC SURFACE* is an imaginary surface defined by the static levels of all points on a given plane in a groundwater body.

CONFINED GROUNDWATER is groundwater, occupying the full thickness of an aquifer, overlain by an aquifuge or aquiclude.

UNCONFINED GROUNDWATER is groundwater in which the upper surface is formed by surface water or by permeable rock containing air at atmospheric pressure.

A *WATER BORE* is a hole which is drilled, jetted or augered to withdraw or replenish groundwater.

A *SPRING* is a place of natural discharge of groundwater as a liquid (see p. 45).

ARTESIAN WATER is groundwater whose static level is above the ground surface. *SUB-ARTESIAN WATER* is groundwater for which the static level is above the upper surface of the groundwater body but below the ground surface

The *WATER TABLE* is the surface within a groundwater body at which the hydrostatic pressure is equal to atmospheric pressure.

GEOGRAPHY

RELIEF

The basin has a youthful relief. The relief is generally moderate but is high adjacent to the major watersheds and near Rhyndaston.

The Coal River basin is bounded by two N-S ridges, each with high points up to 915 m (3,000 ft). The western ridge extends from Lake Tiberias (442 m) on the watershed to Single Hill (208 m) at the coast south of Seven Mile Beach. Other high points include Flat Top Tier (688 m), Quoin Mt (899 m), Butlers Hill (670 m), Gunns Sugar Load (375 m), Grasstree Hill (534 m), Craigow (395 m) and Mt Rumney (378 m). All drainage to the west is into the Jordan River system. The eastern ridge extends south from Mt Seymour township to Black Charlies S.L. (383 m), other high points include Mt Ponsonby (796 m) and Brown Mt (792 m). Most drainage east of this divide passes to the Prosser River.

For ease of discussion the Coal River basin has been divided into subsidiary basins by delimiting the principal internal catchments. These are separated by ridges up to 305 m (1,000 ft) high. Examples of points on such ridges are: Longs Hill (315 m), Butchers Hill (244 m), Mt Lord (279 m), Coal River S.L. (380 m) and Nairns S.L. (374 m).

There are large tracts of near-level or gently sloping country within the basin. Approximately 80 km^2 (30 square miles) of the Tunnack-Stonor region is gently undulating with an average elevation of some 450 m ((1,480 ft). This is deeply dissected on its western side by the Coal River gorge which extends S of Rhyndaston where it is 183 m (600 ft) deep.

At Cambridge, Penna and Seven Mile Beach much land is less than 6 m (20 ft) above sea level and is marshy in places. Around Richmond and Duck Hole Creek there is a northward slope from sea level to approximately 60 m (200 ft) as at Campania. Other minor level areas occur where the Coal River or its tributaries are aggraded.

The topography is dominated by two rock types: Jurassic dolerite and unconsolidated Tertiary sediments. The dolerite forms the high ridges and many individual hills, whilst the low lying gently undulating surfaces south of Campania and in the Pitt Water area are underlain by Tertiary strata. Many of the dolerite intrusions south of Colebrook produce characteristic rounded hills (plate 1) on which small landslides and soil slips are common.

DRAINAGE

All drainage is toward the Coal River and thence to Pitt Water. The subsidiary drainage systems, into which the basin has been subdivided for hydrological discussion, and their streams and rivulets, both perennial and intermittent, are shown on Figure 14.

The northern margin of the basin is ill-defined, but follows a low ridge extending from Mt Seymour to Stonor. Drainage to the north is towards York Rivulet and Macquarie River.

The Tunnack-Baden-Stonor region drains directly into the Coal River; the streams are small and regular with slight gradients. Exceptions occur adjacent to the gorge between Stonor and Rhyndaston where gradients may exceed 10% (500 ft/mile). The Coal River is the only stream to drain the Tunnack plateau region and there is a considerable change in the character of the drainage from north of Rhyndaston to the sea compared with that described above.

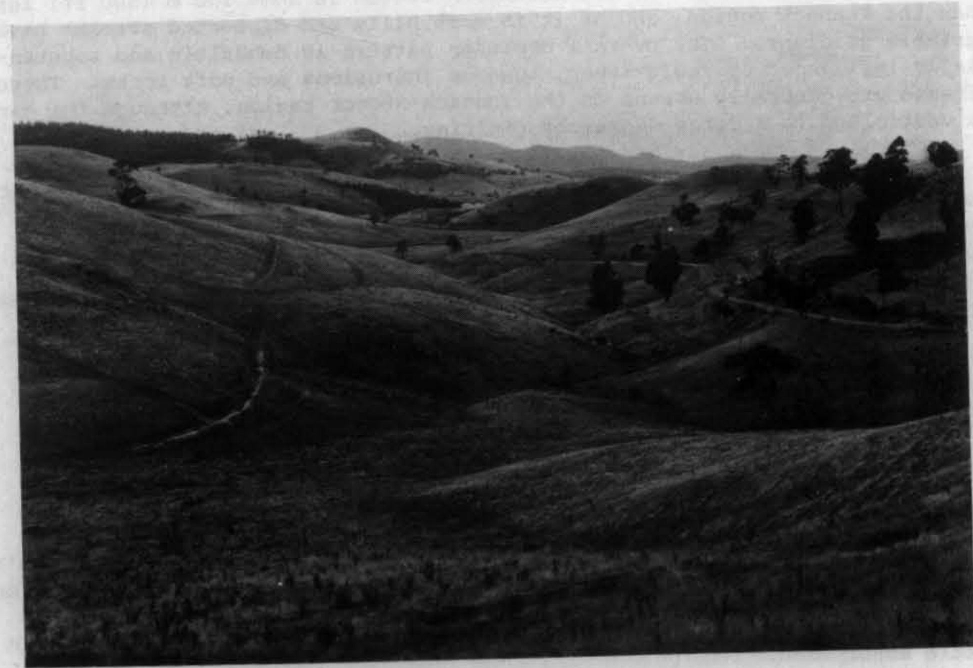


Plate 1. *Dolerite topography, Colebrook.*

Plate 2. *Permo-Triassic unconformity, Tunnack.*

5 cm

The average height of the Colebrook region is some 150 m (500 ft) less than the Tunnack region, and as it is more hilly and dissected streams have variable gradients. The overall drainage pattern is dendritic and substantially influenced by fault lines, igneous intrusions and soft rocks. These effects are generally absent in the Tunnack-Stonor region, although the gorge is controlled to a large degree by faulting.

The stream patterns in the White Kangaroo Rivulet, Native Hut Rivulet and Campania - Colebrook section of the Coal River are essentially simple, dendritic and not significantly affected by rock types or rock structures. The Coal River does, however, flow for some miles in a downthrown block of Upper Triassic sediments, and at some places it has cut narrow gorges through dolerite bodies.

Streams in the Colebrook and White Kangaroo Rivulet regions tend to have small but perennial flows, whereas most of the other drainage north and west of Campania is ephemeral or intermittent, *e.g.* Dry Creek, Coal Mine Rivulet and Wallaby Rivulet.

From Campania to Pitt Water the Coal River flows in incised meanders in basalt and sandy clay. At the northern end of Pitt Water the river is joined by a further large tributary, Duck Hole Creek. This stream and its tributaries are at best intermittent and normally ephemeral. Stream gradients are very gentle. The limited drainage from the hills west of Cambridge is also ephemeral, as gradients are high and there is considerable run-off and little absorption.

The Penna Region is drained toward Pitt Water which may be regarded as the estuary of the Coal River. Pitt Water Bluff and Midway Point form the mouth of the river for the purposes of this report. There is no surface drainage of any significance near Seven Mile Beach, as there is a great deal of absorption and evaporation and little run-off dur to lack of elevation.

CLIMATE

The climate of the basin is characterised by winters that are cool inland but milder near the coast, and by warm to hot summers. The prevailing winds are westerly but much of the rainfall comes from depressions held stationary in the western Tasman Sea.

The Commonwealth Bureau of Meteorology maintains five stations of long standing within the area, and several of recent date. Only one of the more recent stations (Tunnack) is included in the table below. Oatlands, 10 km (6 miles) north of the basin, is also included for comparison.

Within the basin, topographic features and climate are closely related. This results, generally, in local and varied climates. Rainfall is fairly evenly distributed throughout the year, April and October are the wettest months. The variation in rainfall is caused predominantly by rain shadow and rain slope effects. For example, the exposed coastal region of which Hobart Airport is typical receives more rainfall than the relatively sheltered and narrow Coal River valley between Richmond and Campania. Further north, Colebrook and Tunnack are again more exposed, particularly to easterly weather. The entire basin is in the rain shadow of Brown Mountain to the east and the Central Highlands to the west. Within the basin, the undulating character of the relief produces similar effects on a much smaller scale. Some of the wetter areas are from Eldon to White Kangaroo Rivulet and on the eastern face of the Quoin Mountain - Grasstree Hill divide.

Table 1: AVERAGE RAINFALL (in points)*

	Hobart Airport	Richmond	Campania	Colebrook	Tunnack	Oatlands
January	149	147	169	179	150	137
February	165	171	191	200	151	186
March	156	162	170	196	243	155
April	252	210	191	248	380	225
May	227	156	191	209	157	196
June	211	176	203	221	246	199
July	165	143	146	187	234	173
August	175	163	172	209	168	186
September	179	160	153	210	164	158
October	280	231	248	298	255	242
November	205	169	175	226	144	218
December	222	229	225	292	306	251
	2,386	2,117	2,234	2,675	2,598	2,326

*One point = 0.254 mm.

The average annual rainfall within the area is approximately 610 mm (24 inches). The mean deviation, as a percentage of the average rainfall, is 18-20 south of Campania and 20 elsewhere. The maximum rainfall occurs in the Colebrook - Yarlington region.

Rain falls as showers of light to moderate intensity over periods of less than one hour from westerly sources and by periods of uniform light rainfall up to one week from easterly sources. The latter is the more effective and important source.

The annual mean temperature range is approximately 7.2 - 16.6°C (45 - 62°F) south of Richmond and 5.6 - 15°C (42 - 59°F) near Colebrook. Frosts may occur at any time between April and November over much of the basin. Conditions are milder south of Richmond. Snow is uncommon except on the principal N-S watersheds.

SOILS

Soils within the basin fall within three main groups:

(1) Alluvial soil, meadow podzolic soil.

(2) Soils on the siliceous Permian and Triassic sedimentary rocks.

(3) Soils on the basalt and dolerite.

The neutral to alkaline alluvial soils occur on the flood plains of many of the tributaries of the Coal River and in slightly-graded sections of the river itself. Only occasionally do these soils cover sizeable areas, as near Campania. Such soils are often well drained due to the presence of a gravel substrate. They are highly productive and show little profile development.

The meadow podzols are duplex, saline soils found on the terraces and Tertiary sediments. They occur generally south of Campania.

Podzols and yellow podzols have developed on the Permian and Triassic rocks which, although very siliceous, contain sufficient feldspar to produce significant amounts of clay upon weathering. These soils have acid reactions.

Brown earths, black earths and prairie soils are characteristic of basalt and dolerite in the south-east of the State. Two distinct soils occur on the dolerite, depending upon rainfall and relief - brown and black earths. Both soils are generally slightly acid to neutral at the surface and slightly alkaline below. Free carbonate commonly occurs in the black earths as large deposits of Travertine, *e.g.* near Rekuna and Campania.

Prairie soils are found on the gentle basalt terrain, and are commonly associated with brown earths or more rarely, black earths.

VEGETATION

A very large proportion of the district has been cleared for agricultural purposes. The remainder is generally open, dry sclerophyll forest dominated by one or two species of eucalypts with a sparse or low shrub layer of acacias. Little land is in a virgin state. Differences of vegetation from one rock type to another are not always obvious, but are often readily shown by grasses and ferns: Tussocky grass is common on dolerite, whilst ferns are common on the sandy Triassic soils.

GEOMORPHOLOGY

Landforms of particular interest may be divided into three main groups:

(1) Coastal and river terraces.

(2) Stream channels.

(3) Landforms produced by igneous intrusions.

The terraces are at 1, 4.5, 12-15 and 49 m (3, 15, 40-50 and 160 ft) above the present sea level. The two lower levels are the Milford and Llanherne levels of Davies (1959). Since the late Tertiary the coastline has been one of emergence. Investigations have shown that during Tertiary times and Coal River cut deep narrow ravines to a level at least 183 m (600 ft) below the present sea level. The coastline is thus one of submergence, by some 134 m (440 ft) but the latest movement is one of emergence.

All streams within the basin show signs of recent active downcutting and are consequently entrenched in terrace deposits of an earlier stage. The valley deposits and entrenched meanders are probably related to the period of higher rainfall and run-off during the ice age.

A diminished volume of water at the present day is strongly indicated by the stream profiles, the changed curvature of meanders and by deposition.

Control of landforms by igneous intrusion has been mentioned previously (p.12). Plug-like intrusions have resulted in rounded forms, and the more massive intrusions in high ridges. Many of the basalt centres also produced rounded forms which stand out clearly from the more easily eroded sediments.

HUMAN ACTIVITY

Human activity is based primarily on grazing and dairying although some cereal growing is undertaken around Richmond. Timber industries and potato growing are of minor importance, and are restricted mainly to the Tunnack area.

GEOLOGY

STRATIGRAPHY

GEOLOGICAL FORMATIONS REPRESENTED IN THE COAL RIVER BASIN

System	Formation	Rock Type	Maximum thickness (*m*)	(*ft*)
Quaternary		Alluvium, river gravels and beach deposits	>3	>10
Tertiary		Basalt		
		Clay, sand, coal	>204	>670
		unconformity		
Jurassic		Tholeiitic dolerite		
Triassic		Feldspathic sandstone mudstone, coal	>152	>500
		Quartz sandstone mudstone, shale	>305	> 1,000
		disconformity or unconformity		
Permian	Cygnet Coal Measures	Carbonaceous shale and feldspathic sandstone	58	190
		disconformity or unconformity		
	Ferntree Mudstone	Siliceous pebbly siltstone	168-183	550-600
	Risdon Sandstone	Pebbly quartz sandstone	4.6	15
	Malbina Formation	Siliceous siltstone sandstone	>37	>120
	Cascades Group	Fossiliferous mudstone, limestone	>30	>100

PERMIAN

Rocks of Permian age outcrop over ten per cent of the area of the basin. The dominant rock type is siliceous siltstone.

Cascades Group

Two members of the Cascades Group, as defined in the Hobart area (Banks, 1957) have been located in the middle reaches of White Kangaroo Rivulet, at Single Hill and near Tunnack. The units present are Grange

Mudstone and Berriedale Limestone. The maximum exposed thickness of the Group is approximately 30 m (100 ft).

At Single Hill only the Grange Mudstone crops out but in White Kangaroo Rivulet the limestone crops out in the creek and is overlain by up to 30 m (100 ft) of calcareous mudstone. There is no sharp boundary between the two members as beds and lenses of limestone interdigitate with the mudstone. Individual beds range in thickness from 15-60 cm. The limestone contains quartzite erratics up to 30 cm across.

Brachiopods such as *Spirifer* and *Strophalosia* are the principal fossils but fenestellids, stenoporids and some pelecypods are also abundant.

At Single Hill and Tunnack the group is conformably overlain by the Malbina Formation but in White Kangaroo Rivulet exposures are restricted to an upthrown fault block and the top of the group is not exposed.

Malbina Formation

This formation is also incompletely exposed, the basal members, A and B (Banks & Read, 1962) crop out at Single Hill, Tunnack and White Kangaroo Rivulet and the upper members D and E, in Barilla, Crosses and Belbin Rivulets. The formation consists predominantly of siliceous siltstone containing pebbles of metamorphic rocks which are usually less than 10 cm across. Occasional fossils have been observed below the Risdon Sandstone in Belbin Rivulet (member E). A small outcrop of the basal member (A) a fossiliferous, pebbly, coarse siltstone occurs on the south side of Single Hill and east of Tunnack. The total exposed thickness of the formation is about 37 m (120 ft). It is overlain conformably by the Risdon Sandstone in several localities south of Grasstree Hill. Individual beds average 23-30 m in thickness.

Risdon Sandstone

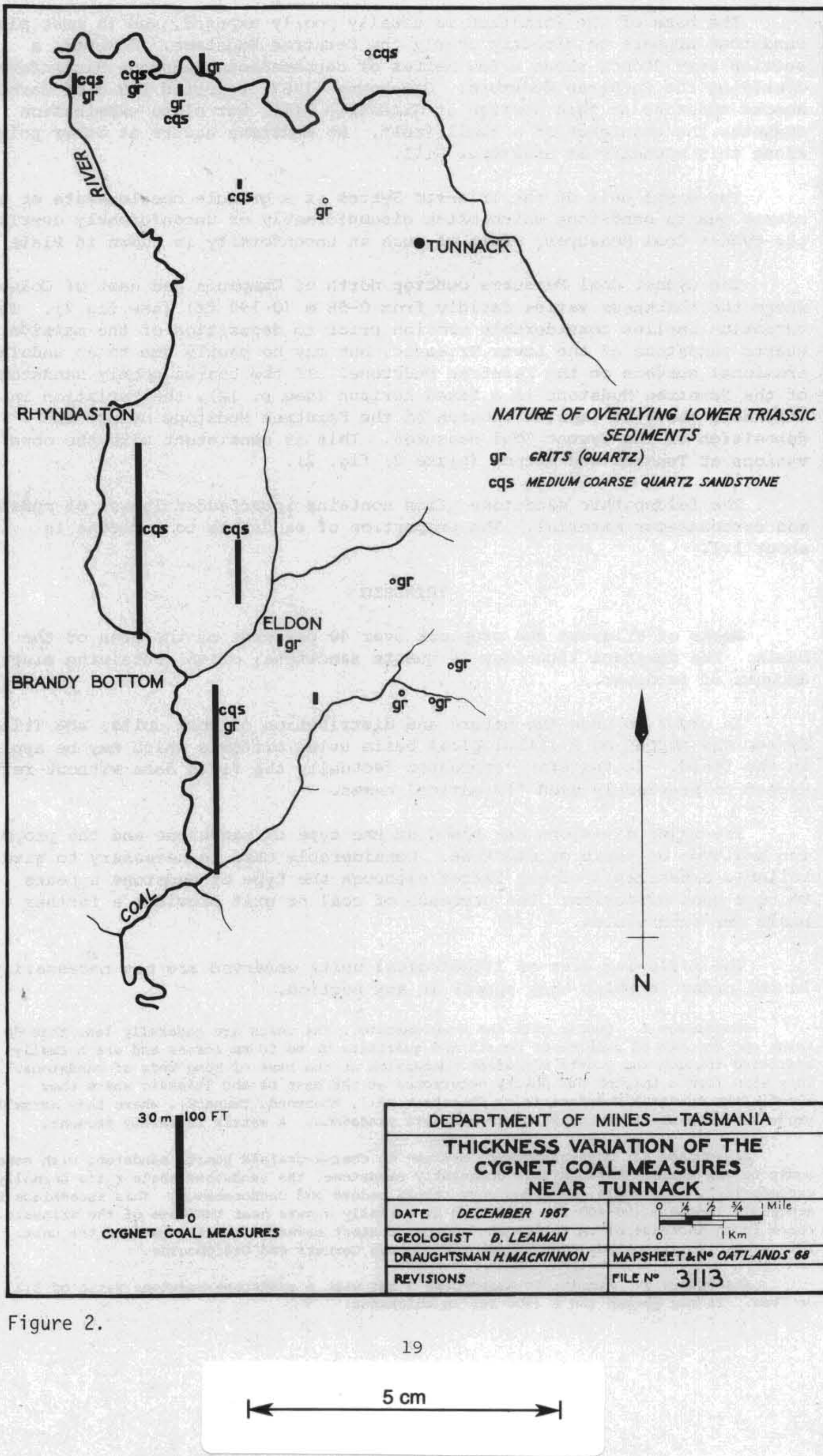
The Risdon Sandstone is a medium- to coarse-grained, pebbly, quartz sandstone up to 4.6 m (15 ft) thick. It contains some feldspar.

Ferntree Mudstone

The Ferntree Mudstone 168-183 m (550-600 ft); is the thickest Permian formation and dominates the outcrop of the Permian rocks. It occurs principally in two main areas; north-west of Cambridge and south of Tunnack. The dominant lithology is siliceous siltstone but there are sandy zones and a coarse, pebbly, quartz sandstone 3-4.6 m (10-15 ft) thick occurs 24-37 m (80-120 ft) from the top of the formation. The latter is not unlike the Risdon Sandstone and is a valuable marker horizon. It also forms a capping at or near the top of some small hills in the Tunnack Region. Fossils have also been observed at a similar horizon in the Richmond - Cambridge area, for example in Barilla Rivulet, on Grasstree Hill and Mt Lord. The formation is well jointed, with individual beds up to 60 cm thick.

Cygnet Coal Measures

The term Cygnet Coal Measures applies to the feldspathic sandstone, carbonaceous mudstone and shale directly overlying the Ferntree Mudstone but underlying the first medium- to coarse-grained proto-quartzite of the Triassic System. This definition includes the Barnetts Member of the Springs Sandstone (Banks and Naqvi, 1967).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RIVER
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TUNNACK
RHYNDASTON
NATURE OF OVERLYING LOWER TRIASSIC SEDIMENTS
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CYGNET COAL MEASURES
DEPARTMENT OF MINES—TASMANIA
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DATE DECEMBER 1967
GEOLOGIST D. LEAMAN
DRAUGHTSMAN H. MACKINNON
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MAPSHEET & Nº OATLANDS 68
FILE Nº 3113

Figure 2.

The base of the formation is usually poorly exposed, and in most places sandstone appears to directly overly the Ferntree Mudstone. However, a section near Stonor shows a few metres of carbonaceous mudstone disconformably overlying the Ferntree Mudstone. Gatehouse (1967) reported 1.8 m of carbonaceous mudstone at this horizon at Grasstree Hill, but close examination suggests the existence of a small fault. No mudstone occurs at other points along this boundary at Grasstree Hill.

The basal unit of the Triassic System is a granule conglomerate or a coarse quartz sandstone which often disconformably or unconformably overlies the Cygnet Coal Measures. Part of such an unconformity is shown in Plate 2.

The Cygnet Coal Measures outcrop north of Campania and east of Colebrook where the thickness varies rapidly from 0-58 m (0-190 ft) (see fig 2). This variation implies considerable erosion prior to deposition of the massive quartz sandstone of the Lower Triassic, but may be partly due to an undulating erosional surface on the Ferntree Mudstone. If the coarse pebbly sandstone of the Ferntree Mudstone is a fixed horizon (see p. 18), the variation in thickness above it implies erosion of the Ferntree Mudstone before the deposition of the Cygnet Coal Measures. This is consistent with the observations at Tunnack and Stonor (plate 2; fig. 2).

The feldspathic sandstone often contains interbedded lenses of mudstone and carbonaceous material. The proportion of sandstone to mudstone is about 1:1.

TRIASSIC

Rocks of Triassic age crop out over 40 per cent of the area of the basin. The dominant lithology is quartz sandstone, often containing minor amounts of feldspar.

In order to show the nature and distribution of rock units, the Triassic System was mapped on a lithological basis using criteria which may be applied in the field. It therefore expresses factually the field data without reference to previously used 'formation' names.

The major divisions are based on the type of sandstone and the proportion and type of shale or mudstone. Considerable care is necessary to give reliable assessments of the latter although the type of mudstone appears to be a good criterion. The presence of coal or grit provides a further basis for subdivision.

The following list of lithological units observed are not necessarily in the order in which they appear in any section.

Assemblage 1. Quartz grit and conglomerate. The units are generally less than 60 cm thick and consist of pebbles of quartz and quartzite up to 50 mm across and are normally scattered through the quartz sandstone succession at the base of some beds of sandstone. They also form a thicker but patchy occurrence at the base of the Triassic where they overlie the Ferntree Mudstone (*e.g.* Grasstree Hill, Richmond, Tunnack), where they normally grade very rapidly into coarse-grained quartz sandstone. A matrix is rarely present.

Assemblage 2. Massive-bedded, medium- to coarse-grained quartz sandstone with some mudstone and shale. This unit is dominantly sandstone, the sandstone:shale ratio normally exceeds 10:1. The shale, is often very thinly bedded and carbonaceous. This assemblage is generally 15-120 m (50-400 ft) thick and it normally occurs near the base of the Triassic. There is an increase of up to 10% in feldspar content upwards from the base of the unit. This assemblage is common near Rhyndaston, Native Corners and Craigbourne.

Assemblage 3. Similar to Assemblage 2 but with a sandstone:mudstone ratio of 3:1 or less. It may exceed 150 m (500 ft) in thickness.

Assemblage 4. Fine-bedded, generally fine-grained micaceous quartz sandstone containing some mudstone and shale and often plant remains. The sandstone:mudstone ratio is often greater than 4:1. Coarser sandstone may be interbedded and the feldspar content of the sandstone may exceed 10%. This assemblage may be thicker than 90 m (300 ft) and is well developed around Pitt Water.

Assemblage 5. Occasional massive units of quartz sandstone with much massive mudstone and some shale. There are occasional beds of feldspathic sandstone present *e.g.* [22605745]*. The sandstone:mudstone ratio is often less than 1:2. The mudstone is the most stable of the Triassic mudstone and shale and exhibits a high degree of compaction. It also shows pink blotches on unweathered faces, and is often green-grey where fresh. The principal occurrences are east of Campania and south of Colebrook.

Assemblage 6. Clay pellet conglomerate. This is often only a few inches thick and sometimes contains vertebrate remains (*e.g.* in the Pitt Water region). This assemblage may occur in any of Assemblages 2, 3, 4 and 5.

Assemblage 7. Lithic feldspathic sandstone and mudstone. These have previously been called salt and pepper rocks, and are greenish grey in colour when fresh. The sandstone:mudstone ratio is often 1:1. The sandstone shows a characteristic fretting upon weathering.

Assemblage 8. As for Assemblage 7 but containing carbonaceous lenses and coal seams, such carbonaceous material being readily visible. The total thickness is unknown but it exceeds 150 m (500 ft) and from indirect structural evidence may be in excess of 305 m (1,000 ft). Deposition of this unit was presumably terminated by the Jurassic dolerite and indeed much of the flora suggests a Lower Jurassic age. (Townrow, 1962).

Correlations are possible within this basin and with other areas on lithological grounds; with the possible exception of the feldspathic sandstone no time correlation should be assumed.

Assemblage 2 is possibly equivalent to the Mountain Lodge Member of the Springs Sandstone (Banks and Naqvi, 1967) and the Ross Sandstone at Poatina.

Assemblages 3 and 4 are possibly equivalent to the Knocklofty Sandstone and Shale (Hale, 1962; Jennings, 1955), and the Cluan Formation (McKellar, 1957).

Assemblage 5 appears to have been noted previously only at Wayatinah (Jennings, 1955). McKellar's green and grey laminated shales (Tiers Formation) may be equivalent except that the associated sandstone in that section is feldspathic and is only rarely so in the area under discussion.

The nature of facies variations is indicated in a summary of the measured sections (fig. 3). The lower parts of the section in the north being dominated by sandstone, that in the south by sandstone with mudstone. Sandstone exceeds mudstone overall.

On palaeontological evidence the quartz sandstone and mudstone are considered to be Lower Triassic in age (Playford, 1965; Evans, 1966; J. Cosgriff, pers. comm.) whereas the feldspathic sandstone and mudstone are Upper Triassic - Lower Jurassic in age (Hale, 1962; Townrow, 1962).

The total thickness of the Lower Triassic beds is probably of the order of 300 m (1,000 ft) but no complete unfaulted sections are available. In a small area addition of units probably approximates the total thickness with minor reduction due to large scale facies or erosion variations. On a small

* All locations lie within kiloyard grid square 57, zone 7.

scale the sandstone and mudstone beds in Assemblages 2, 3, 4 and 5 may show rapid and extreme variation while maintaining the overall character of the unit. For this reason no attempt has been made to map any particular bed.

The total thickness of the Upper Triassic sediments is also unknown but borings for coal penetrated 150 m (500 ft) at Richmond and 103 m (337 ft) at Colebrook (Hills *et al*, 1922). Details of these bores are given on pages 27, 28.

JURASSIC

Tholeiitic dolerite of Jurassic age crops out over about one-third of the basin. It is intruded as sheets and dykes into all levels of the Permian and Triassic rocks. The structure of the intrusions is discussed in more detail under Structural Geology.

The dolerite consists principally of labradorite and augite, although pigeonite is often common. Subsidiary minerals include magnetite, quartz and orthoclase. Away from contact zones the grain size increases rapidly and the rocks may become porphyritic if the body of material is of sufficient size as at Craigow, Brown Mountain, and Flat Top Tier. Fuller details on the composition and differentiation of the Tasmanian dolerites have been given by Edwards (1942), McDougall (1962, 1965) and in the Dolerite Symposium (1958).

The ultimate stage in the differentiation of the Tasmanian dolerite is a granophyre. Granophyre has been observed at several localities, none of which is at the centre of a large intrusion as might have been expected. All granophyre occurrences are marginal to the intrusive body and are usually in the contact zone (or chilled margin). Descriptions of two such granophyres are given below by G. Everard:

Specimen 1. *Richmond Highway - Craigow Entrance*. The hand specimen is a greyish, mesocratic, medium-grained rock, consisting of feldspar laths up to 3 mm long, irregular yellowish weathered prisms of a ferromagnesian mineral and black micaceous hematite in a feldspathic matrix. In thin section the texture is granophyric, about half the specimen consisting of granophyric intergrowth, mainly of anorthoclase and quartz while the larger crystals consist of labradorite. Quartz occurs as acicular growths in radiating masses, and as interstitial material. Pyroxene in long prismatic crystals has been altered to a yellowish brown biotite, associated with skeletal masses of an iron ore mineral. There are also a few irregular masses of yellowish brown serpentinous material with cores of dark brown iddingsite, possibly derived from olivine. Sphene occurs very sparsely.

Specimen 2. *Native Corners*. In thin section the specimen is a medium-grained rock consisting of completely sericitised, lath-like crystals of feldspar in a finer grained matrix which displays two different but intermingled textures. One texture consists of a mosaic of allotriomorphic crystals of quartz and feldspar. The feldspar grains show differing degrees of alteration, but many grains are almost entirely clear. These are optically negative with a wide axial angle and have a higher refractive index and birefringence than contiguous quartz grains. They consist, therefore, of bytownite. The other texture consists of needles of quartz up to 2-3 mm in length, usually in bundles or brushes, with interstitial feldspathic material not giving a clear interference figure, but with a refractive index lower than that of balsam. The needles and interstitial material are frequently intermingled in micrographic intergrowth. There are also frequent skeletal crystals and irregular aggregates of ilmenite almost entirely altered to white opaque leucoxene, stained pale brown with iron oxides. These seem to be specially associated with the larger, euhedral sericitised feldspar crystals which may also contain a little acicular quartz.

Specimen 1 was close to a contact with quartz sandstone and Specimen 2 with feldspathic sandstone of the Cygnet Coal Measures.

The next description is of the contact rock and inclusions of more differentiated material at Single Hill. While many of the occurrences at this locality are vein and fracture fillings with chilled margins the description covers an ovoid inclusion with no obvious connection to any other late phase material. The inclusion was removed in order to show complete separation. The rocks of the Cascades Group lie less than 2.4 m away across an unfaulted nearly vertical contact.

Specimen 3. *Single Hill.* The hand specimen is a medium-grained leucocratic doleritic rock in contact with a dark grey aphanitic rock. The contact is sharp and marked by a linear concentration of small crystals of magnetite. Along part of the contact is interposed a patch about 6 mm wide, of granularity and colour intermediate between the coarser and finer grained rocks, but the contacts of this intermediate rock with both the finer and coarser grained rocks are still quite sharp. In thin section the finer grained rock has an intergranular texture with minute granules of pale brownish green augite. The granules average 0.02 mm across and occur in a network of labradorite laths averaging 0.05 mm in length. Octahedra of magnetite from 0.01 mm across down to the finest dust are disseminated through the rock. There are also rare platelets of brown biotite. The mode is approximately labradorite 50%, augite 47.5% and magnetite 2.5%. The rock is a fine-grained dolerite. The intermediate rock is slightly coarser grained with labradorite laths up to 0.2 mm long. The texture is also different, being in part sub-ophitic. Most of the feldspar crystals are more or less equidimensional and form a mosaic with patches of micrographic intergrowth and ragged crystals of augite. Magnetite occurs in larger single crystals and irregular aggregates of minute crystals. Minute needles of apatite are common and there is a little epidote. Flakes of sericite appear in the plagioclase crystals. The mode is approximately plagioclase 60%, augite 25%, micrographic intergrowth and mesostasis 12% and magnetite 3%. The rock is a quartz dolerite. In the medium-grained rock the texture is largely granophyric, consisting of irregular altered crystals of plagioclase alternating with patches of micrographic intergrowth and sheaves of acicular quartz. A few laths and irregular crystals of plagioclase remain relatively unaltered, but the ferromagnesian minerals have been reduced to dark irregular patches associated with magnetite, or may have been replaced by carbonate. The rock consists approximately of plagioclase 50%, granophyric intergrowth 37.5%, pyroxene 7.5%, magnetite 2.5%, carbonate 2.5%.

The problem of these granophyres at present cannot be solved. The former type (Specimen 1) may be the result of contamination whilst the latter type (Specimen 2) is suggestive of later stage injection while the original material was still viscous. Edwards (1942) notes such inclusions and others have been observed in the Hobart district. (see also Sutherland, 1964; Leaman, 1971).

A further matter of interest is the differentiation of the Gunnings S.L. intrusion. Edwards (1942) considered this intrusion to be a large dyke several miles long and one mile wide. A gravity survey (Leaman, 1971) has now shown this conclusion to be incorrect although many of the contacts to the body are apparently dyke-like. This means that the presence of a highly acid residuum (not a granophyre) at the top of the hill is not a result of the basic phases dropping out of the system as in an unfloored body. The suggested solution is that the body was the elbow of a major intrusion (Leaman, 1971) and that there has been some lateral circulation of material. If this is correct it may invalidate the use of differentiation studies to determine the structural form of dolerite bodies.

TERTIARY

Sedimentary deposits of this age are restricted to the estuary of the Coal River and Pitt Water, while basalt is to be found as flows or necks in various parts of the basin.

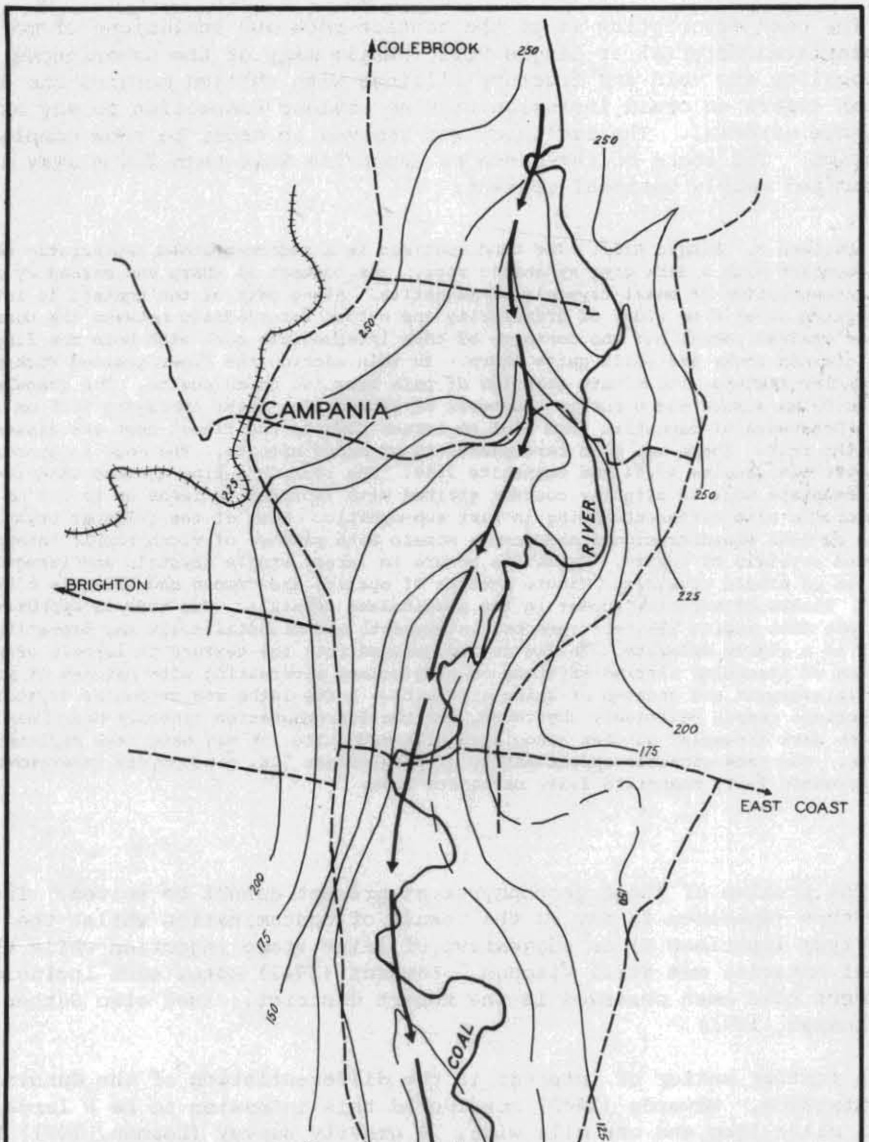


Figure 4a. *Contours of pre-basalt surface.*

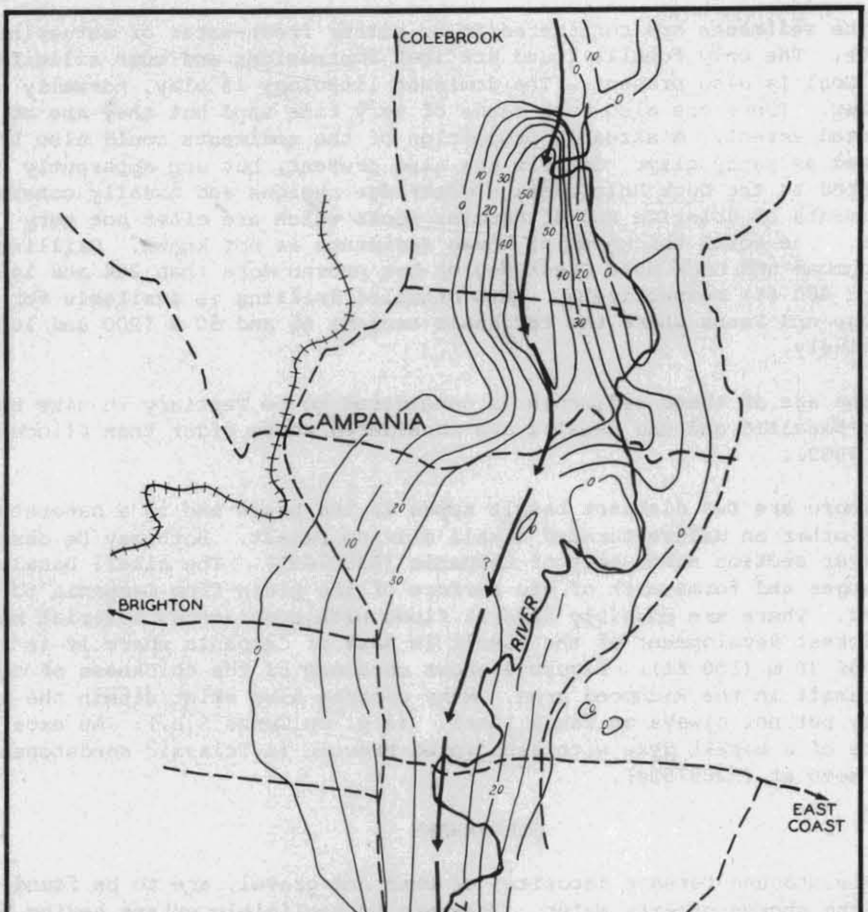


Figure 4b. *Basalt isopachs.*

The sediments are considered to be either fresh-water or estuarine deposits. The only fossils found are leaf impressions and some silicified wood. Coal is also present. The dominant lithology is clay, normally brown in colour. There are also rare bands of very fine sand but they are of restricted extent. A sizeable proportion of the sediments could also be described as sandy clay. Gravels are also present, but are apparently restricted to the Duck Hole Creek - Cambridge regions and usually consist of fragments of dolerite and of Permian rocks which are often not very rounded. The total thickness of these sediments is not known. Drilling in the Richmond and Duck Hole Creek Region has proven more than 204 and 146 m (670 and 480 ft) respectively. Less detailed drilling is available for Cambridge and Penna where the thickness exceeds 61 and 50 m (200 and 165 ft) respectively.

The age of these sediments is considered to be Tertiary in size they are pre-basaltic and the basalts are considered to be older than Pliocene (Spry, 1962).

There are two distinct basalt types in the basin one is a saturated and the other an undersaturated alkali olivine basalt. Both may be observed in a river section north-east of Campania [53007491]. The alkali basalt is the younger and forms much of the surface of the plain from Campania to Richmond. There are possibly several flows with scoriaceous material between. The thickest development of the basalt is east of Campania where it is in excess of 30 m (100 ft). Figure 4 shows contours of the thickness of the upper basalt in the Richmond area. Many centres also exist within the area, commonly but not always on fault lines. (*e.g.* on Gunns S.L.). An excellent exposure of a basalt dyke with associated breccia in Triassic sandstones may be seen at [52857500].

QUATERNARY

Pleistocene terrace deposits, of sand and gravel, are to be found around the shores of Pitt Water. They are of negligible extent having been eroded during Recent times due to a lowering of base level. These deposits may represent the last interglacial stage.

Recent alluvial deposits are found in most stream valleys. They are rarely more than 6 m thick. Gravels are commonly of dolerite pebbles.

Economic Geology

COAL

Colebrook Region

Coal of Upper Triassic age was formerly mined at Colebrook and in Coal Mine Rivulet 3 miles north of Colebrook. Details of the Mines and operations are given by Hills *et al* (1922). Three seams were proved in the Tasma Coal Mine at Colebrook with thicknesses of 91 cm, 1.2 m, 29 cm and 86 cm (3 ft, 4 ft 11.5 in and 2 ft 10 in) respectively. The log of a borehole which was drilled at this mine in 1891, is given on the opposite page:

Description of Strata		Thickness		Total depth	
		ft	*in*	*ft*	*in*
Surface shaft hard cemented gravel		37	6	37	6
Coarse grey feldspathic or tuffaceous sandstone, with carbonaceous markings		22	11	60	5
Light grey shale		3	9	64	2
Grey tuffaceous sandstone, with mud pebbles, and carbonaceous markings		13	8	77	10
Grey clod showing fossil plants		3	0	80	10
Grey tuffaceous sandstone, with coaly markings		14	11	95	9
Coal, *No. 1 seam*		3	0	98	9
Grey tuffaceous sandstone		16	10	115	7
Grey shale, with fossil plants		4	6	120	1
Grey tuffaceous sandstone, with carbonaceous markings		21	1	141	2
Hard grey sandstone, with calcite veins and carbonaceous markings		5	2	146	4
Dark clod with carbonaceous streaks		0	8	147	0
Coal		0	1	147	1
Dark clod		0	5.5	147	6.5
Coal		0	0.5	147	7
Dark clod with coaly streaks	*No. 2 seam*	1	9.5	149	4.5
Coal		0	10.5	150	3
Band		0	0.5	150	3.5
Coal		1	8	151	11.5
Grey clod and tuffaceous sandstone		8	2	160	1.5
Coal		1	8	161	9.5
Band	*No. 3 seam*	0	9	162	6.5
Coal		0	5	162	11.5
Fine grey tuffaceous sandstone		2	6	165	5.5
Grey clod		2	10	168	3.5
Coarse grey tuffaceous sandstone, with a few veins of calcite and carbonaceous markings		58	8	226	11.5
Coal, *No. 4 seam*		0	4	227	3.5
Grey clod, with fossil plants and calcite veins		7	8	234	11.5
Fine-grained sandstone, hard and splintery, with calcite veins		6	8	241	7.5
Coarse feldspathic sandstone, with specks of carbonaceous matter		25	6	267	1.5
Black shales with cubical pyrite		0	4	267	5.5
Grey tuffaceous sandstone, with specks of carbonaceous matter		22	5	289	10.5
Dark shale, hard boring		7	6	297	4.5
Black siliceous fine-grained sandstone		3	0	300	4.5
Black clod showing fossil plants		4	0	304	4.5
Grey tuffaceous sandstone, with carbonaceous markings		25	8	330	0.5
White calcareous shale, sharp and brittle, with plant impressions		7	0	337	0.5
Hard greenstone, fine-grained at top, a little coarser in grain at bottom		6	10	343	10.5

Table 2. ANALYSES OF COAL FROM THE TASMA AND JERUSALEM COAL MINES

	1 %	2 %	3 %	4 %	5 %	6 %	7 %
Water	8.12	8.4	4.6	2.6		2.8	4.1
Volatile hydrocarbons	22.10	26.9	28.3	29.1		12.5	20.6
Fixed carbon	34.44	42.3	50.7	33.9		56.8	57.4
Ash	35.34	22.4	16.4	34.4	19.22	27.9	17.9
Sulphur	0.56				1.12		
Carbon					68.17		
Hydrogen					3.97		
Nitrogen					1.62		
Oxygen					5.90		

Analyses 1, 2, 3, 4 Tasma Coal Mine, Colebrook; 5, 6, 7 Jerusalem Mine, Coal Mine Rivulet

Analyses 1 by W.D. Reid: 2-4 by W.F. Ward; 5 by H.T. De la Beche, 1850; 6-7 see R.M. Johnston (1888, p. 200).

The quantity of coal in the Tasma mine estimated to be 3,648,000 tons (Hills *et al*, 1922). No estimate is available of the total reserves within the area, including those at Coal Mine Rivulet.

Richmond Region

Coal of Upper Triassic age has been known to occur at Richmond for many years (see Hills *et al*, 1922). There are three very thin seams exposed in the Coal River but other very thin seams were located in a borehole, the log of which is given below:

Description of Strata	Thickness *ft*	 *in*	Total depth *ft*	 *in*
Surface shaft	23	0	23	0
Grey clod and shale	4	5	27	5
Coal and shale	1	4	28	9
Grey clod and sandstone	34	3	63	0
Grey sandstone, showing black and grey clods, decayed wood, and coal streaks	190	4	253	4
Coal and shale	1	8.5	255	0.5
Black clod, showing coal streaks	7	2	262	2.5
Grey sandstone, showing decayed wood and coal streaks	121	1.5	393	4
Grey sandstone, showing black and grey clod and streaks of black shale	52	10	436	2
Coal	1	6	437	8
Grey clod	0	3.5	437	11.5
Coal	0	5.5	438	5
Black and grey clod and sandstone	33	5	471	10
Grey sandstone	28	2	500	0

No analyses or estimates of reserves can be given for this coal.

A recent drilling programme in the Tertiary sediments north of Richmond has revealed the presence of thin seams between 30 and 69 m (95 and 226 ft) and between 182 and 200 m (597 and 658 ft) in RC 3 and between 70 and 79 m (230 and 260 ft) in RC 5. The exact amount of coal is unknown, and the seams are very irregular, many being absent from hole RC 5. An analysis of the coal is given below:

	%		%
Moisture	22.8	Ash	7.5
Volatile combustibles	57.7	Sulphur	0.34
Fixed carbon	12.0	Calorific value 8500 BTU	

ROADMAKING MATERIALS

Dolerite has been extensively quarried to provide road bases and surfaces; there are large quarries at Richmond operated by the Richmond Council. Ferntree Mudstone has also been used for this purpose, particularly at Grasstree Hill and Tunnack.

CLAY

The southern areas contain much Tertiary clay, some of which has been used for pipe making and pottery. At present there is no extraction of this material. The reserves of good quality fire-clay are unknown, but they are likely to be small since much of the clay in the area is contaminated with sand (see also Threader, 1971).

SAND

Clean quartz sand has been removed from three localities. The deposits at Seven Mile Beach are extremely large but it is now illegal to remove sand from this source. Deposits, partly of windblown origin and partly due to weathering are to be found at Cambridge and west of Duck Hole Creek. The reserves in each case are more than 460,000 m^3 (60,000 yd^3).

Structural Geology

The principal structural features within the basin are extensive tensional faulting of Jurassic and possibly Tertiary age, partly erosional Tertiary basins, and the form of the dolerite intrusions. Other features include the depositional surface of the Triassic System, the sedimentary structures within the rock units of that system, and basalt intrusions.

Faulting within the basin trends dominantly a little west or east of N-S with a subordinate nearly E-W trend. The character of fault junctions shows that most faults were originally developed simultaneously although some rejuvenation effects may have obscured this. Development has presumabl been by continuous but individual block movement. No definite age can be ascribed to the faults other than that most, if not all, were in existence at, or immediately after, the dolerite intrusion. Plugs and dykes of doleri found in many of the faults support this conclusion.

Rejuvenation of several faults is indicated by dolerite displacements near Cambridge, Richmond and Campania and by the presence of many basalt centres along fault lines in the above areas and also east of Colebrook. North of Campania the rejuvenated movement is usually less than 15 m (50 ft) although movements of 30-46 m (100-150 ft) have occurred on the Coal River fault at Lowdina. The scale of any rejuvenation south of Campania is unknown but it may be up to 300 m (1,000 ft). At Campania there is a marked change in the attitude of the Permo-Triassic rocks. North of Campania the dips are random and usually eastward whereas to the south dips are about 20° W. These steep dips are restricted to a belt some 10 km (six miles) wide; dips are of the order of 5° W elsewhere. Tertiary sedimentation coincides with the belt of high dips. The structure is thus a large monocline with a N-S axis which is hinged at Campania on an E-W cross axis. A fault occupies the position of the E-W hinge at Campania but the throw has not been determined.

The monocline was probably produced by post-Jurassic warping followed by faulting. Post-dolerite step faulting is suggested by the form of a dolerite sill in Lower Triassic sediments in the region of Mt Lord and Brains Hill. The overall structure near Richmond has been suggested in Figure 10. As far as can be determined all faults of post-dolerite age south of Campania downthrow to the east. Rock distribution and wedging out of Tertiary sediments support this.

There are two superimposed fault structures within the basin. Post-dolerite faulting has been superimposed on Jurassic or older, graben faulting. The younger faulting has been more active south of Campania about which it was hinged.

The Richmond graben (Gatehouse, 1967) extends from Pitt Water to a little north of Campania where there appears to be a dichotomy of the structure. The downthrown block forming the western arm passes through Colebrook towards Jericho. All faults producing this structure were of pre-dolerite age. The Richmond graben also appears to be the central block of a much larger scale Jurassic graben structure which is of the order of 16-26 km (10-15 miles) across. This larger structure is bounded to the west by the Bagdad fault (McDougall, 1959; Gatehouse, 1967) which passes SSE from Tea Tree to Cambridge and lies mainly obscured by dolerite, and to the east by the Tunnack Fault. There are smaller horst structures included in the larger structure.

Drilling has shown the Tertiary sediments to be about 210 m (700 ft) thick and to have been deposited in asymmetrical and often steep-sided depressions. The general distribution of these sediments is at first suggestive of a series of lakes: Penna, Richmond - Campania, Pitt Water and Seven Mile Beach. However drilling has conclusively shown that the Pitt Water and Richmond basins are connected by a deep very narrow sediment-filled ravine. The sedimentary basins are thus part of a buried valley system which has been significantly controlled by faulting but in which there has also been much erosion. The thickest deposition is on the western side of the 'basins' as would be expected with the monocline and step faulting. The increasing content of sand and gravel southward and decreasing amounts of wood fragments implies that an estuary was present at Seven Mile Beach - Pitt Water.

Intrusions take the form of nearly concordant sheets up to 300 m (1,000 ft) thick, large dykes often up to 800 m (half a mile) across, plugs up to 1.6 x 1.6 km (one mile by one mile) and smaller dykes and plugs associated with faults and intruded along them.

The structures have been worked out principally from a study of contact locations and characteristics, gravity results and dilation effects.

The nature of the depositional surface of the lower Triassic sediments is difficult to assess due to a lack of detailed information. However, there is considerable variation in thickness of the Cygnet Coal Measures (fig. 2). It is likely therefore that the basal surface was an undulating plain, possibly with a relief of 60 m (200 ft). The Cygnet Coal Measures were probably deposited on an irregular surface subject to some disturbance and erosion, which possibly occurred throughout the period of deposition.

There are some fifteen basalt intrusion centres within the basin. Most are located on fault lines although some are quite separate and may be located on master fractures or reflect fault lines concealed by dolerite or Recent sediments. The intrusions often take the form of cylindrical necks although some can be shown to ovate to dyke-like (*e.g.* plate 3).

GENERAL HYDROLOGY

Methods of Investigation

BOREHOLE DATA

All borehole data from drillers logs and yield tests, are given in the Appendix. Generally there are insufficient bores within each region to enable conclusions of a statistical nature to be made, but summaries and averages have been made which give an indication of prevailing conditions and these are mentioned in the appropriate sections.

GEOPHYSICAL METHODS

Geophysical methods have not yet been used in the selection of bore sites. However, for the purposes of this study, electrical resistivity depth probes have been made at the site of all bores in order to assess the electrical character of differing rock types, the effect of the presence of water and the depth of the water table. No traversing has been undertaken, but its use could locate the precise boundary between Tertiary and Triassic sediments near Cambridge since there appears to be a buried cliff in this region. Traversing could also locate hidden igneous contacts.

The Schlumberger configuration was used almost exclusively. The electrode line was kept, as far as possible, parallel to the topographic strike and the strike of the formations, in order to avoid unnecessary complications to the resistivity curves. The various aspects of the application and usefulness of the method are indicated where appropriate.

The resistivity of a given formation may be exceedingly variable as it is a function of the following factors:

(1) Porosity, or open space due to fracturing.

(2) Disposition of the pores or openings.

(3) Resistivity of the water contained in the formation.

(4) Degree of saturation.

(5) Resistivity of the rock material.

The latter factor is of little significance if the rock contains fluid or is saturated, since the resistivity of a saturated formation is a linear function of its porosity and the resistivity of the water contained in its pores or other openings.

FIELD OBSERVATIONS

Detailed observations have been made on the nature and location of springs and seepages, the attitude, frequency and size of joints and other openings in formations within the area, and the relation of all these features

Plate 3. *Basalt feeder, associated with breccias and tuff, Lowdina.*

Plate 4. *Jointing associated with dolerite intrusion.*

to the contained water and the surrounding geology. Observations were also made on water levels in wells, the effects of pumping and the quality of the water.

Hydrological Properties of Rock Units

The vacant spaces which groundwater may occupy within rocks are responsible for the hydrological characters or properties of that rock. The more spaces there are, the greater will be the storage capacity of the rock; the better the inter-connection, the higher the permeability. It should be noted that as all water moves under the influence of gravity all openings should be of such a size that molecular forces do not exceed gravitational forces. The limiting size for free motion is defined as capillary because in sub-capillary openings water is held too tightly by molecular forces to move under the influence of gravity.

NATURE AND ORIGIN OF HYDROLOGICAL PROPERTIES

Primary Hydrological Properties

The primary or syngenetic hydrological characters are those which are formed at the same time as the rock. Generally, primary hydrological properties are less important than the secondary properties to be described later (p. 34).

Igneous Rocks

Many types of interstices may be developed during the process of solidification. Most primary cavities in crystalline igneous rocks are developed as a result of gas content and only parts of the basalt flows, usually the upper or lower margin, are affected. The dolerite was apparently lacking in volatiles and no such cavities are found in it. Both the basalt and the dolerite contain intercrystal and intracrystal spaces which give them a basic porosity (0.5 - 1%). The resistivity of unaltered rock, which may also be regarded as a primary property is of the order of 1,000 - 10,000 ohm-m.

Sedimentary Rocks

Sedimentary rocks have many more hydrological properties of primary origin than igneous rocks. Sedimentary rocks may be divided into two groups, consolidated and unconsolidated.

Consolidated rocks. These have a considerably higher porosity than the igneous rocks. Results are available for Triassic quartz sandstones (12-15%); Upper Triassic feldspathic sandstone (19-26%) and Permian Ferntree Mudstone (22%). The above figures are based on results quoted by Nye (1924). A high porosity does not necessarily imply high specific yield, particularly in the case of the finer grained rocks since the grain size and atomic forces are such that the water within pore spaces is strongly held.

It has been shown (van Wyk, 1963) that other primary structures such as bedding or planes of stratification and the contacts between layers of sandstone and shale may have very little effect on permeability. This is because no interstices necessarily exist in these zones in the tectonically unaffected state. In the area under discussion most rocks have been stressed and such openings do exist.

The resistivity of unaltered rock, a further primary property, is also useful since divergence from this state may be reflected in the value of the resistivity for the rock.

Unconsolidated rocks. These differ considerably from the consolidated rocks: porosity is normally very much higher and as there is no cement, permeability is also high. Such deposits freely yield any water they may contain. These comments apply only to sand and gravel, since clay deposits are little different from mudstone.

Secondary Hydrological Properties

Secondary or epigenetic hydrological properties develop at some stage after the formation of the rock. They are important because they control the occurrence, storage and movement of groundwater in most rocks in the district.

Secondary hydrological properties are developed as a result of the action of complex geological, physical, chemical, organic and climatic conditions that have affected the rocks after their formation. These properties may be developed in two stages:

(1) the formation of openings by physical or geological processes, and

(2) the modification of these and primary openings by the action of circulating water and weathering.

The more important processes that have affected the hydrological properties of rocks are discussed below.

Near-Surface Phenomena

Although the following processes are only operative near the surface and may have no direct influence on the yields of bores, they are nevertheless of great importance because they are responsible for the countless joints and fissures found near the surface. These not only accelerate weathering and soil formation, but affect the infiltration capacity of the rock below. The processes include elastic response, thermal changes, frost action and organic activity.

Elastic response results from the unloading of rock by uplift and erosion. Low angle joints develop approximately parallel to the ground surface (Ellis, 1906; Hills, 1963) and are called sheeting. Such joints are often seen in dolerite, and show an increasing separation with depth. They are often about 30 cm apart near the surface. The effect in sedimentary rocks, particularly the strongly laminated formations, is to cause partings along bedding where there is an abrupt change in rock character.

Thermal expansion during the day and contraction at night serves to disintegrate the rocks. This effect is particularly noticeable with reference to the igneous rocks.

Frost action is limited throughout most of the district. However, in the elevated areas to the east it may be significant, especially in the igneous rocks.

Organic activity contributes greatly to the development of cavities, particularly the enlargement of pre-existing interstices. Tree roots may extend 15 m below the surface in some localities, and worms, ants, small rodents and the like also contribute an incalculable amount to such development.

Deep-Seated Phenomena

Hydrologically, the more important geological processes are faulting, jointing and igneous intrusion. The resultant features are of more profound significance in that they persist to considerable depth and need not be confined to a zone near or above the water table. The storage capacity and ability of rocks to yield water is determined by the extent, pattern, size, openness, continuity and interconnection of the openings produced. Such openings may be modified by weathering.

Jointing. All consolidated rocks within the district are broken by joints which are undoubtedly the most important and abundant of all the hydrological interstices that rocks contain. Joints may be associated with faulting, igneous intrusion or epeirogeny. Joints produced as a result of epeirogeny are of greatest overall importance. The boring records indicate that only one or two water bearing joints are struck in successful bores.

Faulting. Most faults within the area are of Jurassic age and may be related to the intrusion of the dolerite. Some post-dolerite faults are present, and many older faults show evidence of rejuvenation. Faults may influence groundwater occurrence in three ways. Firstly, they affect the distribution and position of aquifers; secondly, they may act as underground dams; thirdly they could act as conduits to flow.

Whether faults act as dams or conduits depends on the character of the faulted rock. Dams may be developed if an impermeable bed is faulted against an aquifer, or if decomposition in the fault zone produces clay minerals which effectively seal off the rocks along the fault zone. If the faulted rocks are brittle and the weathering products do not include large amounts of clay, the fault zone may remain open enabling it to transmit large quantities of water. The term 'fault zone' refers to the actual zone of breakage as well as the zone about this in which joints result from the faulting are developed. There are commonly large numbers of small joints associated with faults in competent rocks.

Most of the formations in this area tend to seal off by weathering the fracture system associated with faults. Notable exceptions are the Malbina Formation and the Ferntree Formation. Drilling in such a zone increases the chance of success but does not necessarily mean that the yield will be abnormal.

Dolerite intrusion. The effect of the dolerite intrusion on the sedimentary rocks of this area is generally small. As a result of intrusion the rocks in the contact zones are hornfelsed, producing chert and quartzite. In all cases there is a hardening effect. As a result of this thermal metamorphism the porosity of the sediments is decreased, but the permeability of the rocks may be increased due to the development of many joints in the contact zone. This is equally true of the chilled margin of the dolerite. There is usually little crushing, tilting or other disruption of the rocks near the contact.

Van Wyk (1963) showed that the most successful bores in the Karroo rocks of South Africa are placed in the contact zone of dolerite intrusions which supports the above observation. Bores placed to strike contact zones should aim to intersect them 4.5-9 m below the water table. If the hole is too shallow, it may fail by not intersecting sufficient water-bearing fractures, or if too deep by the closure of joints with depth.

The contact zone, even of large dolerite masses, is quite narrow. The actual width depends on the thermal susceptibility of the intruded formation and its position relative to the dolerite intrusion. Rocks with high calcium content, *e.g.* Grange Mudstone, are particularly affected and the contact zone may be more than 6 m wide. Rocks situated toward the roof of an intrusive body are more likely to be affected than those on the sides.

Two sets of tension joints may have developed in the dolerite and adjoining contact zone during cooling, *i.e.* columnar joints perpendicular to the contact and planar joints parallel to it. These joints are more closely spaced near the contact, where they are very numerous, very fine and closely interwoven. Only a small proportion are capillary or super-capillary. The columnar joints are best developed in the dolerite, and the planar joints in the baked sedimentary rock, although both types of joints may occur on either side of the contact zone. The effects of weathering and circulating water are most important in making these joints of hydrological value. Plate 4 shows the nature of the joints in a dolerite contact zone.

Basalt intrusion. Basalt dykes and necks generally have little effect on the country rock due to their small size. Occasionally, there is considerable thermal metamorphism as at Native Hut Rivulet [250490]. Plate 3 shows a basalt feeder with associated breccias and tuff 3 km north of Campania [285500]. Many of the centres are more resistant than the surrounding rocks and stand out clearly.

Effects of Weathering and Circulating Water

Weathering is the second stage in the development of secondary hydrological properties. It is a selective and self-intensifying process, and as a result of its action water is able to circulate more freely.

Weathering begins by incipient alteration along joints and gradually proceeds to rot the rock between them. If there is a high density of joints in any particular locality, basins of decomposition may develop. These features are the most important source of groundwater in igneous rocks (Enslin, 1943; van Wyk, 1963). In rocks less susceptible to weathering, *i.e.* most sedimentary rocks, or where the joints are further apart, the process is usually confined to alteration along joints. There are many variations between these extremes. The Grange Mudstone and the feldspathic sandstone are the most susceptible formations to circulating water, and may be completely reduced to a puggy mass for over 15 m from the surface.

Depth of weathering. Little information is available on this matter within the district. Normally weathering extends to the water table and we may expect to find its effects to the depth of the lowest level of the water table. Groundwater circulation, which assists alteration, may extend to considerable depths in many formations or zones of high permeability such as master joints or fractures. This is deemed unlikely here from a review of the temperature of the water.

In dolerite and basalt the depth of weathering may be up to 6 m from the surface, but it is generally much less than one metre. Great depths are achieved only in favourable conditions, *i.e.* when there are many joints with access to circulating waters. No detailed information is available on any basins of decomposition.

Little is known about the weathering of the sedimentary rocks. Extreme weathering usually occurs to a depth of about 3 m in most formations. Thereafter most weathering is confined to the immediate vicinity of any openings. The Grange Mudstone and feldspathic sandstone are exceptional in this respect and along drainage lines may be completely decomposed to depths of 15 m.

Lateral extent of weathering. No detailed information is available on the lateral extent of any basins of decomposition in any of the consolidated rocks of this area. Such basins are rare and probably of little importance, except in feldspathic sandstone where they may extend across areas of more than 84,000 m^2 (100 yards square).

Effects of weathering on hydrological properties. Weathering may increase the porosity, specific yield and permeability of a formation to such an extent that it may be an excellent supplier, whereas in its unaltered state it was unproductive. The joints, fractures, partings and other interstices, possible or existent, which a rock contains in a closed or disconnected state are usually opened by weathering. This increases the porosity of the rock, whether it be igneous or sedimentary. The extreme condition is the resultant soil. The more openings that are developed, the more likelihood of their being connected. If they are open and connected, the rock will be a potential water bearer and, if the interstices are capillary or larger, a supplier. Should the weathering be extreme, in which case the texture of the rock is destroyed, the rock may be incapable of yielding its contained water.

The weathering of rocks, because it increases the porosity and interconnection of interstices, increases the storage capacity. This is a most important aspect of the hydrology of consolidated rocks since pumping may rapidly remove the water in a fracture system. For optimum satisfaction from a bore, there should be an hydraulic connection with a lake or stream, or with unconsolidated material which lies below the water table.

WATER-BEARING CHARACTERISTICS OF ROCK UNITS

Permian

Cascades Group

In other areas this formation has been shown to be an excellent aquifer, *e.g.* at Cygnet (Leaman, 1967); it is very permeable due to moderate fracturing and the presence of many fissile bands, fossil zones and bedding partings. The limestone zones tend to be more massive and simply fractured. Upon weathering the Grange Mudstone reduces to clay, producing low lying swampy areas and is then unlikely to yield much water.

No bores have been drilled in this formation, however by comparison with other areas a high success rate is anticipated with yields of 1,140-1,600 l/h (250-350 gal/h). Due to the high horizontal transmissibility of this formation best results will be obtained where the dip of the rock and slope of the land surface do not permit ready escape of the contained water.

Malbina Formation

Except for Member A, the water-bearing properties of this formation are essentially similar to those of the Ferntree Formation. The basal sandstone may be porous if no redeposition of silica on the grains has occurred. This formation has not yet been drilled and its distribution and topographic position make it unlikely that much water could be recovered.

Risdon Sandstone

The distribution of the Risdon Sandstone is such that only in exceptional circumstances could it be water bearing. It could be a good aquifer as a result of high porosity and moderately high permeability.

Ferntree Formation

This formation is probably the best consolidated aquifer available in the area. All water is contained in fractures or bedding planes. Water may be confined in the fissile bedding zones if the more massive beds are poorly fractured or if the fractured openings are very small.

The grit or conglomerate band is considerably more porous than rocks of the dominant mudstone lithology, although it is much less fractured. As a result of the overall competence of this formation it is normally well endowed with fractures, both horizontal and vertical.

The yield of wells is normally in the range from 910-2,275 l/h (200-500 gal/h) although in some cases it may reach 4,550 l/h (1,000 gal/h). The highest yielding wells in the basin are in this formation at Tunnack. The yield is not directly influenced by the depth of wells, but rather by the condition of the rock which may be indicated by the resistivity. As fractures tend to be sealed with pyrite or closed tight at depth, bores more than 24-30 m deep are not recommended. The chances of striking a good supply at depth in this formation are very poor. Twenty-three bores have been drilled in this formation; one of these was a failure. The quality of the water is fair to excellent. (see also p.52).

Cygnet Coal Measures

Water may be contained in either the primary pore spaces or in secondary openings such as bedding partings, joints or secondary pore spaces where some cement has been removed. The bedding partings are the most important secondary property.

This formation is rarely of sufficient thickness or in a desirable topographic location to be drilled for water. It is expected that its water bearing characteristics and quality would be similar to that of the Triassic sandstone and mudstone. A small number of bores in the Tunnack Region have passed through this formation but it is not known how much water it contributed. Bore T 13, for example, indicates that it provided none at all, water being struck at the top of the Ferntree Mudstone.

Triassic

As with the Cygnet Coal Measures, water is contained in both primary and secondary openings. It has been found, however, that bedding planes or partings along bedding or compositional variations are the most significant and water often issues forth along such zones. It is common for the rock between fractures or bedding zones to be quite dry due to complete cementation or, with quartz sandstones, solution and redeposition of silica. Cementation is very variable. The mudstones, while being more porous, generally do not yield any contained water due to molecular forces.

Where the section is almost completely quartz sandstone, water can be obtained at any depth, although drilling beyond 30-37 m is often pointless. Most bores recover useful supplies at lesser depths (Table 3, p.41). It is probably better to start again at a new site if water is not recovered within this depth than to drill on. Water can be recovered from the occasional bedding zones or at the boundaries between sandstone and shale. The shale is subordinate and usually occupies or is equivalent to major bedding zones. Beds of sandstone are often 3-6 m thick, although the average thickness is about 1.2 m. Typical yields from sandstone successions are in the range of 910-1,820 l/h (200-400 gal/h). Near-vertical fractures are often more than 1.5 m apart but are important in ensuring a fully saturated section.

Where the section consists of quartz sandstone and mudstone the situation is complicated, the degree of complication depending on the joints present and the continuity of the lithologies. Water is usually recovered from bedding zones or partings at lithological boundaries, although some may be supplied by porosity effects from the sandstone units. Water supply depends in this case on the continuity of the water bearing beds as some beds may be lenticular and shielded almost completely by mudstone and consequently will be dry. The presence of joints continuous across beds or interconnected with the main bedding zones is vital if deeper layers of sandstone are to have a good chance of yielding water. They are also necessary to ensure satisfactory replenishment.

The mudstone often contains a high fracture density, an average of 13 per metre, but the fractures are often very fine, irregular, poorly connected and probably of little importance. The sandstone-mudstone successions also yield 910-1,820 l/h (200-400 gal/h) and in this area water quality is quite good (see p. 53). Failures are generally rare and quite unpredictable, due probably to the lenticular deposition and shielding effects described above. Resistivity methods may help to avoid such failures.

The feldspathic sandstone successions have similar characteristics to the quartz sandstone-mudstone sequences with one major difference; they are much more susceptible to weathering. Where water has passed through such rocks rich in feldspar and rock fragments there may be almost complete decomposition to clays. This effect may persist to considerable depths and is most common in low lying areas. The mudstone associated with these successions is very prone to decomposition. If possible, bores in this formation should commence on a definite outcrop, or where it is known that relatively fresh material occurs at shallow depth. This can be proved by a post-hole digger or resistivity methods. Yields at good sites are of the order of 1,365-1,820 l/h (300-400 gal/h). The water is generally good to fair in quality.

The grit, clay-pellet conglomerate and coal beds generally play little part in supplying water is Triassic rocks since they are usually thin and discontinuous.

Jurassic

All the dolerite within the area occurs in a fractured state with a very thin weathering and soil cover. In certain parts of the area, normally controlled by rock composition, the weathering may be much more extensive as at [53147386], east of Richmond.

The porosity of unweathered dolerite is less than one per cent, and consequently any contained water is found in fractures. Weathering, providing it is not extreme and that it has produced a gravelly material retaining the original texture, considerably increases porosity and permeability (see also p. 37). The fracture system in dolerite is normally extensive, and although rarely orthogonal has many joints at low angles. It is dominated by vertical or near vertical joints. Generally the dolerite is so disposed throughout the area that any proposed bores would be in an unfavourable topographic location, or where the water table, if present, would be very deep.

Tertiary

Tertiary sediments consist predominantly of clay, with some beds of very fine sand and occasional gravel. The gravel is often derived from dolerite and is found only in the region about Pitt Water and Cambridge. The sand is similarly restricted, although a little sand was found north of

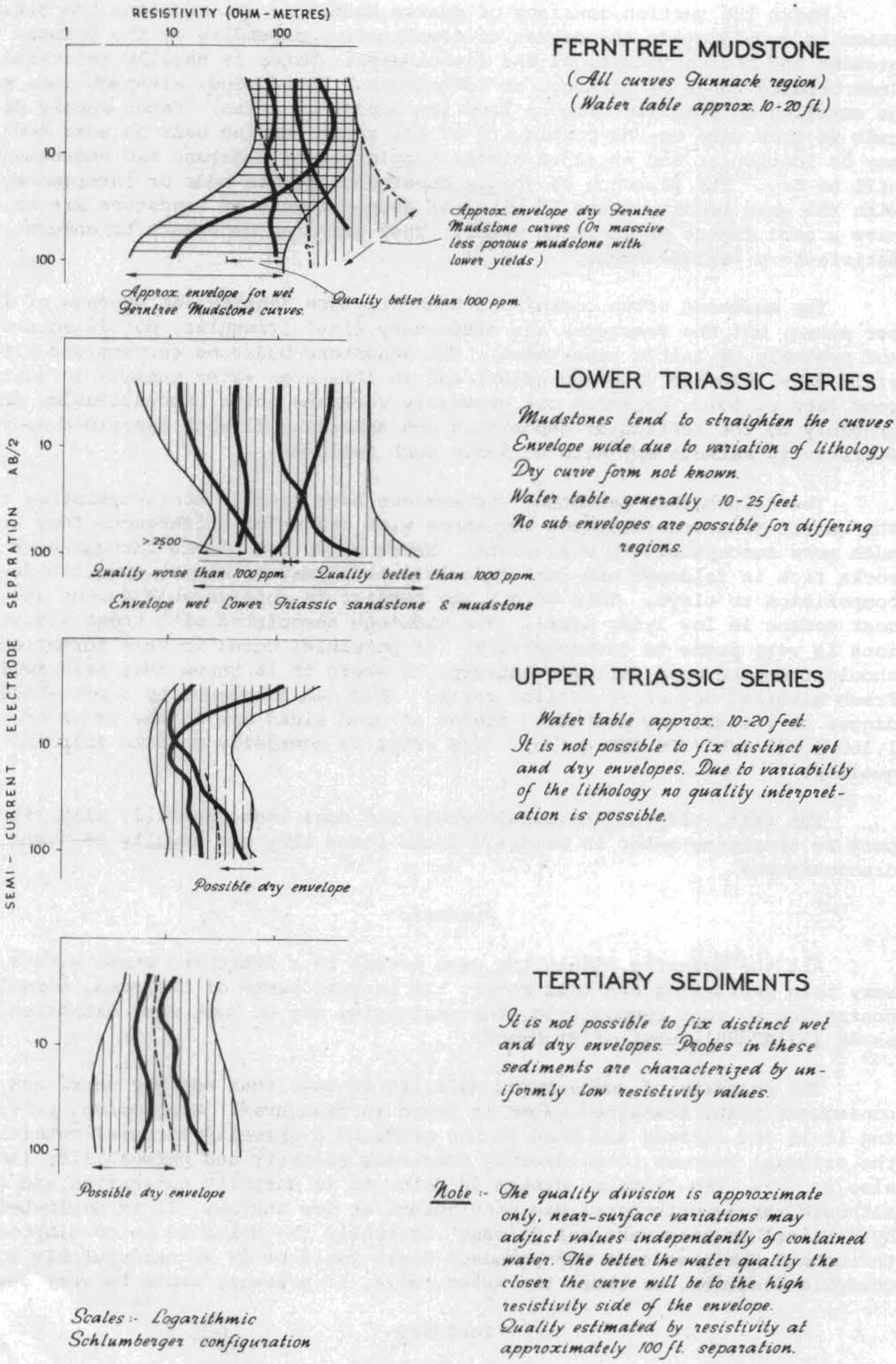


Figure 5. *Typical resistivity depth probe curve forms.*

Table 3. SUMMARY OF ROCK/WATER CHARACTERISTICS

Rock type	Region	No. of bores	No. of failures	Depth water struck	Total depth of bore	Water quality (T.D.S.)	Yield	No. of bores not included in averages
				ft	*ft*	*ppm*	*gal/h*	
Permian	Tunnack	22	0	34.0	57	778	340	2
	Richmond	1	1	-	48	-	-	-
L. Triassic	Tunnack	11	0	39.3	78	245	261	-
	Stonor	15	1	47.5	84	1,501	267	-
	Richmond	1	0	93.0	124	1,200	200	-
	Duck Hole	5	0	104.0	210	2,950	252	-
	Cambridge	4	0	91.6	127	2,200*	187	-
	Penna	2	0	75.0	122	>3,100	250	-
U. Triassic	Colebrook	12	2	49.4	125	707	156	1
Tertiary Sediments	Richmond	4	1	NR	513	8,000	350	-
	Duck Hole	7	1	49.0	131	2,011	675	2
	Cambridge	11	4	53.0	130	4,500	183	4
	Penna	4	4	-	126	-	-	-
Basalt	Penna	2	0	16.0	40	2,900	275	1
Total		101	14					

* One reading only.

Richmond. The overall porosity of these sediments is probably in excess of 20-30% but water has been recovered only from sand and gravel. The clays do not appear to yield water in any significant quantity and the yield per hole is probably an indication of the proportion of sand encountered on drilling.

In the Richmond region, where the amount of sand is small, but where there are occasional coal seams and gravels the yield is of the order of 1,600-2,045 l/h (350-450 gal/h). This yield may be taken to be the approximate effective yield of sandy clays. Similar results could be expected in parts of the Duck Hole Creek region although the presence of a bed of sand 1.5 m thick yielding up to 5,455 l/h (1,200 gal/h) in the east indicates the effect of such beds on yields. Further south yields in excess of this were obtained from thicker sand units.

At Cambridge and Penna many holes were drilled in pure clay and were failures. Water quality is never good (see also p. 53). Resistivity depth probes on Tertiary sediments are characteristic and are shown in Figure 5.

To date only two bores have been drilled in the basalt at Penna. These have yields up to 1,365 l/h (300 gal/h). The water is contained in both vesicular openings and joints. The former give the rock a horizontal permeability and the latter a vertical permeability.

It is not expected that the basalt will be an important aquifer in this area due to its overall thinness, and to the effects of drainage to the Coal River. The entire 9 m of basalt encountered at Hole RC 3 was dry.

Quaternary

The alluvial deposits found in valley floors adjacent to streams may be expected to be excellent suppliers of water providing they are sufficiently thick for a water table to exist within them. Lack of cementing means a very high porosity and permeability.

Similar comments apply to the sands of Seven Mile Beach. Water may be recovered from the dunes but care must be taken not to have an overdeep hole as this will draw in sea water. Beneath the sand at a depth of 1.8-2.4 m, clays are often encountered. These clays effectively separate good water from saline water. This clay layer should not be penetrated. The yield characteristics of the sands near the surface are unknown.

Table 3 presents a summary of the rock water characteristics of the various formations in the different regions. It should be noted that the averages are not necessarily meaningful (depending on information). They are presented only as a convenient way of emphasizing any difference and should not be regarded as an accurate estimate necessarily applicable to proposed holes.

Water Level and Water Table Conditions

GENERAL CONSIDERATIONS

The definition of a water table as 'the surface within a groundwater body at which the hydrostatic pressure is equal to atmosphere pressure' (Jones, 1965) applies to fracture aquifers as well as to porous soils or rocks.

According to this definition a water table exists in all rocks within the area. However, for most rocks it is restricted to the secondary openings and is interrupted by the fresh rock between them (fig. 6). Where the rocks are deeply weathered, or very minutely fractured, an uninterrupted water table may be present, as in porosity aquifers. In such cases the water table lies in the mantle of decomposed or fractured material and is interrupted only by solid rock in places where weathering or fracturing has not proceeded to a depth below the water table. (fig. 6).

WATER TABLE IN RELATION TO WATER LEVELS OBSERVED IN BORES

Many bores drilled within the basin have been sited on consolidated rocks. In most cases the results suggest that the holes tapped confined water. This is indicated by the fact that holes remain dry until at some depth a water-bearing fissure or zone is intersected. Water then enters and rises within the hole. In some cases this has resulted in a flowing bore. The mechanism is clearly shown in Figure 6, bores 1 and 3. Bore 1 strikes a water bearing fracture at A, but since A is some distance below the water table the water contained in the fracture at A is under a pressure equal to

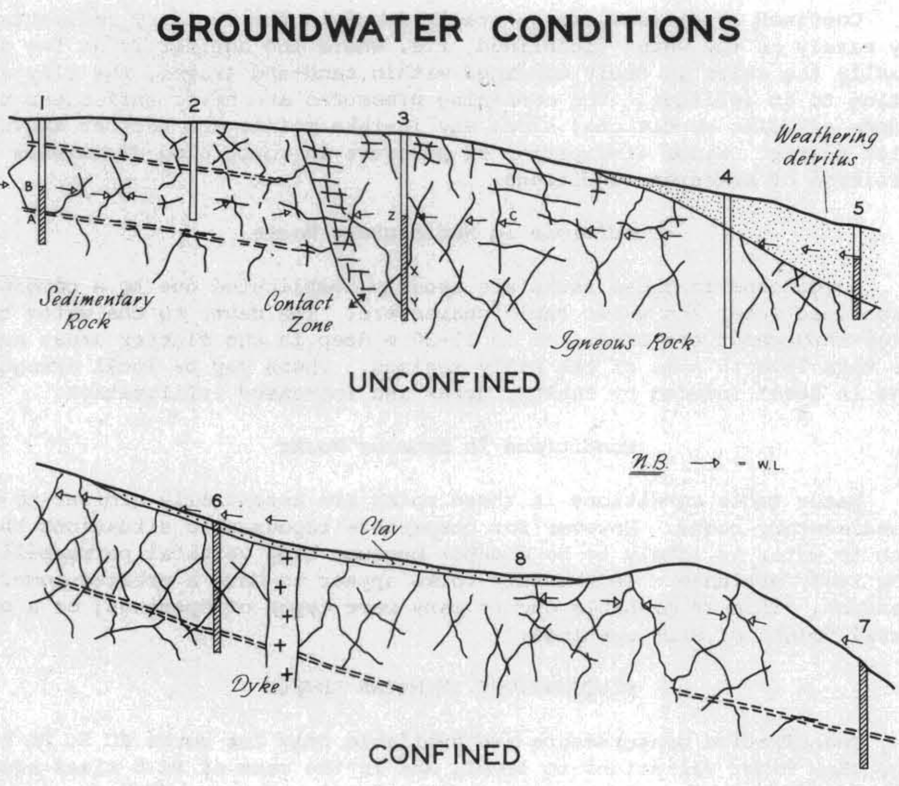


Figure 6.

5 cm

the head A-B of water. The water therefore rises in the bore until its upper surface approximates to the level of the water in the fractures, *i.e.* the water table. Friction losses may prevent a full rise. Similarly bore 3 strikes water at X and Y. The water rises to the level of Z, the position the water table would have occupied in fractures at that point, had it been present.

As a result of the high degree of interconnection, most areas do not have individual water tables in each joint or joint system and there is an apparent continuity of the water table over large areas.

Joint storage is usually small. Therefore any large supplies drawn from it must have been derived from joints over a large area or from a source such as a lake or stream.

The configuration of the water table is generally a subdued replica of the surface topography. The level in bores is near the surface close to springs, streams or marshes. Such water table features dry up in the summer and the water level in the bores falls.

Resistivity probes in various parts of the district, using bore control, have substantiated these observations. The water level in bores will thus be regarded as the water table unless otherwise stated.

Confined conditions are generally found in the Tertiary sediments. Only rarely is the water unconfined, *i.e.* where the aquifer is at the surface. Normally the water is truly confined within sand and gravel, the clay approximating to an aquifuge. The confining pressures are never sufficient to produce artesian conditions, since any in-take points are not far above the outlet points. Minor dissipation of pressure en route also diminishes the likelihood of artesian conditions.

Conditions in Sedimentary Rocks

Conditions in these rocks are usually complicated due to a combination of confined water and water table characters. The depth to the water table varies throughout the area. It is 15-30 m deep in the flatter areas and more than 15 m in some of the hilly regions. There may be local irregularities in level induced by faults, dykes and increased infiltration.

Conditions in Igneous Rocks

Water table conditions in these rocks are essentially similar to those in sedimentary rocks. However for comparable topographic situations the depth to water is likely to be greater because high vertical permeabilities allow ready drainage. Sedimentary rocks appear to have a greater power of retention. This is probably due to many more types of openings, or a greater overall volume of such openings.

FLUCTUATIONS IN WATER LEVELS

Quantitative measurements are available only for bores RC 5, RC 6. These show minor variations in level, and in the case of RC 5 rises are directly related to heavy rainfall but with a lag period of about one week for the maxima to be reached.

Changes may be due to recharge, pumping, tides and atmospheric pressure. Fluctuations are much more pronounced in consolidated rocks since these are of lower permeability and storage capacity. Recharge causes a rise in level over a large area. The change may be immediate or delayed, depending on the efficiency of the hydraulic system within the rocks.

The more significant changes are usually due to pumping, during which the water level in the hole is normally lowered. If the pumping rate exceeds the rate of replenishment for a long period the groundwater supply may be depleted. The time for depletion varies depending upon the extent of the fracture system and its capacity for transferring water. In coastal regions, where fresh water rests on salt water, the effects of pumping may be very serious. Removal of the fresh water causes the level of the saline water to rise. If care is not taken salt water will be pumped. Tidal changes may exaggerate this situation by periodically raising and lowering the salt water interface.

Fluctuations due to atmospheric pressure changes are normally slight and are most noticeable in bores tapping true artesian aquifers.

DRYING-UP OF BORES

Overpumping, or lack of replenishment during a dry season may cause considerable lowering of the water table. The effects of transpiration cannot be neglected in this context. If a bore has not been drilled deep enough to maintain a free water surface during the dry season then the bore will dry up. Bores should thus be drilled 3-6 m below the water level at the time of drilling, in order to have a reasonable safety factor. As further protection, no one area should have so many bores that the water level is continually falling.

Over a period of years bores may also dry up, due to a clogging effect. Water drawn into the hole may carry with it grains of rock material which are usually removed immediately with pumping. If however the bore is spasmodically used this silt may collect at the bottom of the hole or even be drawn back into the rock due to pressure responses. It may then block the openings which allow water to enter the hole. Efficient cleaning with high rate pumping, surging or detergents can restore the hole. It is better, however, to use the hole regularly and avoid clogging since the remedy is by no means always successful.

SPRINGS

'A spring is a place of natural discharge of groundwater as a liquid' (Jones, 1965). Springs are very common and usually occur at any place where there is a hydrological discontinuity, either as a result of topographic or geological conditions or both. Figure 7 shows some typical spring types.

Types A and C are very common throughout the area and simply reflect a permeability difference between the dolerite and Triassic sedimentary rocks. This type of spring is not common at or near contacts with Permian rocks since both Permian sediments and dolerite have equivalent fracture permeabilities. The presence of such springs implies that the dolerite has a high vertical permeability, the sediments a dominantly horizontal permeability and the discontinuity occurs at the contact. Since dolerite has a moderately high vertical permeability even large, steep sided bodies may drain rapidly. As a result springs of this type are often intermittent.

Type B is the reverse of A and C but only occurs when there is no possible drainage path in the igneous rock. If the body were in fact in a depression the water would be emitted from the bedding as in case E and would be immediately absorbed by it. Instead there is flow within the igneous

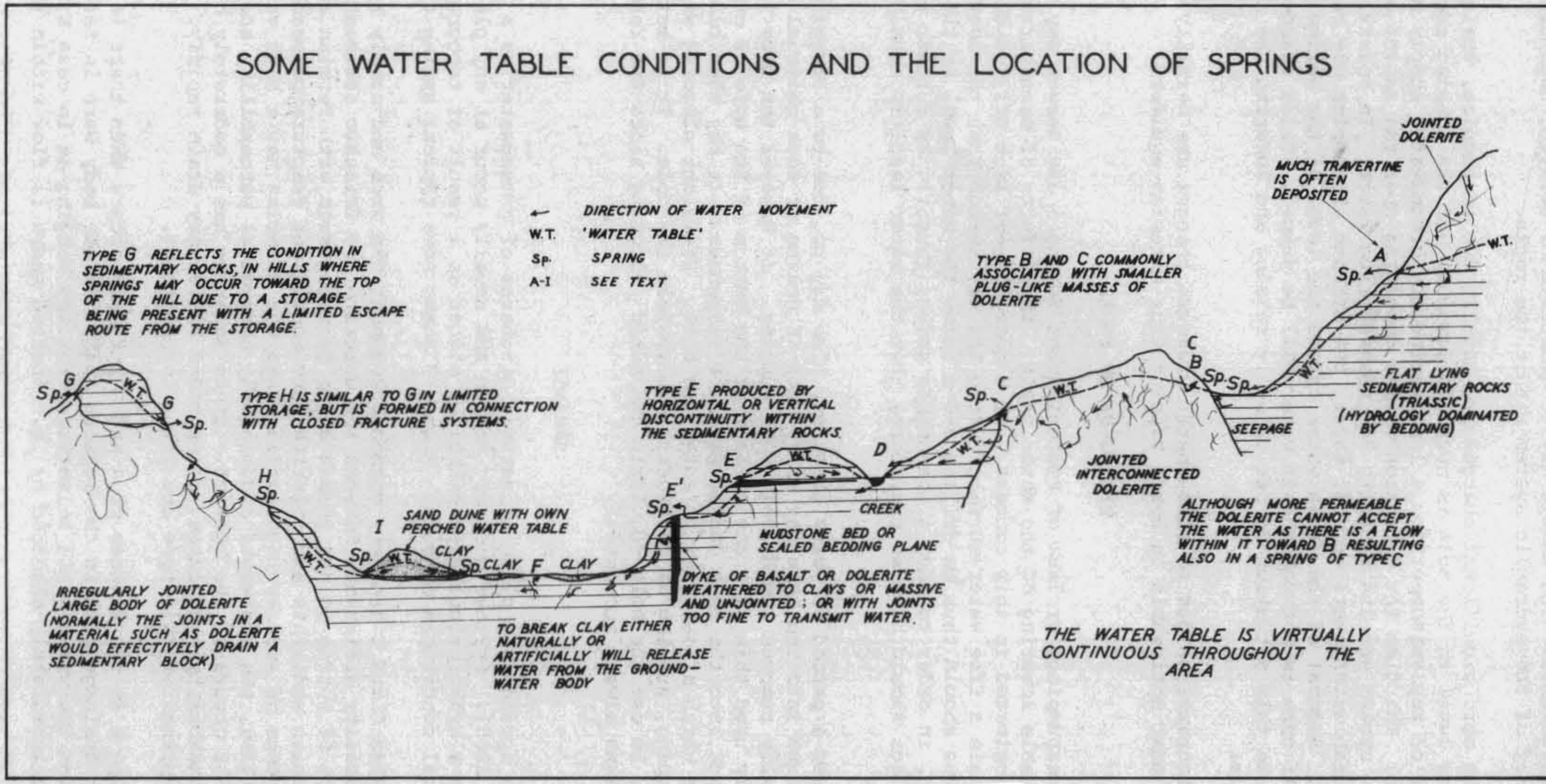

SOME WATER TABLE CONDITIONS AND THE LOCATION OF SPRINGS
DIRECTION OF WATER MOVEMENT
W.T. 'WATER TABLE'
Sp. SPRING
A-I SEE TEXT
TYPE G REFLECTS THE CONDITION IN SEDIMENTARY ROCKS, IN HILLS WHERE SPRINGS MAY OCCUR TOWARD THE TOP OF THE HILL DUE TO A STORAGE BEING PRESENT WITH A LIMITED ESCAPE ROUTE FROM THE STORAGE.
TYPE H IS SIMILAR TO G IN LIMITED STORAGE, BUT IS FORMED IN CONNECTION WITH CLOSED FRACTURE SYSTEMS.
TYPE E PRODUCED BY HORIZONTAL OR VERTICAL DISCONTINUITY WITHIN THE SEDIMENTARY ROCKS.
TYPE B AND C COMMONLY ASSOCIATED WITH SMALLER PLUG-LIKE MASSES OF DOLERITE
MUCH TRAVERTINE IS OFTEN DEPOSITED
JOINTED DOLERITE
FLAT LYING SEDIMENTARY ROCKS (TRIASSIC) (HYDROLOGY DOMINATED BY BEDDING)
SEEPAGE
JOINTED INTERCONNECTED DOLERITE
ALTHOUGH MORE PERMEABLE THE DOLERITE CANNOT ACCEPT THE WATER AS THERE IS A FLOW WITHIN IT TOWARD B RESULTING ALSO IN A SPRING OF TYPE C
CREEK
MUDSTONE BED OR SEALED BEDDING PLANE
DYKE OF BASALT OR DOLERITE WEATHERED TO CLAYS OR MASSIVE AND UNJOINTED ; OR WITH JOINTS TOO FINE TO TRANSMIT WATER.
SAND DUNE WITH OWN PERCHED WATER TABLE
CLAY
IRREGULARLY JOINTED LARGE BODY OF DOLERITE (NORMALLY THE JOINTS IN A MATERIAL SUCH AS DOLERITE WOULD EFFECTIVELY DRAIN A SEDIMENTARY BLOCK)
TO BREAK CLAY EITHER NATURALLY OR ARTIFICIALLY WILL RELEASE WATER FROM THE GROUND-WATER BODY
THE WATER TABLE IS VIRTUALLY CONTINUOUS THROUGHOUT THE AREA

Figure 7.

body toward B, and the two components result in substantial springs.

Type D is the most common of all springs, and supplies creeks and streams of all sizes. It occurs where there is a topographic depression which cuts the water table. Such depressions are usually produced originally by run off, and later maintained, in part at least, by groundwater.

Type E may occur in various topographic situations and is produced by horizontal or vertical anisotropy of rock units. These anisotropies force the water to the surface.

Type F is the type of spring which is normally observed after fields have been ploughed, often for the first time. It may occur naturally and is dependent on a path through clays or hard pans which seal the water beneath in the rock. The volume of water released is often small as its path is frequently narrow and tortuous. The path may be created by natural or manual disturbance of the sealing layer.

Type G is unusual, as it occurs near the top of a hill, and depends on water being trapped high in the hill by closed fracture systems or some other means which can be fed out along some discontinuity *e.g.* at contacts.

Type H occurs when water is passed to the surface through a closed fracture system, as is common in many of the larger dolerite masses. The limitation on the fracture system may be caused by blockages in master joints sealing off closed networks.

The reliability of a spring depends upon its type, the source of the water, the source storage volume and periods between rainfall.

Types, A, C, G, H are related to igneous fracture systems which may be rapidly depleted due to the small volume of the fractures. They thus require a substantial rock-fracture volume and regular recharge. Types B, D, E, F, are much less sensitive since they are supplied by slower yielding rocks with a larger storage volume.

The rock near springs may be completely saturated, and a dry zone need not exist. Bores should not necessarily be placed at spring sites. Springs are related to special conditions either natural or man-made and are thus a function of disturbance. Further disturbance may improve, destroy or leave the spring unaffected.

CAUSES OF VARIATIONS IN YIELD OF BORES

The yield of bores is a function of the following factors:

(1) Nature of the rock type.

(2) Condition of the rock and nature of weathering.

(3) Nature of catchment.

(4) Effects of faults and dykes.

(5) Rainfall.

(6) Nature of vegetation.

(7) Nature of soil.

Rock type is an important factor. In the porous Tertiary sands yields may exceed 4,550-9,100 l/h (1,000-2,000 gal/h) whereas in the Tertiary clays yields are 0-1,820 l/h (0-400 gal/h); even then yield is dependent on lack of sorting and sufficient porosity and pore size so that there is some overall permeability and transmission of water. In the fractured rocks of the Permian system all yields are of the same order 1,820-3,640 l/h (300-800 gal/h); but the more competent the rock, and the more fractures it contains, the better the aquifer, *e.g.* Ferntree Formation. Alternatively, if it contains many more interconnected openings of other types it will again have excellent yield characteristics, *e.g.* Grange Mudstone which is also affected considerably by factors (2) and (7). Unconsolidated rocks offer the best yield possibilities.

Rock in a fractured state may be a reasonable aquifer, but the same rock in the early stages of weathering may be much better (van Wyk, 1963). In this district water is obtained from rocks which are in a relatively unweathered state. If the weathering is extreme and clay is produced in quantity little water can be recovered. Layers of clay in the weathering profile may hinder infiltration, and this indirectly affects the yield from the rock.

The nature of the subsurface catchment depends on the area over which water can be drawn to the bore, the water bearing characteristics of the rock and the effectiveness of infiltration due to rainfall. This will determine the amount of stored water available for release to the bore.

If the site is at the top of a hill not only will the depth to the water be increased but it is also likely that radial underground drainage, determined by the shape of the hill, may also reduce the water available. Also infiltration may be less and run off greater than in level areas. Permian rocks are most affected in this way. The form of the hydrological connection between source or storage area and bore will also be a control. Few and narrow fractures will limit transmissibility and water availability and hence quantity. Also, if the catchment is such that rain has little or no access to the rock recharge is negligible and the yield may be very small. Sealed lenses of sandstone within the Triassic rocks are equivalent to this occurrence.

Rainfall, vegetation and nature of soil are commonly related. Vegetation and soil character affect run-off, infiltration and evaporation, and thus indirectly the capacity of the rock to yield water. Rainfall is considered to be important only with respect to the changes induced in the rock (van Wyk, 1963, p. 67).

In conclusion, it may be said that yield from a well depends upon it passing through secondary water-bearing features. The more secondary water bearing features there are, and the larger they are, the higher the yield. If the catchment is good and the infiltration high, more of the rock will be water bearing because the water level will be higher. Thus, in a bore of given total length, the yield will be greater. Of course, if the bore strikes no aquiferous fissures it must fail (fig. 6, bore 4).

Dry Holes

Dry holes may be the result of any of the following conditions:

(1) Dry rock. Rock is effectively dry above the water table and if the bore is not deep enough no water can be recovered. Permian rocks, dolerite and basalt will also be dry in depth if all fractures are sealed with clays, pyrite or other material or if the fractures are closed tightly or absent altogether. In granular rocks if all the grains are cemented then there will be no porosity.

As water-bearing joints become fewer and smaller with depth in fractured rocks the likelihood of obtaining water also diminishes. Thus if the site is on a hill top, fracture closure and sealing may be complete before a water table level is struck because the depth from surface to water table is greatest beneath a hill top. Bores in this position will probably fail.

In Triassic and Tertiary rocks there may be zones which are isolated from water sources. (see p. 48). Tertiary clays may also be regarded as dry rock in most cases.

Generally, zones of dry rock such as described above are rare away from very hilly areas.

(2) Inadequate fracture systems. If fractures are absent or insignificant then such a fractured rock will not be able to yield any contained water. It will not be dry, but neither will it be an aquifer.

(3) Highly porous fine-grained rocks. Such material, *e.g.* clays, often cannot transmit the water they contain due to the effect of capillary forces induced by small grain size.

(4) Decomposed rock. Decomposition in an extreme state may result in material equivalent to (3) above or blocked fractures. Any water present cannot be surrendered.

(5) Effects of drilling. Drilling often produces small particles which can move into openings in the rock and block them. Many failures are probably due to this. All dry bores should be pumped and surged vigorously in order to remove any such particles. DH 12 was an example of this situation. Tests were made when the hole was 136.5 mm (5.375 inches) diameter, and 30 m deep; 222.2 mm (8.75 inches) in diameter and 30 m deep; and 222.2 mm (8.75 inches) in diameter to 60 m deep, then 146 mm (5.75 inches) in diameter to 90 m deep. Results were: 1,270, 0, 0 l/h (280, 0, 0 gal/h) respectively. Thus a producing hole was made to dry up by further drilling. After thorough cleaning the completed hole yielded 2,045 l/h (450 gal/h).

Conditions (3) and (4) can normally be avoided by careful geological siting. Geophysical resistivity tests may give an indication of (1) and (2) although these conditions are relatively rare.

SITE SELECTION

Two principal methods are available for the selection of bore sites.

(1) Divining or water witching.

(2) Geological and geophysical.

Divining or 'witching' is the location or groundwater by psychic methods and commonly involves the use of a stick or piece of wire and an aura of mystery. Success of the method depends on one or two factors. Firstly that groundwater can be found almost anywhere in some areas (the aim of a diviner and indeed a geologist is to recommend the best site). Secondly that in marginal areas the diviner either unwittingly or otherwise applies some of the hydrogeological methods outlined below. Few diviners are found in difficult areas.

Much investigation has been made into the method but no positive results about the power source have been achieved. It has been shown however that the behaviour of the stick is not induced by water or any other mineral.

The most successful diviners are those who are observant and have a thorough knowledge of the area in which they operate. When a diviner moves from one area to another there are commonly more failures since the factor of familiarity is absent and the diviner lacks the understanding of the geologist. No validity can be ascribed to the figures quoted by diviners on depth of 'streams' and yield.

The previous pages should serve to show that such things as 'underground streams' are non-existent in the rocks of this area, water passing mainly through joints in the rock. Thus any 'streams' as may be present would be part of an interlocking network of water less than the thickness of a piece of paper.

The following figures have been tabulated in New South Wales where complete records over many years are maintained.

Table 4. DIVINED AND NON-DIVINED BORES CONSTRUCTED IN N.S.W. BETWEEN 1918 AND 1945

	Divined		Not Divined	
	Number	%	Number	%
Bores yielding more than 100 gallons per hour	1,291	70.4	1,516	83.9
Bores yielding less than 100 gallons per hour	185	10.1	98	5.3
Bores giving useless water	87	4.8	61	3.4
Absolute failures	269	14.7	133	7.4
	1,832	100.0	1.806	100.0

Since 1945 geophysical methods have been more generally available and the general success rate in the not-divined group has been improved. It is not anticipated that divining methods have improved.

While it is not claimed that diviners are necessarily fraudulent, Heiland (1937) comments: 'It may be perfectly possible that certain persons of supernormal faculties can sense the presence of water, but this is something to be discussed by a psychologist and not a geophysicist. Besides, if the numerous wiggle-stick and doodle-bug men who pretend to be able to locate water possessed such faculty, there would be no need for them to employ any of their mysterious devices.'

Hydrogeological methods involve an assessment of the hydrological, topographical and geological conditions on the property. Experience and a complete understanding of the occurrence and movement of groundwater provide the mental background to this assessment. Information on the best site and the economics of drilling, the nature of any drilling problems, the rocks to be encountered and the depth of hole required can be suggested. This does not mean that the geologist is infallible, but that within the physical concepts of groundwater occurrence all possible variables are considered.

Technical advice on problems or prospects can be obtained on application to the Department of Mines.

Groundwater Temperatures

Where possible temperature measurements were made, after each bore had been pumped for a short time. No warm or hot waters have been reported anywhere in the basin. This fact alone implies that all groundwater is meteoric in origin and that there is no circulation of the water to any great depth. Most waters are within the range 8.9-14.5°C (48-58°F) which approximates the mean annual air temperature range. The highest reading encountered was 18.3°C (65°F) in two holes, both at Colebrook.

Chemical Quality of the Groundwater

The suitability of groundwater for its various uses depends to a large extent on its chemical quality. As part of this investigation many samples from various formations have been collected and analysed. The analyses are given as part of the discussion of water quality in each formation.

EXPRESSION OF DATA

The concentrations of dissolved constituents in the water are given as parts per million by weight (ppm) and equivalents per million (epm). One epm of a cation will react with one epm of an anion. Since the charges are balanced in solution, the total of the equivalents per million of the predominant cations (calcium, magnesium and sodium) is approximately equal to the total of the equivalents per million of the predominant anions (bicarbonate, chloride and sulphate).

Parts per million may be converted to equivalents per million by multiplication with the appropriate factor.

Table 5. CONVERSION FACTORS, PPM TO EPM

Ion	*Factor*	*Ion*	*Factor*
Calcium	0.0499	Bicarbonate	0.0164
Magnesium	0.0822	Carbonate	0.0166
Sodium	0.0435	Sulphate	0.0208
Potassium	0.0256	Chloride	0.0282
		Fluoride	0.0526
		Nitrate	0.0161

The results have also been expressed as percentages of ionic constituents present in the water. Such percentages are based on the proportion of the equivalents of that ion to the total equivalents per million. Data expressed in this way is considered to indicate true proportions of a constituent for comparison purposes; in a way that is not possible on assumed salts composition.

SOURCE OF CHEMICAL CONSTITUENTS

The principal solutes in natural water are calcium, magnesium, sodium, chloride, sulphate and bicarbonate. Silica, iron, aluminium, potassium, fluoride, nitrate and boron are normally present in small amounts. The last two have not been determined by analysis. The amount and type of chemical constituent present depends on the past history of the water.

The source of most groundwater is meteoric. There has been little contamination from other sources in the consolidated rocks. In the case of some Tertiary or Recent sediments the groundwater may be contaminated with connate water (water trapped in the sediments during deposition). This type of contamination may be indicated by a higher than normal SO_4:Cl ratio.

Low sulphate content and low temperature imply no contamination from juvenile waters. Apart from minor connate water contamination which has occurred in some cases, the chemical content of the water has been derived from the rocks in which it has been stored, or through which it has passed.

The greater the extent of the contact between water and the rock, either as a function of exposed surface area, or duration of contact, the more mineralised the water becomes. For example, it is not unusual for water from shale or mudstone to be more saline than that from sandstone or gravel of similar composition simply because the finer grained rocks expose a greater area for reaction with the water. The duration of contact is normally determined by the gradient on the water table in the area.

All groundwater in this district has been derived from rain and snow. Such water initially contains little dissolved matter, except carbon dioxide. Water in this state, is however, a potent weathering agent, and effects decomposition of most minerals contained in rocks. The processes of weathering may be listed as carbonation, solution, oxidation, reduction, hydrolysis and ion exchange. Hydration and solution, are of little importance here. There has been oxidation of the iron sulphides associated with the Ferntree Mudstone to iron sulphate. The most important processes, with respect to the highly siliceous sedimentary rocks, are hydrolysis and ion exchange. Ion exchange will be discussed in a later section.

CHEMICAL CHARACTERISTICS OF THE WATER

Sixty-four analyses have been made of groundwater within the Coal River Basin. The water from each of the principal rock types is represented by a number of analyses which are contained in Tables 6-9. Appendix 1 contains analyses of springs, wells and rivulets within the basin. These have been included separately since it is likely that the contained water commonly reflects the composition of surface waters. Generally water within the basin falls into the category of sodium chloride type or of sodium bicarbonate type.

Permian

Ferntree Mudstone

Analyses of water are given in Table 6. All the water in these analyses is from the Tunnack region. There is a considerable variation in quality of the water (100-2,000 ppm T.D.S.). The water is neutral to alkaline, silica ranges from 18-31 ppm independently of total solid content, iron and aluminium are absent and fluorine is less than 0.4 ppm.

Only water from T 31 is soft; T 1 is moderately hard and all others are very hard (see p. 62). The water is of the calcium chloride-sodium bicarbonate type. The significant constituent variation is of the sulphate which is derived from sulphides contained in the joints. The amount present is probably related to the state of weathering in the rock; the fresher material containing more pyrite.

The water is of varying suitability (see fig. 8, 9). It is mostly unsuitable for irrigation but more than adequate for stock and other general purposes.

Triassic

Quartz Sandstone - Mudstone Assemblage

Analyses are presented in Table 7. Most are of water in the Tunnack-Stonor region. No real comparisons are possible with other regions.

In contrast with water from the Ferntree Mudstone which is alkaline, water from these Triassic rocks is moderately acid. Some of the water is corrosive. It is also clearly of the sodium chloride type in the northern regions. The water from the southern regions however, has a higher pH and a more balanced ionic composition. These two factors are probably influenced by surface water which runs off the surrounding dolerite hills. The weathering of this dolerite results in a high concentration of calcium, magnesium and carbonate in the lower zones where the bores are commonly situated.

Fluorine, iron, aluminium and nitrate are absent. Sulphate ions are also of little significance.

In the northern regions the water is soft and of good to excellent quality (83-600 ppm T.D.S.). The suitability for irrigation is doubtful because of the high sodium content.

In the southern regions the water is very hard, of much poorer quality (1,000-3,000 ppm T.D.S.), and generally unsuitable for irrigation. The higher evaporation rates, lower rainfall and flushing in the southern regions accounts for the quality differences.

The silica content of the water is dependent on the amount of dissolved solids (compare Ferntree Mudstone) and ranges from 20-60 ppm.

Feldspathic Sandstone - Mudstone Assemblage

Analyses of water from this formation are presented in Table 8. All are from the Colebrook region. Although there is considerable variation in quality (140-1,400 ppm T.D.S.) the water is characteristically slightly alkaline with a balanced composition and there is more bicarbonate and magnesium than similar water from the Ferntree Mudstone. However the sulphate content is much lower.

The absence of sulphate, and presence of a significant amount of magnesium and bicarbonate reflects the composition of the rock. The grains of ferromagnesian minerals and feldspar provide the latter constituents. Such active components are absent from other Triassic rocks and also from the Ferntree Mudstone.

With few exceptions the water is generally only suitable for stock purposes. The water is generally hard to very hard although that of analyses 37 and 38 is very soft.

Tertiary

Sediments

Analyses of water from such rocks are presented in Table 9. The quality of the water is variable (637-8,500 ppm T.D.S.) but is rarely good.

Table 6. ANALYSES OF WATER FROM FERNTREE MUDSTONE

Analysis	1	2	3	4	5	6	7
Bore no.	T 1	T 8	T 11	T 13	T 17	T 18	T 19
				parts per million			
Total dissolved solids	116.0	874.0	1756.0	914.0	1976.0	1131.0	822.0
CO_3	0.0	0.0	0.0	44.0	0.0	0.0	0.0
HCO_3	54.0	74.0	245.0	185.0	218.0	72.0	207.0
Cl	34.0	60.0	489.0	273.0	669.0	168.0	342.0
SO_4	9.0	455.0	615.0	9.0	537.0	501.0	25.0
NO_3	0.1	0.2	nd	0.2	0.0	0.0	0.0
F	0.0	0.0	0.4	0.0	0.2	0.1	0.3
SiO_2	21.0	31.0	26.0	18.0	23.0	27.0	25.0
Ca	18.0	107.0	306.0	105.0	267.0	143.0	128.0
Mg	7.0	45.0	102.0	25.0	112.0	48.0	48.0
Fe + Al	0.0	0.0	tr	0.0	tr	0.0	tr
K	4.0	4.0	4.0	2.5	21.0	14.5	3.0
Na	17.0	67.0	158.0	180.0	243.0	97.0	75.0
NH_4	nd	nd	nd	nd	0.0	nd	0.0
Total hardness	74.0	452.0	1183.0	365.0	1127.0	553.0	517.0
permanent	30.0	391.0	1038.0	140.0	1074.0	494.0	370.0
temporary	44.0	61.0	145.0	225.0	53.0	59.0	147.0
Alkalinity	44.0	61.0	145.0	225.0	53.0	59.0	147.0
Total epm	2.2	12.2	35.7	13.5	33.7	16.0	13.7
				percentage constituents by equivalence			
CO_3	0.0	0.0	0.0	2.7	0.0	0.0	0.0
HCO_3	20.1	4.3	6.6	11.3	5.3	3.9	12.5
Cl	21.9	6.9	22.6	28.7	28.2	14.8	35.1
SO_4	4.3	39.0	20.9	0.7	16.8	32.5	1.9
Ca	20.6	22.0	25.0	19.5	19.8	22.3	23.4
Mg	13.2	15.2	13.7	7.7	13.7	12.3	14.5
K	2.3	0.4	0.2	0.2	0.8	1.2	0.3
Na	16.9	12.0	11.2	29.1	15.7	13.1	11.9
Na adsorption ratio	0.9	1.4	2.0	3.8	3.1	1.8	1.4
Per cent Na	36.2	25.0	22.0	52.3	31.6	29.2	24.4
pH	7.5	7.5	7.1	8.4	6.7	8.2	7.6

Analyses by Department of Mines Laboratory, Launceston

Table 6. ANALYSES OF WATER FROM FERNTREE MUDSTONE — continued

Analysis Bore no.	8 T 28	9 T 31	10 T 32
	parts per million		
Total dissolved solids	1761.0	183.0	666.0
CO_3	0.0	0.0	0.0
HCO_3	259.0	17.0	412.0
Cl	810.0	43.0	225.0
SO_4	87.0	42.0	32.0
NO_3	0.0	0.2	5.0
F	0.1	0.0	0.0
SiO_2	27.0	32.0	23.0
Ca	150.0	5.0	60.0
Mg	101.0	9.0	40.0
Fe + Al	tr	0.0	0.0
K	6.0	6.5	8.0
Na	298.0	31.0	98.0
NH_4	0.0	nd	nd
Total hardness	790.0	50.0	
permanent	585.0	36.0	
temporary	205.0	14.0	338.0
Alkalinity	205.0	14.0	338.0
Total epm	28.9	2.5	12.3
	percentage constituents by equivalence		
CO_3	0.0	0.0	0.0
HCO_3	7.4	5.8	27.4
Cl	39.4	24.9	25.8
SO_4	3.1	17.9	2.7
Ca	13.0	5.1	12.2
Mg	14.4	15.2	13.3
K	0.3	3.5	0.8
Na	22.4	27.6	17.3
Na adsorption ratio	4.6	1.91	7.6
Per cent Na	45.3	60.6	41.6
pH	7.6	7.0	7.5

Analyses by Department of Mines Laboratory, Launceston

Table 7. ANALYSES OF WATER FROM L. TRIASSIC SANDSTONES AND MUDSTONES — cont.

Analysis Bore no.	18 ST 4	19 ST 5	20 ST 7	21 ST 8	22 ST 9	23 ST 11	24 ST 12
				parts per million			
Total dissolved solids	1852.0	2425.0	112.0	1933.0	1524.0	1186.0	1173.0
CO_3	0.0	0.0	0.0	3.6	0.0	0.0	1.2
HCO_3	1.2	47.6	239.0	30.5	492.0	24.4	35.4
Cl	970.0	1061.0	497.0	731.0	630.0	562.0	366.0
SO_4	12.0	18.0	2.0	8.0	7.0	9.0	11.0
NO_3	nd	nd	nd	nd	nd	nd	nd
F	0.0	0.3	0.1	nd	0.3	0.2	0.2
SiO_2	64.0	142.0	18.5	102.0	13.0	47.0	52.0
Ca	85.0	184.0	76.0	188.0	151.0	68.0	116.0
Mg	145.0	119.0	112.0	100.0	120.0	64.0	58.0
Fe + Al	tr	tr	0.0	tr	0.0	tr	0.0
K	9.0	9.0	4.0	4.0	14.0	21.0	5.0
Na	260.0	425.0	112.0	212.0	262.0	200.0	116.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	809.0	934.0	650.0	782.0	871.0	417.0	528.0
permanent	808.0	900.0	454.0	748.0	468.0	397.0	496.0
temporary	1.0	34.0	196.0	34.0	403.0	20.0	32.0
Alkalinity	1.0	34.0	196.0	34.0	403.0	20.0	32.0
Total epm	27.8	34.4	18.0	24.4	27.6	17.4	13.6
				percentage constituents by equivalence			
HCO_3	0.0	1.1	10.8	1.0	14.6	1.1	2.1
Cl	49.3	43.4	39.0	42.6	32.0	45.5	37.9
SO_4	0.4	0.5	0.1	0.4	0.3	0.6	0.8
Ca	7.0	13.4	10.6	19.4	13.6	10.1	21.7
Mg	22.5	14.3	25.6	17.1	17.9	16.1	18.0
K	0.4	0.0	0.3	0.0	0.8	1.6	0.5
Na	20.3	26.9	13.6	19.0	20.7	25.0	18.8
Na adsorption ratio	3.9	6.0	1.9	3.1	3.9	4.1	2.2
Per cent Na	41.3	49.6	27.4	34.4	39.6	50.4	32.6
pH	5.3	6.8	6.3	7.0	7.5	6.0	7.2

Analyses by Department of Mines Laboratory, Launceston

Table 7. ANALYSES OF WATER FROM LOWER TRIASSIC SANDSTONES AND MUDSTONES

Analysis	11	12	13	14	15	16	17
Bore no.	T 16	T 21	T 25	T 30	T 33	ST 1	ST 2
				parts per million			
Total dissolved solids	165.0	123.0	202.0	255.0	83.0	1186.0	479.0
CO_3	0.0	0.0	0.0	0.0	0.0	1.2	0.0
HCO_3	0.0	0.0	19.5	11.0	9.2	36.6	13.4
Cl	131.0	45.0	87.0	112.0	19.0	422.0	197.0
SO_4	4.0	13.0	1.0	20.0	4.0	6.0	6.0
NO_3	nd	0.0	nd	0.0	0.0	nd	nd
F	0.02	0.3	0.2	0.1	0.1	0.2	0.0
SiO_2	5.0	12.0	20.8	13.0	21.0	50.0	3.0
Ca	9.0	1.6	4.2	9.3	1.3	92.0	29.0
Mg	6.1	2.9	5.5	9.0	0.7	83.0	17.0
Fe + Al	0.2	tr	tr	tr	tr	0.0	0.0
K	3.0	1.0	4.0	2.0	2.0	2.0	5.0
Na	55.0	24.0	47.0	58.0	14.0	156.0	95.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	nd	nd	nd	nd	nd	555.0	135.0
permanent	42.0	0.0	28.0	25.0	0.0	522.0	124.0
temporary	5.0	16.0	5.0	35.0	6.0	33.0	11.0
Alkalinity	5.0	19.0	5.0	35.0	10.0	33.0	11.0
Total epm	3.6	1.5	2.8	3.9	0.8	15.5	6.6
				percentage constituents by equivalence			
HCO_3	0.0	0.0	5.7	2.3	9.6	1.9	1.7
Cl	51.4	43.1	43.9	40.7	35.3	38.5	42.8
SO_4	1.1	9.2	0.4	5.4	5.1	0.4	0.9
Ca	6.3	2.7	3.8	5.9	3.8	14.9	11.5
Mg	6.9	8.1	8.0	9.5	3.8	22.0	10.7
K	1.1	1.0	1.8	0.6	3.2	0.2	1.0
Na	33.2	35.3	36.5	35.2	39.1	22.0	31.4
Na adsorption ratio	3.5	2.5	3.5	3.6	2.5	2.8	3.4
Per cent Na	72.1	77.0	76.5	72.5	84.6	37.6	59.3
pH	5.1	6.2	5.1	6.2	5.4	7.0	7.0

Analyses by Department of Mines Laboratory, Launceston

Table 7. *ANALYSES OF WATER FROM L. TRIASSIC SANDSTONES AND MUDSTONES — cont.*

Analysis Bore no.	25 ST 13	26 ST 14	27 ST 15	28 C 11	29 DH 9	30 DH 12	31 RC 2
				parts per million			
Total dissolved solids	1775.0	889.0	619.0	2706.0	4786.0	1610.0	1230.0
CO_3	0.0	0.0	0.0	67.0	0.0	0.0	0.0
HCO_3	17.1	37.8	tr	365.0	932.0	50.0	87.0
Cl	914.0	267.0	359.0	1200.0	2169.0	654.0	656.0
SO_4	3.0	10.0	1.0	81.0	169.0	40.0	21.0
NO_3	nd	nd	nd	0.0	0.0	nd	0.0
F	<0.1	0.0	0.0	0.1	0.9	0.2	0.2
SiO_2	59.1	48.0	11.0	49.0	42.0	67.0	56.0
Ca	90.0	90.0	25.0	164.0	94.0	80.0	15.0
Mg	118.0	66.0	46.0	235.0	392.0	126.0	38.0
Fe + Al	0.0	0.0	0.0	0.0	0.0	tr	0.0
K	7.0	4.0	7.0	8.0	60.0	6.0	17.5
Na	332.0	75.0	105.0	477.0	954.0	262.0	364.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	736.0	471.0	246.0	1376.0	1848.0	789.0	194.0
permanent	722.0	440.0	245.0	965.0	1084.0	748.0	123.0
temporary	14.0	31.0	1.0	411.0	764.0	41.0	71.0
Alkalinity	14.0	31.0	1.0	411.0	764.0	41.0	71.0
Total epm	27.8	10.7	10.2	43.8	79.9	23.3	20.0
				percentage constituents by equivalence			
HCO_3	0.5	2.9	0.0	6.8	9.6	1.8	3.6
Cl	46.4	35.0	49.8	38.6	38.3	39.5	46.3
SO_4	0.1	1.0	0.1	0.9	2.2	1.7	0.6
Ca	8.1	21.0	5.9	4.7	2.9	8.6	0.9
Mg	18.5	25.2	21.2	22.4	20.1	23.6	7.9
K	0.3	0.5	0.9	0.2	0.9	0.3	1.1
Na	26.0	14.5	22.2	23.70	25.8	24.5	39.6
Na adsorption ratio	5.3	1.4	2.7	6.1	9.6	4.2	11.9
Per cent Na	49.7	24.4	45.9	46.9	52.8	43.5	82.1
pH	6.4	6.9	4.4	8.3	7.0	7.0	8.0

Analyses by Department of Mines Laboratory, Launceston

Table 8. ANALYSES OF WATER FROM UPPER TRIASSIC FELDSPATHIC SERIES

Analysis	32	33	34	35	36	37	38
Bore no.	CO 1	CO 5	CO 6	CO 8	CO 9	CO 11	CO 12
				parts per million			
Total dissolved solids	797.0	819.0	1319.0	1226.0	776.0	141.0	450.0
CO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HCO_3	457.0	400.0	301.0	469.0	374.0	75.1	208.0
Cl	211.0	234.0	587.0	492.0	259.0	18.0	136.0
SO_4	26.0	21.0	54.0	9.0	11.0	1.0	19.0
NO_3	0.0	0.0	nd	nd	nd	nd	nd
F	0.1	0.1	0.1	0.2	0.2	0.1	0.4
SiO_2	37.0	55.0	28.0	28.0	29.0	24.0	23.0
Ca	86.0	103.0	147.0	204.0	138.0	12.0	36.0
Mg	60.0	64.0	45.0	104.0	54.0	8.0	25.0
Fe + Al	tr	tr	tr	tr	0.1	0.4	tr
K	1.0	1.0	2.0	1.0	1.0	1.0	1.0
Na	109.0	73.0	265.0	69.0	53.0	11.0	87.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	-	-	-	-	-	-	-
permanent	81.0	182.0	337.0	590.0	218.0	0.0	0.0
temporary	379.0	348.0	215.0	347.0	348.0	63.0	193.0
Alkalinity	379.0	348.0	215.0	347.0	348.0	71.0	284.0
Total epm	14.0	13.6	22.6	21.8	13.7	1.8	7.7
				percentage constituents by equivalence			
HCO_3	26.8	24.2	10.9	17.7	22.4	34.5	22.2
Cl	21.2	24.2	36.6	31.9	26.7	14.3	25.0
SO_4	1.9	1.6	2.5	0.4	0.8	0.6	2.6
Ca	15.3	18.9	16.2	23.5	25.2	16.9	11.7
Mg	17.6	19.3	8.4	19.7	16.2	18.5	13.4
Na	16.9	11.7	25.5	6.9	8.5	13.5	24.7
Na adsorption ratio	2.2	1.4	4.9	1.0	1.0	o.6	8.6
Per cent Na	34.2	23.6	52.6	13.9	17.3	28.6	50.0
pH	7.6	7.2	7.9	7.4	7.4	7.2	7.5

Analyses by Department of Mines Laboratory, Launceston

Table 9. ANALYSES OF WATER FROM TERTIARY ROCKS

Analysis Bore no.	39 C 4	40 C 6	41 DH 2	42 DH 6	43 DH 11	44 DH 13	45 RC 3
				parts per million			
Total dissolved solids	4486.0	4919.0	1222.0	637.0	3474.0	4356.0	7480.0
CO_3	0.0	40.0	58.0	25.0	60.0	0.0	0.0
HCO_3	404.0	379.0	390.0	249.0	521.0	756.0	153.0
Cl	2320.0	2450.0	385.0	194.0	1570.0	2113.0	3620.0
SO_4	247.0	215.0	39.0	29.0	142.0	334.0	317.0
NO_3	0.0	0.0	0.0	0.0	0.0	nd	0.0
F	<0.1	0.1	0.3	0.1	<0.1	0.2	0.1
SiO_2	36.0	32.0	47.0	52.0	17.0	32.5	9.0
Ca	274.0	133.0	85.0	48.0	156.0	218.0	328.0
Mg	414.0	260.0	103.0	45.0	250.0	375.0	500.0
Fe + Al	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	18.5	17.5	3.5	0.5	25.0	20.0	25.0
Na	806.0	1213.0	229.0	118.0	746.0	865.0	1228.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	2388.0	1402.0	636.0	305.0	1418.0	2087.0	2876.0
permanent	2059.0	1025.0	172.0	38.0	841.0	1467.0	2751.0
temporary	329.0	377.0	464.0	267.0	577.0	620.0	125.0
Alkalinity	329.0	377.0	464.0	267.0	577.0	620.0	125.0
Total epm	79.9	80.6	20.7	10.6	57.0	79.0	110.8
				percentage constituents by equivalence			
CO_3	0.0	0.4	2.4	2.0	1.8	0.0	0.0
HCO_3	3.7	3.4	13.8	17.2	7.5	7.8	1.0
Cl	41.0	42.8	26.3	25.9	38.8	37.8	45.8
SO_4	3.2	2.8	2.0	3.1	1.3	4.4	3.0
Ca	8.5	4.1	10.3	9.6	3.4	6.9	7.4
Mg	21.2	13.3	20.2	17.4	18.3	19.1	18.6
K	0.3	0.3	2.2	0.0	0.6	0.4	0.3
Na	21.9	32.8	24.2	24.2	28.4	23.8	24.2
Na adsorption ratio	12.1	14.2	3.9	9.6	9.3	8.4	10.0
Per cent Na	42.7	65.6	44.2	47.4	57.2	47.8	48.5
pH	7.9	7.8	8.2	8.9	7.7	7.1	7.8

Analyses by Department of Mines Laboratory, Launceston

Table 9. ANALYSES OF WATER FROM TERTIARY ROCKS — continued

Analysis	46	47	48	49
Bore no.	RC 5	RC 6	P 5	P 6
	parts per million			
Total dissolved solids	8518.0	760.0	2128.0	4173.0
CO_3	110.0	1.2	16.0	53.0
HCO_3	526.0	23.2	543.0	503.0
Cl	3840.0	204.0	907.0	1880.0
SO_4	421.0	24.0	276.0	196.0
NO_3	0.0	nd	0.0	0.0
F	<0.1	0.5	0.2	1.2
SiO_2	9.0	47.0	44.0	55.0
Ca	315.0	24.0	87.0	157.0
Mg	585.0	45.0	203.0	319.0
Fe + Al	0.0	0.0	0.0	0.0
K	35.0	4.0	8.0	5.5
Na	1615.0	128.0	396.0	895.0
NH_4	nd	nd	nd	nd
Total hardness	3194.0	245.0	1052.0	1705.0
permanent	2580.0	223.0	566.0	1160.0
temporary	614.0	22.0	486.0	545.0
Alkalinity	614.0	22.0	486.0	545.0
Total epm	130.8	8.7	40.8	69.7
	percentage constituents by equivalence			
CO_3	0.7	0.2	0.3	0.6
HCO_3	2.9	2.2	10.9	5.9
Cl	41.5	33.5	34.6	38.2
SO_4	3.4	2.9	7.1	2.9
Ca	6.1	6.9	5.3	5.6
Mg	18.4	21.4	20.4	18.8
K	0.3	0.6	0.3	0.1
Na	26.8	32.4	21.1	28.9
Na adsorption ratio	12.5	3.6	5.4	4.2
Per cent Na	52.7	57.0	46.4	53.4
pH	8.2	7.6	8.2	8.4

Analyses by Department of Mines Laboratory, Launceston

Water from the Richmond and Cambridge regions is very poor (see also Nye, 1922, 1924). The best water from these rocks is recovered from the sands of the Duck Hole Creek region.

Water from the Tertiary sediments has a very high pH, low sulphate content and very high chloride content. The water is generally very hard although there are exceptions.

The water is usually unsuitable for irrigation purposes (see p. 64; fig. 8, 9), particularly that which comes from the low lying areas adjacent to Pitt Water where there is a high clay content in the soil with consequent poor drainage. In no case is the water suitable for domestic purposes but it may be used for stock water.

Basalt

Analyses of water from basalt at Penna are given in Table 9 (Analyses 48-49). The water is very alkaline, very hard and has a moderately high salinity. The water is only suitable for stock purposes.

SUITABILITY OF THE WATER

Chemical Constituents in Relation to Use

The chemical character of groundwater, as determined by the actual constituents and their quantity, governs its suitability for different uses.

Total Dissolved Solids

The total dissolved solids are the residue on evaporation of the water sample. They consist of all mineral constituents including a little water of hydration and some organic material. It should be noted that bicarbonate may be partially or totally reduced to carbonates during the evaporation.

Generally water with less than 500 ppm T.D.S. is suitable for drinking purposes and domestic uses, but water with 500-1,000 ppm T.D.S. may be unsuitable as a result of taste or too much of a given constituent. Only rarely is the water in the district suitable for drinking and some domestic purposes, but all water is suitable for some agricultural use.

Hardness

The hardness is a chracteristic of groundwater and is commonly shown by the amount of soap required to form a lather. It may be produced by two types of compounds. The bicarbonates of calcium and magnesium produce what is termed 'temporary hardness' which can be removed by boiling. 'Permanent hardness' is caused by the sulphates and chlorides of calcium and magnesium and cannot be removed by boiling. Total hardness is the sum of both types. Most of the hardness in the samples analysed was of the carbonate type. This causes the formation of deposits in cooking utensils and boilers. The scale of hardness given below, while arbitrary, is in standard use in North America. It gives an indication of the usefulness of the water.

0 - 60 ppm $CaCO_3$	Soft
60 - 120 ppm $CaCO_3$	Moderately hard
121 - 180 ppm $CaCO_3$	Hard
>180 ppm $CaCO_3$	Very hard

Iron

Iron is expressed as $Fe_2O_3 + Al_2O_3$ in the analyses. If present in excess of 0.3 ppm staining occurs; if the iron content is large, growth of iron bacteria may result in blockage of pipes. Little water in this district contains more than 0.3 ppm of iron. Removal of iron may be accomplished by any of the following methods:

(1) Aeration by spraying and then filtering.

(2) Neutralisation of the water with milk of lime. This is necessary where the iron is held in solution by carbonic acid. Aeration and filtering will then remove the iron.

(3) Precipitation by addition of alum.

(4) Precipitation by the Permutit process.

Calcium and Magnesium

Compounds of these elements produce hardness in the water. Domestic and industrial uses may be limited if magnesium sulphate is present in any quantity.

Sodium

Sodium does not cause problems in domestic water unless it is present in very large amounts. However, it is of considerable importance if the water is to be used for irrigation, as it causes soil destruction by ion exchange. The applicability of water for irrigation is evaluated in terms of per cent sodium and sodium adsorption ratio:

$$\text{Per cent sodium} = \frac{100\ \text{Na}}{\text{Ca+Mg+Na}}$$

$$\text{Sodium adsorption ratio} = \frac{\text{Na}}{\sqrt{(\text{Ca+Mg})/2}}$$

All concentrations are given in equivalents per million.

Per cent sodium in the above context is distinct from percentage sodium in the tables of analyses which is determined by the true equivalent proportion of the element.

Carbonate and Bicarbonate

There is little carbonate in the water from this district, since it can occur only in waters with a pH of >8.2. The only water lacking bicarbonate is that of Analyses 11, 12, 27. Bicarbonates occur in water with a pH of >4.5 (Williamson, 1965). The importance of this constituent has been shown under 'Hardness'.

Sulphate

This ion is derived from sulphides and fertilizers. If it is in the form of sodium or calcium sulphate, it imparts a bitter taste to the water.

Chloride

Chlorides are derived from rocks, sea spray and sewerage. Chloride

Hydrogen Ion Concentration

The hydrogen ion concentration of water (pH) is a measure of the acidity or alkalinity of the water and hence of its corrosiveness. A pH of <7 means that the water is acid, of >7 alkaline, and equal to 7 neutral. Some of the water would cause acid (*e.g.* T 16, T 25, T 33, ST 15) or alkaline corrosion (DH 6).

Utilization of Groundwater

Domestic Supplies

None of the water analysed is really suitable for usage under the standards laid down by the U.S. Public Health Service (Durfor and Becker, 1964). Table 10 shows the suggested limits on the composition for domestic supplies.

Table 10. COMPOSITION LIMITS FOR DOMESTIC SUPPLIES

	ppm		*ppm*
Fe	0.3	Cl	250
Mg	125	F	1.5
SO_4	250	T.D.S.	500

The factor which makes much of the water from this area unsuitable is the low pH of low salinity waters. The water of Analyses 1, 9 and 17 (p.54→) is the most suitable for domestic use. Exceptions exist, principally in the Tunnack region, however, and corrosion may be a problem with some waters.

Agricultural Uses

Stock. The following table shows the upper limits of salinity for stock usage, as adopted by the New South Wales Department of Agriculture.

Table 11. SALINITY LIMITS FOR STOCK USAGE

	ppm		*ppm*
Sheep	14,000	Horses	7,000
Cattle	10,000	Pigs and Poultry	4,000

There is no lower limit for salinity, and generally the lowest salinity water available is considered the most desirable. Dairy cattle require sodium chloride in their diet and consequently will often prefer bore water to fresher water. If water near the upper limit is being used, lush herbage is necessary to offset any harmful effects which may arise from drinking water which is too hard or too mineralized. Chickens prefer fresh water and pigs on a high protein diet require good quality water.

Sulphates are the most injurious common constituents of groundwater and the water of Analyses 2, 3,5 and 6 should not be exclusively used for stock watering. Reservations on the use of water for pigs and poultry should be noted.

Irrigation. The suitability of a groundwater for irrigation is

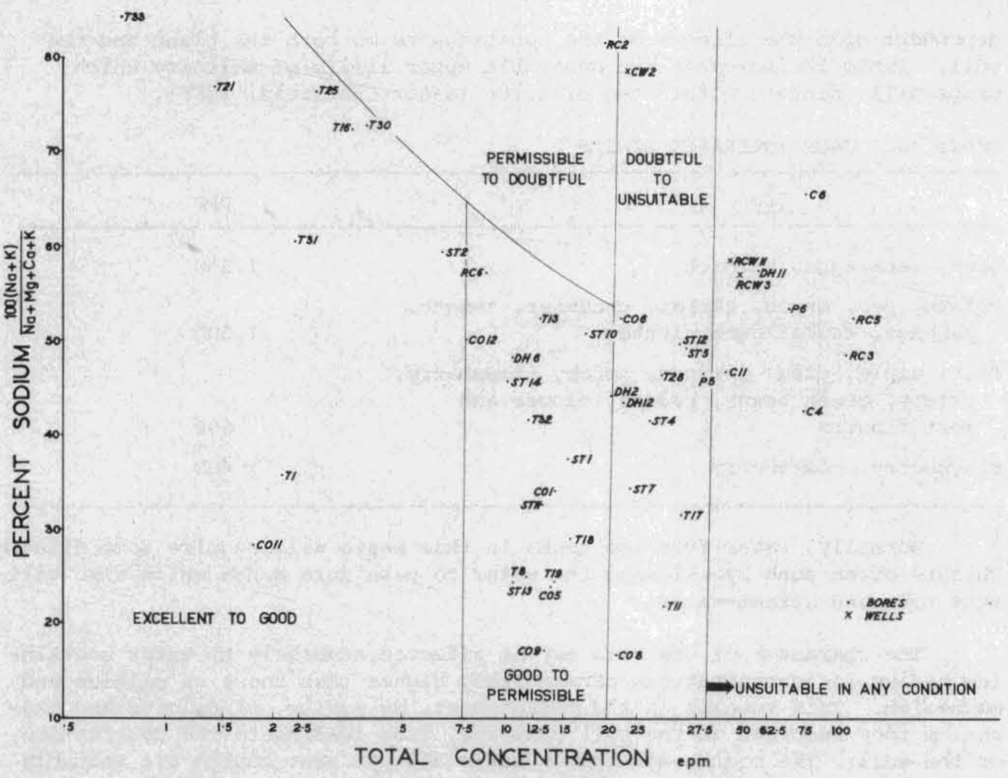


Fig. 8. *Classification of water for irrigation use. Per cent Na criterion.*

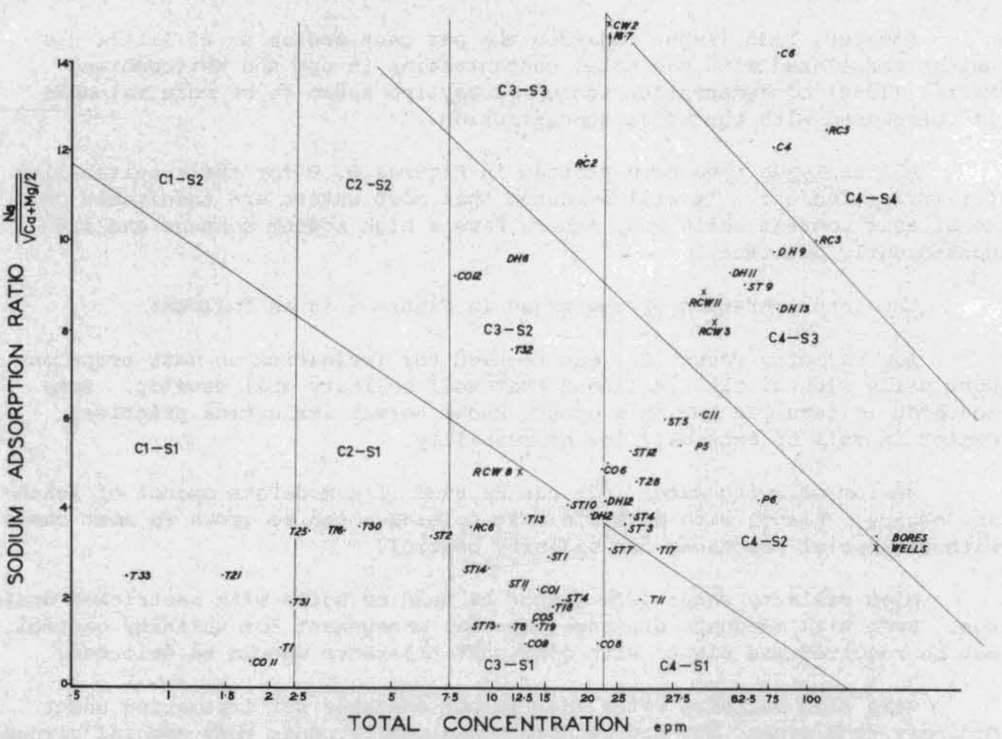


Fig. 9. *Classification of water for irrigation use. Na adsorption criterion.*

dependent upon the effects of the constituents on both the plant and the soil. Table 12 indicates the desirable upper limits of salinity which crops will tolerate within the district (after Chatfield, 1965).

Table 12. CROP TOLERANCE LIMITS

Crop	ppm
Beet, asparagus, spinach	1,850
Potato, pea, onion, carrot, cucumber, tomato, cabbage, cauliflower, lettuce	1,600
Pear, apple, plum, apricot, peach, strawberry, celery, green beans, radish, clover and most flowers	600
Blackberry, gooseberry	400

Normally, water from the rocks in this basin will require some dilution. This is often done by allowing the water to pass into a dam which also collects rain and stream-water.

The character of the soil may be affected adversely by water containing sodium in concentrations considerably higher than those of calcium and magnesium. This results in the replacement, by sodium, of calcium and magnesium ions adsorbed on the soil colloids, thus leading to the destruction of the soil. The sodium adsorption ratio and per cent sodium are valuable criteria for determination of the suitability of water as an irrigation supply.

However, Todd (1959) regarded the per cent sodium as of little use unless correlated with the total concentration in epm and Whitcomb and Morris (1964) considered the sodium adsorption ratio to be more valuable if correlated with the total concentration.

All analyses have been plotted in Figures 8, 9 for their suitability for irrigation use. It will be noted that most waters are unsuitable on total salt content while many others have a high sodium content and are consequently doubtful.

The interpretation of the zones in Figure 9 is as follows:

Low salinity water (C1) can be used for irrigation on most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required but this occurs under normal irrigation practices except in soil of extremely low permeability.

Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation

Table 13. SUMMARY OF ROCK WATER CHARACTERISTICS

Ferntree Mudstone	Ca>Mg
	$Cl \approx HCO_3 > Na$
	SO_4 up to 40%
	pH 7.0-8.0
Lower Triassic rocks	$Ca \approx Mg$
	HCO_3 0-10%
	Cl 40-50% Na
	SO_4 0-10%
	pH 5.0-7.0 (Tunnack-Stonor)
	7.0-9.0 (southern regions)
Upper Triassic rocks	$Ca \approx Mg \approx Na$
	$Cl \approx HCO_3 > Na$
	SO_4 0-3%
	pH 7.0-8.0
Tertiary sediments	$Na \approx Mg \approx 2Ca$
	$Cl > HCO_3$
	$Cl \gg Na$
	SO_4 0-5%
	pH 7.5-9.0
Tertiary basalt	$Na \approx Mg \approx 4Ca$
	$Cl \geqslant 3HCO$
	Cl>Na
	SO_4 0-10%

water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

The classification of irrigation waters with respect to sodium adsorption ratio is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations.

Medium sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management - good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, however, they may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

It will thus be seen that soil type, drainage, rainfall and salinity of added water confuse the simple picture and that the diagrams can only give an indication of usefulness. There is an overlap of the two sodium criteria, and one or other may be more useful in individual cases.

Aquifer Parameters

It is possible to determine the ability of an aquifer to transmit and store water, by controlled pump-testing of bores in that aquifer. In this region several bores have been pump tested, five in Tertiary rocks and in Triassic rocks. All pumping information has been derived from the pumped hole, there being no observation holes, and is therefore restricted.

Using the Theis (1935) equation for discharging wells, (see Ferris *et al*, 1963, p. 92):

$$s = 95.5Q/T[W(u)]$$

$$W(u) = \int_{1.87r^2S/Tt}^{\infty} e^{-u} du/u$$

$$u = 1.87r^2S/Tt$$

where s = drawdown in feet at point of observation

Q = discharge in imperial gallons per minute

T = transmissivity in gallons per day per foot

S = coefficient of storage

t = time in days since pumping started

r = distance from discharging well to observation point, in feet.

Since for tests in the Coal River basin,

$r = O$, $u = O$, $W(u) \rightarrow 34$

Triassic sandstone: DH 12

$s = 200$ $Q = 7.5$ $T = 120$

Tertiary sand and silt: RC 3

$s = 130$ $Q = 8.2$ $T = 204$

DH 11

$s = 100$ $Q = 20$ $T = 650$

RC 6

$s = 20 \qquad Q = 5.8 \qquad T = 940$

DH 13

$s = 30 \qquad Q = 19.5 \qquad T = 2{,}113$

Recharge, Runoff and Storage Conditions

Examination of hydrographs on the Coal River has yielded considerable information on the recharge characteristics of the basin. Only two recording stations exist, at Craigbourne bridge and immediately upstream of the confluence with White Kangaroo Rivulet.

Recession from four flood peaks in 1969 has been examined. In each case there had been no rainfall for several weeks and the river was at low stage, totally fed by groundwater base flow.

River flow, Q = groundwater flow + surface water flow. Surface water flow normally only occurs during or after consistently heavy or continued rainfall. The components of the exponential recession curve will clearly show differentiation of such features due to the different exponents involved and the critical time factor, groundwater transmission taking far longer. Groundwater outflow may be outlined as the opposite to a replenishment case as outlined by Jacob (1943); Ferris *et al* (1962) p. 131:

$$\frac{T}{w} = \frac{ax}{ho} - \frac{x^2}{2ho}$$

where w = rate of recharge or discharge

a = distance of stream to observation point or divide

ho = height of divide with respect to stream level

also $h = 16a^2w/\pi^3T\sum_{n=1}^{\infty} \frac{1}{(2n-1)^3} e^{-(2n-1)^2\pi^2Tt/4a^2S} \sin(2n-1)\pi x/2a$

but $Q/1 = T(\partial h/\partial x)$

$$Q = 8Qo/\pi^2\sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} e^{-(2n-1)^2\pi^2Tt/4a^2S}$$

$$= 8Qo/\pi^2[e^{-\pi^2Tt/4a^2S} + 1/9e^{-9\pi^2Tt/4a^2S} + 1/25e^{-25\pi^2Tt/4a^2S} \ldots]$$

This model, derived from Long Island, New York, is applicable to this area, which has distinct divides, drains, and in the case of the Colebrook region above Craigbourne has fairly uniform surface sand materials.

Events of 4 February, 28 May, 19 November, 12 December 1969 were compared on both hydrographs and plotted as log Q versus time. The recession constants were found to fall in the range 0.98 to 1.00 and there were no lower figures derived anywhere from the curves to suggest any surface runoff. Indeed the base slope represented by the first term of the above series is little different from any other indicating that the other terms are of little consequence due to the long times involved. Also surface water flow is either non-existent or negligible.

As the recession constant is very nearly unity, then

$-1 = -\pi^2T/4a^2S$

Taking a as 18,000 (Craigbourne)

then $T/S = (4 \times 18 \times 18 \times 10^6)/\pi^2 = 131 \times 10^5$ gal/day/ft

This value may be regarded as the rock 'effectiveness' of all the materials in the basin, as this figure was derived from results of both hydrograph stations. In the case of Craigbourne, where the water bearing rocks are predominantly Lower Triassic quartz rocks, an estimate of the storage coefficient of such material can be given since the transmissivity is known.

i.e. $S = (1.2 \times 10^2)/(1.3 \times 10^7) = 0.92 \times 10^{-5}$

This figure can only be a rough estimate of order of magnitude until pump test data from observation holes becomes available which will allow more precise evaluation. The figures obtained for the Triassic rocks are not unrealistic and reflect the fact that most water is transmitted in fractures and bedding planes and that little water is held or passed in or from pores.

Further examination of the hydrographs in times of low flow show that winter flows are higher by 0.20-0.30 ft (6-9 cm). Indeed there are marked steps in flow at about the time of the first frosts of the year and also at the commencement of the growing season. The change in flow is thus related to the activity of the plants and the gain/loss in water reflects accretion/depletion of the stream due to evapotranspiration from those plants with roots to the capillary fringe.

LOCAL HYDROLOGY

Tunnack - Baden Region

This region covers most of the high plateau country that forms the headwaters of the Coal River. The margins of the region are well defined topographically. It is bounded on the east by Mt Ponsonby, on the west by Flat Top Tier, on the north by a low ridge from Mt Seymour to Stonor and on the south by the change from plateau to semi-mature dissected topography approximately 150 m lower.

The geology is shown in Figure 13. The region is chiefly underlain by faulted Upper Permian and Lower Triassic sediments. A dolerite sheet may once have passed over the area and have been subsequently eroded, remnants remaining in the divides to the east and west. There are four smaller plug like bodies which may protrude from an underlying sheet. Little dolerite is likely to be encountered in bore holes within the region. The only perennial streams are the Coal River and Aarons Creek.

The form of the water table is shown in Figure 14, and is a nearly flat surface with occasional undulations determined by the minor topographic irregularities. The water table is unconfined and only one bore has been reported as truly sub-artesian or artesian (T 8). This occurrence is probably related to a limited and partly closed set of fractures although the exact source of water is not known.

The base level of the water surface is controlled by the Coal River and the water surface over the greater part of the region dips gently towards it. The water table is a subdued image of the topography.

Springs are not common since the necessary topographic features are generally lacking. Some springs of types C and E (fig. 7) occur between units of Triassic rocks along the more dissected southern margin of the region. Several springs of type D are found along the course of the river.

The water table is normally at a depth of less than 6 m *i.e.* less than the depth from the land surface to the level of the Coal River nearby. The water table is generally much closer to the land surface due to fairly even and regular infiltration and to the nearly flat surfaces.

All recharge is from rainfall, and all water movement, both surface and subsurface is toward the Coal River. The rate of movement is extremely slow as it is governed by the gradient of the water table. Tributaries of the river and minor undulations of the land surface induce subsidiary movement within the overall movement pattern.

All water recovered is of good quality, and some is excellent and can be used for all purposes (see p. 64, fig. 8, 9). There is a significant difference in quality between waters from the Triassic sandstone and Permian mudstone, which contain 100-600 ppm and 300-1,600 ppm T.D.S. respectively. The more permeable rocks (Triassic sandstones), in this elevated region of moderately high rainfall, are easily flushed of any saline content.

There have been no outright failures of bores in the district although one was abandoned due to drilling problems (T 20) and three others have subsequently gone dry (T3, T 6, T 15). The last three are in Ferntree Mudstone: bores in this formation should be kept cleaned and regularly used. (see also p. 45).

With the exception of marginal areas, as near the Coal River gorge at Stonor-Rhyndaston or the dissected areas in the south of the region, bores with excellent prospects may be sited anywhere. The best sites appear to be in the sandstones of the plain at Tunnack although the yield from these rocks averages about 455 l/h (100 gal/h) less than the Permian rocks.

Stonor Region

This region has a similar topographic disposition to the Tunnack-Baden region and is situated on the western side of the Coal River gorge. It is thus bounded on the east by the Coal River and on the west by the range of hills enclosing Lake Tiberias. The lake occupies a shallow surface depression.

The Stonor region is in reality part of the same water regime as that of the Tunnack region although it has been separated from it by the dissection of the gorge. There is very little surface drainage and the Coal River receives a negligible amount of water from this source. The region is an enclosed basin with the lake on one side.

The area is part of a 'window' in a large sheet of dolerite, exposing mainly Triassic sandstones.

The water table within this area is very nearly horizontal (at lake level) but rises very gently northward. There is a low groundwater divide just east of the lake. Most bores are situated east of this divide (fig. 14).

Springs are present, type A near the dolerite contact in the west and type E along the side of the gorge (see also fig. 7). The water level within the region is generally about 3 m below the surface. Water movement is of two types; that east of the groundwater divide passes to the Coal River, whereas all other movement is toward Lake Tiberias.

All water is of moderately good quality, and usable for all stock purposes although there are certain restrictions on other uses (see also p. 64, fig. 8, 9). The total salt content of the water is within the range 500-2,500 ppm. Several of the samples analysed had a very low pH, and these particular waters (bores ST 14, ST 15), should be used in plastic piping to avoid corrosion.

Results have shown this to be an excellent area for water boring. The water is of good quality (see also p. 41) and may be used for most purposes. The average yield of bores is 120 l/h (267 gal/h) and there have been no failures.

No drilling should be contemplated adjacent to the gorge or on the dolerite hills to the west as such areas are rapidly drained due to the effects of the topography: there would be little chance of success.

Colebrook Region

The Colebrook region is perhaps the best watered of the nine divisions of the Coal River basin. It is also characterised by gentle rounded topography in a dominantly sedimentary terrain. This region is a large basin with several large tributary streams draining the divides west of Yarlington and east of Craigbourne.

The geology is shown in Figure 13. The dolerite intrusions generally have the form of plugs which produce the characeristic rounded topography, although the dolerite in the principal divides is a large sheet, or parts of two or three smaller sheets.

The character of the water table, is subdued and gentle: its form is suggested in Figure 14. It is generally shallow and commonly less than 6 m below the surface. Springs are not common and are usually marginal to igneous intrusions.

Two aquifers occur within the region: the sedimentary series of the Lower and Upper Triassic. The reliability of the former can be gauged from Table 8, whereas the feldspathic series is subject to deep weathering and failures and low yields are more common.

Groundwater movement is essentially similar to surface water movement, although there is a suggestion that the graben faults running across the region act as dams due to weathering and clay formation. This effect is more pronounced when dolerite dykes occur in the fault plane. Groundwater flow is suggested in Figure 7, but minor distortions probably occur against the principal faults.

No water has been recovered from the Lower Triassic rocks, but the quality to be expected will be similar to the Stonor region, where the geological conditions are comparable. The water from the Upper Triassic rocks is of good quality (280-1,100 ppm T.D.S.) and usable for most purposes (see also p. 64 , fig. 8, 9).

Good prospects for successful water bores exist in most of the region. Sites in steeply sloping areas should be avoided as should those adjacent to cliffs of sandstone, as near Eldon. Generally the best sites in either of the main rock types are in the valleys. In the zones of feldspathic rocks, sites should be considered on firm outcrops. If this is not done there is a chance that the bore will go into impermeable deeply weathered material and may fail.

The average yield of bores from the feldspathic rocks of this region is 70 l/h (156 gal/h) and there have been two failures.

White Kangaroo Rivulet Region

The region comprises an area of 155 km^2 (60 square miles) adjacent to the Brown Mountain divide. The region is of moderately high relief, with very steep gradients on the tributary streams. White Kangaroo Rivulet is gently graded and in several places large alluvial flats and gravel beds have been formed. The rainfall within this region is about 635 mm (25 inches).

The geology is shown in Figure 13. The dolerite intrusions are commonly plug-like although the structure of Brown Mountain has not been determined. It is possibly a large dyke, but is more likely to have an interlocking sheet structure comparable to the Herring Back near Huonville (Leaman, 1971). The significant aquifers are the Recent alluvial deposits and the Triassic sediments along the broad tributary valley in the south-west of the region.

The water table is apparently a gently sloping surface within the primary valley. Elsewhere the water table is probably very irregular and often perched, particularly in the dolerite of Brown Mountain, while types E, F are found in the sedimentary areas.

The water table is generally at an unknown depth, but it is less than 2-3 m in the alluvial deposits along the valley, and at great depth in the valley sides due to the steepness of the slopes. The dip of the sedimentary rock is very nearly horizontal and has little influence on the water body.

Within the two large areas of low-lying Triassic rocks, the water table is again very shallow.

All groundwater movement parallels surface water movement. The quality of the groundwater is unknown but is likely to be comparable with that from the Tunnack region.

Bore sites could be recommended only in the valley floor of White Kangaroo Rivulet, either in the alluvial deposits or in any of the rock types of the lower slopes. Good prospects also exist in the Triassic rocks of the tributary valley [315545]. A similar area to the south of the rivulet is not recommended as it is intruded by a complex of small dykes and sills.

Elsewhere the topography is such that the rock is easily drained, and there are variable storages. Also the depth to water may often be excessive. Failures are likely in such areas.

Native Hut Rivulet Region

Topographically and geologically this basin is very similar to that of White Kangaroo Rivulet. The rainfall is estimated to be within the range 508-635 mm (20-25 inches). The geology is shown in Figure 13.

The water table is probably irregular and often perched within the dolerite hills which form the principal watersheds in the region.

The depth to the water table is about 3 m within the alluvial deposits and gravels which occur at various places along the course of the rivulet; but it may be in excess of 15 m in the hills adjacent to the rivulet.

Groundwater movement is essentially a reflection of surface water movement. The quality of the groundwater is unknown but is expected to be comparable with that in the Colebrook-Yarlington district.

Bore sites are not recommended in any of the dolerite areas or adjacent to steep sided valleys cut in the sandstone north of Native Corners. The best prospects exist in the low ridge forming the western boundary of the region near Campania or in the low relief areas around Native Corners; both are sandstone areas.

Richmond - Campania Region

This region comprises the immediate valley of the Coal River from Pitt Water to a low divide south of Colebrook where the river has cut a narrow gorge through a plug of dolerite. The total area is in excess of 205 km^2 (80 square miles).

The region can be divided into three parts, each of which are similar hydrologically but which contain different rock distributions. The hydrology is controlled by the Coal River, centrally disposed in the valley, and by limited subsidiary drainage. The valley is shadowed by the substantial ranges which confine it, and the rainfall is 50-125 mm (2-5 inches) per year less than regions situated around the margins of the catchment.

The geology is clearly shown in Figure 13. The southern parts of the region contain thick successions of Tertiary sands and clays. South of Campania the consolidated rocks and sheets of dolerite, have been tilted up to angles of 25° to the west. Dips north of Campania are of the order of 5-10°. The different structural environments of the northern and southern parts of this region have been fully discussed on pages 29-30.

NORTH OF CAMPANIA

Gradients on the water table are very gentle throughout the base of the valley. At the margins of the area, in the abrupt hills to the west of the river and in the rounded dolerite hills in the north of the region; the water table is irregular, variable in gradient and discontinuous. Springs of types A, C, G, H are common in these hilly areas. The depth of the water table in the Triassic rocks adjacent to the river probably rarely exceeds 10 m.

No information is available about the quality of the water from this zone as only one bore has been drilled and this was dry. However, it is expected that the quality of water from the feldspathic series of Triassic sandstones will be similar to that in the Colebrook region and that water from the quartz sandstone is comparable to that at Stonor.

Excellent bore sites exist within the sandstone areas in the valley and in the hills to the east, but the restrictions outlined on page 48 apply. Drilling in the basalt should be avoided unless it can be shown that the basalt is of sufficient thickness to persist as an aquifer below the level of the water table, which is generally not the case.

Water could also be obtained from the gravels in Native Hut Rivulet at Campania. Drilling should not be undertaken where a section does not show such gravels or an outcrop of solid rock.

The feldspathic sandstone has been shown to weather, in zones, to clay (RC 4 placed in such a zone failed) and test diggings or the use of resistivity methods are necessary to check that this has not occurred, particularly

Plate 5. *View of Richmond - Campania region.*

RICHMOND TERTIARY BASINS

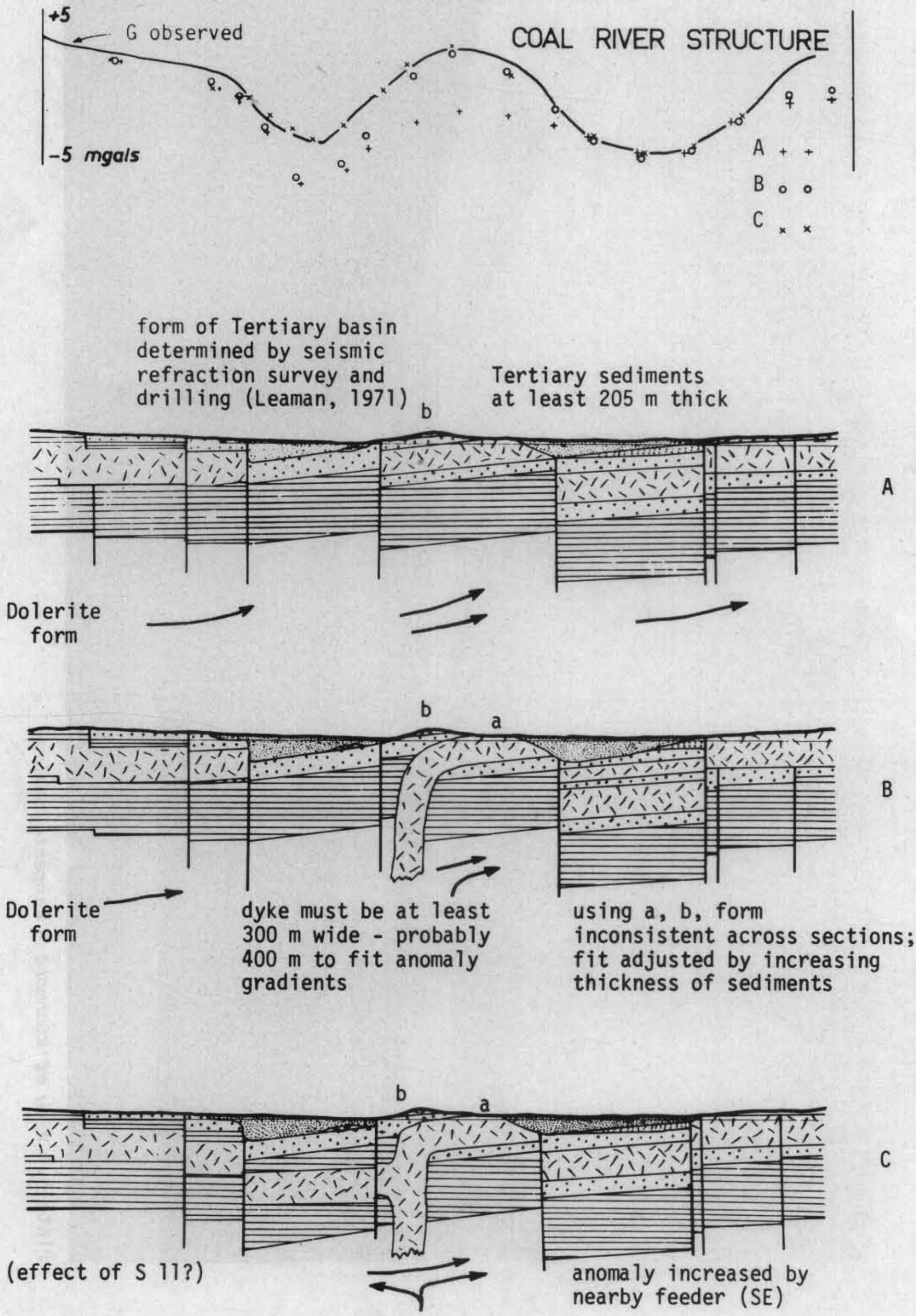


Figure 10.

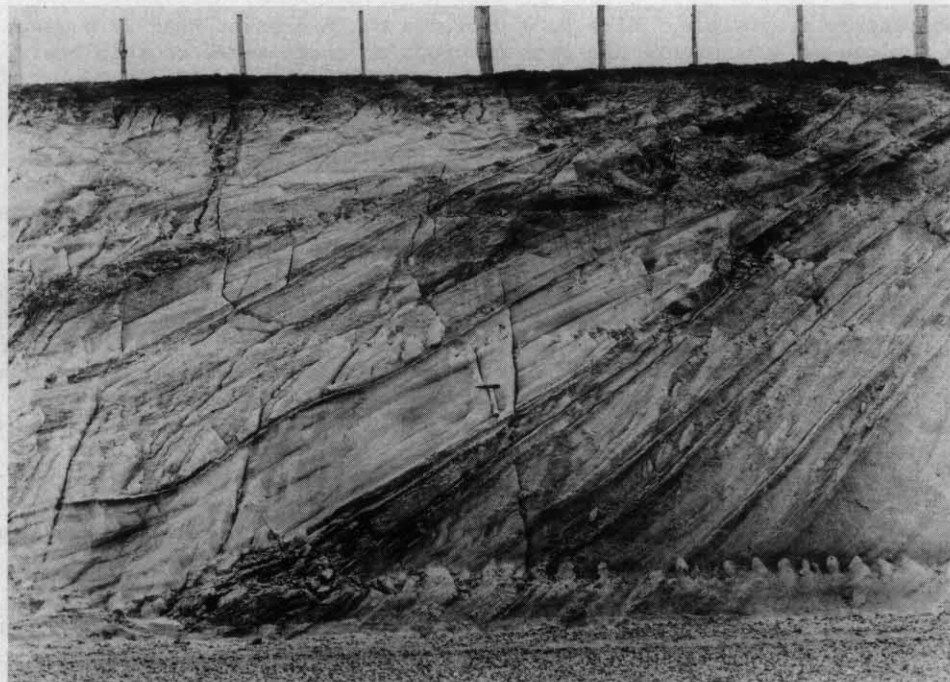


Plate 6. *Tertiary sands and clays, Campania.*

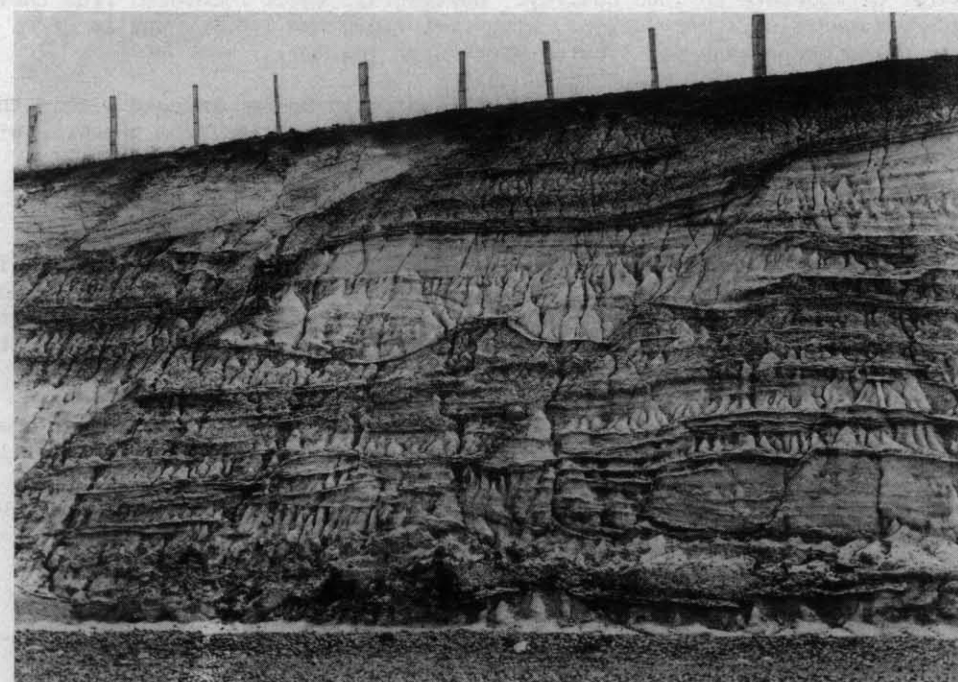


Plate 7. *Tertiary sands and clays, Campania.*

if no outcrop is visible. Site RC 4 proved a basin greater than 27 m deep, with a slope of 40°. There are rock outcrops on three sides of this basin.

CAMPANIA - PITT WATER

The suggested form of the water table is shown in Figure 10. The water table throughout the undulating area east of the Richmond plain is disrupted due to the presence of many dolerite bodies, including small dykes. Springs of Types A and B are common.

Little is known of the water table throughout the low-lying plain either north or south of Richmond. Limited drilling suggests that it is very nearly planar and grades up-stream with the river bed. Within the plain the depth to water rarely exceeds 10 m. South of Richmond the water is unconfined, but to the north and in particular close to the margins of the Tertiary basin, the water may be perched above a near-surface clay horizon or be sub-artesian. The water in hole RC 5 is sub-artesian.

This observation may be explained by the neterogeneity of the unconsolidated sediments, particularly near the margins. This results in various travel paths for the groundwater; some of which may be confined.

As far as is known no water table exists within the basalts which cap the surface of the plain.

Water table conditions on Longs Hill are similar to those in Figure 7, between A and C.

Most drilling to date has been undertaken in the Tertiary sediments. Some wells have been placed in the Triassic sandstones which have resulted in water of moderate to good quality. However all water recovered from the Tertiary materials is very saline, with over 7,000 ppm T.D.S., and is of little value other than for limited stock uses (p. 64).

From the quality aspect little drilling could be recommended within the plain about Richmond. Better quality water can be obtained from the Triassic sandstones on the lower slopes of the surrounding hills (*e.g.* RC 1).

COLD BLOW

Geologically the Cold Blow zone forms part of the Duck Hole Creek region. Comments made with reference to the geology of that region, its aquifers and their behaviour also apply here. Hydrologically, however, it forms parts of the Richmond zone, as it is connected with it by a narrow water-gap immediately west of Richmond township.

No bores have been drilled within the zone but numerous wells have been sunk in the Triassic rocks and upper parts of the dolerite weathering profile in the north (see fig. 14). The quality of the water so obtained is good, but it may be influenced by surface water run-off and therefore not be a true indicator.

Comments on drilling within the Tertiary sediments (see above) also apply here. There are also sites in the Cold Blow valley in dolerite and sandstone, however drilling the dolerite would present difficulties for conventional drilling plants.

Duck Hole Creek Region

This region comprises the eastern slopes of Grasstree Hill and Craigow

Plate 8. *Coal River valley north of Campania.* *[Photo: Vern Reid]*

and includes the low level Tertiary deposits adjacent to the estuary of the Coal River.

The dolerite body in the west is part of a large dyke-like step in a sheet. The Tertiary sediments have filled a deep valley system to a depth of more than 150 m near Pitt Water. The structure of the rocks is shown in

Water table conditions are extremely variable and complex throughout the Tertiary sediments and normal within the consolidated rocks. All present knowledge is summarised in Figure 14. The Tertiary sediments in this region contain large amounts of fine sand which appear to form continuous bodies; the units range in thickness from 1.5->60 m. The important aquifer normally occurs within 12 m from the surface. The water is apparently unconfined. This sand has been recorded in DH 2, DH 5, DH 6, DH 11, DH 13. The water-bearing sand horizons are overlain by up to 12 m of clay. Over parts of the region coarse gravels up to 13 m thick, are common and perched water tables exist within them. The continuity of the gravel bodies is not known, but they do appear to be restricted to the western margin of the basin.

Permanent springs are common at the interface between Tertiary clays and Triassic or Permian rocks. At a lower level such flow provides replenishment for the sand aquifers. Several springs occur within the basin where the sand body is near the surface. Other springs occur at or near the margins of the dolerite bodies where significant changes of permeability occur.

All aquifers exist within 24 m of the surface and some water can be recovered in the gravels within 5 m. However all significant yields (>5,050 l/h >1,100 gal/h); are obtained from the sands in the Tertiary sediments which may be encountered generally within 15-18 m from the surface, although water was only reached at 90 m in DH 4. Normally in the sandstone or mudstone areas of gentler topography a hole should be stopped about 30-37 m if no water has been struck.

Within the consolidated rocks groundwater movement is directly E-W. Movement within the Tertiary sands is unknown, but is probably induced only by leakage to Pitt Water or draw-off by springs, wells or bores.

Water from the Triassic rocks is generally of fair quality (about 3,000 ppm T.D.S.) whereas that from the Tertiary sediments is much more variable. The water from the gravels, where catchment and movement is limited, and is restricted to surface and rain sources, is of excellent quality (600 ppm T.D.S.). Toward Pitt Water where the water passes slowly through fine grained rocks, there is a significant increase in the salt content. Water from the sand aquifers has a salinity range of 2,900 to 3,500 ppm.

The Tertiary sediments in this region, as distinct from those within the Penna, Cambridge or Richmond regions, contain good aquifers. However certain restrictions on drilling should be noted. Drilling should be avoided around the margins where the section contains less sand and more clay (DH 1 encountered this problem). Bores should not be sunk beyond a depth of 55-60 m since test drilling reveals that this is the base limit of the upper sand. A lower sand, confined below a further clay contains more saline water and should not be drilled into as this will contaminate the higher aquifer. Bores recovering water from the sand should contain either slotted casing enclosed in fine gravel packs or several feet of good quality fine screens to ensure proper development of the hole and prevent damage to pumps and other installations. If this is not done sand would be drawn in with the water and the hole would collapse.

Should these sand aquifers be drilled extensively, care will be necessary to ensure that depletion of the aquifer does not occur. It is likely that its storage and rate of replenishment is restricted and under the provisions of the Underground Water Act (1966), may require protection if misused. Depletion is indicated by a continuous fall in rest-water levels. This is not a problem at the moment as little water is being extracted.

Cambridge - Seven Mile Beach Region

This area falls within three topographic zones, and has a total area of 65 km^2 (25 square miles); a low level area of Recent and Tertiary deposition, a middle zone of Permo-Triassic rocks which form lower hill slopes, and high ridges of dolerite. Drainage is directly downslope toward Pitt Water.

The geology is shown in Figure 13. Tertiary and Recent sediments have filled a deep and probably narrow river valley and its tributaries which were eroded in downfaulted Permian and Triassic rocks. The western margin of deposition is often very steep and cliff-like, as near Single Hill and at a property south of Cambridge (compare C 8, C 9, C 10, C11). Tertiary sediments lap into the many tributary valleys which have now been revealed by more recent erosion. The much-faulted older rocks were intruded by dolerite in the form of a large dyke which forms the western divide of the basin. At Single Hill several dykes and sills are present in one complex intrusion.

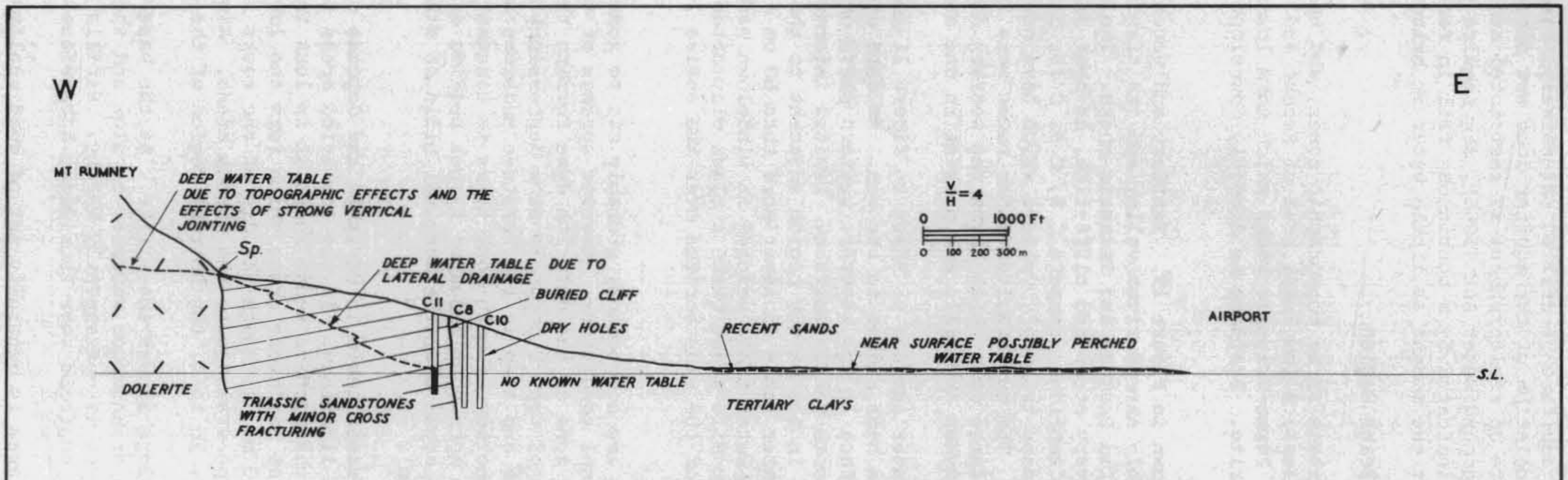
The form of the water surface is shown in Figure 11 and is a simple sloping surface from the high ridges to the sea. No data are available regarding the water surface in the steeper, western parts of the region, but elsewhere there is a smooth gentle surface. Limited information is available on groundwater surfaces in the marshy region adjacent to the airport, where it is likely that the water table is never more than 60 cm - 1 m from the surface. This may be a water table perched in windblown sands which overlie an aquifuge, as at Seven Mile Beach where a black clay often confines saline water. The continuity of the clay horizon over the entire low area has not been demonstrated.

Permanent springs are not common, probably due to zones of uniform lithological and topographical conditions. However springs of type C (fig. 7) occur along the contact zone of the dolerite dyke forming the western margin of the region. Springs of type E occur in some depressions in the sandstone areas south of Cambridge and also in the Ferntree Mudstone adjacent to Barilla Rivulet. Since the lithology of both rock types is constant such springs are probably related to more continuous or larger bedding or joint openings. Seepages of type I also occur near the marginal hills of windblown sands, as at 'Milford' and 'Cilwen'.

The depth to the water table is variable and depends principally on topography, but also on lithology. In the low-lying areas the water table only exists as such in the surface sands where it is less than one metre from the surface. In the sandstone areas which form the low hills the depth to water can be up to 20 m. Although the dip of the rocks is westerly there is considerable downslope drainage to the marshy areas. Also evapotranspiration is significant, in this, the hottest region of the basin.

Water moves downslope across the strike. At the base of the slopes in the wide level areas groundwater movement is slow and the water is closer to the surface. This area is consequently marshy. Barilla Rivulet is the principal stream and it controls some subsidiary subsurface drainage.

Water within the area is generally not of good quality: the range of



WATER TABLE CONDITIONS — SOUTH OF CAMBRIDGE

Figure 11.

5 cm

total dissolved solids is 1,500-4,500 ppm. Two springs were observed with considerably better quality water but it is thought this may have been related to recent surface runoff and rainfall and not truly indicative of groundwater quality. Water from the Triassic rocks contains 1,500-2,200 ppm T.D.S. whereas that from the Tertiary rocks contains 3,500-4,500 ppm. The usefulness of the water from various rock types according to the total dissolved solids is given on p. 64.

Over one-third of the water bores in the Tertiary area have been failures. Drilling in these rocks cannot, therefore be strongly recommended, especially as the quality of the water is such that it can only be used for some stock purposes.

The Triassic rocks have provided the best prospects of reasonably good water in the past, and should continue to do so. The Tunnel Hill saddle is an example of a zone in these rocks unlikely to yield much water. This results from a combination of topographical and hydrological effects.

The Ferntree Mudstone in the valley floor and low slopes adjacent to Barilla Rivulet and its principal tributary parallel to the Tasman Highway from Tunnel Hill offers excellent prospects of quite good water (410-1,600 ppm T.D.S. on indication of springs).

As mentioned on page 39 care should be taken to ensure siting of bores on outcrops of Permian and Triassic rocks and not on quasi-outcrop. In many places buried cliffs exist (fig. 11) and some physical method, such as test boring or resistivity, must be applied to test any such 'outcrop', particularly adjacent to Tertiary areas or in valleys leading to them.

No sites can be recommended in the basalt areas since these form hill cappings and are of limited extent. Similar comments apply to the dolerite which because of its general topographic situation could not be considered as an accessible potential aquifer. The valley floor of Barilla Rivulet at Cambridge is a possible exception. Again certainty of outcrop is necessary. The difficulties of drilling should also be considered.

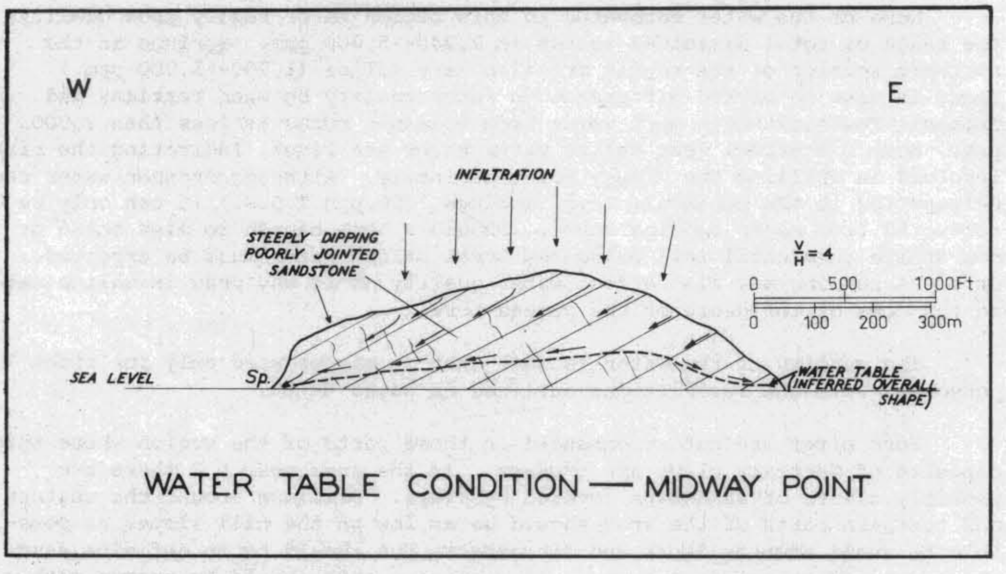


Figure 12.

Penna Region

This region lies at the SE margin of the surveyed area, and has an area of some 23 km^2 (9 square miles). The region is bounded in the west by the Mt Lord divide, in the east by a spur of She-Oak Hill, and in the south by Pitt Water. The geology is shown in Figure 13. The most important geological features are the 20-25° dip of the Triassic sediments and the thick Tertiary deposits in the centre of the region.

The character of the water table is determined by rock type, structure and topography. The general form of this water surface is indicated in Figure 14. It is parallel to the terrain and is very subdued on the low lands adjacent to Pitt Water. Water in bore P 3 and P 4 was sub-artesian; it rose some 10 m in the hole (see also discussion p. 43). There is no reason to believe that this surface is other than a true water table.

Springs occur at the boundaries between rock types, where there is a permeability discontinuity or where there is an accumulation of impermeable material along the boundary. Springs of types A and C (fig. 7) occur along the divides and types B and E are common along or adjacent to the main stream through the region. Although this stream has a deeply eroded channel it is intermittent.

No information is available about the water table in the area of Tertiary sediments between P 5 and P 8 as bores which have been within such sediments have failed. It is unlikely that any water surface exists. Where basalt occurs near the surface, as near P 5, it is the aquifer and the water is unconfined. The depth to water in the basalt area is 6-10 m. In the hillier sandstone areas the depth to water may be up to 30 m.

The conditions on the sandstone peninsula at Midway Point are indicated in Figure 12. The water table slope is much shallower to the west since water tends to be rapidly drained by the dip of the sediments. The limited vertical permeability allows the level to reduce to a nearly uniform grade. The ultimate condition is horizontal at sea level.

None of the water recovered in this region is of really good quality; the range of total dissolved solids is 1,240->5,000 ppm. Springs in the northern section of the region are also very saline (1,700->5,000 ppm.) There is also no marked difference in water quality between Tertiary and Triassic rocks although most water from Triassic rocks is less than 3,000 ppm. Bore P 3 struck very saline water below sea level, indicating the risks involved in drilling the Midway Point peninsula. Although fresher water can be expected in the peninsula (*e.g.* springs, 290 ppm T.D.S.) it can only be recovered from major bedding zones. Should a bore happen to miss these or not strike them until well below sea level saline water must be expected. Careless pumping may also affect water quality as it may draw in saline water to the cone of influence of the pumped bore.

The quality of the water is such that it may be used only for stock purposes, with the restrictions outlined on pages 64-66.

Bore sites are not recommended in those parts of the region where thick deposits of Tertiary clays are present. In the area near P 7 there are possibly cliffs of sandstone covered by clays. Drilling around the western and northern parts of the area should be as low on the hill slopes as possible to avoid adverse depth and dip effects but should be on definite sandstone outcrop to ensure success. If necessary this should be proven with a post hole digger or resistivity methods (p. 31). Bores in sandstone should be about 30 m deep to ensure striking water and having an adequate column of water in the hole to cover pumping and drought conditions.

All bores drilled to the present time in the Tertiary sediments have failed whereas the yield from the basalt or sandstone is of the order of 910-1,365 l/h (200-300 gal/h). The water recovered is of limited use and is only suitable for some stock purposes (fig. 8, 9).

SUMMARY AND CONCLUSIONS

The Coal River Basin contains a considerable volume of groundwater although supplies of surface water are restricted both in amount and availability.

At the present time it is not possible to assess accurately the factors of infiltration, evaporation, recharge and storage but some estimates can be made. Assuming about 20% of the annual rainfall is added to the groundwater reserve, then the recharge is approximately 17,000 million gallons annually. At most seasons of the year there is little or no runoff and probably a very high proportion of the rainfall (>20,000 million gallons) is added to the groundwater storage. The figures estimated for recharge are based on a 20% infiltration rate which must be regarded as an absolute minimum. The limited river flow analyses and pump testings that have been made suggest a very much higher rate. The figures suggested for storage volume are based on estimates of various hydrologic factors suitably weighted. The recharge and estimated use within individual regions is summarized below.

Region	Estimated minimum annual recharge *(million gallons)*	Estimated volume usable water storage *(million gallons)*	Estimated present usage of groundwater from bores, wells, or springs *(million gallons)*
Tunnack - Baden	1,900	100,000	56
Stonor	1,200	100,000	28
Colebrook	3,700	600,000	15
White Kangaroo Rivulet	2,500	200,000	nil
Native Hut Rivulet	1,100	100,000	nil
Campania - Richmond	3,600	400,000	3
Duck Hole Creek	1,600	200,000	20
Cambridge - Seven Mile Beach	1,400	70,000	14
Penna	300	30,000	2

It should also be noted that the recharge volume is that volume which could be added to the storage if storage is available to receive it. Thus any drawdown of the storage by demand would be replenished providing the drawoff does not exceed recharge. Most recharge to the groundwater reserve overflows as springs and seepages to creeks and rivers soon after reception since there are no voids available to retain it.

At the present time aquifer storage and yield problems are not generally encountered although they may become important in those parts of the Tunnack Region where the bore density is high. At the township there is a bore density of 4 per square kilometre (10 per square mile) at the present time. About one fifth of the total storage is contained in the dolerite which is not easily drilled. There is no one specialized aquifer within the basin.

Little of the groundwater can be used for domestic purposes but some could be used for irrigation and all can be used for stock watering. If water is to be used for irrigation it should first be analysed and its per cent sodium and sodium adsorption ratio checked for suitability.

Excellent bore sites are available throughout the basin in accordance with the theory and practice outlined in the chapter on 'General Hydrology'. The best sites are adjacent to drainage lines and away from geological or topographical irregularities and discontinuities.

Bores in consolidated rocks should be regularly cleaned, while those in unconsolidated deposits should be properly screened in order that the aquifer be fully developed without danger of collapse. All bores should be drilled well below the level of the initial water level to safeguard against periods of drought, local over-use or pump drawdown.

There is virtually no artesian water within the basin and all groundwater appears to be meteoric in origin. There are no warm waters. The water table is continuous and unconfined.

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APPENDIX 1

Drilling Results

Many details are available for bores placed by the Department of Mines. Prior to the Underground Water Act (1966) private drillers were not required to supply details of drilling operations, and much information has been lost.

All bores were drilled by the Department of Mines, other drillers are indicated by a symbol following the date of drilling:

t Tasmanian Drillers, Hobart.
f D. Flood.
u Driller unknown.
w Wreck-Air, Hobart.

Figures for yield are from tests following drilling.

Quality (T.D.S.) was determined using a conductivity meter.

BORE RECORDS

TUNNACK - BADEN REGION

Bore no.	Date drilled	Owner	Depth water struck	Total depth	Yield	T.D.S.	Analysis no.	Water temp.	Altitude	Bore log	Water level (Dec. 1966)
			ft	*ft*	*gal/h*	*ppm*		*°F*	*ft*	*ft*	*ft*
T 1	26.9.51	D.J. Nettlefold	26	60	450	100	1	52	-	0-2 soil, 2-6 clay, 6-60 mudstone	-
T 2	9.10.51	R. Mayne	30	65	250	-	-	-	-	0-2 soil, 2-5 clay, 5-65 mudstone	20
T 3	22.10.51	R. Mayne	30	65	60 now dry	-	-	-	-	0-1.5 soil, 1.5-2.5 clay, 2.5-45 mudstone, 45-65 sandstone	-
T 4	31.10.51	T.W. Byrne	10	68	300	-	-	-	-	0-3.5 soil and boulders, 3.5-12.5 mudstone, 12.5-68 sandstone	4
T 5	8.11.51	L. Burke	60	120	240	-	-	-	-	0-4.5 soil and sand, 4.5-85 sandstone, 85-105 shale, 105-120 sandstone	-
T 6	15.11.51	P.E. Cornish	20	65	300 now dry	-	-	-	-	0-5 soil and clay, 5-60 mudstone	-
T 7	3.12.51	M.G. Palmer	40	115	280	-	-	-	-	0-5 soil and clay, 5-115 sandstone	27
T 8	16.12.51	E. Woolford	30	50	500+ occasionally flows in	350	2	52	-	0-2 soil, 2-3.5 boulders, 3.5-50 mudstone	1

TUNNACK - BADEN REGION — continued

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level (Dec. 1966) *ft*
T 9	16.12.52	G.N. Earley	25	90	300	-	-	-	1,510	0-1.5 sand, 1.5-3.5 sand, 3.5-5.5 clay, 5.5-90 sandstone	-
T 10	5.5.53	D. McConnon	35	95	300	-	-	-	1,480	0-1.5 soil, 1.5-4 clay, 4-22 sandstone, 22-45 mudstone, 45-95 sandstone	-
T 11	4.5.60	I. Scott	30	40	250	1,300	3	55	-	0-8 soil and clay, 8-20 clay and pebbles, 20-40 mudstone	9.25
T 12	27.5.60	G.A. Scott	40	58	200	-	-	-	-	0-1 soil, 1-10 clay and pebbles, 10-30 fine grit, 30-58 Permian mudstone	12
T 13	4.6.60	G.T. Young	46	70	200	650	4	48	-	0-4 soil and clay, 4-10 decomposed sandstone, 10-46 sandstone and clay, 46-70 Permian mudstone	30
T 14	9.6.60	W. Bowerman	40	67	250	-	-	-	-	0-67 Permian sandstone	-
T 15	21.6.60	K.H. Lynch	40	62	150 now dry	-	-	-	-	0-6 sandstone and clay, 6-62 Permian mudstone	-
T 16	27.6.60	W.H. Hart	35	75	150	290	11	54	-	0-1 soil, 1-5 sand, 5-50 decomposed sandstone, 50-75 sandstone with clay	-
T 17	1961*u*	G.K. & N.E.Palmer	-	-	-	1,600	5	51	-	-	11
T 18	29.11.62	B.W. Dean	20	50	350	800	6	54	-	0-50 grey and blue mudstone	6
T 19	1962*f*	G. Behrens	60	98	110	600	7	54	-	-	12
T 20	1962*f*	A. Palmer	-		30 abandoned	-	-	-	-	-	18
T 21	1962*f*	M. Bresnehan	-	-	300+	100	12	51	-	-	7
T 22	3.12.62	B.W. Dean	20	58	300-350	-	-	-	-	0-58 grey and dark grey mudstone	9
T 23	5.12.62	B.W. Dean	30	60	300-350	-	-	-	-	0-60 dark grey mudstone containing pyrite	-
T 24	11.12.62	G. Lane	45	60	300-350	-	-	-	-	0-60 sandstone	-

TUNNACK - BADEN REGION — continued

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level (Dec. 1966) *ft*
T 25	10.63	D.F. Byrne	33	45	-	160	13	52	-	-	7
T 26	1963	J. Smith	-	-	-	-	-	-	-	-	20.25
T 27	22.1.65*t*	G. Behrens	48	53	700	600	-	55	-	0-2 soil, 2-48 mudstone, 48-53 hard grey mudstone	-
T 28	28.1.65*t*	G. Behrens	48	53	700	1,550	8	51	-	0-2 soil, 2-48 mudstone, 48-53 hard grey mudstone	-
T 29	28.1.65*t*	A. Palmer	30	35	400	1,000	-	54	-	0-1.5 soil, 1.5-7 clay, 7-35 sand-stone and mudstone	14
T 30	20.3.65*t*	M.T. Byrne	25	33	400	250	14	53	-	0-1 soil, 1-6 clay, 6-33 soft sandstone	7.25
T 31	20.3.65*t*	R. Kenna	30	36	400	130	9	50	-	0-2 soil, 2-9 clay, 9-36 mudstone	15.5
T 32	22.4.65*t*	M. Byers	50	53	350	580	10	50	-	0-1.5 soil, 1.5-10 clay, 10-53 mudstone	12.5
T 33	23.11.65*t*	B. Scott	35	45	200	70	15	58	-	0-3 soil, 3-10 clay, 10-15 sandstone	6
T 34	18.2.67*t*	G. Behrens	63	80	640	-	-	-	-	0-1 gravel, 1-7 clay, 7-80 mudstone	-

STONOR - TIBERIAS REGION

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level *ft*
ST 1	18.7.49	J.V. Earley	35	55	250	-	16	-	1480	0-1.5 soil, 1.5-5 clay, 5-12.5 mudstone, 12.5-29 sandstone, 29-38 mudstone, 38-52 sandstone, 52-55 dolerite	-
ST 2	25.7.49	J.V. Earley	25	85	300	-	17	-	1460	0-2 soil, 2-5.5 clay, 5.5-19 pug and sand, 19-85 sandstone	-
ST 3	4.8.49	F. Devine	60	130	150	-	-	-	1510	0-1.5 soil, 1.6-3 sand, 3-5 clay, 5-130 sandstone	-
ST 4	22.8.49	W.F. Bevan	30	75	150	-	18	-	1510	0-1.5 surface soil, 1.5-75 sandstone	-
ST 5	18.11.49	J.V. Earley	12	45	400	-	19	-	1460	0-1.5 soil, 1.5-5 clay, 5-45 sandstone	-
ST 6	15.8.50	E.C. Gregory	-	205	-	-	-	-	-	0-2 soil, 2-5 clay, 5-205 sandstone	-
ST 7	4.9.50	W.H. Bevan	45	80	300	-	20	-	1510	0-2 soil, 2-5.5 clay, 5.5-78 sandstone, 78-80 dolerite	-
ST 8	7.9.50	J. Jabour	30	45	400	-	21	-	1460	0-2.5 soil, 2.5-4 clay, 4-45 sandstone	-
ST 9	14.9.50	F. Devine	50	105	250	-	22	-	1480	0-2 soil, 2-32 clay and sand, 32-43 sandstone, 43-57 mudstone, 57-105 sandstone	-
ST 10	20.9.50	E.H. Porter	20	80	350	-	64	-	1480	0-2 soil, 2-8 clay, 8-20 mudstone, 20-29 sandstone, 29-36 mudstone, 36-80 sandstone	-
ST 11	20.12.51	R. Byrne	110	150	200	-	23	-	1510	0-2 soil, 2-6 clay, 6-150 sandstone	-
ST 12	24.4.53	D. McConnon	30	45	400	-	24	-	1470	0-2 soil, 2-6.5 clay, 6.5-45 sandstone	-
ST 13	28.6.60	P.L. Wickham	40	65	200	-	25	-	1490	0-1 soil, 1-20 sandstone, 20-65 shale	-
ST 14	8.7.60	G. Palmer	54	81	200	-	26	-	1490	0-2 soil, 2-5 clay, 5-20 sandstone and clay, 20-58 sandstone, 58-81 shale	-
ST 15	22.7.60	R. Wickham	124	136	200	-	27	-	1520	0-2 soil, 2-60 sandstone, 60-136 shale	-

COLEBROOK

Bore no.	Date drilled	Owner	Depth water struck ft	Total depth ft	Yield gal/h	T.D.S. ppm	Analysis no.	Water temp. °F	Altitude ft	Bore log ft	Water level (Dec. 1966) ft
CO 1	15.5.50	C.H. Brock	50	100	300	800	32	65	-	0-2 soil, 2-4.5 clay, 4.5-30 dolerite wash, 30-100 sandstone	12
CO 2	24.5.50	S.J. Munnings	60	125	60 abandoned	-	-	-	-	0-1.5 soil, 1.5-5.5 sandstone, 5.5-25 mudstone, 25-47 sandstone, 47-56 black mudstone, 56-75 sandstone, 75-100 mudstone, 100-112 coal, 112-125 mudstone	-
CO 3	5.7.50	J.T. Bevan	-	250	dry, abandoned	-	-	-	-	0-2 soil, 2-4.5 clay, 4.5-45 sandstone, 45-58 mudstone, 58-85 sandstone, 85-96 mudstone, 96-120 sandstone, 120-168 shale, 168-174 sand shale, 174-205 shale, 205-250 puggy shale	-
CO 4	20.7.50	B.J. Bevan	55	195	4 abandoned	-	-	-	-	0-1 soil, 1-6.5 clay, 6.5-10.5 sandstone, 10.5-40 mudstone, 40-48 sandstone, 48-70 puggy shale, 100-105 coaly matter, 105-120 sandy shale, 120-125 coaly matter, 125-138 puggy shale, 138-142 coaly matter, 142-152 puggy shale, 152-195 sandy shale	-
CO 5	9.8.50	J.T. Bevan	110	205	8?	540	33	51	-	0-2 soil, 2-32 clay, 32-130 shale, 130-155 sandstone, 155-178 shale, 178-205 sandstone	7
CO 6	28.9.50	O.C. Moore	30	130	150	1030	34	65	-	0-1.5 soil, 1.5-5.5 clay, 5.5-10 gravel, 10-15 soft sandstone, 15-94 sandstone, 94-100 mudstone, 100-110 sandstone, 110-130 mudstone	15
CO 7	6.8.52	Closer Settlement Board (Lot 1)	-	40	-	-	-	-	-	0-1.5 soil, 1.5-3.5 clay, 3.5-8 dolerite wash, 8-34 mudstone, 34-40 dolerite	-
CO 8	12.8.52	E. Barwick	30	85	400	900	35	52	-	0-1.5 soil, 1.5-2.5 sand, 2.5-10 puggy shale, 10-40 sandstone, 40-52 black mudstone, 52-85 mudstone	-

COLEBROOK — continued

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level (Dec. 1966) *ft*
CO 9	20.8.52	E. Barwick	45	85	300	700	36	48	-	0-2 soil, 2-4.5 clay, 4.5-7 wash, 7-20 sandstone, 20-37 mudstone, 37-45 coaly matter, 45-85 sandstone	-
CO 10	24.11.52	C. Cahill	45	90	300	900	-	55	-	0-2 soil, 2-10 clay and boulders, 10-35 mudstone, 35-90 sandstone	-
CO 11	4.12.52	A.E. White	20	70	350	280	37	55	-	0-2 soil, 2-10 clay, 10-24 soft sandstone, 24-53 mudstone, 53-57 coaly matter, 57-68 hard mudstone, 68-70 dolerite	-
CO 12	- *u*	A. Jones	-	-	-	510	38	55	-	-	-

RICHMOND - CAMPANIA REGION

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level *ft*
RC 1	18.6.56	H. Banks	-	48	0	-	-	-	-	0-11 sand, 11-14 clay, 14-18 alluvium, 18-25 weathered mudstone, 25-48 mudstone	-
RC 2	27.6.56	H. Banks	93	124	200	1200	31	-	-	0-2.5 sand, 2.5-3 clay, 3-124 sandstone	76
RC 3	16.6.67	A. Bowen	-	672	350	7000	45	-	-	0-3 soil, 3-5 clay, 5-28.5 basalt, 28.5-43 clay, 43-63 basalt, 63-90 clay, 90-177 clay with coal, 177-282 clay, 282-291 basalt, 291-512 clay, 512-625 clay with coal, 625-672 clay	56
RC 4	24.6.67	D. Harding	-	93	0	-	-	-	-	0-1 soil, 1-93 clay	-
RC 5	7.7.67	A. Bowen	-	660	450	7000	46	-	-	0-2 soil, 2-35 clay, 35-50 clay with coal, 50-230 clay, 230-260 clay with coal, 260-660 clay	4
RC 6	29.9.67	L. Lazenby	-	665	450	-	47	-	-	0-1 soil, 1-5 clay, 5-20 gravel, 20-25 sand, 25-50 clay and gravel, 50-60 clay, 60-80 coal and clay, 80-110 clay, 110-120 coal and clay, 120-240 clay, 240-255 sand, 255-570 clay with coal, 570-622 clay with boulders, 622-665 weathered dolerite	24

DUCK HOLE CREEK REGION

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level (Aug. 1967) *ft*
DH 1	15.9.56	M.M. Gregg	-	36	-	-	-	-	-	0-3 black clay, 3-22 clay, boulders, sandstone and dolerite, 22-36 alluvial matter	-
DH 2	26.9.56	M.M. Gregg	78	79	300	1050	41	-	-	0-4 clay, 4-33 alluvium, 33-34 gravel etc., 44-78 clay, sand, 78-79 gravel	-
DH 3	12.11.56	G. Casimaty	74	114	300	-	-	-	-	0-2.5 soil, 2.5-72 yellow sandstone, 72-77 sandstone, 77-83 shale, 83-114 grey sandstone	-
DH 4	20.11.56	G. Casimaty	294	330	90	-	-	-	-	0-2.5 soil, 2.5-186 shale, 186-210 grey sandstone, 210-292 shale, 292-294 grey sandstone, 294-330 sandstone with shale bands	-
DH 5	8.12.61	W. Blackburn	-	31	-	-	-	-	-	0-1 soil, 1-4 clay, 4-16 dolerite boulders, 16-29 gravel, 29-31 clay and grit	-
DH 6	15.12.61	W. Blackburn	43	43	100	620	42	-	-	0-1 soil, 1-5 clay, 5-12 sand, 12-38 gravel, 38-43 clay and grit	15
DH 7	19.12.61	P. Murdoch	42	85	-	-	-	-	-	0-0.5 soil, 0.5-3.5 clay, 3.5-10 coarse gravel, 10-85 clay	-
DH 8	7.66w	G. Casimaty	-	63	-	-	-	-	-	sandstone	33
DH 9	7.66w	P. Graves	-	65	60-80	3000	29	-	-	sandstone	23
DH 10	7.66w	P. Graves	-	45	-	-	-	-	-	sandstone	28
DH 11	21.7.67	E.V. Hodge	35	220	1200	3200	43	-	-	0-2 soil, 2-3 clay, 3-18 sand, 18-23 clay, 23-35 sandy clay, 35-40 sand, 40-180 sandy clay, 180-200 clay and boulders, 200-220 dolerite	35
DH 12	25.8.67	E.V. Hodge	50	306	450	2900	30	-	-	0-4 soil, 4-22 sandstone, 22-40 Triassic mudstone, 40-105 siltstone, 105-115 sandstone, 115-306 siltstone	16
DH 13	15.9.67	T.R. Hanslow	48	494	1100	2900	44	-	-	0-2 soil, 2-7 clay, 7-15 boulders, 15-30 clay, 30-100 sandy clay, 100-203 sand, 203-245 clay, 245-470 sandy clay, 470-494 sandstone	48

CAMBRIDGE - SEVEN MILE BEACH REGION

Bore no.	Date drilled	Owner	Depth water struck ft	Total depth ft	Yield gal/h	T.D.S. ppm	Analysis no.	Water temp. °F	Altitude ft	Bore log ft	Water level (May 1967) ft
C 1	17.7.56	G. Casimaty	101	141	200	-	-	-	-	0-2 sand and mud, 2-19 yellow sandstone, 19-96 yellow slate, 96-119 fine sandstone, 119-141 sandstone	-
C 2	24.7.56	G. Casimaty	70	110	200	-	-	-	-	0-3 soil, 3-34 yellow shale, 34-110 sandstone	35
C 3	3.8.56	G. Casimaty	70	111	200	-	-	-	-	0-3 sand, 3-111 sandstone	64
C 4	20.8.56	G. Casimaty	74	82	200	4500	-	-	-	0-3 soil, 3-5 clay, 5-42 clay, sand, 42-44 gravel, 44-74 shale, 74-82 gravel	-
C 5	3.9.56	T. Pipkin	-	126	-	-	-	-	-	0-25 sand, 25-49 sand and shells, 49-126 clay	-
C 6	7.11.61	D. Martin	40	79	100	4500	-	-	-	0-1 soil, 1-40 clay and grits, 40-79 clay and sand	+1
C 7	13.11.61	D. Martin	45	72	250	-	-	-	-	0-2 soil, 2-69 clay, 69-72 gravel	-
C 8	17.11.61	E.M. Sutcliffe	-	170	-	-	-	-	-	0-2 soil, 2-170 clay, some pebbles	-
C 9	24.11.61	E.M. Sutcliffe	-	190	-	-	-	-	-	0-3 soil, 3-190 clay, some pebbles	-
C 10	30.11.61	E.M. Sutcliffe	-	190	-	-	-	-	-	0-3 sand, 3-6 clay, 6-190 clay with some pebbles	-
C 11	5.12.61	E. N. Sutcliffe	125	145	150	2200	28	-	-	0-1 sand, 1-145 sandstone	70
C 12	pre-1920	J. Kennedy	-	-	dry	-	-	-	-	-	
C 13	pre-1920	J. Kennedy	-	-	dry	-	-	-	-	-	
C 14	pre-1920	J. Kennedy	-	-	water struck, abandoned	-	-	-	-	-	
C 15	pre-1920	J. Kennedy	-	-	formerly used	-	-	-	-	-	

PENNA REGION

Bore no.	Date drilled	Owner	Depth water struck *ft*	Total depth *ft*	Yield *gal/h*	T.D.S. *ppm*	Analysis no.	Water temp. *°F*	Altitude *ft*	Bore log *ft*	Water level (June 1967) *ft*
P 1	9.4.63	C. Reynolds	-	165	dry	-	-	-	90	0-90 clay with pebbles, 90-95 sand, 95-165 clay with pebbles	-
P 2	23.4.63	Golf Club	-	35	dry	-	-	-	70	0-34 clay sand, 34-35 basalt	-
P 3	26.4.63	Golf Club	60	100	250-300	very salty	-	-	25	0-10 clay, 10-100 mudstone	-
P 4	30.4.63	B. Lovell	90	115	200-250	1240	-	-	260	0-6 soil, clay, 6-115 sandstone	60
P 5	7.5.63	E. Iles	-	39.5	abandoned	2000	48	-	50	0-20 clay, 20-39.5 vesicular hard basalt	31
P 6	25.5.63	A. Duncombe	16	40	250-300	3600	49	-	40	0-10 clay, 10-17 clay and basalt boulders, 17-40 basalt	15
P 7	30.5.63	K. Eddington	-	165	-	-	-	-	140	0-165 clay	-
P 8	4.6.63	C. Reynolds	-	138	-	-	-	-	90	0-138 clay and pebbles	-

WELLS

Well no.	Date dug	Owner	Depth water struck ft	Total depth ft	Yield gal/day	Shaft size ft	T.D.S.	Analysis no.	Altitude ft	Well log	Water level ft
TW 1	-	M. Byers	-	22	-	3.5 diam.	280	-	-	sandstone	8.5
TW 2	-	D.R. Duggan	-	3	0 collapsed	6 x 6	10	-	-	-	-
TW 3	1965	I. Scott	0	6	-	10 x 10	250	-	-	0-1.5 soil, 1.5-6 yellow clay, dolerite wash	0
CW 1	-	J. Kennedy	-	15	-	-	-	-	-	-	-
CW 2	-	R. McKay	4	88	-	-	1500+	56	-	-	53
DHW 1	-	W. Blackburn	21	24	100	2 diam.	620	-	-	0-1 soil, 1-5 clay, 5-12 sand, 12-24 gravel	16
RCW 1	-	M. Brodribb	-	-	-	-	-	-	-	clay (see Nye 1924)	-
RCW 2	-	M. Brodribb	-	-	-	-	-	-	-	clay (see Nye 1924)	-
RCW 3	-	Morton	-	110	2400	6 x 4	2500	58	-	-	80
RCW 4	-	H. Dunn	-	-	-	5 x 4	- saline	-	-	-	-
RCW 5	-	L.R. Barwick									
RCW 6	-	I.B. Hardwick	-	76	1000	5 diam.	-	-	-	-	4
RCW 7	-	L.R. Barwick	-	8	600	5 x 3	-	57	-	soil and clay	3
RCW 8	-	L.R. Barwick	-	10	1000	6 x 4	salty	-	-	soil and clay	3

APPENDIX 2

MISCELLANEOUS ANALYSES

Analysis	50	51	52	53	54	55	56
			parts per million				
Total dissolved solids	8366.0	593.0	2890.0	2807.0	866.0	760.0	1571.0
CO_3	0.0	15.0	0.0	3.6	0.6	1.2	41.0
HCO_3	594.0	212.0	375.0	43.9	15.9	23.2	337.0
Cl	5098.0	177.0	1240.0	1216.0	246.0	204.0	632.0
SO_4	273.0	38.0	0.0	50.0	35.0	24.0	50.0
NO_3	nd	nd	nd	nd	nd	nd	nd
F	0.8	0.1	0.3	0.3	2.4	0.5	0.9
SiO_2	tr	16.0	47.0	173.0	24.0	47.0	17.0
Ca	534.0	60.0	145.0	55.0	40.0	24.0	15.0
Mg	528.0	15.0	255.0	266.0	64.0	45.0	88.0
Fe + Al	tr	0.0	0.0	0.0	tr	0.0	0.0
K	19.0	8.0	12.0	6.0	12.0	4.0	8.0
Na	2038.0	130.0	487.0	446.0	100.0	128.0	416.0
NH_4	nd	nd	nd	nd	nd	nd	nd
Total hardness	3506.0	212.0	1411.0	2307.0	351.0	245.0	489.0
permanent	3328.0	0.0	1104.0	2262.0	336.0	223.0	110.0
temporary	178.0	212.0	307.0	45.0	15.0	22.0	379.0
Alkalinity	178.0	211.0	307.0	45.0	15.0	22.0	379.0
Total epm	159.2	8.7	43.4	40.2	10.1	8.7	24.3
			percentage constituents by equivalence				
HCO_3	3.1	20.0	7.1	0.9	1.3	2.2	11.4
Cl	45.4	28.8	39.5	42.7	34.3	33.5	36.7
SO_4	1.8	2.2	0.0	1.2	3.5	2.9	1.1
Ca	8.4	8.6	4.1	3.4	10.0	6.9	2.6
Mg	13.6	3.6	24.5	27.3	26.9	21.4	7.6
K	0.2	1.2	0.4	0.2	1.5	0.6	0.4
Na	27.9	32.6	24.4	24.2	21.9	32.4	37.3
Na adsorption ratio	15.0	5.5	6.1	5.3	2.3	3.6	16.7
Per cent Na	56.0	73.3	46.3	44.2	38.8	57.0	78.7
pH	6.8	7.9	8.8	7.3	7.4	7.6	9.0

Analyses 50-61, 64 by Department of Mines Laboratory, Launceston;

KEY TO ANALYSES 50-64:

50: Spring; M.G. Zantuck, Colebrook
51: Spring; M. Lewis, Cambridge
52: Spring; M. McDermitt, Cambridge
53: Spring; G. Gangell, Rekuna
54: Well (RCW 6); C. Bessel, Richmond
55: Spring; L. Lazenby, Richmond
56: Well (CW 2); A. McKay, Cambridge

MISCELLANEOUS ANALYSES — continued

Analysis	57	58	59	60	61	62	63	64
				parts per million				
T.D.S.	2784.0	2960.0	179.0	813.0	719.0	334.0	340.0	3988.0
CO_3	4.8	182.0	0.0	0.0	0.0	nd	nd	0.0
HCO_3	58.6	464.0	51.9	308.0	397.0	nd	nd	411.0
Cl	1195.0	1170.0	52.0	337.0	257.0	93.0	109.0	1987.0
SO_4	105.0	61.0	13.0	12.0	12.0	10.4	8.0	63.0
NO_3	nd	nd	nd	3.0	0.0	nd	nd	0.0
F	0.9	0.2	0.1	0.3	0.1	nd	nd	0.1
SiO_2	231.0	14.0	16.0	19.0	15.0	9.8	16.2	13.5
Ca	36.0	134.0	14.0	107.0	84.0	13.0	7.4	272.0
Mg	255.0	243.0	9.0	60.0	59.0	21.0	20.0	180.0
Fe + Al	0.0	0.0	tr	tr	tr	1.0	1.4	0.0
K	7.0	19.5	1.0	1.0	2.0	2.6	1.7	14.0
Na	652.0	645.0	26.0	105.0	113.0	70.0	68.0	792.0
NH_4	nd	nd	0.0	0.0	0.0	nd	nd	nd
Hardness	1104.0	1334.0	73.0	514.0	453.0	161.0	138.0	1420.0
perm.	1044.0	498.0	2.0	275.0	246.0	nd	nd	1083.0
temp.	60.0	836.0	71.0	239.0	207.0	nd	nd	337.0
Alkalinity	60.0	836.0	71.0	239.0	207.0	120.0	84.0	337.0
Total epm	43.0	49.7	2.6	14.9	14.0	-	-	63.8
				percentage constituents by equivalence				
HCO_3	1.1	7.6	16.3	17.0	23.1	-	-	5.2
Cl	39.2	33.2	28.3	32.0	25.7	-	-	44.0
SO_4	2.6	0.7	5.2	0.8	0.9	-	-	1.0
Ca	2.1	3.4	13.5	17.9	14.9	-	-	10.6
Mg	21.5	20.4	14.2	16.6	17.3	-	-	11.8
K	0.2	0.6	0.6	0.0	0.2	-	-	0.4
Na	33.1	28.2	21.7	15.3	17.5	-	-	27.1
Na adsorption ratio	8.9	8.2	1.3	2.1	2.3	-	-	9.3
% Na	58.5	54.7	44.6	30.9	35.4	-	-	54.7
pH	7.7	9.0	7.4	7.8	7.8	7.7	7.6	6.7

analyses 62-63 courtesy of Rivers and Water Supply Commission

57: Well (RCW 7); L. Barwick, Richmond
58: Well (RCW 3); Morton, Richmond
59: Kangaroo Rivulet
60: Wallaby Rivulet
61: Native Hut Rivulet
62: Coal River, Craigbourne
63: Coal River, Laburnum Park
64: Bore (ST 10); E.H. Porter, Lake Tiberias

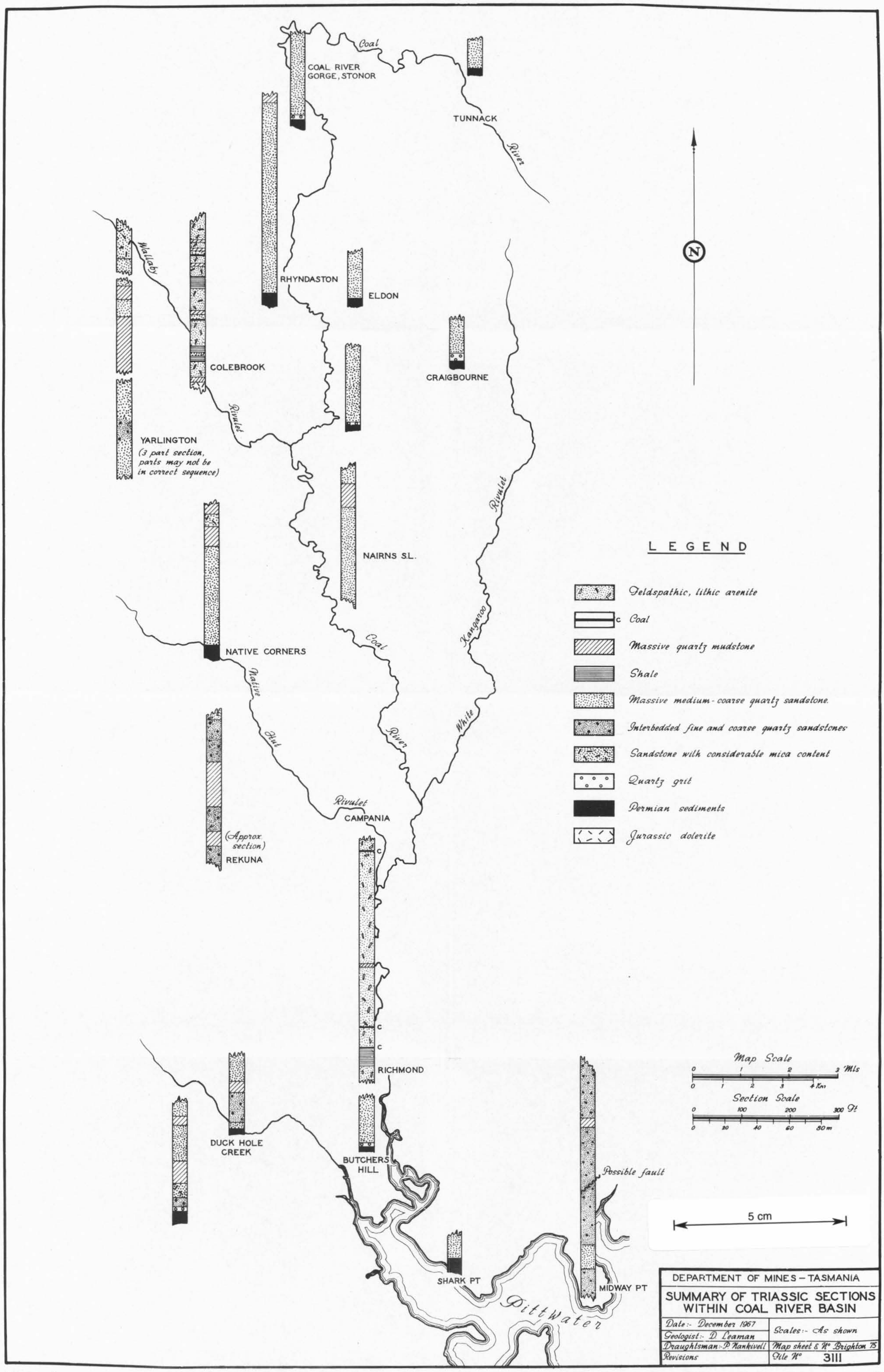

COAL RIVER GORGE, STONOR
Coal
TUNNACK
River
RHYNDASTON
ELDON
Wallaby
COLEBROOK
Rivulet
CRAIGBOURNE
YARLINGTON
(3 part section, parts may not be in correct sequence)
NAIRNS SL.
Rivulet
Kangaroo
NATIVE CORNERS
Native
Coal
Hut
River
White
Rivulet
CAMPANIA
(Approx section)
REKUNA
c
c
c
RICHMOND
DUCK HOLE CREEK
BUTCHERS HILL
SHARK PT
MIDWAY PT
Possible fault
Pittwater
N
LEGEND
Feldspathic, lithic arenite
c Coal
Massive quartz mudstone
Shale
Massive medium-coarse quartz sandstone.
Interbedded fine and coarse quartz sandstones
Sandstone with considerable mica content
Quartz grit
Permian sediments
Jurassic dolerite
Map Scale
0 1 2 3 Mls
0 1 2 3 4 Km
Section Scale
0 100 200 300 Ft
0 20 40 60 80 m
5 cm
DEPARTMENT OF MINES – TASMANIA
SUMMARY OF TRIASSIC SECTIONS WITHIN COAL RIVER BASIN
Date:- December 1967
Geologist:- D. Leaman
Draughtsman:- P. Nankivell
Revisions
Scales:- As shown
Map sheet & Nº Brighton 75
File Nº 3111

Figure 3.

Fig 13

GEOLOGY
OF THE
COAL RIVER BASIN

D.E.LEAMAN B.Sc. (Hons) Ph.D.

MILES 1 0 1 2 3 4 MILES

KILOMETRES 0 1 2 3 4 5 6 7 KILOMETRES

SCALE 1 MILE TO 1 INCH

Contour interval 20 metres

5 cm

DEPARTMENT OF MINES TASMANIA

REFERENCE

CAINOZOIC — QUATERNARY (Q)

Qrd	Dune and windblown sand.
Qra	Alluvial deposits,including younger gravel marsh and swamp deposits.
Qrg	Older gravel.
Qds	Dolerite scree.
Qdt (Qt)	Dolerite talus.
Qbt (Qt)	Basalt talus.
Qpt (Qt)	Permian siltstone talus

CAINOZOIC — TERTIARY

Ts	Predominantly sub basalt silt and fine sand, with lignite bearing material stippled

MESOZOIC — TRIASSIC (R)

Ru	Upper Triassic lithic arkose and lutite, coal bearing, undifferentiated
Rlm (Rl)	Predominantly massive quartz mudstone, minor quartz sandstone, occasional beds of lithic sandstone, coal
Rlf, Rlc (Rl)	Dominantly medium and fine quartz sandstone, minor mudstone. Much mica and graphite on bedding contains 10 °/o feldspar and clay pellet lenses (indicated).
Rlq, Rlc (Rl)	Dominantly medium–coarse quartz sandstone with minor mudstone minor mica, feldspar content, contains clay pellet beds.
Rls, Rlg (Rl)	Thickly bedded, medium–coarse quartz sandstone,with grit (Rlg) and very minor usually black shale layers.

PALAEOZOIC — PERMIAN (P)

Pcm	Cygnet Coal Measures (including quartz arkose, carbonaceous mudstone, rocks containing carbonaceous fragments.)
Pf	Ferntree Group of unfossiliferous quartz siltstone including observed Risdon sandstone and correlates at base (marker horizon indicated).
Pm	Malbina Formation (quartz sandstone and siltstone, fossiliferous in upper and lower members only.)
Pc	Cascades Group of fossiliferous beds dominantly mudstone and siltstone with Berridale Limestone indicated where present.

Igneous Rocks

Tb	Tertiary basalt.
Jd	Jurassic dolerite with granophyres stippled.

Geological boundary – observed

Geological boundary – position approximate.

Geological boundary – inferred.

Airphoto linear.

Strike and dip of beds.

Horizontal bedding.

Fault – exposed (downthrown side indicated.)

Fault – position approximate. (downthrown side indicated.)

Fault – position inferred and concealed (downthrown side indicated.)

Fault – position probable and concealed (downthrown side indicated.)

Faulted igneous boundary position approximate.

Landslip

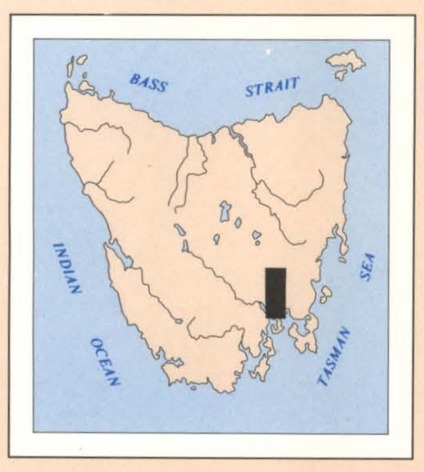
Macro fossil locality

Plant fossil locality

Volcanic centres.

Position where known of dolerite feeder axis or feeder dyke as indicated by gravitational anomaly, with thickness of cover, in metres if concealed.

LOCALITY MAP



RELIABILITY MAP

1

2

3

Base map sources :–
1. Forestry Commission 1" – 2 miles (1944)
2. Lands and Survey Dept. (Derwent – D'Entrecasteaux photography 1966)
3. Australian Survey Corps 1944

Cartography by P.B. Nankivell

Produced by Department of Mines, Tasmania. 1970

FIGURE 14

HYDROLOGY
OF THE
COAL RIVER BASIN
D. E. LEAMAN B.Sc. (Hons) Ph.D.
SCALE 1 MILE TO 1 INCH
MILES
KILOMETRES
5 cm
LOCALITY MAP
BASS STRAIT
INDIAN OCEAN
TASMAN SEA
Contour on depth of basal surface of superficial aquifers (metres)
Perennial stream with flow direction.
Seasonal stream.
Intermittent stream.
Disappearance point of stream.
Gauging station.
Marsh
Areas inundated in floods.
Principle water divides.
Spring
Contours on water table (metres)
Direction of groundwater flow.
Depth (feet) interface fresh / salt water.
Gravels
Borehole
(artesian)
Dugwell (used)
(abandoned)
Groundwater observation station without recorder.
Area where drilling is not generally to be recommended and where very detailed examinations for site selection are required. Dolerite areas should not be drilled anywhere without special consideration
Contour interval 20 metres
QUALITY CODE
Colour within spring or well symbol
0 – 1000 p.p.m.
1000 – 3000 p.p.m.
3000 – 6000 p.p.m.
6000 p.p.m.
WATER TABLE CONDITIONS — MIDWAY POINT
WATER TABLE CONDITIONS — SOUTH OF CAMBRIDGE
SOME WATER TABLE CONDITIONS AND THE LOCATION OF SPRINGS
Water table
Direction of water movement
LAKE TIBERIAS
2 STONOR
Stonor
1 TUNNACK
Baden
Rhyndaston
3 COLEBROOK
Colebrook
4 WHITE KANGAROO RIVULET
5 NATIVE HUT RIVULET
Campania
6 CAMPANIA-RICHMOND
Richmond
7 DUCK HOLE CREEK
9 PENNA
PITT WATER
Barilla Bay
8 CAMBRIDGE-SEVEN MILE BEACH
Cartography by D.M. Hardy and P.B. Nankivell
Produced by Department of Mines, Tasmania, 1970