Geological Survey of Victoria

HYDROGEOLOGICAL INVESTIGATION AND ASSESSMENT
BARWON DOWN GRADEN, OTWAY BASIN, VICTORIA

By

J LEONARD, R LAKEY AND R BLAKE

UNPUBLISHED REPORT 1983/54

DEPARTMENT OF MINERALS AND ENERGY

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PREFACE

This report is a preprint of a paper that was submitted for inclusion and presentation at the International Conference on Groundwater and Man, to be held in Sydney from 5-9 December, 1983.

KEYWORDS

Hydrogeology, groundwater resource evaluation, hydrostratigraphy hydrograph separation, effective infiltration, flow net, volume in storage, recharge, resource development.

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ABSTRACT

The structurally complex Barwon Downs Graben in southwesten Victoria has been investigated by the Geological Survey of Victoria as a source of groundwater to augment the surface supply for the city of Geelong. An extensive drilling program supported by wireline logging, surface geophysics and detailed surface mapping has been undertaken to delineate the Tertiary aquifer system. Data obtained from aquifer tests, water level monitoring, hydrochemical sampling and stream gauging records were analyzed to evaluate the resource prior to numerical modelling.

INTRODUCTION

In the late 1960's, the Geelong Waterworks and Sewerage Trust (GWST), anticipating a substantial increase in water demand, commissioned Australian Groundwater Consultants to undertake a preliminary assessment of groundwater resources in the Geelong region with a view to identifying those areas with potential to augment Geelong's existing water supply. This work indicated that the Tertiary sediments along the western flanks of the Otway Ranges warranted further investigation (Fig.1).

The Geological Survey of the Department of Minerals and Energy, Victoria (DME) commenced (1971) a detailed investigation of the groundwater resources in the Tertiary sediments in the Barwon Downs Graben. This investigation led to the design and construction of a borefield for GWST near the Barwon Downs township (Fig.2). This borefield commenced pumping during February 1983.

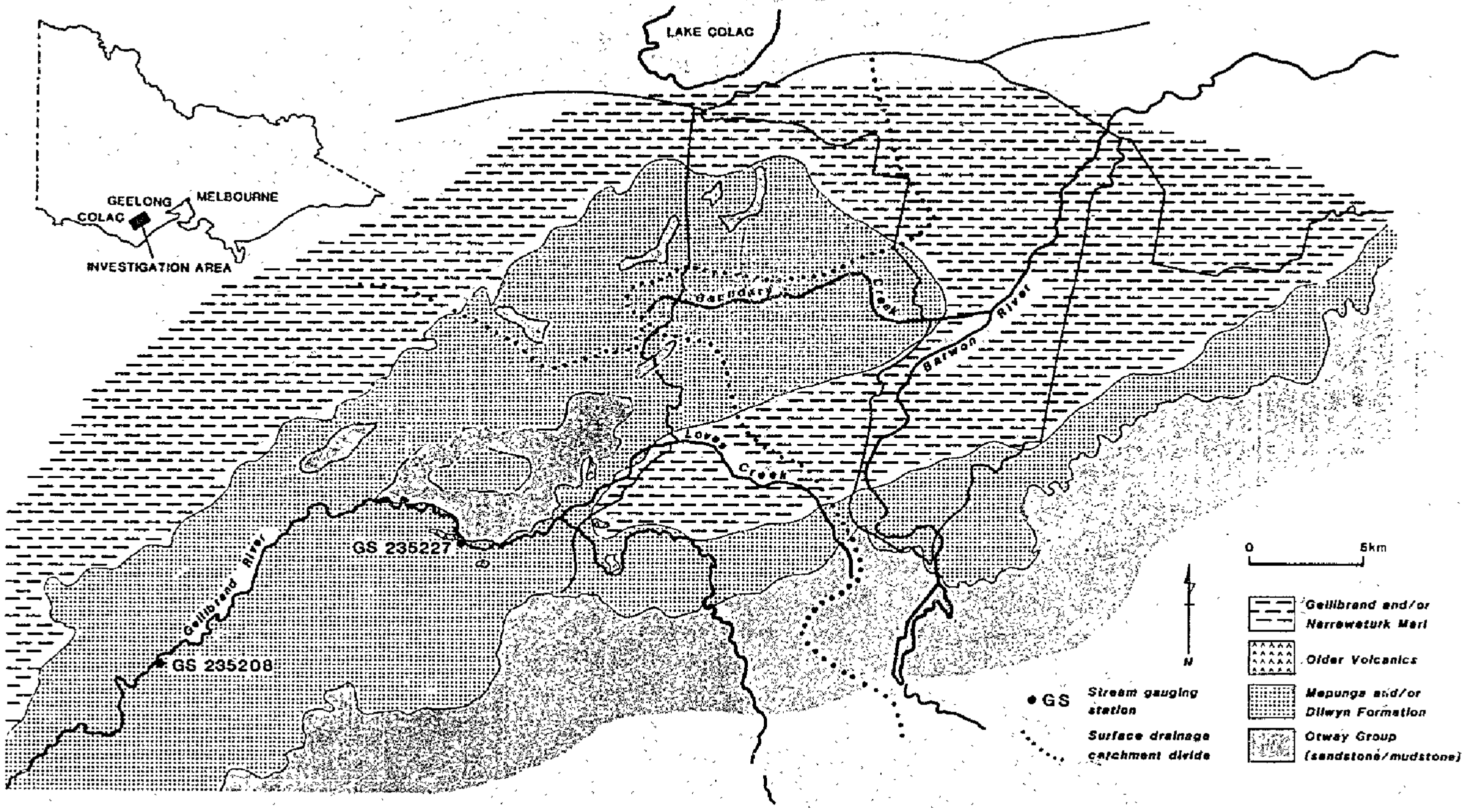

Figure 1: Geological Map

GEOLOGY

The investigation area contains a complex suite of Cainozoic sediments reflecting a combination of cyclic depositional events and tectonic activity. Establishing the identity of surface exposures of Tertiary sand, clay and marl especially where deep weathering profiles exist is difficult and can be further complicated by the presence of overlying Quaternary deposits of similar lithological character. Sub-surface, units are commonly observed to interdigitate laterally and exhibit transitional facies changes.

Structure

Early attempts to map the structure of this area were largely based on topographic indicators such as scarps and drainage pattern disruptions. More recent structural analysis incorporating geophysical and drilling data has shown the structure to be far more complex than previously thought. Figure 2 depicts the major structural elements.

Seismic and gravity evidence indicate that the Lower Cretaceous Otway Group basement is block faulted and tilted to form half grabens Both high angle normal and reverse basement faults have been recognized (Blake, 1980). Some of these faults extend to the surface but often they have no topographic expression even though drilling results indicate that there are sometimes hundreds of metres of vertical displacement across the buried structures. This lack of surface expression is considered to be due to masking by erosional and depositional features, with younger, unconsolidated sediments being drapped over basement faults, such that these faults are often reflected as monoclines in the overlying strata. Faults may pass laterally as well as vertically into monoclinal flexures. Consequently the interpretation of many structural and depositional features has been and still remains controversial; nevertheless there is general agreement that faulting and folding have dominantly northeastly and northwesterly alignments although the direction of individual structures are frequently at variance with the dominant trends.

Two grabens, the Barwon Downs and Carlisle River grabens (Fig.2) separate the upthrown Otway and Barongarook blocks. The Tertiary sediments deposited in these grabens contain major aquifers. The relationship of the Tertiary sediments to the bounding Otway Group rocks in the investigation area has not been fully resolved; for the most part the contact is considered to be faulted but there are zones where the Tertiary sediments are draped over the basement faults. The change in the relationship can be explained by intermittent movement on faults bounding the grabens. Where the displacement occurred gradually, Tertiary sediment was deposited contemporaneously with faulting i.e., sedimentation kept pace with subsidence. As a result the younger sediments are draped over the basement structures forming monoclinal flexures in the Tertiary. Where fault movement occurred relatively rapidly younger sediments are faulted out against the basement rocks. Sections A-A and B-B (Fig.3) demonstrate the structural relationship of the Tertiary sediments to the uplifted Otway Group rocks. These sections also illustrate how faulting in the basement rocks gives way to folding in the overlying sediments. Section locations are shown on Figure 2.

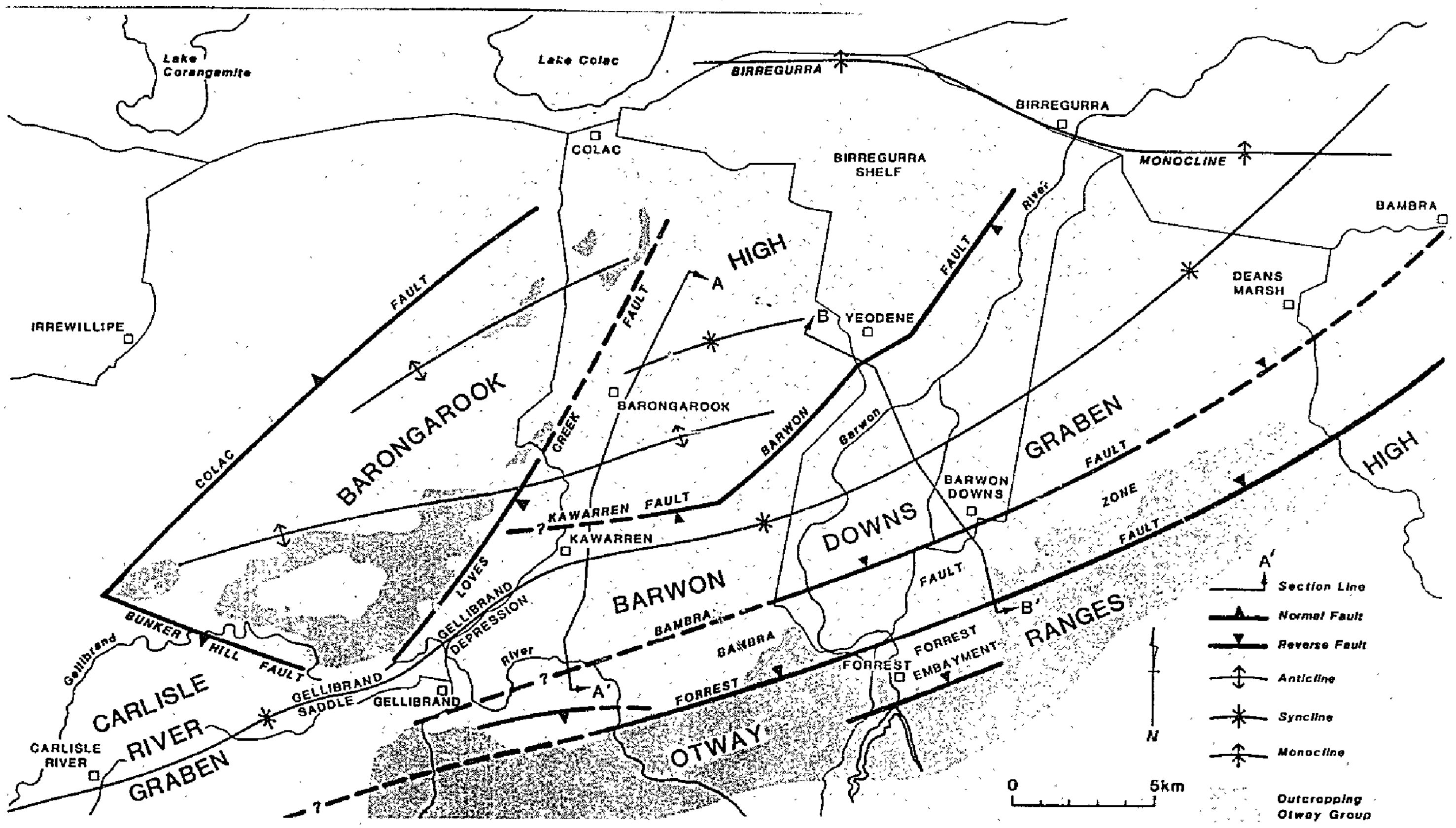

Figure 2: Tectonic Setting

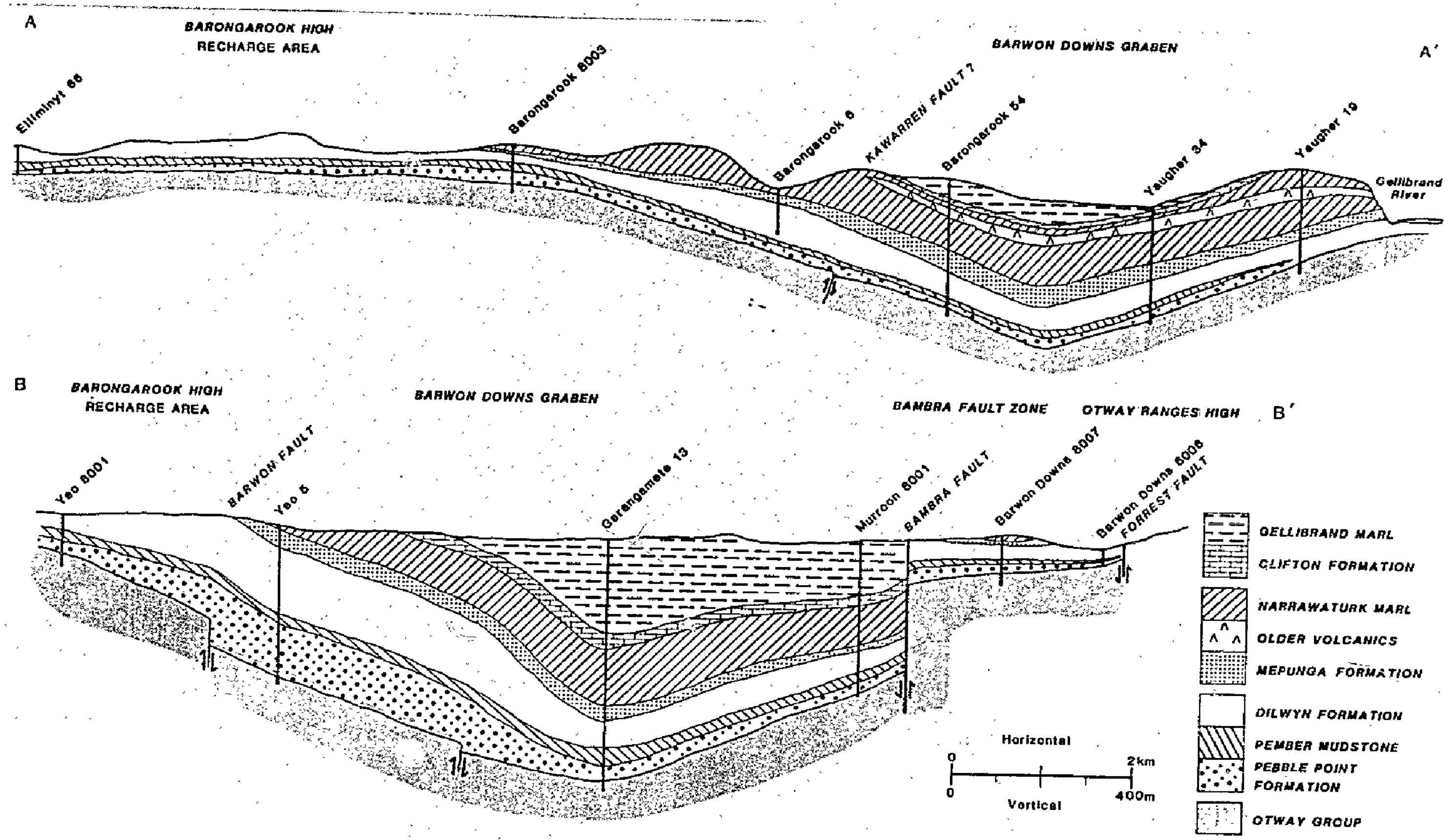

Figure 3: Geological Cross-Sections

Hydrostratigraphy

A simplified geological map depicting the aquifer outcrop pattern is shown in Figure 1, and a stratigraphic column is presented in Figure 4. Major aquifers in the investigation area occur in the basal Tertiary sand and gravel sequences of the Pebble Point, Dilwyn and Mepunga formations. The aquifer in the Pebble Point Formation is essentially confined between the underlying Otway Group and the overlying Pember Mudstone. The latter unit is of low hydraulic conductivity and forms an aquitard between the Pebble Point Formation and Dilwyn Formation aquifers. The dominant sand sequences of the Dilwyn and Mepunga formations are in direct hydraulic continuity and can be considered as a single hydrostratigaphic unit. The Dilwyn-Mepunga aquifer ranges from confined to unconfined. In the Barwon Downs Graben it can be regarded as confined to semi-confined beneath the overlying clay, silt and marl of the Nirranda and Heytesbury groups. Where the aquifer material outcrops over the Gellibrand Saddle, in the Carlisle River Graben and on parts of the Barongarook High it is unconfined. The basal Tertiary aquifers i.e., the Pebble Point, Dilwyn and Mepunga formations, are considered to constitute an aquifer system (Fig.5). The hydrogeological characteristics of the Narrawaturk Marl, Clifton Formation and Gellibrand Marl are not known in detail. The marl units are of low hydraulic conductivity and function as leaky or confining layers. The more sandy limestone facies of the Clifton Formation constitutes an aquifer. Groundwater in this formation is essentially confined between the Narrawaturk and Gellibrand marls.

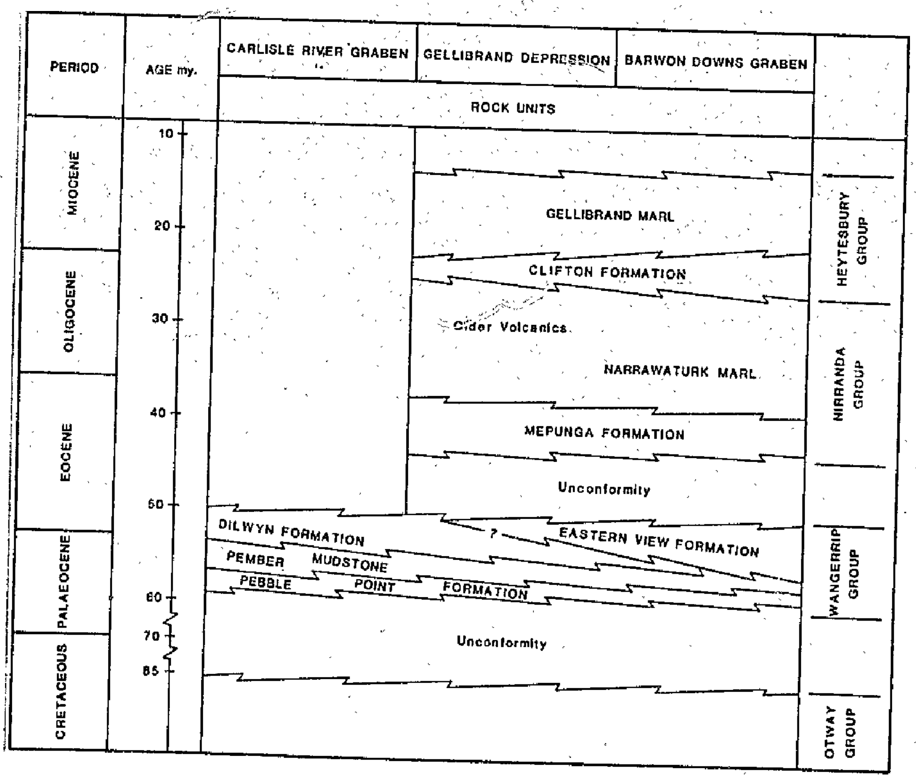

Figure 4 : Stratigraphic Column

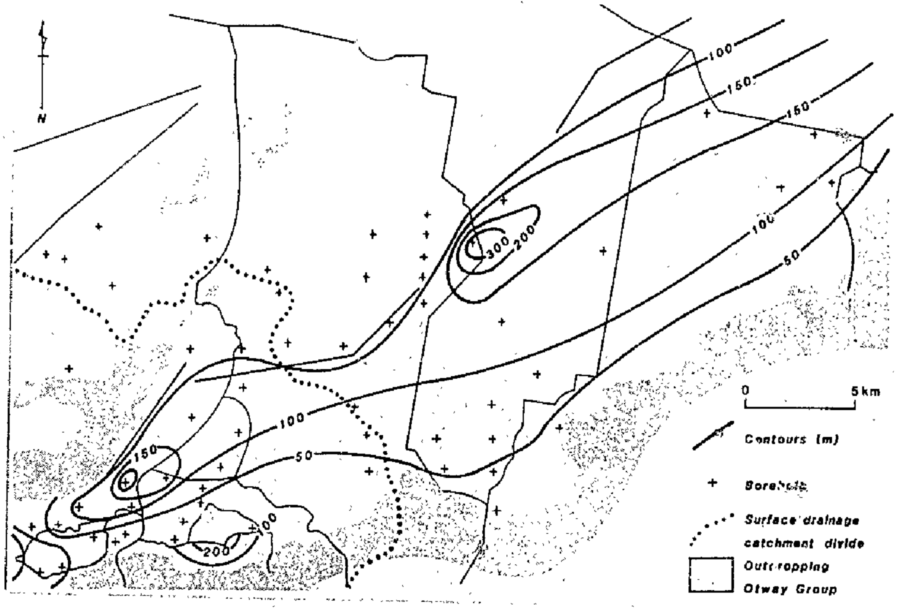

Figure 5 : Isopach Map of Basal Tertiary Aquifer System in the Barwon Downs Graben

Drilling results on the Barongarook High indicate the presence of two valley-like features flanking the Yeo Dome. These basement valleys have been largely infilled by basal Tertiary sediments. The valley on the western side of the dome trends approximately south-north from Kawarren towards Barongarook, and parallels the postulated extension of the Loves Creek Fault (Fig.2). The second valley is inferred to extend from the Yeodene area westward under the present course of Boundary Creek towards Barongarook. These valleys are considered to provide important pathways for groundwater recharge from the area of outcropping aquifer on the Barongarook High to the confined aquifer system in the Barwon Downs Graben.

RESOURCES EVALUATION

Groundwater flow in the Basal Tertiary Aquifer System

The potentiometric surface and water table contours shown on Figure 6 indicate that the exposed Dilwyn Formation sand on the Barongarook High acts as an intake area for the basal Tertiary aquifer system. Groundwater flow off the Barongarook High into the Barwon Downs Graben basal Tertiary aquifer system is considered to be predominantly via two basement valleys flanking the marl covered Yeo Dome and designated here as the Yeodene and Kawarren recharge avenues.

From Yeodene, groundwater flows in two general directions; to the north east and to the south west with the latter component flowing under the surface divide into the Gellibrand River catchment. Groundwater inflow via Kawarren flows directly into the Gellibrand River Catchment

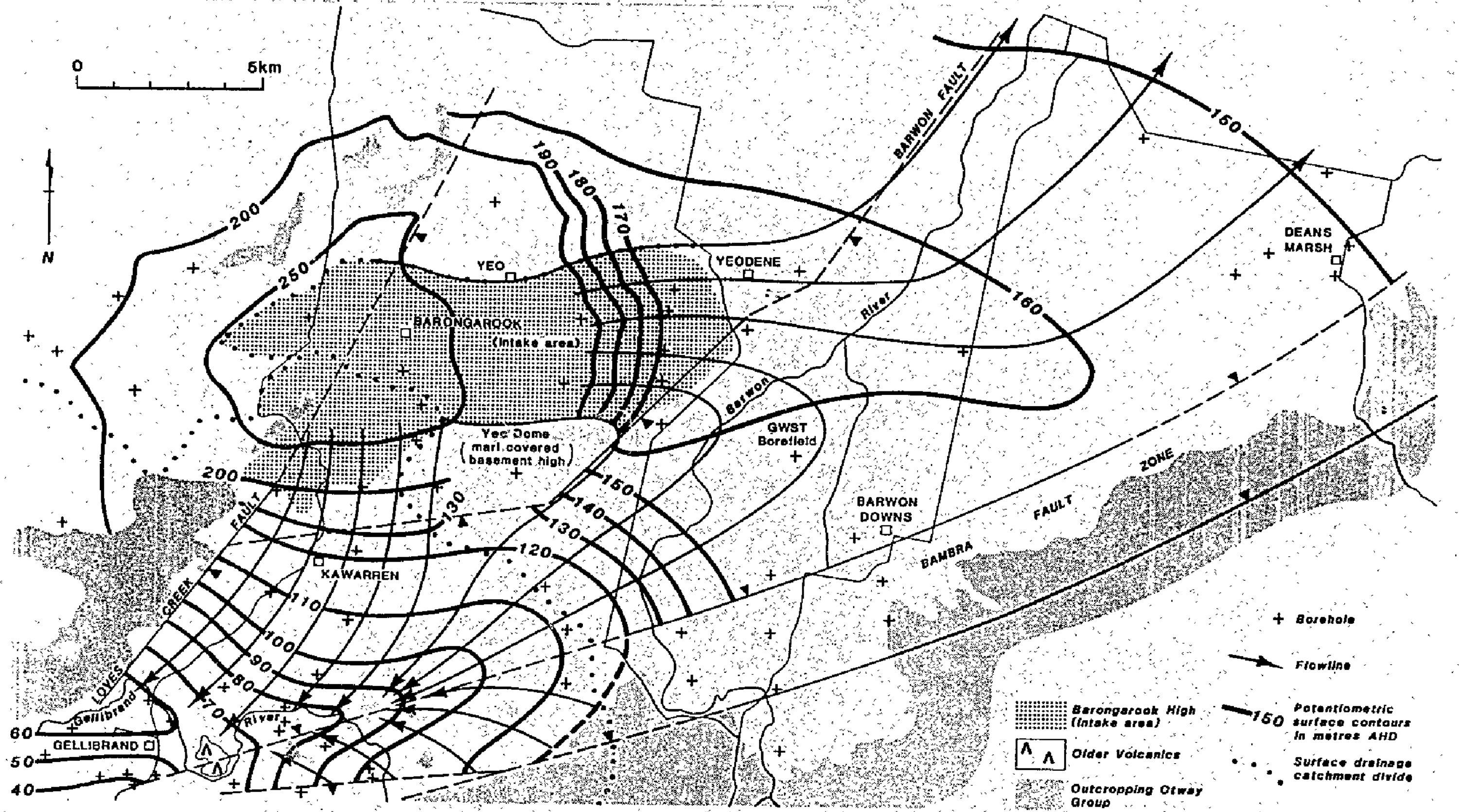

Figure 6: Potentiometric Surface for the Basal Tertiary Aquifer System

and is mostly discharged to the Gellibrand River. Discharge to the surface streams continues as the flow path is constricted in the vicinity of Gellibrand township. Underflow is controlled by the active hydraulic cross-section and regional hydraulic gradient. As the cross-section is reduced discharge to streamflow via the unconfined Dilwyn Formation increases; the hydraulic gradient remains relatively constant. As the cross-section increases beyond Bunker Hill the process is reversed and underflow increases possibly in part at the expense of stream flow. Within the Gellibrand River catchment local intake also occurs predominantly via the exposed Dilwyn Formation sediments. A partial flow net has been constructed on Figure 6 in an attempt to quantify the recharge component derived from the Barongarook High. Flow net calculations indicate that under the present steady state equilibrium conditions about 14800 ML/annum flow off the Barongarook High into the basal Tertiary aquifer system in the Barwon Downs Graben. This volume is split between the Yeodene (6300 ML) and Kawarren (8500 ML) recharge avenues with inflow via the Yeodene avenue further split into a north easterly component (3200 ML) and a southwesterly component (3100 ML). The Yeodene and Kawarren recharge avenues together are considered to provide approximately 12000 ML/annum of recharge to the Gellibrand River catchment.

On the Barongarook High groundwater flow is considered to be essentially under unconfined conditions controlled by surface catchment divides and the radial drainage network. The estimated intake area for the Barwon Downs Graben on the Barongarook High is approximately 54 km^2. 14800 ML over this area is equivalent to an effective infiltration of 27.4 cm/annum or (using a value of 900 mm for the mean annual precipitation) 30% of the annual precipitation. While this value appears high, the cleared, gently undulating sand outcrop on the Barongarook High could reasonably be expected to feature high recharge characteristics.

Recent numerical modeling by the authors indicates that the above recharge estimate is in fact too high. This work also suggests that there is a structural or stratigraphic barrier within the Barwon Downs Graben between the GWST borefield and Kawarren which significantly reduces the postulated southwesterly flow from the Yeodene recharge avenue. A drilling and seismic programme is proposed to clarify the nature and extent of this barrier.

Hydrograph Separation and Effective Infiltration Analysis

Hydrograph separations were undertaken for the Gellibrand River at gauging station GS 235208 and gauging station GS 235227. The results are tabulated in Table 1. Gauging station locations are shown on Figure 1. Underflows at GS 235227 and 235208 have been derived from the application of Darcy's law to relevant cross-sections (not presented here) and river diversion data has been obtained from the SRWSC. In Table 1 the mean annual base flows determined from the hydrograph separations have been adjusted for diversions, underflow and inflow before determining the precipitation and the effective infiltration.

Weighted effective infiltrations have been calculated in Table 2 and used to derive a recharge component for each of the rock units outcropping within the catchment for GS 235208.

	Gellibrand River at GS 235227	Gellibrand River at GS 235308
Catchment area (km^2)	300.0	548.5
Mean annual flow 1979-80 (ML)	132000	205900
	+ 3400 (D1)	+ 3400 (D1)
	= 135400	+ 8700 (D2)
		+ 1800 (D3)
		= 219800
Mean annual yield (mm)	451	400
% Precipitation	35	30
Mean annual precipitation (mm)	1300	1300
Mean annual baseflow (ML)	32460 + 11300*	45600 + 8500**
% Precipitation	5.4	7.4
% Mean annual flow	23.9	24.6
Effective infiltration overall (cm)	7.1	9.9

D1 Diversions from West Gellibrand Res. and Olangolah Ck and private diversions above GS 235227 (not added to baseflow)
D2 Diversions to Otway System (added to baseflow)
D3 Total private diversions above GS 235208 (added to baseflow)
* Inflow from outside catchment (12000 ML) - underflow at GS 235227 (700 ML)
** D2 (8700 ML) + D3 (1800 ML) + underflow at GS 235208 (10 000) - inflow from other catchments (12 000 ML)

Table 1 : Results of Stream Flow Data Analysis

Table 2 suggests that the basal Tertiary aquifer (Dilwyn Formation) outcrop accepts an annual infiltration of about 16 cm or 15% of the overall mean annual precipitation for GS 235208 catchment (1300 mm). This value is considered reasonable in view of the nature of the sediments and the low drainage density observed on the aquifer outcrop. The low total dissolved solids content of groundwater obtained from all bores drilled in the area and the persistent nature of the precipitation are additional factors which further support a high effective infiltration. However unlike the aquifer outcrop on the Barongarook High much of the outcrop within the GS 235208 catchment is covered by low woodlands and closed heath and could be expected to incur high interception and evapotranspiration losses. This in part explains the higher effective infiltration suggested for the Barongarook High.

Total Volume in Storage

The Barwon Downs Graben extends from the Gellibrand Saddle to the Birregurra Monocline (Fig.2) over an area of approximately 250 km^2. There are two components of storage elastic and unconfined. In order to determine the volume in elastic storage an isopach of the

Rock Units	Outcrop area km^2	Relative hydraulic conductivity	Effective area km^2	Weighted effective infiltration cm	Mean annual volume infiltration ML
Alluvium	4.0	0.8	3.2	12.9	515
Nirranda	54.5	0.1	5.4	1.6	877
Dilwyn	218.5	1 0	218.5	16.1	35178
Older Volcanics	1.5	0.6	0.9	9.7	145
Otway	270.0	0.4	108.0	6.4	17388
	548.5		336.0		54103

Mean annual total stream flow 1970-1980 = 219800 ML
Mean annual baseflow from hydrograph separation 1970-1980 = 54100 ML

$$\text{effective infiltration} = \frac{54100}{548.5 \times 1\,000} = 9.9\text{cm}$$

$$\text{weighted effective infiltration} = \frac{54100}{336.0 \times 1000} = 16.1\text{cm}$$

Table 2 : Calculation of Weighted Effective Infiltrations for GS 235208 Catchment.

vertical distance between the potentiometric surface and the top of the aquifer system was constructed. Planimetric integration of this isopach and applying a value for the storage coefficient of 3×10^{-4}, indicate that approximately 15,000 ML are held in elastic storage.

ie. $4.97 \times 10^{10}m^3 \times 3 \times 10^{-4} = 14,910$ ML

To determine the volume in unconfined storage the aquifer is considered to be unconfined and fully saturated. Planimetric integration of Figure 5 provided a volume for the basal Tertiary aquifer system of 2.96×10^{10} m^3. Applying a specific yield of 0.20 to this volume indicates that approximately 5,920,000 ML are held in unconfined storage.

ie. 2.96×10^{10} $m^3 \times 0.20 = 5,920,000$ ML

Recharge

The principle source of recharge for the Barwon Downs Graben is considered to be inflow from the Barongarook High intake area. Under the present hydrogeological equilibrium virtually all this inflow (discussed earlier) except the component from Yeodene flowing to the northeast is considered to discharge to the Gellibrand River between the point where the river first crosses the Otway Group/Tertiary boundary and GS 235227 (Fig.1).

Potential sources of additional groundwater recharge after borefield development include :

(i) enhanced natural recharge as a consequence of lowered water levels in intake areas and a reduction in rejected recharge and evapotranspiration losses;

(ii) induced stream bed infiltration as water levels fall below stream level;

(iii) leakage from overlying silty marl members particularly within the Barwon Downs Graben;

(iv) Leakage from intercalated clay and silt layers within the basal Tertiary aquifer system;

(v) leakage from the fractured Otway Group basement rocks underlying and flanking the grabens;

(vi) natural recharge from possible as yet undelineated recharge zones along the Bambra Fault and other bounding structures.

Evaluation of these potential sources is a highly subjective task at present and most aspects will only be resolved by careful monitoring during progressive staged development of the resource. (i), (ii) and (iii) may become quite significant sources after borefield development.

RESOURCE DEVELOPMENT

Thus far the groundwater resource within the Barwon Downs Graben is undeveloped and a steady state equilibrium disturbed only by relatively small seasonal water level fluctuations presides, (i.e. 1 to 2m). The onset of pumping from the GWST borefield (end of February '83) represents a significant groundwater development in the central part of the Barwon Downs Graben. The borefield is licensed to extract up to 80,000 ML over a ten year period with a maximum of 12,500 ML in any year. Stage I of the GWST borefield comprises three bores with a combined daily extraction of 35 ML. This borefield would need to be pumped continuously to extract the annual maximum of 12,500 ML. A second borefield is now under consideration and depending upon the results of a long term(i.e. 6 months) pumping test, and further resource evaluation, is to be sited in the Kawarren township area and designed to intercept recharge flowing into the graben along the Kawarren recharge avenue.

Under the present hydraulic gradients the major inflow of recharge to the existing GWST borefield is via the Yeodene recharge avenue. If the preceding recharge calculations are correct, an annnual extraction of 12,500 ML will exceed the recharge currently derived from this source by a factor or two. It is estimated from pumping test results that drawdowns within the borefield after twelve months pumping will be in the 80-100 m range. Creation of a cone of depression in the potentiometric surface in the borefield area will distort the present flow pattern and absorb the northeasterly and southwesterly components of recharge from the Yeodene recharge avenue. Underflow via the Barwon Downs Graben to the Gellibrand River catchment will cease; gradient reversal will result in components of recharge being drawn in from the northeast and southwest and from any as yet undelineated recharge zones along the Bambra Fault.

As the cone of depression developes, negative vertical hydraulic gradients may be established across the Narrawaturk Marl resulting in vertical leakage from the silty marl into the underlying aquifer system and after sustained pumping, there is the additional possibility of vertical leakage from the Clifton Formation aquifer (source bed) via the underlying Narrawaturk Marl into the aquifer system. A piezometer has been installed in the Clifton Formation aquifer within the GWST borefield to enable the potentiometric surface within that aquifer to be monitored during development. Sustained borefield development may eventually result in the attainment of a new equilibrium within the recharge-discharge regime.

However, sustained development beyond the maximum available rate or recharge will lead to an unstable situation, manifested by rapidly declining water levels, as groundwater storage decreases. Accurate monitoring of the observation bore network during the pumping and recovery cycles of stage 1 of the GWST borefield will enable progressive reassessment and evaluation of development options to ensure that over-development does not occur.

CONCLUSIONS

Several aspects, in particular the assessment of enhanced natural recharge and vertical leakage after development require further work. One of the major advantages of staged groundwater development is that it enables progressive re-evaluation and refinement of resource estimates. Analysis of the impact of Stage I of the GWST borefield will provide a sound basis for the management of that borefield and considerable insight into the nature and significance of recharge processes affecting the central part of the Barwon Downs Graben. The conceptual model developed during this investigation has provided a firm basis for the preparation of a finite element numerical model which is now proving to be of considerable use in determining borefield development strategy.

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