The Department of
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Review of Tertiary Gambier Limestone aquifer properties, lower South East, South Australia

Report DWLBC 2002/24

Government
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Review of Tertiary Gambier Limestone aquifer properties, lower South-East, South Australia

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Foreword

South Australia's natural resources are fundamental to the economic and social wellbeing of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisms and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

Bryan Harris
Director, Resource Assessment Division
Department of Water, Land and Biodiversity Conservation

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ABSTRACT

Transmissivity and storage coefficients are important properties in the characterisation of aquifers. Transmissivities and storage coefficients have been calculated from aquifer test programs for all known wells from the Tertiary Limestone Aquifer in the Lower South-East and located within the study area. The Tertiary Limestone Aquifer consists of the Gambier Limestone in the Gambier Basin.

Transmissivity and specific yield data for the Tertiary Limestone Aquifer (unconfined aquifer) were collated and examined for their reliability. Most of the reported data were of low reliability. Limited data was collected from aquifer tests using one or more observation wells. Some of the observation wells were completed within different intervals from that of the production well. Therefore the specific yield values obtained were rated 'low' reliability.

Specific capacity data are usually more abundant than aquifer test data and is used as a measure of the productivity of a well. An empirical relationship was established between transmissivity values calculated from aquifer tests and their related specific capacity data. The resulting best-fit line is $T = 3.95 \times SC^{0.89}$ with $R^2 = 82$.

INTRODUCTION

This report is part of an assessment to more precisely define the level of sustainable groundwater use in the area around Mount Gambier, both in terms of groundwater quality and quantity, for the development of appropriate management policies.

Determination of aquifer properties is an important aspect for the sustainable, long-term management of groundwater resources. More accurate calculated values of aquifer properties will result in better management of the water resources.

The objective of this report is to collate all available data on aquifer properties including transmissivity (T) and storage coefficient (S) – specific yield (Sy) values. This is achieved from aquifer test records collected over the last 30 years for the Tertiary Limestone Aquifer (unconfined aquifer) in the lower southeast region of South Australia (Fig. 1). The Tertiary Limestone Aquifer consists of the Gambier Limestone in the Gambier Basin. This data is then rated for its reliability and then used to determine gaps in the spatial distribution of T and S values so that further aquifer test analyses can be conducted.

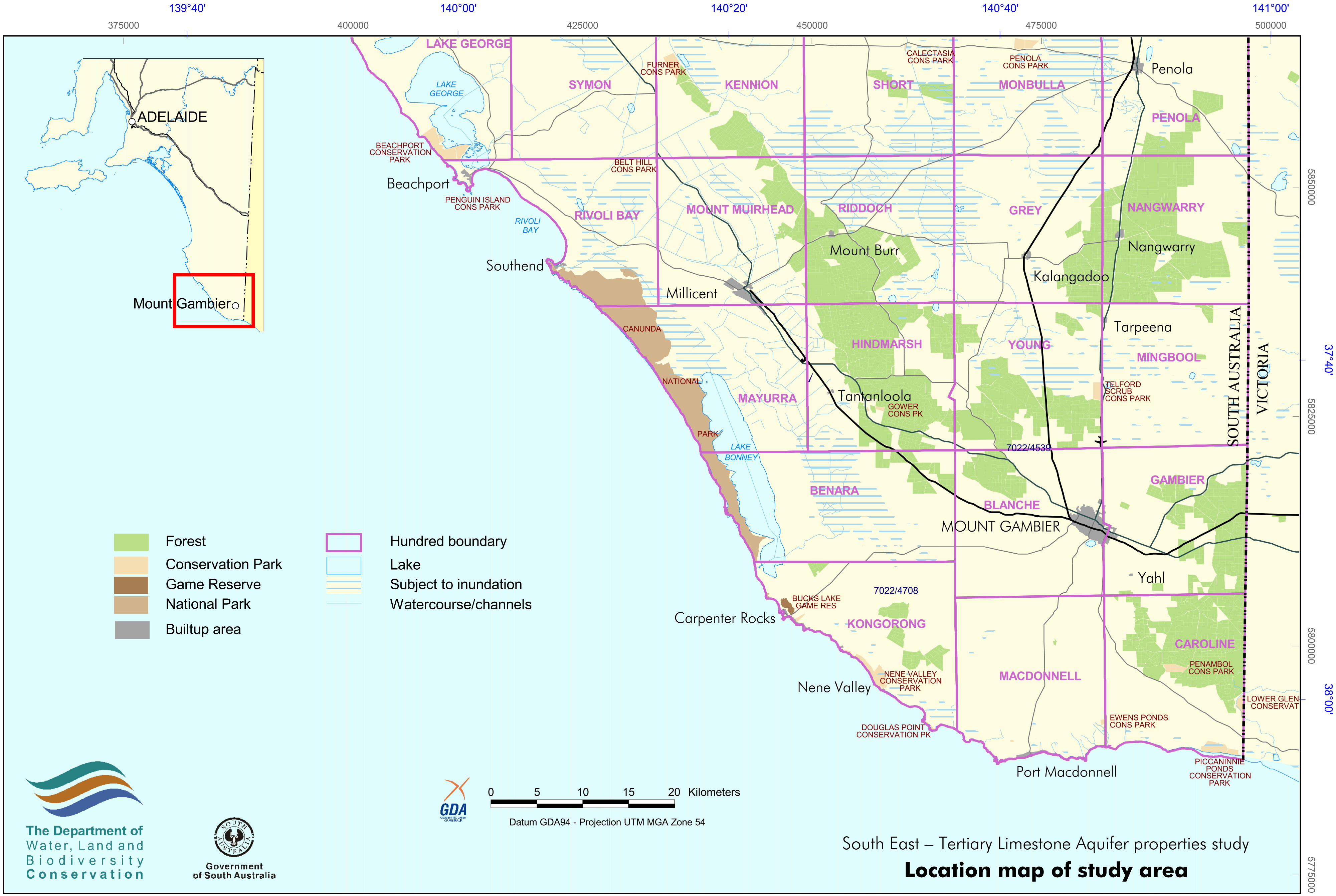
South East – Tertiary Limestone Aquifer properties study
Location map of study area
139°40'
140°00'
140°20'
140°40'
141°00'
375000
400000
425000
450000
475000
500000
5850000
5825000
5800000
5775000
37°40'
38°00'
ADELAIDE
Mount Gambier
Forest
Conservation Park
Game Reserve
National Park
Builtup area
Hundred boundary
Lake
Subject to inundation
Watercourse/channels
LAKE GEORGE
SYMON
KENNION
SHORT
MONBULLA
PENOLA
RIVOLI BAY
MOUNT MUIRHEAD
RIDDOCH
GREY
NANGWARRY
HINDMARSH
YOUNG
MINGBOOL
MAYURRA
BENARA
BLANCHE
GAMBIER
KONGORONG
MACDONNELL
CAROLINE
SOUTH AUSTRALIA
VICTORIA
Penola
Beachport
Southend
Millicent
Mount Burr
Kalangadoo
Nangwarry
Tarpeena
Tantanloola
MOUNT GAMBIER
Yahl
Carpenter Rocks
Nene Valley
Port Macdonnell
LAKE GEORGE
RIVOLI BAY
LAKE BONNEY
CANUNDA NATIONAL PARK
BEACHPORT CONSERVATION PARK
PENGUIN ISLAND CONS PARK
FURNER CONS PARK
BELT HILL CONS PARK
CALECTASIA CONS PARK
PENOLA CONS PARK
GOWER CONS PK
TELFORD SCRUB CONS PARK
BUCKS LAKE GAME RES
NENE VALLEY CONSERVATION PARK
DOUGLAS POINT CONSERVATION PK
EWENS PONDS CONS PARK
PENAMBOL CONS PARK
LOWER GLEN CONSERVAT
PICCANINNIE PONDS CONSERVATION PARK
7022/4539
7022/4708
0 5 10 15 20 Kilometers
Datum GDA94 - Projection UTM MGA Zone 54
GDA
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Figure 1

GEOLOGY

The study area is located within Gambier Basin, which overlies the Otway Basin. The Gambier Basin is bounded to the north by the outcropping granitic basement of the Padthaway Ridge and to the east by the Dundas Plateau, while to the northeast it is bounded by the Murray Basin. The Otway Basin consists of a mixed sequence of marine and terrestrial deposits, which were formed during the separation of Australia and Antarctica (Lawson et al., 1993). The stratigraphic and hydrostratigraphic units in the Gambier Basin and Otway Basin are presented in Figure 2.

The Tertiary Limestone Aquifer consists of the Gambier Limestone in the Gambier Basin. The Gambier Limestone is one of several extensive, shallow-water shelf carbonates of Eocene to Miocene age exposed along the southern margin of Australia (James and Bone, 1989). The Gambier Limestone is generally fine-grained bryozoan marl to calcisiltite (marl) with units of fossiliferous calcirudite (coarse limestone) to calcarenite (limestone lacking strong fossil definition). Black to dark-brown flint is common in the finer-grained units. The limestone can vary from a few metres thick north of Mount Gambier, at the crest of the uplift, to more than 250 m along the southern coast. In Li et al. (2000), the geology is described as consisting mostly of grey to creamy bryozoan calcarenites (limestone) with thin intervals of marls (calcareous clay).

McGowran (1973) pointed out the heterogeneous nature of Gambier Limestone and subdivided it into three-part divisions:

1. First unit (upper part): which is a mixture ranging from calcilutite (marl) to calcarenite (limestone), mostly grey in colour, with bryozoa, abundant flint in places and prominent calcite rhombs.
2. Second unit: a cream calcarenite (limestone) with relatively little finer material, minor flint, and less-rich in microfauna, the permeability higher than the above or below units.
3. Third unit: is essentially calcilutite or calcisiltite (marl) with coarse bioclastics, partly silicified and with abundant flint.

The non-homogenous nature of the Gambier Limestone has a large impact on the aquifer property, which is evident by the large variation in T, and S measured from aquifer test analyses carried out in the area. The presence of low permeability materials like marl enabled the Gambier Limestone to be subdivided into unconfined and semi-confined subaquifers in some localities in the region (Bleys, 1965, 1967; Williams, 1979). Other factors that have an important role, are the spatial variation in the thickness of the Gambier Limestone, along with development of karstification (cave–solution features), and dolomitisation. The process of karstification has been ongoing in the region since the Middle Miocene and commonly developed in soft to friable sediments illustrating that carbonates do not need to be well-cemented to be karstified (James and Bone, 1989). The Gambier Limestone can be locally dolomitised. Dolomitisation alters lithified calcarenite, replacing grains, mud and cement (James and Bone, 1989).

Gambier Limestone has been further subdivided into seven stratal units related to sequence biostratigraphy (based on the existence of certain fossil groups), as an alternative to the traditional lithostratigraphic (based on the rock types) division of the Limestone into members. They are time-constrained, and each has a combination of lithological and biofacies characteristics (Li et al., 2000).

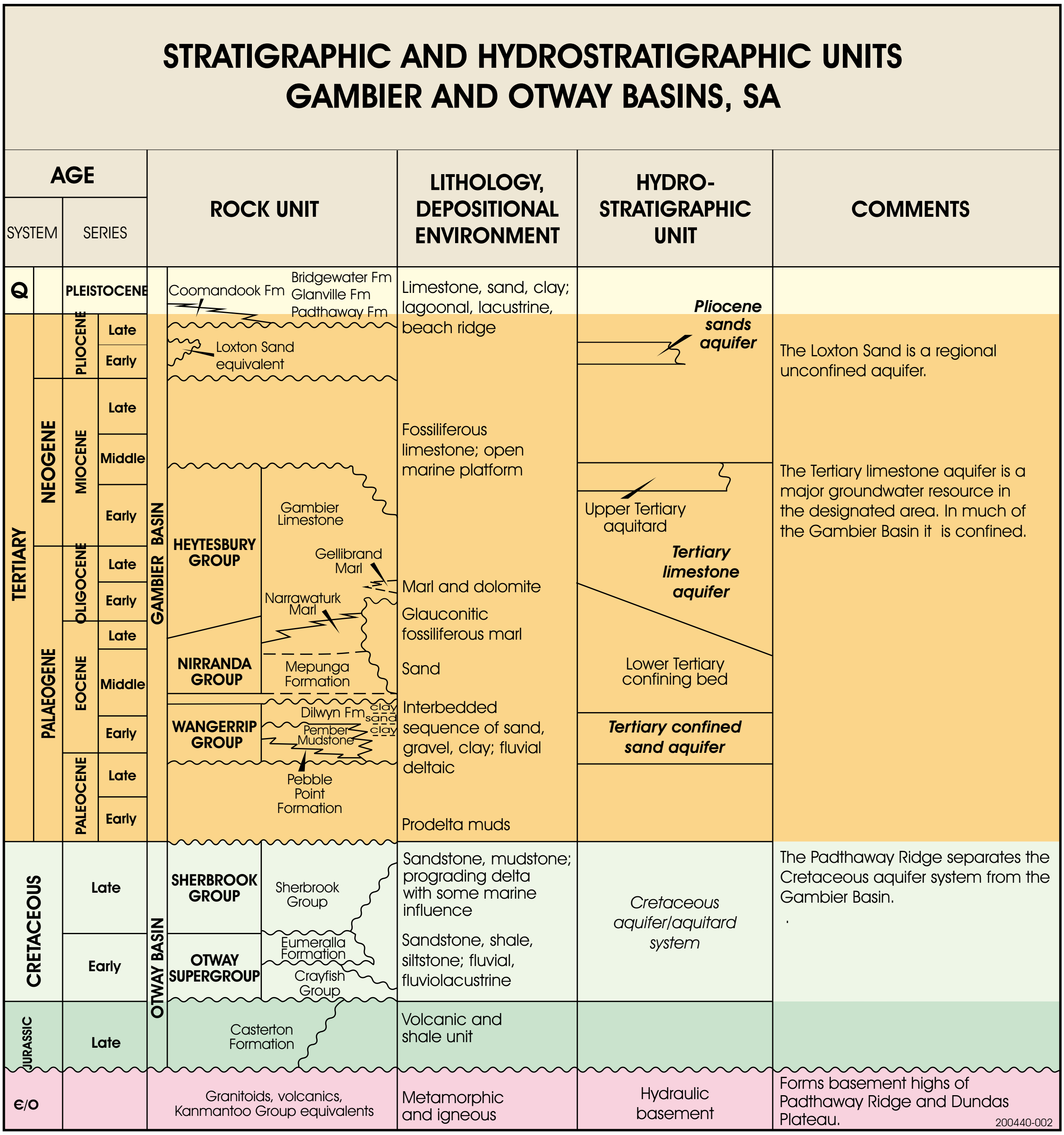
STRATIGRAPHIC AND HYDROSTRATIGRAPHIC UNITS
GAMBIER AND OTWAY BASINS, SA
AGE
SYSTEM
SERIES
ROCK UNIT
LITHOLOGY, DEPOSITIONAL ENVIRONMENT
HYDRO-STRATIGRAPHIC UNIT
COMMENTS
Q
PLEISTOCENE
Coomandook Fm
Bridgewater Fm
Glanville Fm
Padthaway Fm
Limestone, sand, clay; lagoonal, lacustrine, beach ridge
Pliocene sands aquifer
TERTIARY
NEOGENE
PALAEOGENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
Late
Early
Middle
GAMBIER BASIN
Loxton Sand equivalent
The Loxton Sand is a regional unconfined aquifer.
Fossiliferous limestone; open marine platform
Gambier Limestone
HEYTESBURY GROUP
Upper Tertiary aquitard
The Tertiary limestone aquifer is a major groundwater resource in the designated area. In much of the Gambier Basin it is confined.
Gellibrand Marl
Marl and dolomite
Tertiary limestone aquifer
Narrawaturk Marl
Glauconitic fossiliferous marl
NIRRANDA GROUP
Mepunga Formation
Sand
Lower Tertiary confining bed
WANGERRIP GROUP
Dilwyn Fm
clay
sand
clay
Pember Mudstone
Interbedded sequence of sand, gravel, clay; fluvial deltaic
Tertiary confined sand aquifer
Pebble Point Formation
Prodelta muds
CRETACEOUS
SHERBROOK GROUP
Sherbrook Group
Sandstone, mudstone; prograding delta with some marine influence
OTWAY SUPERGROUP
Eumeralla Formation
Crayfish Group
Sandstone, shale, siltstone; fluvial, fluviolacustrine
Cretaceous aquifer/aquitard system
The Padthaway Ridge separates the Cretaceous aquifer system from the Gambier Basin.
OTWAY BASIN
JURASSIC
Casterton Formation
Volcanic and shale unit
Є/O
Granitoids, volcanics, Kanmantoo Group equivalents
Metamorphic and igneous
Hydraulic basement
Forms basement highs of Padthaway Ridge and Dundas Plateau.
200440-002

Figure 2

AQUIFER PROPERTIES

Transmissivity and S properties for an aquifer are important factors to understanding aquifer behaviour in terms of water storage and transmittance within a specific aquifer type. Transmissivity of an aquifer is a measure of the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under hydraulic gradient of 1. The storage coefficient, or storativity, is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head in a confined aquifer (Fetter, 1994). The term specific yield (S_y) is used for unconfined aquifers and it is the ratio of the volume of water that drains from a saturated rock owing to the attraction of gravity to the total volume of the rock. In an unconfined unit the level of saturation rises or falls with change in the amount of water in storage. As the water level falls, water drains from the pore spaces. This storage or release is due to the S_y of the unit. Water is also stored or expelled depending on the specific storage of the unit (Fetter, 1994).

Accurate estimation of the aquifer properties is important for the long-term and sustainable management for a groundwater resource.

METHODOLOGY

In assessing the Tertiary Limestone Aquifer properties, the following steps has been considered:

- Collation of the available estimated T and S values for the Tertiary Limestone Aquifer within the study area.
- Calculating T and S from aquifer tests where data is available but has not been interpreted.
- Reviewing and analysing the methodology used to obtain the T and S values.
- Adopting T and S values and assigning reliability rating for these properties considering the calculation method used for the estimation of the data.
- Preparing maps of the spatial distribution for the adopted T and S values.
- Identifying areas that are lacking in reliable T and S data, where no data is available and/or the available T and S values are of low reliability.
- Estimation of T from available specific capacity (SC) data using empirical equations and comparing the results with other T obtained using other empirical equations.

Reported T and S data for the Tertiary Limestone Aquifer

Reported T and S data for the Tertiary Limestone Aquifer in the area has been collected from existing reports and microfiche archives at the Department of Water, Land and Biodiversity Conservation (DWLBC) Mount Gambier Office (see Appendix A, Table A1). These data included information on well completion, well logs, aquifer tests, and water chemistry. Figure 3 shows the locations of pumped wells where the aquifer properties have been calculated.

Existing reports covering: well performance tests; constant rate aquifer test (in a single well without observation wells); and aquifer test with one or more observation wells, were used to calculate aquifer hydraulic properties. Duration for pumping varies from less than an hour to a few days of continuous constant pumping rate; with the majority of the wells tested for short period of ~30 min with no observation bores. These wells are listed in Cobb's report (1979). Details, long-term constant aquifer tests and reviewing of results from these tests were undertaken on wells drilled for town water supplies and industrial production wells, such as for Millicent town water supplies (Smith, 1979) and Kimberly-Clark Australia (APCEL Pty Ltd) at Snuggery (Williams and Cobb, 1976; Williams, 1979).

Williams and Cobb (1976) and Williams (1979) reported on aquifer tests conducted on bores constructed at APCEL Pty Ltd and reviewed previous works for calculating T and S values for Tertiary Limestone Aquifer in and around the Snuggery area. After interpreting the data collected from the aquifer tests for bores 11 and 12, Williams and Cobb (1976) concluded that the Gambier Limestone can be subdivided vertically into two distinct subaquifers (limestones) separated by a zone of much lower hydraulic conductivity (marls, calcisilitite etc.). This subdivision has also been recognised in previous works. The estimated aquifer characteristic values for T were between 150 and 600 m^2/d, with S_y of 0.075–0.30 for the phreatic or upper sub-aquifer; while for the lower or semi-confined aquifer, T was between 200 and 500 m^2/d, with S of 0.001–0.0001.

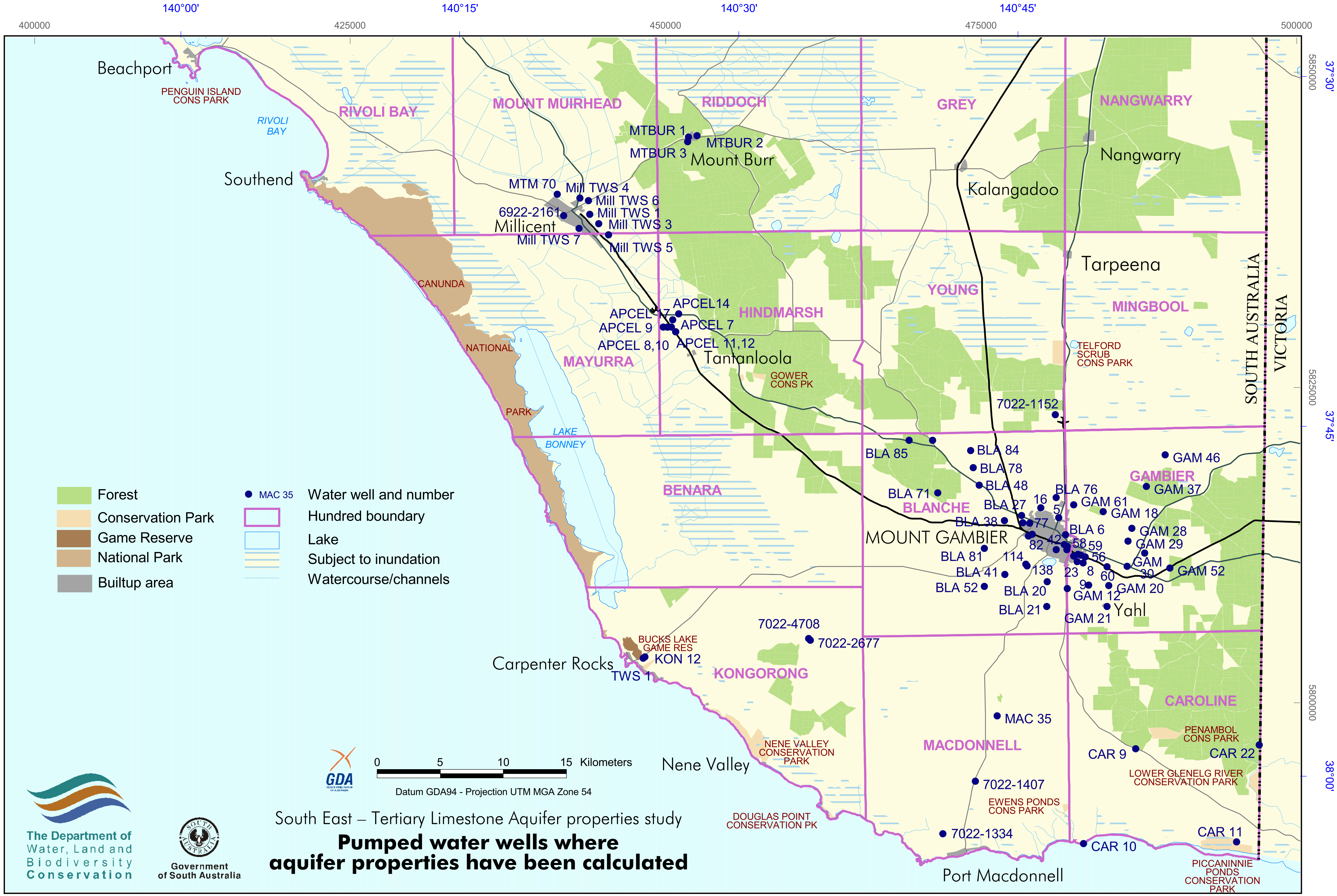

Figure 3

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They also noted that T and S values previously calculated were over estimated as the observation bores were finished in the upper unconfined sub-aquifer while the pumped bores were open through the whole geological section and hence deriving their supply from both subaquifers.

Smith (1979) reviewed town water supply bore numbers 1–6 at Millicent. These bores were finished into the lower semi-confined portion of the Gambier Limestone. Transmissivity and S values were listed for bores 1, 2, 5 and 6. Aquifer test results for bore numbers 1 and 2 were discussed in detail.

Reliability assessment of T and S data

A methodology used by Sinclair Knight Merz (1998) in assessing the reliability of T and S values was adopted in evaluating the reliability rate of the Tertiary Limestone Aquifer. This method has already been used to assess the aquifer properties for data collected on the Victorian portion of the legislated border-sharing strip between Victoria and South Australia. Ratings of ‘high’, ‘medium’ or ‘low’ were used for the T and S values depending on the following factors:

- nature and duration of the test
- number of observation wells used
- calculation method
- conformation of data to type curve.

For this report, the criteria adopted to assign these ratings are presented in Table A2.

Transmissivity for the Tertiary Limestone Aquifer

Most of the aquifer tests were conducted for a short duration; ~30 min or less in a single well. The estimated T from these tests were given a ‘low’ reliability rating, since the duration of pumping was not long enough to obtain better and more reliable data. The most significant amount of data is related to well aquifer tests conducted by Cobb (1979). The pumping rates for these wells was too low, (220 m^3/d) to develop a wider cone of depression and therefore allow estimation of the T to be more representative of the aquifer characteristics. These reported values (Cobb, 1979) were considered to be conservative, since no correction for the field data had been undertaken to take into account the effects of partial penetration of the aquifer; nor for the reduction in T of the aquifer near the well with phreatic water level decline. Under unconfined conditions, gravity drainage of interstices (due to discharge) may cause an appreciable decrease of the saturated thickness of the aquifer and, therefore, aquifer transmissivity (Walton, 1996).

The reported hydraulic properties for all available aquifer tests were examined and re-calculated (using different methods where the plot of the drawdown data corresponded to certain type curves) where applicable or, in some cases, new aquifer test data were available. The adopted T values with their rate of reliability are summarised in Table A3, and Figures 4a and 4b show the spatial distribution of the adopted T values. Case studies are discussed in Appendix 1.

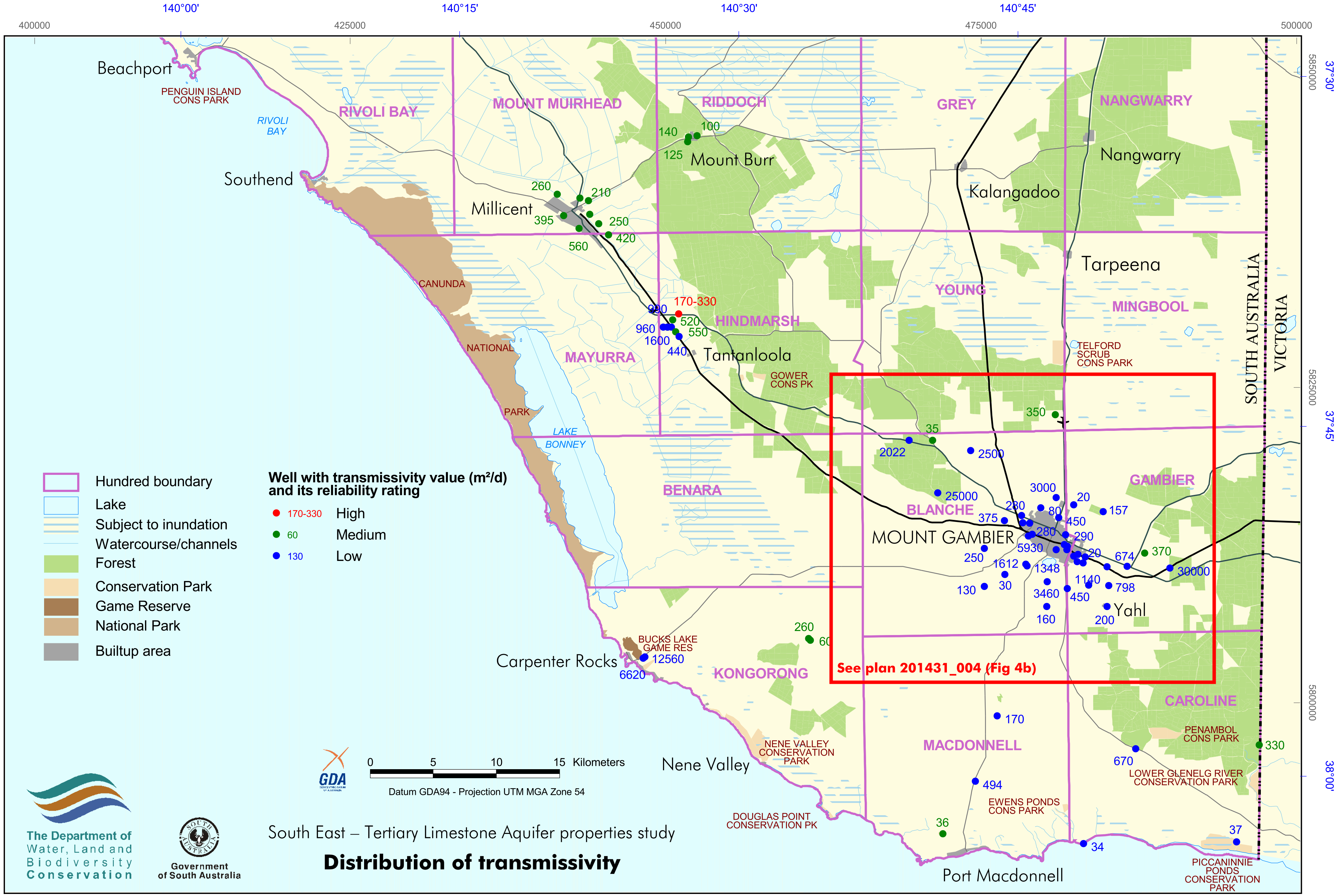

Figure 4a

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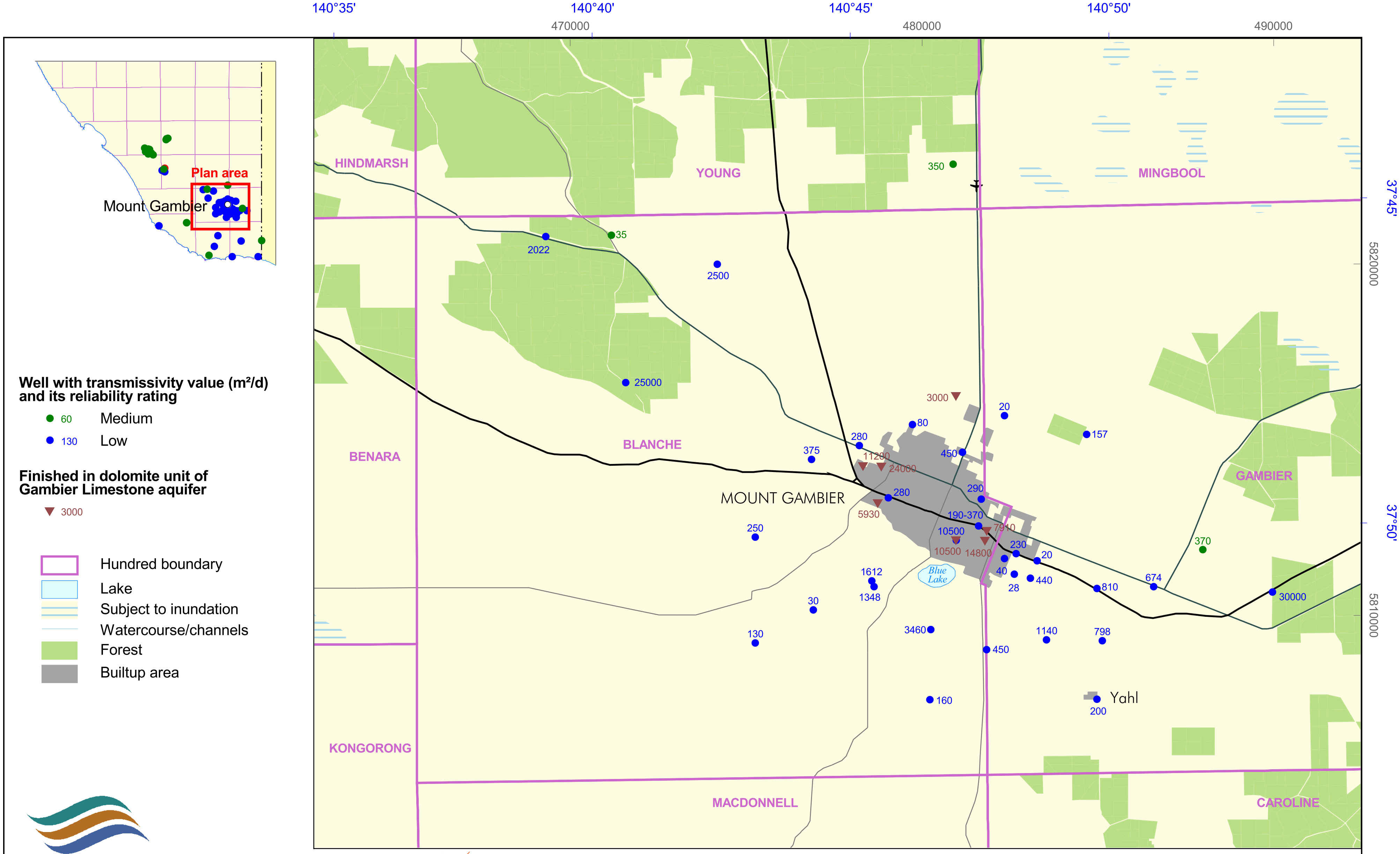

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South East – Tertiary Limestone Aquifer properties study

Detailed distribution of transmissivity

Figure 4b

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Specific yields – S for the Tertiary Limestone Aquifer

There are few S values available (reported in Table A1), which is mainly due to the fact that few aquifer tests were conducted using observation wells to record drawdown data. Most of the S values are rated as ‘low’ reliability (Table A4), due to several reasons, some of which are:

- The observation wells were not finished within the same aquifer interval as the pumping well, or the well was deriving its water from both the unconfined and confined subaquifers of the Gambier Limestone, while the observation well monitored the unconfined sub-aquifer only. This was the case for APCEL 7, 8, 9, 10 and 11 at the Kimberly-Clark site at Snuggery.
- Drawdown readings in the observation well was for a short period of time and was not enough to calculate reliable S values.
- The diameter of the observation well is an important aspect in the calculation of aquifer properties. Rapid and accurate measurements can best be made in small diameter piezometers (Kruseman and de Ridder, 1992). However, most of the wells tested in this region had holes of larger diameter.

Figure 5 shows the spatial distribution of the storage coefficient and specific yield values for the Tertiary Limestone Aquifer.

Determination of T from SC tests

A specific capacity test is a method used to determine the productivity of a well. The well is usually pumped for at least a few hours at a constant rate and the resulting drawdown is measured. The SC of a well is the product of the pumping rate (Q), divided by the measured decline in hydraulic head (the drawdown) in the well (Δh):

$$SC = \frac{Q}{\Delta h} \qquad (1)$$

Records of reliable aquifer tests and aquifer test data are not always available. However, where there is abundant data for SC, this can be used to estimate T in aquifers that have few good-quality aquifer tests.

Empirical relationship is one of several methods and different approaches used by several authors to estimate T from SC tests (Mace, 1997). Razack and Huntley (1991) and Huntley et al. (1992) found that an analytical solution for the relationship between the T and SC under predicted T in heterogeneous alluvial aquifers and over predicted T in fractured rock aquifers. This is because analytical solutions assume negligible well loss and that the aquifer is homogeneous, isotropic and granular (Mace, 1997). Fabbri (1997) presented an empirical relationship between SC and T for the limestone fractured aquifer of the Euganean field. The fit between geostatistical and hydrogeological analysis shows that a geostatistical approach is useful for both mapping purposes and hydrogeological interpretation (Fabbri, 1997).

Figure 5

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Mace (1997) presented an empirical relationship between T and uncorrected SC for a karst aquifer to avoid uncertainties in estimating well loss. The uncertainties in estimating well loss were contained within the uncertainty of estimating T from SC.

A significant number of SC data is available from tests carried out on private wells drilled mainly for irrigation purposes within the study area; and this data spatially covers areas where no drawdown data is available. Most of these tests were carried out using an orifice plate and water level probe. Useful values of T could be obtained from applying such an empirical relationship between T and SC, and when related to the lithostratigraphy of an area would help in the understanding of the spatial distribution of T.

Cobb (1979) modified the normal well parameter of SC per unit drawdown to specific capacity per metre (SC_m) open hole. This was suggested to enable comparison between more realistic inter-well values and the calculated T value for each well. An empirical equation was established from plotting values of T obtained from well tests against the specific capacity per meter of open hole: $T = 32.15 \times SC_m^{0.84}$ for all data; and $T = 35.81 \times SC_m^{0.84}$ for values of SC_m <200 m^2/d (Cobb, 1979).

Transmissivity values calculated from aquifer tests and their related specific capacities were used to establish an empirical relationship for T prediction. The best-fit line to the test data was:

$$T = 3.95 \times SC^{0.89} \qquad (2)$$

Where: T and SC are in m^2/d
coefficient of determination $R^2 = 0.82$ (Fig. 6).

Using the above relationship, equation (2), transmissivities have been re-calculated from SC (see T^8, Table A5). The values show relatively good agreement within the large range of SC data for karstic conditions to semi-confined aquifer conditions.

Transmissivity values obtained from the empirical relationship show higher T values related to the calculated T from drawdown data, particularly at SC values <40 m^2/d. This could be due to the fact that T values obtained by aquifer test methods are already underestimated, or the calculated SC values were over estimated, since most of these tests were conducted for short periods of time (<30 min); for example, GAM 23 and GAM 61. The empirical relationship also shows lower T than the reported values from drawdown tests, as for APCEL 9 and 10, where the reported values were over estimated (Williams and Cobb, 1976). A comparison between T calculated from different empirical relationships is summarised in Table A5.

The graphical comparison among different empirical relationships and recent relationships shows that the Cobb (1979) equation over estimated the T values, which could be caused by the use of modified SC_m. Figure 7 shows that all relationships, except for Cobb (1979), rest within a similar order of magnitude. Also slopes are similar between the relationships except for the Razack and Huntley (1991) relationship, which has a slope that is lower than the rest.

The relationship obtained by Mace (1997) for a karst aquifer in Florida shows a closer correlation to the present equation (2). The two equations were applied to data collected from SC tests on private wells; Table A6 is a summary of the calculated T values. Figures 8 and 9 present a spatial distribution of the T obtained from both Mace (1997) and equation (2) respectively.

Potentiometric contours of the groundwater overlying the empirical formula calculations for T show good correlation with predicted T values (Figs 8, 9). Most of the low T values overlie the steep gradient zone north and northwest of Mount Gambier despite, some high values. This could be caused by the presence of a solution cavity or karst development. High values of T coincide with the flat gradient zone south of Mount Gambier in the Hundred of MacDonnell. The majority of these values are for wells finished in the dolomite unit. In the Hundred of Mingbool high T values are related to wells finished within the shallow Bridgewater Sandstone Aquifer.

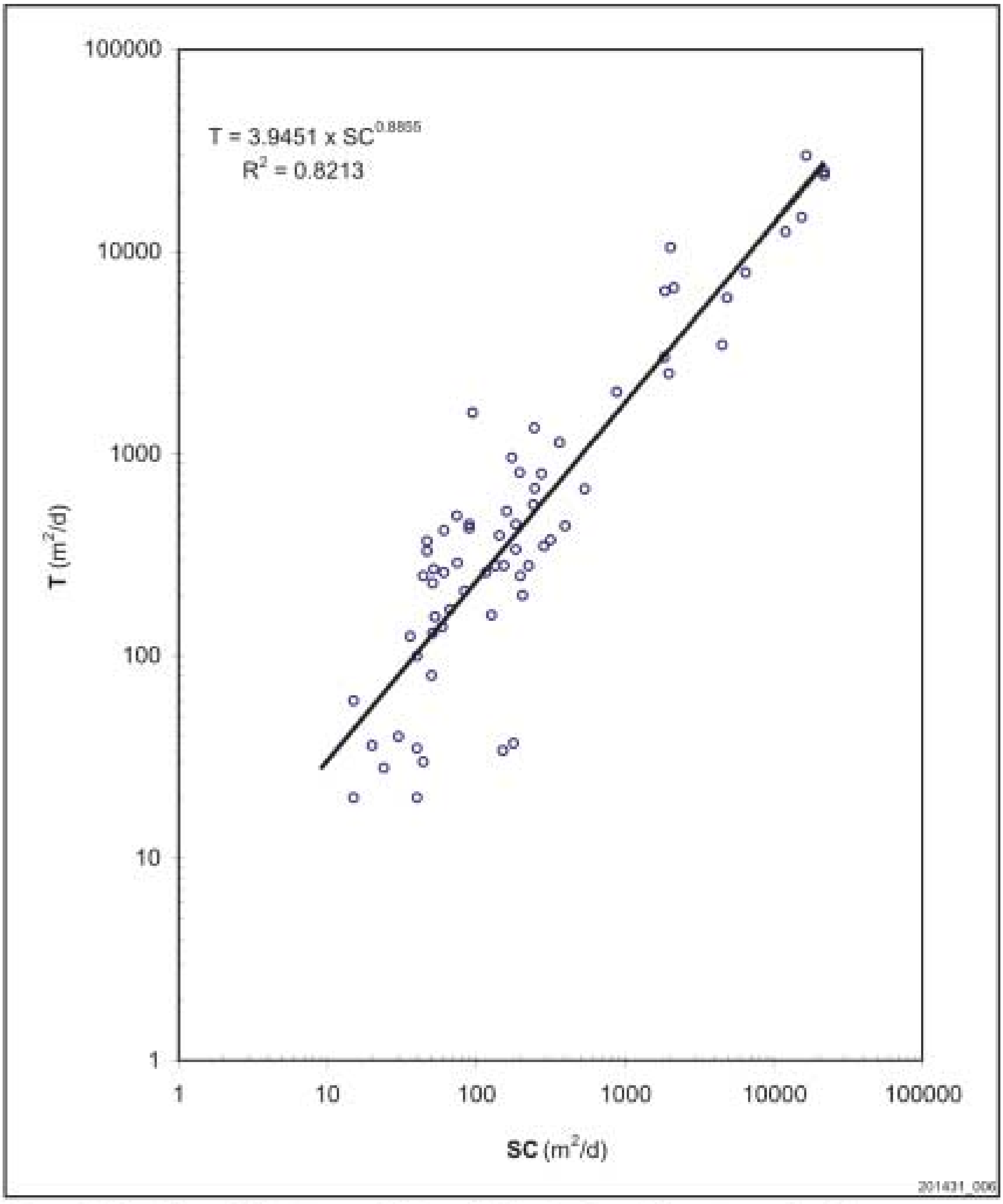

Figure 6 Relationship between SC and T for Tertiary Limestone Aquifer.

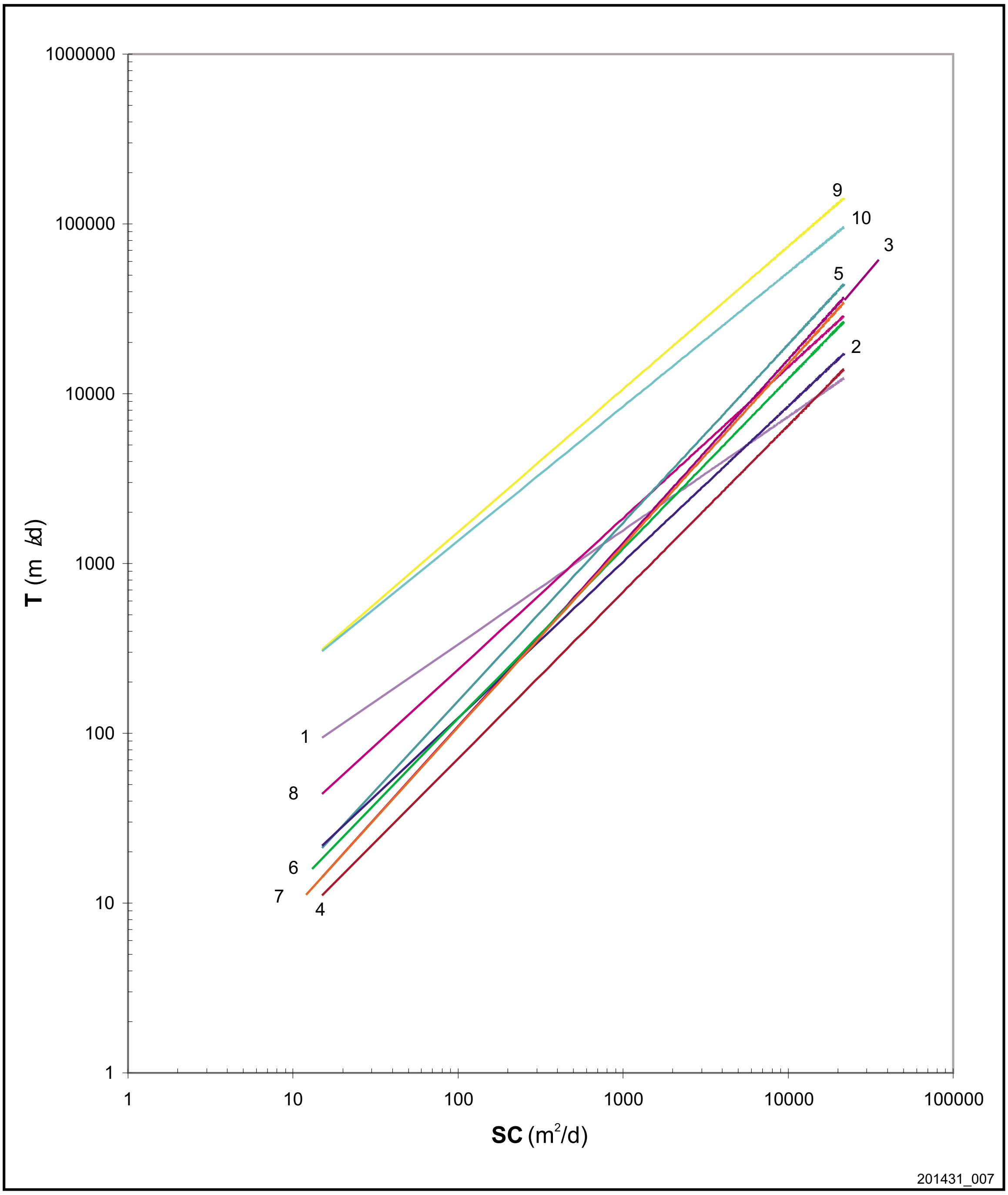

Figure 7 Comparison among the different empirical relationships and between the analytical approaches:

(1) Razack and Huntley (1991) for heterogeous alluvial aquifer
(2) El-Naqa (1994) for a fractured carbonate aquifer
(3, 4) Mace (1997) for a karstic aquifer in Texas
(5) Mace (1997) for karstic aquifer in Florida
(6) Logan's (1964)
(7) Fabbri (1997) for fractured carbonate aquifer
(8) report for Tertiary karstic limestone Aquifer South East South Australia
(9) Cobb (1979) for Tertiary Limestone Aquifer South Australia including all data for SC_m
(10) Cobb (1979) for Tertiary Limestone aquifer South Australia including data for SC_m <200 m^2/d.

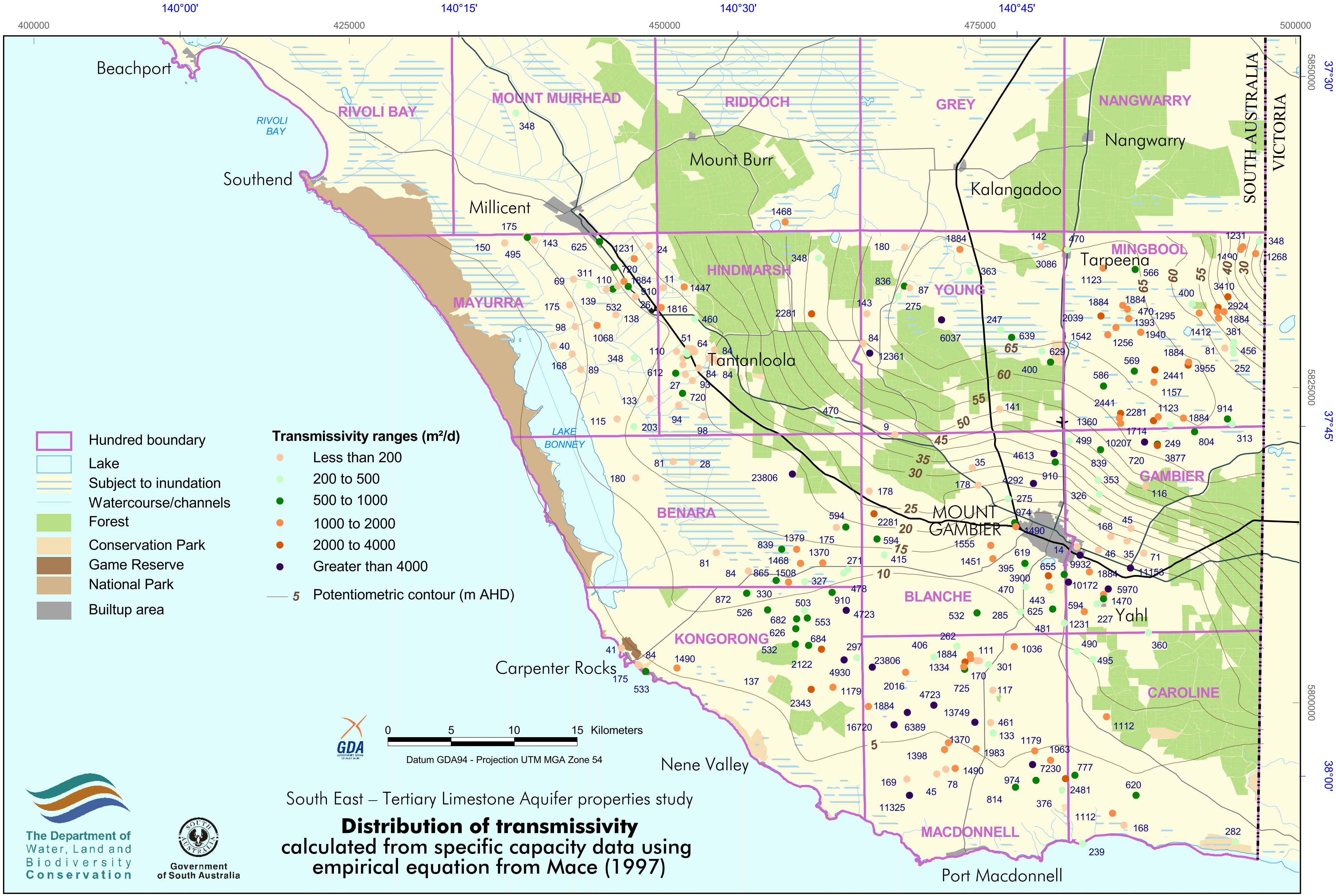

Figure 8

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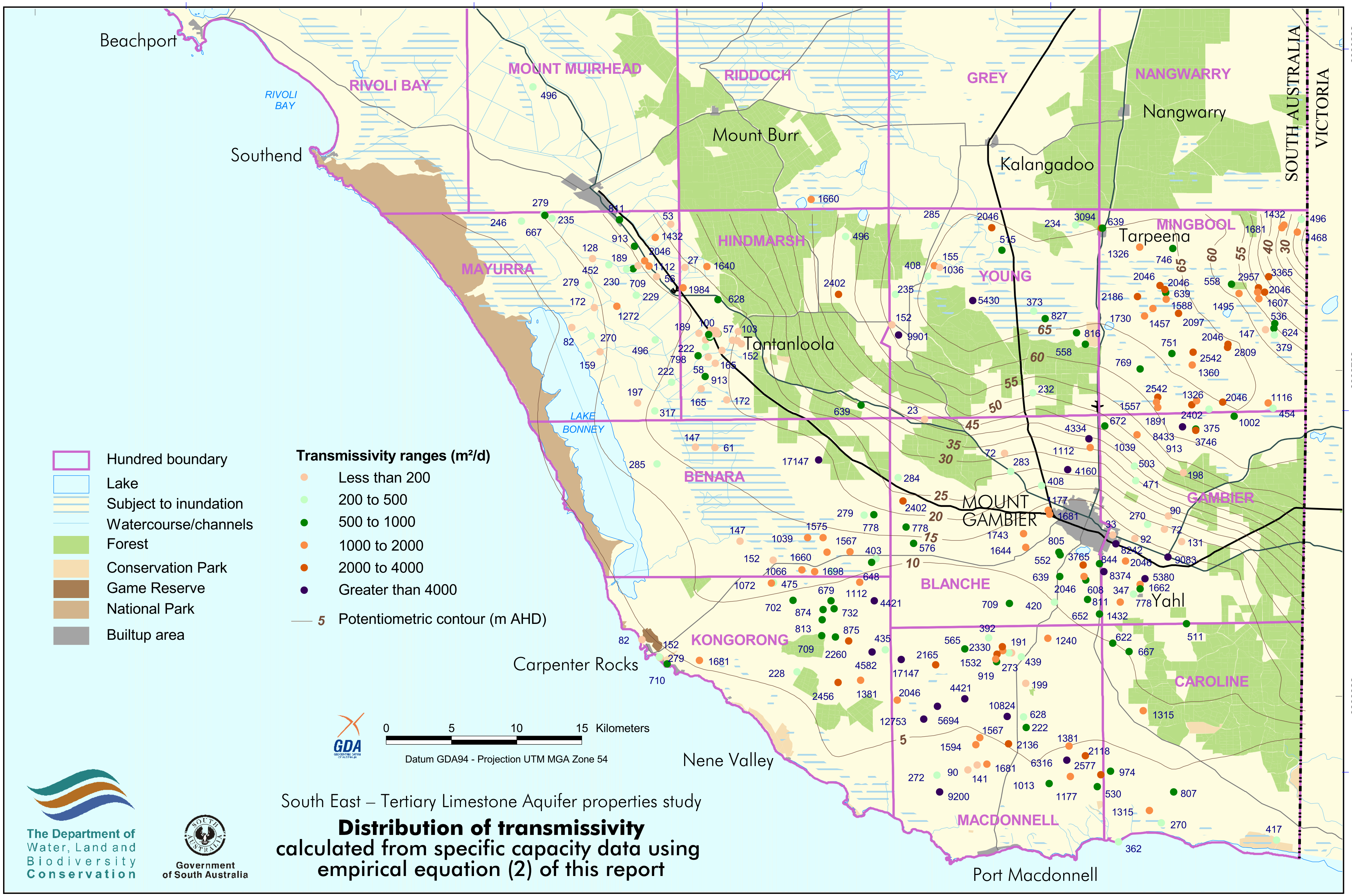

Figure 9

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CONCLUSIONS AND RECOMMENDATIONS

The spatial distribution of the Tertiary Limestone Aquifer T values (Fig. 3) show a wide range: from 20 m^2/d, for the less permeable parts of the aquifer, to over 25 000 m^2/d. The high values of T are indicative of karst development and that solution and conduit features are effective within the aquifer. The variability also reflects the inhomogeneous and non-isotropic character of the aquifer, which makes it hard to implement a unique and representative T value, particularly for the unconfined portion of the aquifer.

Transmissivity calculated from the dolomite unit of the Gambier Limestone shows high values and this could be due to the process of dolomitisation, which increases the porosity conditions of the rock and the volume of the connected pore space. This unit is an important aspect on the city side of the Blue Lake, where wells finished within the unit are used as drainage wells, which recharge storm water into the Tertiary Limestone Aquifer.

Studying results from a previous investigation conducted at the Finger Point sewage treatment work site (EWS, 1986) shows that the Tertiary Limestone Aquifer has a low T in this area. The hydraulic conductivity ranges between 0.13 and 1.46 m/d calculated from three test wells and for a depth range between 3 and 50 m, and average T values of ~10 m^2/d. This low T value was noticed in other locations in the vicinity of the coast.

Specific capacity data is usually more available than aquifer test data and is used to obtain T values within an aquifer in the absence of good aquifer test data. There are several approaches for estimating T from SC; analytical, empirical, and geostatistical (Mace, 1997). Specific capacity data has been used to calculate T in heterogeneous alluvial, fractured, and karst aquifers. The use of an empirical equation to calculate T value is a useful tool when there is inadequate good aquifer test data. These values corresponded with acceptable agreement when overlaid by the potentiometric contours of the groundwater.

It is recommended that:

- Further work is required to estimate more reliable T and S values for the dolomite unit of the Gambier Limestone in particular Zone 1 of the Blue Lake Capture Zone.
- Careful attention is needed for calculating and mapping the aquifer properties close to the coast, which will provide a better understanding regarding any salt water intrusion in the aquifer.
- No reliable S_y values exist. Aquifer tests using small diameter observation wells to obtain reliable S values are critical in any calculation for the water budget of the aquifer or the Blue Lake Water Budget calculations.
- New drilling wells targeting specific units of the Tertiary Limestone Aquifer are required to fill in the gaps in T and S values.
- Repeating aquifer tests on selective wells that have been assigned a ‘low’ rate using available wells, or drilling new observation wells for data collection.
- Duration of any new aquifer tests is to be extended for sufficient time to obtain sufficient data for better evaluation of the aquifer behaviour and characteristics.

- Due to the poor-quality of S_y values, it is recommended that a aquifer test program is instigated for production wells, with preferably three small diameter observation wells to be available or drilled so that more accurate results can be obtained (Kruseman and de Ridder, 1992; Walton, 1996).

SHORTENED FORMS

Measurement

Most units of measurement used in this volume are those of the International System of Units (SI).

Name	Symbol	Definition in terms of other metric units	Quantity
Day	d	86.4 x 10^3 s	Time interval
Hour	h	3.6 x 10^3 s	Time interval
Milligram	mg	10^{-3} g	Mass
Millimetre	mm	10^{-3} m	Length
Minute	min	60 s	Time interval
second	s	Base unit	Time interval
Millilitre	mL	10^{-6} m^3	Volume
Litre	L	10^{-3} m^3	Volume

General

Shortened form	Description
AHD	Australian height datum
Δh	measured decline in hydraulic head (drawdown)
K	hydraulic conductivity
Q	pumping rate
R^2	coefficient of determination
S	storage coefficient
Δs	drawdown per log cycle
$\Delta s/Q$	drawdown per log cycle divided by pumping rate
SC	specific capacity
SC_m	specific capacity per metre of open hole
S_y	specific yield
T	transmissivity

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APPENDIX A WELL DATA

Table 1. Reported Tertiary Limestone Aquifer parameters

Map number	Unit number	Well name	Easting	Northing	K (m/d)	T (m^2/d)	S	Source	Comments
6922	47	TWS 1	448231	5803534	325	4870	0.00400	Barnett (1976)	
6922	49	KON 12	448364	5803637	815	12560		Barnett (1976)	
7022	59	BLA 20	480256	5809602		7700		Cobb (1979)	
7022	59	BLA 20	480256	5809602		3460		Lawson et al. (1993)	
7022	76	BLA 21	480231	5807613		160		Cobb (1979)	
7022	76	BLA 21	480231	5807613		670		Lawson et al. (1993)	
7022	161	GAM 52	489964	5810667		30000		Cobb (1979)	
6922	221	APCEL 14	451031	5830841		130-194	0.00009		T and S for the unconfined subaquifer
6922	221	APCEL 14	451031	5830841		310-350	0.00018	Williams (1979)	T and S for the confined subaquifer
7022	252	GAM 21	484978	5807626		180		Cobb (1979)	
7022	252	GAM 21	484978	5807626		212		Lawson et al. (1993)	
7022	261	GAM 20	485133	5809283		930		Cobb (1979)	
7022	261	GAM 20	485133	5809283		1035		Lawson et al. (1993)	
7022	264	GAM 30	486587	5810821		1340		Lawson et al. (1993)	
7022	283	GAM 60	484977	5810777		240		Cobb (1979)	
7022	283	GAM 60	484977	5810777		412		Lawson et al. (1993)	
7022	284	GAM 9	483537	5809309		1400		Cobb (1979)	
7022	284	GAM 9	483537	5809309		1140		Lawson et al. (1993)	
7022	293	GAM 12	481833	5809030		510		Cobb (1979)	
7022	293	GAM 12	481833	5809030		450		Lawson et al. (1993)	
7022	522	CAR 9	487278	5796320		670		Cobb (1979)	
7022	538	CAR 22	497057	5796632		110		Cobb (1979)	
7022	538	CAR 22	497057	5796632		210-460	0.00052	Barnett (1976)	
7022	538	CAR 22	497057	5796632		300		Bradley et al. (1995)	
7022	813	GAM 37	488101	5817137		17		Lawson et al. (1993)	
7022	837	GAM 46	489586	5819652		34		Lawson et al. (1993)	
6922	1042	MTM 70	441426	5840314		193		Smith (1979)	Millicent Town Water Supply 2
6922	1075		443892	5839817		40		Bleys (1966)	
6922	1075		443892	5839817		142-210		Smith (1979)	
7022	1152		480884	5822837	8	317-372		Read et al. (1974)	
7021	1334		471984	5789582		36		Not cited	
7021	1407		474550	5793752		141-494		Not cited	

Map number	Unit number	Well name	Easting	Northing	K (m/d)	T (m^2/d)	S	Source	Comments
7022	1476		481849	5812412		7910		Lawson et al. (1993)	Drainage well-dolomite unit of Gambier Limestone
7022	1486		481799	5812132		14800		Lawson et al. (1993)	Drainage well-dolomite unit of Gambier Limestone
6922	1510	Mill-TWS 7	443152	5837623		560		Barnett (1975)	
7022	1532	GAM 8	483082	5811060		440		Cobb (1979)	
7022	1532	GAM 8	483082	5811060		433		Lawson et al. (1993)	
7022	1533	GAM 56	483274	5811563		20		Cobb (1979)	
7022	1533	GAM 56	483274	5811563		20		Lawson et al. (1993)	
7022	1537	GAM 58	482678	5811761		230		Cobb (1979)	
7022	1537	GAM 58	482678	5811761		64		Lawson et al. (1993)	
7022	1538	GAM 23	482621	5811176		28		Cobb (1979)	
7022	1539	GAM 59	482928	5811691		215		Lawson et al. (1993)	
7022	1682	GAM 18	484682	5815158		65		Cobb (1979)	
7022	1682	GAM 18	484682	5815158		157		Lawson et al. (1993)	
7022	1686	GAM 29	486649	5812800		5		Lawson et al. (1993)	
7022	1687	GAM 28	486946	5813825		10		Cobb (1979)	
7022	1687	GAM 28	486946	5813825		2		Lawson et al. (1993)	
7022	1973		480976	5812140		10500		Lawson et al. (1993)	Drainage well-dolomite unit of Gambier Limestone
6922	2106	APCEL 7	450477	5829794		990	0.00073	Bleys (1965)	
6922	2111	APCEL 8	450147	5829794		350	0.00011	Bleys (1965)	
6922	2112	APCEL 9	449831	5829788		960	0.00143	Bleys (1965)	
6922	2117	APCEL 10	450169	5829792		1600	0.00120	Bleys (1965)	
6922	2118	APCEL 11	450795	5829420		550	0.00160 – 0.01200	Williams et al. (1976)	S for the unconfined subaquifer
6922	2118	APCEL 11	450795	5829420			0.00028	Williams et al. (1976)	S for the confined subaquifer
6922	2128	APCELL 12	451071	5829047		440	0.04000 – 0.00400	Williams et al. (1976)	
6922	2161		441944	5838620		340		Williams et al. (1976)	
6922	2174	Mill-TWS 1	444004	5838715		413-780	0.00013 – 0.00019	Smith (1979)	
7022	2262		487992	5811871	16	355		Smith (1979)	
7022	2283	MAC 35	476283	5798940	0.83	170		Cobb (1979)	
7022	2397	BLA 85	469304	5820785		2850		Cobb (1979)	
7022	2411	BLA 71	471578	5816632		25000		Cobb (1979)	
7022	2459	BLA 78	474384	5818617		3		Lawson et al. (1993)	
7022	2460	BLA 84	474184	5819997		2500		Cobb (1979)	
7022	2460	BLA 84	474184	5819997		17723		Lawson et al. (1993)	
7022	2489	BLA 48	474852	5817228		12		Lawson et al. (1993)	
6922	2512	APCEL 17	450552	5830363		950	0.09900	Lawson (1991)	S estimated for the unconfined subaquifer
6922	2512	APCEL 17	450552	5830363			0.00000	Lawson (1991)	S estimated for the confined subaquifer
7022	2566	BLA 41	476910	5810161		30		Cobb (1979)	
7022	2566	BLA 41	476910	5810161		30		Lawson et al. (1993)	

Map number	Unit number	Well name	Easting	Northing	K (m/d)	T (m^2/d)	S	Source	Comments
7022	2570	BLA 52	475255	5809220		130		Cobb (1979)	
7022	2570	BLA 52	475255	5809220		69		Lawson et al. (1993)	
6922	2578	Mill-TWS 5	445473	5837108		27		Smith (1979)	
7022	2677		461487	5804932		59		Smith (1978)	
7022	2710	BLA 81	475259	5812234		250		Cobb (1979)	
7022	2721	BLA 38	476864	5814443		400		Cobb (1979)	
7022	2721	BLA 38	476864	5814443		540		Lawson et al. (1993)	
7022	2732	BLA 76	480970	5816252		2800		Cobb (1979)	Dolomite unit of Gambier Limestone
7022	2732	BLA 76	480970	5816252		3970		Lawson et al. (1993)	Dolomite unit of Gambier Limestone
7022	2737	GAM 61	482351	5815690		20		Lawson et al. (1993)	
7022	2773	BLA 27	478221	5814837		280		Cobb (1979)	
7022	2773	BLA 27	478221	5814837		1572		Lawson et al. (1993)	
7022	2777		478328	5814253		11200		Harris (1970)	Dolomite unit of Gambier Limestone
7022	2785	BLA 77	478855	5814242		30000		Cobb (1979)	Dolomite unit of Gambier Limestone
7022	2785	BLA 77	478855	5814242		24000		Lawson et al. (1993)	
7022	2794	BLA 16	479733	5815437		80		Cobb (1979)	
7022	2794	BLA 16	479733	5815437		95		Lawson et al. (1993)	
7022	2801	BLA 5	481149	5814652		500		Cobb (1979)	
7022	2801	BLA 5	481149	5814652		450		Lawson et al. (1993)	
7022	2818	GAM 19	482351	5811622		42		Cobb (1979)	
7022	2823	BLA 42	481608	5812548		190		Cobb (1979)	
7022	2823	BLA 42	481608	5812548		370		Lawson et al. (1993)	
7022	2828	BLA 6	481690	5813308		190		Cobb (1979)	
7022	2828	BLA 6	481690	5813308		290		Lawson et al. (1993)	
7022	2864	BLA 82	479050	5813355		280		Cobb (1979)	
7022	2864	BLA 82	479050	5813355		280		Lawson et al. (1993)	
7022	2924	BLA 114	478569	5810987		1612		Lawson et al. (1993)	
7022	4148	BLA 138	478643	5810827		4000		Lawson et al. (1993)	
7022	4539		471169	5820816		26-34		Not Cited	
7022	4708		461332	5805090		265-283		Not Cited	
7022	6584		478754	5813201		50000		Lawson et al. (1993)	Dolomite unit of Gambier Limestone

Table 2. Transmissivity and SC ratings criterion

Rating	Criteria
High	Extended aquifer test >24 h with one or more observation wells and showing good correlation to type curves.
Medium	Pumping duration >6 h and <24 h with one/or no observations, showing a good correlation to the type curves.
Low	Short term pumping <6 h, no observation, and no good correlation to a type curve or SC data only.

Table 3. Reliability rating assigned to T values for the Tertiary Limestone Aquifer

Map number	Unit number	Well name	Easting	Northing	Adopted **T** (m^2/d)	Reliability rating	Analysis method	Type of aquifer test	Comments
6922	47	TWS 1	448231	5803534	6620	Low	Straight-line	Step drawdown and constant discharge	
6922	49	KON 12	448364	5803637	12560	Low	Straight-line	Constant discharge	
7022	59	BLA 20	480256	5809602	3460	Low	Straight-line	Constant discharge	
7022	76	BLA 21	480231	5807613	160	Low	Logan method	Constant discharge	
7022	161	GAM 52	489964	5810667	30000	Low	Logan method	Constant discharge	
6922	221	APCEL 14	451031	5830841	170	High	Straight-line, curve fitting	Step drawdown and constant discharge	Unconfined subaquifer of Gambier Limestone
6922	221	APCEL 14	451031	5830841	330	High	Straight-line, curve fitting	Step drawdown and constant discharge	Confined subaquifer of Gambier Limestone
7022	252	GAM 21	484978	5807626	200	Low	Straight-line	Constant discharge	
7022	261	GAM 20	485133	5809283	798	Low	Straight-line	Constant discharge	
7022	264	GAM 30	486587	5810821	674	Low	Straight-line	Constant discharge	
7022	283	GAM 60	484977	5810777	810	Low	Straight-line	Constant discharge	
7022	284	GAM 9	483537	5809309	1140	Low	Straight-line	Constant discharge	
7022	293	GAM 12	481833	5809030	450	Low	Straight-line	Constant discharge	
7022	522	CAR 9	487278	5796320	670	Low	Logan method	Constant discharge	
7022	538	CAR 22	497057	5796632	330	Medium	Straight-line, curve fitting	Constant discharge	
6922	1042	MTM 70	441426	5840314	260	Medium	Gambier Limestone	Constant discharge	Millicent town water supply 2
7021	1058	CAR 11	495248	5788954	37	Low	Straight-line	Constant discharge	
6922	1075	Mill-TWS 6	443892	5839817	210	Medium	Straight-line, curve fitting	Constant discharge	
7021	1099	CAR 10	483118	5788829	34	Low	Gambier Limestone	Constant discharge	
6922	1147	MTBUR 2	452485	5844961	100	Medium	Straight-line	Constant discharge	
7022	1152		480884	5822837	350	Medium	Straight-line	Constant discharge	
6922	1164	MTBUR 1	451831	5844861	140	Medium	Straight-line	Constant discharge	
6922	1167	MTBUR 3	451763	5844472	125	Medium	Straight-line	Constant discharge	
7021	1334		471984	5789582	36	Medium	Straight-line	Constant discharge	
7021	1407		474550	5793752	494	Low	Straight-line	Constant discharge	
7022	1476		481849	5812412	7910	Low	Logan method	Constant discharge	Finished in dolomite–drainage borehole
7022	1486		481799	5812132	14800	Low	Straight-line	Constant discharge	Finished in dolomite–drainage borehole
6922	1510	Mill-TWS 7	443152	5837623	560	Medium	Straight-line	Step drawdown and constant discharge	
7022	1532	GAM 8	483082	5811060	440	Low	Straight-line	Constant discharge	
7022	1533	GAM 56	483274	5811563	20	Low	Straight-line	Constant discharge	
7022	1537	GAM 58	482678	5811761	230	Low	Straight-line	Constant discharge	
7022	1538	GAM 23	482621	5811176	28	Low	Logan method	Constant discharge	
7022	1682	GAM 18	484682	5815158	157	Low	Straight-line	Constant discharge	
6922	1972	Mill-TWS 3	444707	5837967	250	Medium	Straight-line	Step drawdown and constant discharge	
7022	1973		480976	5812140	10500	Low	Straight-line	Constant discharge	

Map number	Unit number	Well name	Easting	Northing	Adopted **T** (m^2/d)	Reliability rating	Analysis method	Type of aquifer test	Comments
6922	2106	APCEL 7	450477	5829794	990	Low	Straight-line, curve fitting	Step drawdown and recovery data	
6922	2111	APCEL 8	450147	5829794	350	Medium	Gambier Limestone	Constant discharge	
6922	2112	APCEL 9	449831	5829788	960	Low	Straight-line, curve fitting	Constant discharge	
6922	2117	APCEL 10	450169	5829792	1600	Low		Constant discharge	
6922	2118	APCEL 11	450795	5829420	550	Medium	Straight-line, curve fitting	Constant discharge	
6922	2128	APCELL 12	451071	5829047	440	Low	Gambier Limestone	Constant discharge	
6922	2140	Mill-TWS 4	443225	5840023	270	Medium	Straight-line	Step drawdown and constant discharge	
6922	2161		441944	5838620	395	Medium	Straight-line	Step drawdown and constant discharge	
6922	2174	Mill-TWS 1	444004	5838715	430	Medium	Straight-line, curve fitting	Step drawdown and constant discharge	
7022	2262		487992	5811871	370	Medium	Gambier Limestone	Constant discharge	
7022	2283	MAC 35	476283	5798940	170	Low	Straight-line	Constant discharge	
7022	2397	BLA 85	469304	5820785	2022	Low	Straight-line	Constant discharge	
7022	2411	BLA 71	471578	5816632	25000	Low	Logan method	Constant discharge	
7022	2460	BLA 84	474184	5819997	2500	Low	Logan method	Constant discharge	
6922	2512	APCEL 17	450552	5830363	520	Medium	Straight-line, curve fitting	Step drawdown and constant discharge	
7022	2566	BLA 41	476910	5810161	30	Low	Gambier Limestone	Constant discharge	
7022	2570	BLA 52	475255	5809220	130	Low	Straight-line	Constant discharge	
6922	2578	Mill-TWS 5	445473	5837108	420	Medium	Straight-line	Step drawdown and constant discharge	
7022	2677	Kong-PS	461487	5804932	60	Medium	Straight-line	Constant discharge	
7022	2710	BLA 81	475259	5812234	250	Low	Logan method	Constant discharge	
7022	2721	BLA 38	476864	5814443	375	Low	Straight-line	Constant discharge	
7022	2732	BLA 76	480970	5816252	3000	Low	Straight-line	Constant discharge	Finished in dolomite–drainage borehole
7022	2737	GAM 61	482351	5815690	20	Low	Straight-line	Constant discharge	
7022	2773	BLA 27	478221	5814837	280	Low	Logan method	Constant discharge	
7022	2777		478328	5814253	11200	Low	Distance drawdown	Constant discharge	Finished in dolomite
7022	2785	BLA 77	478855	5814242	24000	Low	Straight-line	Constant discharge	Finished in dolomite–drainage borehole
7022	2794	BLA 16	479733	5815437	80	Low	Straight-line	Constant discharge	
7022	2801	BLA 5	481149	5814652	450	Low	Straight-line	Constant discharge	
7022	2818	GAM 19	482351	5811622	40	Low	Straight-line	Constant discharge	
7022	2823	BLA 42	481608	5812548	190-370	Low	Straight-line	Constant discharge	
7022	2828	BLA 6	481690	5813308	290	Low	Straight-line	Constant discharge	
7022	2864	BLA 82	479050	5813355	280	Low	Straight-line	Constant discharge	
7022	2924	BLA 114	478569	5810987	1612	Low	Straight-line	Constant discharge	
7022	4148	BLA 138	478643	5810827	1348	Low	Straight-line	Constant discharge	
7022	4539		471169	5820816	35	Medium	Straight-line	Constant discharge	
7022	4708		461332	5805090	260	Medium	Straight-line	Constant discharge	
7022	6584		478754	5813201	5930	Low	Logan method	Constant discharge	Finished in dolomite–drainage borehole

Table 4. Reliability rating assigned to S and S_y values for the Tertiary Limestone Aquifer

Map number	Unit number	Observation well	Easting	Northing	Adopted S – Sy	Reliability rating	Comments
6922	47	Carpenter-TWS 1	448231	5803534	0.004000	low	
6922	221	APCEL 14	451031	5830841	0.000180	high	Confined subaquifer of Gambier Limestone
7022	538	CAR 22	497057	5796632	0.013000	medium	
6922	2106	APCEL 7	450477	5829794	0.000730	low	
6922	2111	APCEL 8	450147	5829794	0.000113	low	
6922	2112	APCEL 9	449831	5829788	0.001430	low	
6922	2117	APCEL 10	450169	5829792	0.001200	low	
6922	2118	APCEL 11	450795	5829420	0.001600 – 0.01200	low	Unconfined subaquifer of Gambier Limestone
6922	2118	APCEL 11	450795	5829420	0.000280	low	Confined subaquifer of Gambier Limestone
6922	2174	Mill-TWS 1	444004	5838715	0.000200	medium	
6922	2512	APCEL 17	450552	5830363	0.084000	low	Unconfined subaquifer of Gambier Limestone
6922	2512	APCEL 17	450552	5830363	0.005700	low	Confined subaquifer of Gambier Limestone

Table 5. Transmissivity values obtained from drawdown data compared with T estimated from different empirical relationships

Well name	Easting	Northing	SC (m^2/d)	T $(m^2/d)^*$	T^8 (m^2/d)	T^9 (m^2/d)	T^{10} (m^2/d)	T^3 (m^2/d)	T^4 (m^2/d)	T^5 (m^2/d)	T^2 (m^2/d)	T^1 (m^2/d)	T^7 (m^2/d)	T^6 (m^2/d)
TWS 1	448231	5803534	2141	6620	3736	20179	15318	3005	1433	3864	2050	2607	2875	2612
KON 12	448364	5803637	12010	12560	17040	85901	59820	19352	7763	23628	9968	8279	18196	14652
BLA 20	480256	5809602	4500	3460	7183	37660	27545	6703	2966	8429	4052	4289	6365	5490
BLA 21	480231	5807613	127	160	311	1881	1644	142	90	199	154	393	140	155
GAM 52	489964	5810667	16615	30000	22673	112824	77304	27476	10671	33222	13424	10290	25752	20270
APCEL 14	451031	5830841	185	336	433	2580	2213	213	130	295	217	505	209	226
GAM 21	484978	5807626	204	200	472	2801	2391	237	143	327	237	540	232	249
GAM 20	485133	5809283	276	798	616	3610	3036	329	192	450	313	661	321	337
GAM 30	486587	5810821	248	674	561	3300	2790	293	173	402	284	615	286	303
GAM 60	484977	5810777	196	810	456	2708	2317	227	138	314	229	525	223	239
GAM 9	483537	5809309	362	1140	782	4534	3762	441	251	598	402	793	429	442
GAM 12	481833	5809030	90	450	230	1408	1253	98	64	139	112	312	97	110
CAR 9	487278	5796320	539	670	1110	6335	5152	678	371	908	579	1035	657	658
CAR 22	497057	5796632	47	330	130	816	750	49	34	70	62	202	48	57
MTM 70	441426	5840314	117	260	289	1756	1541	130	83	183	143	372	128	143
MilliTWS6	443892	5839817	84	210	216	1329	1186	91	60	129	105	298	90	102
MTBUR 2	452485	5844961	40	100	113	713	660	41	29	59	53	181	41	49
7022-1152	480884	5822837	286	350	635	3720	3123	342	199	467	324	677	334	349
MTBUR 1	451831	5844861	59	140	158	988	897	62	42	89	76	235	62	72
MTBUR 3	451763	5844472	36	125	103	652	607	36	26	53	48	169	36	44
7021-1334	471984	5789582	20	36	61	398	382	19	15	29	28	114	19	24
7021-1407	474550	5793752	74	494	193	1195	1073	79	53	113	94	274	79	90
7022-1476	481849	5812412	6480	7910	9901	51157	36741	9938	4241	12361	5661	5476	9403	7906
7022-1486	481799	5812132	15428	14800	21242	106013	72907	25362	9923	30735	12542	9792	23788	18822
6922-1510	443152	5837623	241	560	547	3222	2728	284	168	390	277	603	278	294
GAM 8	483082	5811060	395	440	844	4879	4030	484	273	655	435	840	471	482
GAM 56	483274	5811563	40	20	113	713	660	41	29	59	53	181	41	49
GAM 58	482678	5811761	51	230	139	874	800	53	37	76	67	213	53	62
GAM 23	482621	5811176	24	28	72	464	441	24	18	35	33	129	24	29
GAM 18	484682	5815158	53	157	144	903	824	55	38	80	69	219	55	65
Mill-TWS3	444707	5837967	44	250	122	772	712	45	32	65	58	193	45	54
7022-1973	480976	5812140	2025	10500	3557	19257	14658	2830	1356	3645	1948	2512	2709	2471
APCEL 9	449831	5829788	173	960	408	2439	2099	199	122	275	204	483	195	211
APCEL 10	450169	5829792	95	1600	241	1474	1307	104	68	147	118	323	103	116
Mill-TWS4	443225	5840023	52	270	142	888	812	54	37	78	68	216	54	63

$T^{1–10}$ Transmisivity values estimated from different empirical relationships (Fig. 6)

Well name	Easting	Northing	SC (m^2/d)	T (m^2/d)*	T^8 (m^2/d)	T^9 (m^2/d)	T^{10} (m^2/d)	T^3 (m^2/d)	T^4 (m^2/d)	T^5 (m^2/d)	T^2 (m^2/d)	T^1 (m^2/d)	T^7 (m^2/d)	T^6 (m^2/d)
6922-2161	441944	5838620	144	395	347	2090	1816	163	102	227	173	427	160	176
Mill-TWS1	444004	5838715	90	430	230	1408	1253	98	64	139	112	312	97	110
7022-2262	487992	5811871	47	370	130	816	750	49	34	70	62	202	48	57
MAC 35	476283	5798940	67	170	177	1099	992	71	48	102	86	256	71	82
BLA 85	469304	5820785	884	2022	1715	9598	7616	1156	602	1526	911	1441	1116	1078
BLA 71	471578	5816632	21800	25000	28795	141737	95804	36842	13925	44186	17220	12344	34436	26596
BLA 84	474184	5819997	1982	2500	3491	18912	14412	2765	1328	3563	1910	2476	2647	2418
APCEL 17	450552	5830363	160	520	381	2284	1974	183	113	254	190	459	179	195
BLA 41	476910	5810161	44	30	122	772	712	45	32	65	58	193	45	54
BLA 52	475255	5809220	51	130	139	874	800	53	37	76	67	213	53	62
Mill-TWS5	445473	5837108	61	420	163	1016	921	64	44	92	78	240	64	74
Kong-PS	461487	5804932	15	60	47	313	304	14	11	21	22	94	14	18
BLA 81	475259	5812234	198	250	460	2731	2335	230	139	317	231	529	225	242
BLA 38	476864	5814443	316	375	694	4045	3379	381	220	518	355	724	371	386
BLA 76	480970	5816252	1842	3000	3273	17784	13601	2555	1236	3300	1786	2357	2448	2247
GAM 61	482351	5815690	15	20	47	313	304	14	11	21	22	94	14	18
BLA 27	478221	5814837	225	280	515	3041	2584	264	157	363	260	576	258	275
BLA 77	478855	5814242	21800	24000	28795	141737	95804	36842	13925	44186	17220	12344	34436	26596
BLA 16	479733	5815437	50	80	137	860	787	52	36	75	65	210	52	61
BLA 5	481149	5814652	185	450	433	2580	2213	213	130	295	217	505	209	226
GAM 19	482351	5811622	30	40	87	560	526	30	22	44	41	149	30	37
BLA 42	481608	5812548	154	280	369	2212	1915	175	109	244	183	447	172	188
BLA 6	481690	5813308	75	290	196	1208	1085	81	54	114	95	276	80	92
BLA 82	479050	5813355	135	280	328	1980	1726	152	95	212	163	409	149	165
BLA 138	478643	5810827	245	1348	555	3266	2763	289	171	397	281	610	283	299
7022-4539	471169	5820816	40	35	113	713	660	41	29	59	53	181	41	49
7022-4708	461332	5805090	61	260	163	1016	921	64	44	92	78	240	64	74
7022-6584	478754	5813201	4860	5930	7686	40175	29272	7284	3199	9138	4348	4516	6911	5929
CAR 10	483118	5788829	151	34	343	2175	1885	171	107	239	180	441	168	184
CAR 11	495248	5788954	178	37	398	2498	2147	205	125	284	210	493	201	217

* Transmissivity values estimated from aquifer test data

Table 6. Transmissivity values for Tertiary Limestone Aquifer estimated from SC data

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
7022	389	482701	5804071	299	622	490
7022	680	464531	5810530	170	403	271
7022	813	488101	5817137	76	198	116
7022	889	482082	5820742	305	672	499
7021	1058	495248	5788954	177	417	282
7021	1099	483118	5788829	151	362	239
6922	1244	447571	5835195	720	1432	1231
6922	1272	447701	5832169	18	56	26
6922	1413	453530	5827310	56	152	84
6922	1414	453886	5827275	56	152	84
6922	1419	454191	5827051	56	152	84
6922	1463	451637	5826017	19	58	27
7022	1535	482675	5812352	10	33	14
7022	1539	482928	5811691	5261	8242	9932
6922	1542	446240	5822488	76	197	115
6922	1613	447571	5827341	216	496	348
7022	1686	486649	5812800	24	72	35
7022	1687	486946	5813825	31	90	45
6922	2004	442468	5831530	112	279	175
7022	2044	463621	5813886	112	279	175
7022	2105	465255	5803566	186	435	297
7022	2191	474914	5803326	73	191	111
7022	2262	487992	5811871	47	131	71
7022	2459	474384	5818617	24	72	35
7022	2489	474852	5817228	114	283	178
6922	2581	450946	5802734	864	1681	1490
6922	2641	451736	5827757	135	328	212
6922	2642	452035	5827818	112	279	175
6922	2646	451761	5827667	19	57	26
6922	2681	451852	5827761	42	118	63
7022	2682	484459	5816537	203	471	326
7021	3231	479442	5793827	576	1177	974
7021	3258	481762	5793977	1404	2577	2481
7021	3266	469202	5793927	109	272	169

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
7021	3273	486422	5790277	108	270	168
7021	3275	469422	5792627	5962	9200	11325
7021	3284	485502	5791227	654	1315	1112
7021	3287	481502	5793047	233	530	376
7021	3307	487372	5792637	375	807	620
7021	3336	477813	5793294	486	1013	814
6922	3475	442787	5833573	46	128	69
6922	3476	451432	5826788	86	222	133
6922	3486	451537	5832968	840	1640	1447
6922	3487	448852	5824098	86	222	133
6922	3488	451437	5827357	56	152	84
6922	3496	452276	5827842	43	120	64
6922	3497	447953	5802942	56	152	84
6922	3512	442902	5829818	65	172	98
6922	3532	444622	5829928	629	1272	1068
6922	3535	453087	5822717	65	172	98
6922	3547	448516	5802484	324	710	533
6922	3550	454102	5811877	54	147	81
6922	3553	451112	5823568	62	165	94
6922	3594	437322	5836438	97	246	150
6922	3597	439012	5837008	112	279	175
6922	3598	451865	5828083	35	100	51
6922	3599	452032	5827941	26	76	37
6922	3600	451888	5828042	26	76	37
6922	3603	447102	5832998	540	1112	910
6922	3608	452130	5828034	16	50	23
6922	3609	452048	5827968	22	65	31
6922	3610	451880	5827718	207	479	333
6922	3611	452148	5828049	43	120	64
6922	3616	446767	5833418	1080	2046	1884
6922	3617	444827	5836558	378	811	625
6922	3621	452045	5827935	14	46	20
6922	3633	446572	5804327	28	82	41
6922	3634	452272	5828034	19	57	26
6922	3637	445882	5832807	324	709	532
6922	3638	445372	5832767	90	230	139
6922	3643	442662	5827658	108	270	168
6922	3650	444012	5833097	194	452	311
6922	3651	450932	5827863	72	189	110
6922	3652	453947	5827997	36	103	53

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
6922	3654	438192	5846758	216	496	348
6922	3656	439652	5836667	93	235	143
6922	3661	443362	5826418	59	159	89
6922	3662	452162	5819077	20	61	28
6922	3665	451801	5827557	378	811	625
6922	3671	451799	5827629	151	363	239
6922	3681	452102	5827849	11	36	15
6922	3683	447552	5821877	130	317	203
6922	3688	451407	5824522	432	913	720
6922	3694	452707	5826518	56	152	84
6922	3695	452384	5827826	288	639	470
6922	3698	450662	5819097	54	147	81
6922	3702	445997	5834518	432	913	720
6922	3703	439132	5836882	302	667	495
6922	3715	448782	5836208	17	53	24
6922	3719	452187	5825528	62	165	93
6922	3720	451698	5827757	259	583	421
6922	3727	447722	5817827	115	285	180
6922	3735	452347	5827827	28	82	40
6922	3737	449862	5832888	8	27	11
6922	3753	447907	5803027	112	279	175
6922	3757	446122	5830777	90	229	138
6922	3760	441172	5828278	28	82	40
6922	3764	446252	5833037	72	189	110
6922	3772	449732	5831348	1043	1984	1816
6922	3781	452339	5827878	15	47	21
6922	3800	452412	5830433	282	628	460
7022	3848	473406	5835963	1080	2046	1884
7022	3893	476017	5811421	842	1644	1451
7022	3894	481657	5810172	395	844	655
7022	3823	471950	5830366	3275	5430	6037
7022	3999	485361	5813160	108	270	168
7022	4063	450862	5826132	370	798	612
7022	4102	481669	5806285	295	625	481
7022	4148	478643	5810827	244	552	395
7022	4150	480611	5808909	272	608	443
7022	4170	474735	5803309	109	273	170
7022	4183	487727	5829364	1111	2097	1940
7022	4232	479852	5836144	92	234	142
7022	4442	484793	5808552	853	1662	1470

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
7022	4496	493883	5831325	2642	2957	2924
7022	4497	493907	5830477	821	1607	1412
7022	4498	493814	5831008	670	1343	1140
7022	4499	491790	5831613	247	558	400
7022	4451	485140	5829166	398	1730	1542
7022	4507	491497	5826749	2189	3809	3955
7022	4508	494642	5832182	1901	3365	3410
7022	4510	484786	5825110	355	769	586
7022	4607	480893	5827001	380	816	629
7022	4630	484792	5808242	360	778	594
7022	4686	486755	5830982	288	639	470
7022	4687	486682	5831205	1080	2046	1884
7022	4688	486299	5831502	1080	2046	1884
7022	4689	484599	5830651	1161	2186	2039
7022	4690	486798	5830466	810	1588	1393
7022	4694	464346	5813921	360	778	594
7022	4702	494329	5831014	1080	2046	1884
7022	4725	480403	5810051	2160	3765	3900
7022	4778	483265	5807205	720	1432	1231
7022	5026	476045	5797598	282	628	461
7022	5061	478215	5807210	179	420	285
7022	5089	485151	5809020	3240	5380	5970
7022	5258	491543	5826985	1080	2046	1884
7022	5299	468990	5833023	498	1036	836
7022	5389	477500	5828968	386	827	639
7022	5391	474191	5834211	225	515	363
7022	5447	475998	5800986	77	199	117
7022	5452	478626	5809170	288	639	470
7022	5467	475832	5812472	900	1743	1555
7022	5528	486932	5810662	5875	9083	11153
7022	5702	482013	5809540	5357	8374	10172
7022	5755	484284	5807826	144	347	227
7022	6048	475832	5798409	86	222	133
7022	6169	488745	5822361	1296	2402	2281
7022	6184	479242	5817383	2419	4160	4292
7022	6272	486147	5822920	1382	2542	2441
7022	6354	480945	5819062	540	1112	910
7022	6414	461085	5807308	307	676	503
7022	6469	486457	5822456	987	1891	1714
7022	6470	467402	5811703	256	576	415

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
7022	6606	488868	5826403	1382	2542	2441
7022	6711	480485	5809188	1080	2046	1884
7022	6833	489044	5820489	432	913	720
7022	6893	483658	5810370	1080	2046	1884
7022	6910	483946	5803423	302	667	495
7022	6980	484541	5820061	500	1039	839
7022	7179	476622	5829534	156	373	247
7022	7207	460468	5806651	411	874	682
7022	7294	496863	5835614	741	1468	1268
7022	7308	484342	5817647	219	503	353
7022	7447	465742	5828493	56	152	84
7022	7450	497147	5836578	216	496	348
7022	7473	462183	5835265	216	496	348
7022	7477	466822	5812978	360	778	594
7022	7479	466222	5816778	114	284	178
7022	7486	464197	5810277	292	648	478
7022	7487	495052	5828207	280	624	456
7022	7488	495122	5828577	236	536	381
7022	7536	475672	5803003	188	439	301
7022	7540	479902	5827877	247	558	400
7022	7555	481819	5835921	1728	3094	3086
7022	7654	495682	5835957	864	1681	1490
7022	7655	481919	5835921	288	639	470
7022	7657	474682	5796348	1134	2136	1983
7022	7699	461322	5806697	336	732	553
7022	7700	462412	5804227	1210	2260	2122
7022	7710	488352	5805567	223	511	360
7022	7743	456662	5808717	206	475	330
7022	7764	474242	5803497	1002	1915	1741
7022	7765	473762	5802627	435	919	725
7022	7800	456622	5810447	56	152	84
7022	7805	471332	5803618	250	565	406
7022	7836	471592	5794327	31	90	45
7022	7857	463352	5801207	691	1381	1179
7022	7863	477732	5814247	576	1177	974
7022	7867	473022	5794778	864	1681	1490
7022	7887	464232	5803377	2700	4582	4930
7022	7908	477237	5816152	173	408	275
7022	7946	473152	5804467	165	392	262
7022	7966	472492	5796798	798	1567	1370

Well number	**Unit number**	**Easting**	**Northing**	**Specific capacity** (m^2/d)	**T** (m^2/d)*	**T** (m^2/d)†
7022	7979	487292	5834358	343	746	566
7022	7980	495102	5827727	159	379	252
7022	7984	458152	5807357	320	702	526
7022	7989	478572	5811052	374	805	619
7022	7994	477860	5813957	864	1681	1490
7022	7999	484772	5834468	660	1326	1123
7022	8008	474756	5807101	324	709	532
7022	8043	484400	5812080	32	92	46
7022	8050	479322	5796157	691	1381	1179
7022	8053	463382	5822327	288	639	470
7022	8059	469392	5832892	58	155	87
7022	8060	468482	5832208	173	408	275
7022	8133	468252	5821258	6	23	9
7022	8134	460372	5804628	324	709	532
7022	8136	469092	5802407	1152	2165	2016
7022	8137	469102	5800097	34560	43194	71682
7022	8158	480872	5819711	43	120	64
7022	8159	480867	5819738	2534	4334	4613
7022	8163	488802	5825397	679	1360	1157
7022	8168	492381	5820884	756	1495	1295
7022	8220	468197	5798227	8640	12753	16720
7022	8222	474575	5798422	7171	10824	13749
7022	8230	495847	5836153	720	1432	1231
7022	8256	476572	5823272	91	232	141
7022	8259	466257	5827717	6480	9901	12361
7022	8277	466472	5802799	12096	17147	23806
7022	8295	494422	5828123	54	147	81
7022	8297	487222	5826273	346	751	569
7022	8330	472282	5794717	52	141	78
7022	8334	460752	5811057	852	1660	1468
7022	8335	469022	5836118	115	285	180
7022	8345	472182	5796258	813	1594	1398
7022	8367	486042	5822578	792	1557	1360
7022	8376	464382	5807307	2592	4421	4723
7022	8414	466152	5799677	1080	2046	1884
7022	8456	488052	5820678	5400	8433	10207
7022	8462	461422	5804537	411	875	684
7022	8463	462522	5811077	798	1567	1370
7022	8464	460452	5812177	802	1575	1379
7022	8473	461632	5830842	1296	2402	2281

Well number	Unit number	Easting	Northing	Specific capacity (m^2/d)	T (m^2/d)*	T (m^2/d)†
7022	8484	466582	5814977	1296	2402	2281
7022	8487	461102	5809597	204	472	327
7022	8488	461602	5801058	1329	2456	2343
7022	8539	456512	5808677	518	1072	872
7022	8556	471342	5799797	2592	4421	4723
7022	8559	477722	5804427	611	1240	1036
7022	8561	458459	5801865	89	228	137
7022	8571	463260	5808750	540	1112	910
7022	8578	479172	5795077	3888	6316	7230
7022	8583	494632	5822478	543	1116	914
7022	8584	494992	5822098	195	545	313
7022	8585	485022	578877	654	1315	1112
7022	8587	469232	5799207	3456	5694	6389
7022	8588	459292	5812157	500	1039	839
7022	8589	459822	5809557	874	1698	1508
7022	8590	458842	5809678	515	1066	865
7022	8593	460134	5818121	12096	17147	23806
7022	8599	489047	5820397	2148	3746	3877
7022	8621	460392	5805847	378	813	626
7022	8654	473802	5803207	1252	2330	2200
7022	8655	474212	5803777	1080	2046	1884
7022	8723	466027	5830838	93	235	143
7022	8801	480762	5807413	378	811	625
7022	8934	482522	5794237	465	974	777
7022	8970	490070	5822035	157	375	249
7022	9113	480575	5795437	1123	2118	1963
7022	9121	491137	5822570	1080	2046	1884
7022	9137	485769	5829741	734	1457	1256
7022	9148	489115	5822661	660	1326	1123
7022	9170	492012	5821495	480	1002	804
7022	9234	473700	5802836	778	1532	1334
7022	9334	459532	5838114	852	1660	1468

* Transmissivity values estimated using the present empirical relationship

† Transmissivity values estimated using Mace (1997) relationship for karst aquifer in Floridathe

APPENDIX B AQUIFER TEST RESULTS

Aquifer test of well number 7022-538 (CAR 22)

Cobb (1979) conducted a short duration (30 min) aquifer test on CAR 22 and a T value of 110 m^2/d was calculated using Logan's method, as it was considered that the well reached steady-state conditions.

A second aquifer test was later conducted using CAR 22 with CAR 35 which is 7.1 m away as an observation well. The test was conducted for 12 h at an average pumping rate of 428 m^3/d, followed by a recovery test for 4 h. Drawdown measurements were taken in both the pumped and observation wells. The data showed irregular fluctuations when plotted on semi-log axis. It was suggested that this irregularity probably resulted from conduit flow in solution features, but also could be due to the fluctuation in the pumping rate (between a lower limit of 417 m^3/d and higher limit of 490 m^3/d, compared to the average rate used in the calculations). An approximate straight-line was fitted with a resulting T of 210 m^2/d. The recovery curve yielded a value of 460 m^2/d. The observation well drawdown was free of the above irregularities and T obtained from a straight-line method was 300 m^2/d and a S of 0.00052 was observed. Storage coefficient is an underestimated value, as it reflects a confined aquifer condition, which is not obvious from the geological log of the well. The well is of shallow depth (~28 m) and no correction for a partial penetration of the aquifer or de-watering of the phreatic zone has been undertaken.

Re-calculating the data using the straight-line method provided T values of 198 m^2/d from drawdown data measured in the pumped well, and 395 m^2/d from recovery data; this is in good correlation to the previous estimated values. The value for T obtained from the observation well was 603 m^2/d for early time and 326 m^2/d for late time, an average value of 465 m^2/d. This value is consistent with the value obtained from recovered data of the pumped well. Plotting the data on log–log showed it corresponded with a Neuman Type curve for the unconfined aquifer and gave an average of T from early and late matching of 203 m^2/d and an average S value of 0.013.

The above results reflect the inhomogeneous characteristics of the Gambier Limestone in the area. This is clear from the lithological log of CAR 35, which shows that the limestone consists of fine and less permeable materials (e.g. calcisilitite below 22 m). A transmissivity value of 330 m^2/d with an average S value of 0.013 appears to be a good average figure for the Gambier Limestone in this area and assigned a 'medium' rating.

Aquifer test of Carpenter town water supply Wells 1 and 2

Barnett (1976) reported on the completion of two production wells drilled in the Hundred of Kongorong, Section 500. The first production well (unit number 6922-47) was drilled 350 m inland from the coast and was later abandoned due to high salinity, a presence of hydrogen sulphide and suspect bacteriological quality. A second well was drilled a further 500 m inland and proved successful with low salinity and with hydrogen sulphide absent.

A three-stage step drawdown test was performed on the first well (6922-47) without recovery between stages except for the final recovery. Each stage was of 100 min duration with different discharge rates. A main 72 h test was conducted using well unit number 6922-48 as an observation well at a distance of 6.9 m from the production well. The test was discontinued after 3 h due to a rise in salinity. The average pumping rate was 23.7 L/s. A second attempt commenced the next day at a reduced pumping rate of 11.4 L/s. Again the test was abandoned after 30 h due to rising salinity. The aquifer test was followed by recovery measurements for 6 h. Water levels were taken in both pumping and observation wells.

Data were analysed for the main test by Barnett (1976), who used a straight-line method and reported calculated values of T = 4870 m^2/d and S = 0.004. These values should be considered very approximate, since the Gambier Limestone surrounding Well 1 is not homogenous and isotropic because of solution features and the pumped well is not fully penetrating. These conditions do not fulfil the general conditions for the application of the Jacob straight-line method. The base of Gambier Limestone is estimated to be at 350 m which means the pumped well is only penetrating 8% of the aquifer. The well was drilled to 28 m and finished at 17 m due to a rise in salinity with depth. The observation well was finished at a depth of 40 m. A cavernous solution feature was intersected by both pumping and observation wells at depth between 16.5 and 18 m.

Step test data was re-calculated using the refined method by Lennox (Hazel, 1975). Transmissivity values obtained from the first and second stage were 6370 and 7830 m^2/d respectively. Data from the third stage showed an irregularity and was unreliable for obtaining a T value.

Transmissivity values of 7506 m^2/d were obtained from re-calculating the recovery data for the pumped well; and 7206 and 6005 m^2/d from pumping and recovery respectively for the observation well. An average T value of 6620 m^2/d and S value of 0.004 was adopted and assigned ‘low’ rating for the reasons provided above.

Another well (6922-49) was drilled 500 m further inland due to the failure of well 1. The well sunk to a depth of 25 m. When the 152 mm casing was withdrawn so that it could be replaced with slotted casing, the well collapsed back to 20 m. The final slotted section was from 5 to 20 m (Barnett, 1976). The driller at the final depth of 25 m noticed a caving effect.

A main aquifer test with an average pumping rate of 16.7 L/s was carried out in Well 2 for 48 h. Values of drawdown were irregular with a maximum value of 0.12 m after 48 h pumping. A straight-line method was used, with the same limitations in Jacob’s method of calculating T for Well 1 apply to Well 2. The very small irregular drawdowns made fitting a straight-line difficult. The calculated value of T was ~12 560 m^2/d, which must be considered as very approximate (Barnett, 1976). This value was assigned ‘low’ rating.

Aquifer test of APCEL 14, Snuggery

A drilling and aquifer test program was arranged for well APCEL 14 (unit number 6922-221; Williams, 1979):

1. Two shallow wells were drilled, APCEL 14A (HIN 51, unit number 6922-222) and APCEL 14B (HIN 52, unit number 6922-223), 5 and 15 m from the production well and a step drawdown test was conducted on one well using the other for observation.
2. Production well APCEL 14 was drilled to 130 m, the upper 50 m was cemented, and step drawdown and main tests were conducted using observation well HIN 38 (unit number 6922-1361; monitoring the upper

unconfined interval) and HIN 50 (unit number 6922-1959; monitoring the lower semi-confined interval), and HIN 51 and HIN 52.

In the first stage of the test, a 5 x 40 min step drawdown test was carried out on HIN 51, using HIN 52 as an observation well during the first 40 min of the test. The average T obtained from HIN 51 was 170 m^2/d, using Jacob's correction method for measured drawdown data. Williams (1979) concluded that the $\Delta s/Q$ and T results vary significantly between stages, indicating some inhomogeneity within the aquifer.

The second stage of the test carried out on APCEL 14 with a 5 x 40 min step drawdown test. Hazel (1975) method used to calculate average T value of 310 m^2/d for the unconfined interval of the Gambier Limestone.

A main test of 27.5 h (1650 min) was carried out on APCEL 14, followed by a recovery test. Wells HIN 51, HIN 52, and HIN 38 and HIN 50 were again used as the observation wells. Williams (1979) calculated an average T value of 310 m^2/d (drawdown and recovery curves) from the production well APCEL 14 using straight-line fit up to 600 min. From then on points deviated upward from the lines due either to leakage, a recharge boundary or the slight decline in pump rate during the test. The former two are more likely to exert stronger influences. Another alternative is a change in pumping conditions at the APCEL site ~1 km west (Williams, 1979).

A semi-log plot for data collected from observation well HIN 50 shows evidence of a discharging boundary and is not suitable for calculating an S value, and the log–log plot shows evidence of leakage and possibly the effect of slight pump rate decline (Williams, 1979). The average value of T calculated from both plots was ~350 m^2/d, which is in good agreement with the values obtained from step drawdown and continuous aquifer tests in the pumped well APCEL 14, and a S of 0.00018. These values were allocated a 'high' rating.