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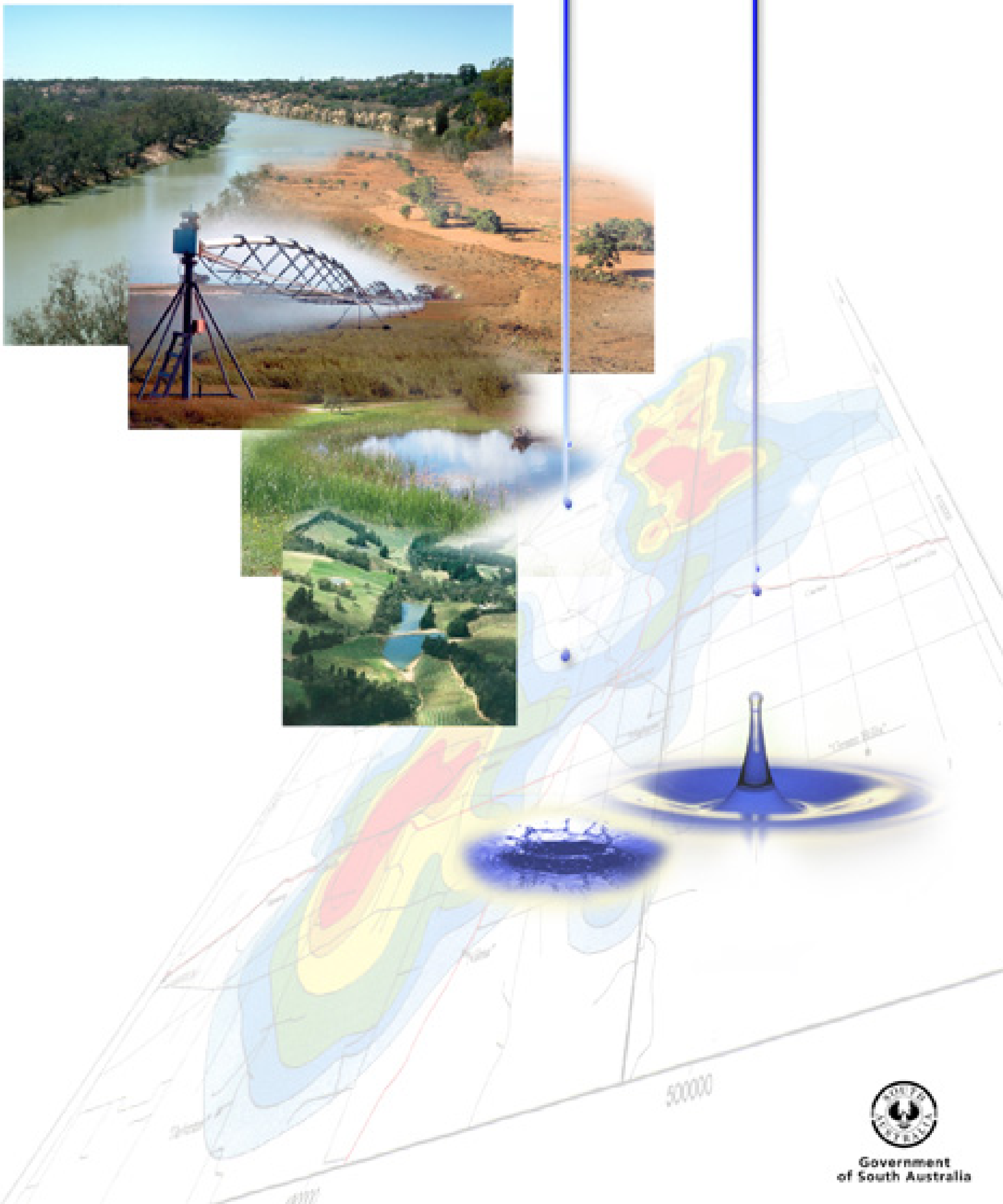
Kangaroo Flat Hydrogeological Investigation: pump test results

Report DWR 2001/008



Government of South Australia

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Julianne M. James-Smith and Kwadwo Osei-Bonsu

Resource Assessment Division
Department for Water Resources

August 2001

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Government of South Australia

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FOREWORD

South Australia's water resources are fundamental to the economic and social wellbeing of the State. Water resources are an integral part of our natural resources. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of surface and groundwater resources changes the natural balance and causes 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. Degradation may also be very gradual and take some years to become apparent, imparting a false sense of security.

Management of water resources requires a sound understanding of key factors such as physical extent (quantity), quality, availability, and constraints to development. The role of the Resource Assessment Division of the Department for Water Resources is to maintain an effective knowledge base on the State's water resources, including environmental and other factors likely to influence sustainable use and development, and to provide timely and relevant management advice.

Bryan Harris
Director, Resource Assessment Division
Department for Water Resources

ABBREVIATIONS

General

AHD	Australian height datum
b\`	thickness of confining bed
b	thickness of aquifer from which water is pumped
K_v	vertical hydraulic conductivity
K_h	horizontal hydraulic conductivity of aquifer from which water is pumped
r	radial distance
r_o	intersection of the straight-line slope with zero drawdown
r/B	dimensionless parameter defined by the following relation $r = r \sqrt{kv/Tb`}$
Q	pumping rate
Δs	drawdown per log cycle
S	storativity or storage coefficient
s	drawdown
SWL	standing water level
t	time
T	transmissivity
TDS	total dissolved solids
u	dimensionless parameter defined by the following relation $u = r^2 s/4Tt$
W(u, r/B)	leaky well function
W(u)	well function
y	year

Measurement

Units of measurement used in this volume are those of the International System of Units (SI) as well as units outside the SI which have been authorised for use within Australia's metric system.

d	day (time interval; 86.4×10^3 s)
ha	hectares (area 10^4 m^2)
h	hour (time interval; 3.6×10^3 s)
min	minute (time interval; 60s)

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ABSTRACT

The aim of the investigation was to determine the hydraulic properties of the T2 aquifer and the leakage properties of the overlying confining bed of the Port Willunga Formation. A pumping test, involving four production wells and one disused well in the Kangaroo Flat area, was carried out over the period 26–28 September 2000.

Analysis of the pump test data was conducted by using a combination of type-curve fitting on log–log paper and semi-log straight-line plots.

Analyses using the Cooper–Jacob semi-log straight-line method indicated an average transmissivity of 252 m^2/d and an average storage coefficient of 0.001. Analyses based on the Hantush (1964) curve-matching method yielded a transmissivity value of 192 m^2/d, a storage coefficient of 0.0015 and a vertical hydraulic conductivity for the confining bed of 0.0024 m/d. Results indicate the aquifer is semi-confined and leaky.

The hydraulic resistance of the confining bed was calculated at 419 days, which suggests the confining bed is highly transmissive and the potential for downward leakage is high. The potential therefore exits, for poor-quality water in the overlying Q4 aquifer to move down through the confining bed to the T2 aquifer during periods of intense pumping of the T2 aquifer.

INTRODUCTION

Kangaroo Flat lies ~42 km north-northeast of Adelaide, adjacent to the Northern Adelaide Plains Prescribed Wells Area (NAPPWA). The study area extends between longitudes 283000E and 284000E and between latitudes 617200N and 6172500N, and is ~70 km^2 in area (Fig. 1). Groundwater with salinity between 1200 and 1500 mg/L is extracted for irrigation from the T2 aquifer. It is estimated that approximately 420 ha are under irrigation in the Kangaroo Flat area, of which potatoes compromise 340 ha.

There was a substantial increase in groundwater extraction from the area, with a rise in Groundwater consumption from 330 ML/y in 1997, to 2150 ML/y in 1998 (Gerges, 2000). This has ultimately resulted in declining groundwater levels in the area. Any further increase in extraction would potentially lower the groundwater level in the T2 aquifer and consequently degrade the quality of groundwater in the T2 aquifer,

Department for Water Resources

0 10 20 Kilometers

Datum GDA94 - Projection MGA Zone 54

Kangaroo Flat
Hydrogeological Investigation
LOCATION PLAN

Figure 1

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causing additional strain on the NAPPWA water resources. This increased pumping has the potential to degrade the groundwater resources in the area and have a substantial impact on the NAPPWA. The Kangaroo Flat area was placed under a Notice of Restriction in March 2000.

To ensure that groundwater resources in the area are sustainable and can maintain a long-term water supply, a management strategy needs to be formulated to regulate the rates of withdrawal of groundwater and monitor the potential impact that declining water levels may have in and around the Kangaroo Flat area.

As part of the Department for Water Resources Kangaroo Flat Hydrogeological Investigation of groundwater resources, a pumping test of a major production well was conducted within the restricted area on 26–28 September 2000. The aim of the pumping test was to determine the hydraulic properties of the aquifer and the confining bed. The pumping test was carried out for a period of 24 hours with water levels monitored in four surrounding wells. The observation wells were located at distances between 89 m and 923 m away from the pumping well.

Sustainable management of groundwater in the Kangaroo Flat area requires an understanding of the occurrence, movement, behaviour and quality of the groundwater. A sustainable management plan should consider aquifer capabilities and include protection of groundwater quality.

The geology of the study area is shown in Figure 2, while Figure 3 shows the locations of pumping and observation wells and Figure 4 depicts the lithology along cross-section A–A′.

HYDROGEOLOGY

Quaternary and Tertiary consolidated and unconsolidated sedimentary deposit formations underlie the Kangaroo Flat area and are considered to contain the main aquifer systems of the area. The Quaternary lithological sequence ranges between 35–40 m thick and consists of minor dune sands underlain by Hindmarsh Clay. Beneath the Hindmarsh Clay is the fine-grained, poorly consolidated Carisbrooke Sand aquifer (Q4).

The area is located to the north of the depositional boundaries of the Munno Para Clay Formation and therefore does not include the Hallett Cove, Dry Creek Sand Formation (T1 aquifer) and Munno Para Clay areas. Lying beneath the Carisbrooke Sand is a fragile semi-confining layer of weathered Quaternary and Tertiary sediments. The Tertiary sequence containing several sub-aquifers lies under this semi-confining layer.

T2 AQUIFER

In this investigation the aquifer of principal interest is T2 aquifer, the top of which is situated 44–48 m beneath the surface. The T2 aquifer at the pumping site is approximately 20–30 m thick and it is partially penetrated by the wells used in this study, which tap only the upper 5–15 m of this aquifer.

A layer of clayey silt overlies the T2 aquifer, which is under semi-confined conditions. The semi-confining layer is very thin and the vertical leakage through this layer suspected to be very high. One of the aims of the pumping test was to determine the vertical hydraulic conductivity of this confining bed.

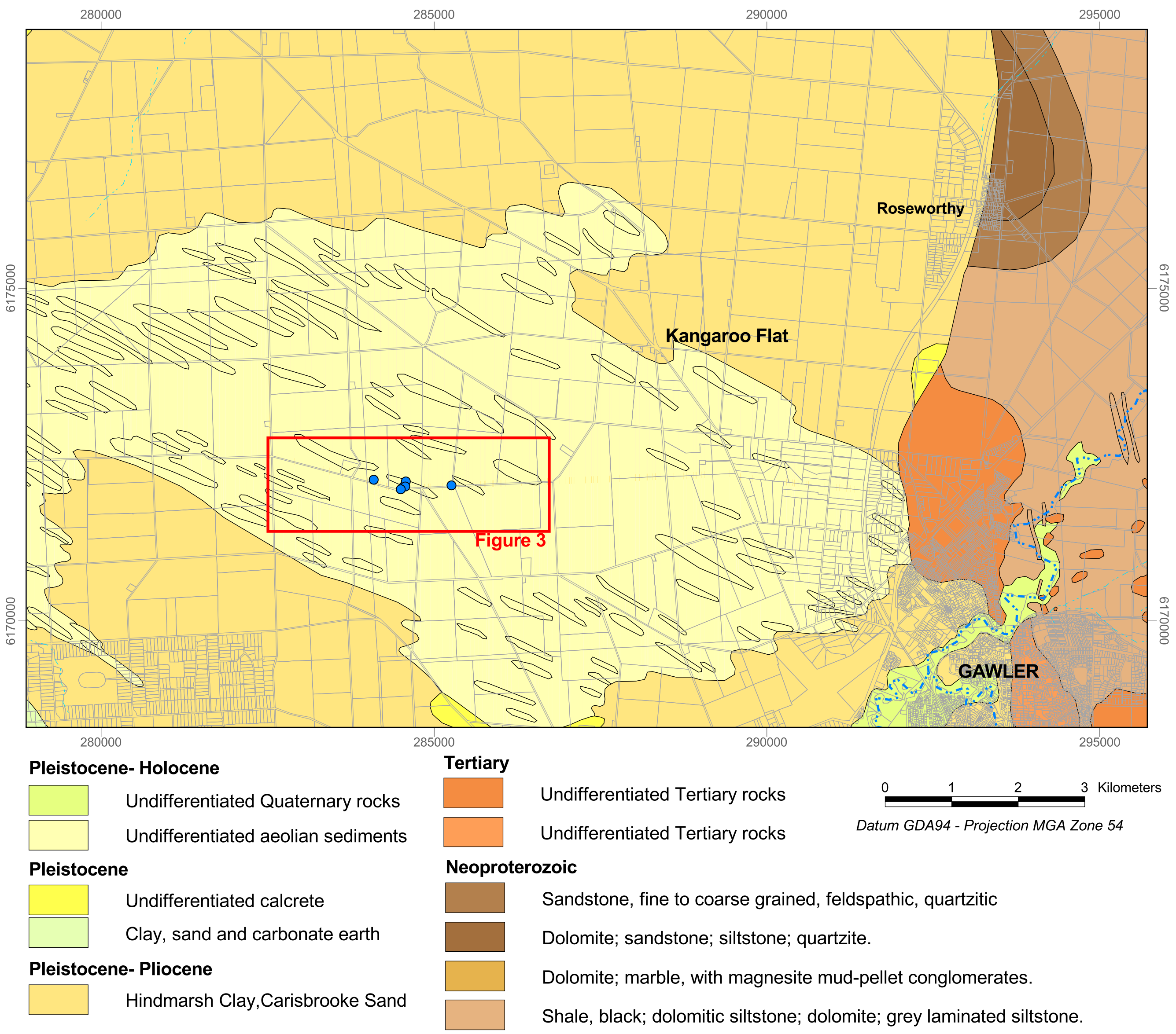

Figure 2 Geology of Kangaroo Flat

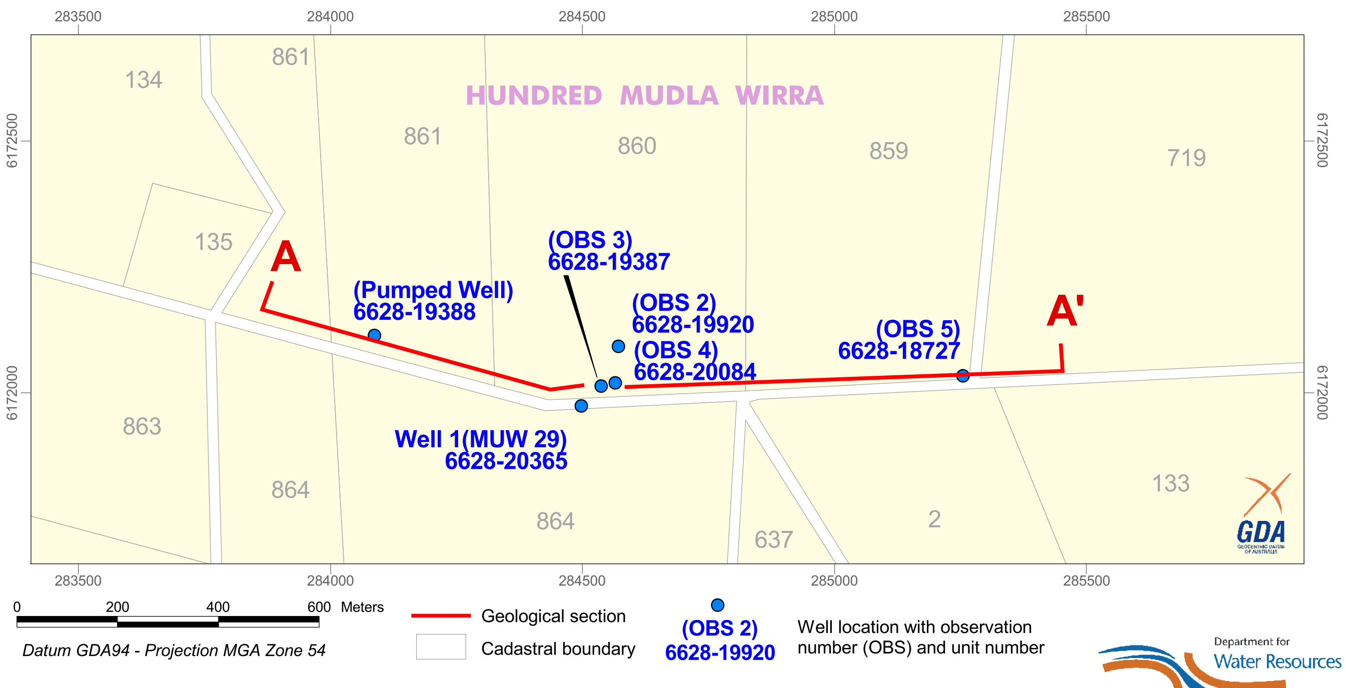

Figure 3 Location of pumping and observation wells and geological section A-A', Kangaroo Flat

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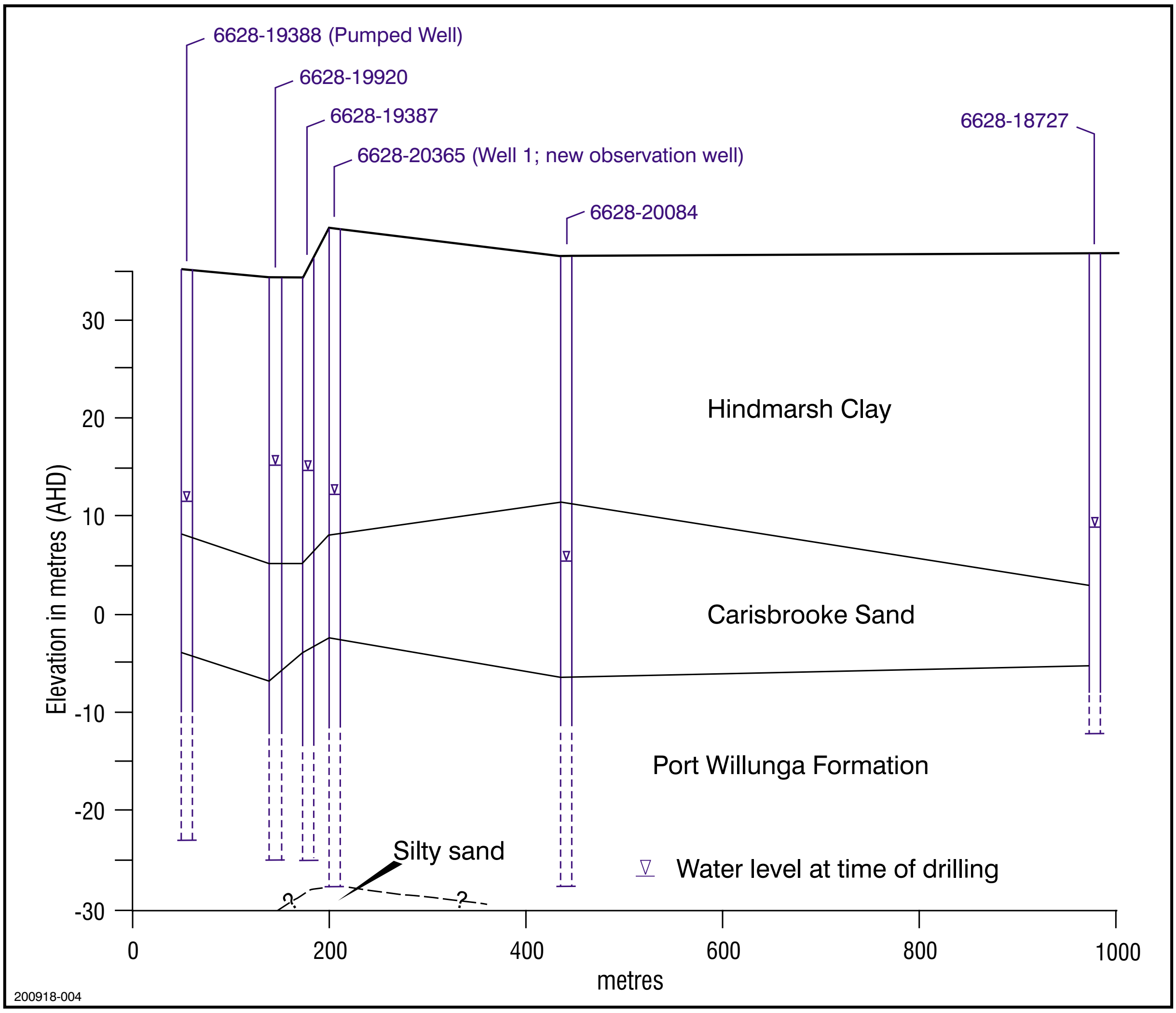

Figure 4 Kangaroo Flat hydrogeologic cross-section A–A´ (constructed from drillers log)

Groundwater is extracted predominantly from the T2 aquifer. Reported groundwater abstraction for agricultural purposes from the T2 aquifer, increased from 330 ML/y in 1997, to 2150 ML/y in 1998 (Gerges, 2000).

Salinity of groundwater in the T2 aquifer at the study area ranges between 1200–2300 mg/L. There is an increasing trend from low to higher salinity to the north and northwest. Saline groundwater is generally contained in the shallow Quaternary aquifers ranging from 2000 mg/L to 22 000 mg/L. Since the semi-confining layer is thin and made up of clayey silt, there is potential for downward-leakage of more saline water from the overlying Quaternary aquifers into the T2 aquifer during periods of high extraction from the T2 aquifer.

At Virginia, southwest of the Kangaroo Flat area and approximately 5 km from the boundary of the Kangaroo Flat restricted area is the centre of a cone of potentiometric depression for the T2 aquifer. The potentiometric contours indicate natural groundwater outflows from the Kangaroo Flat area towards the centre of the cone of depression.

PUMP TEST

DESCRIPTION

To obtain field values for hydraulic conductivity, storativity and leakage of the T2 aquifer and confining bed, a 24-hour pumping test was conducted using existing wells partially completed in the T2 aquifer. The wells used in the pumping test are labelled as 'Pumped Well' (well number 6628–19388), 'Obs 2' (6628–19920), 'Obs 3' (6628 –19387), 'Obs 4' (6628–200084) and 'Obs 5' (6628–18727) and their locations are shown in Figure 3. The pumping test was performed on Pumped Well and wells Obs 2, Obs 3, Obs 4 and Obs 5 were used as observation wells, located 89 m, 126 m, 386 m and 923 m away from the Pumped Well respectively. The Pumped Well was completed as open hole from 45–58 m. Details of the wells are shown in Table 1.

The test involved the pumping of Pumped Well at a constant rate of 18 L/s for 24 hours and observing the response of the hydraulic head in the Pumping Well as well as the four observation wells. Water levels were measured using water level probes and water samples were taken from the Production Well approximately every 100 minutes for total dissolved solids (TDS) analysis. Following the pumping test, recovery was monitored for 180 minutes (3 hours).

Prior to conducting the pumping test, wells Pumped Well, Obs 2, Obs 3, and Obs 4 had been continuously pumping for an unknown duration (the landowner gave an approximate estimate of 18 hours). The pumps were switched off and recovery of the wells was monitored for 1440 minutes (24 hours). Following the recovery, the pumping tests were undertaken, however, the water levels had not recovered in the 24-hour period to the standing water level measured nine days earlier. Figure 5 shows arithmetic plots of drawdown and recovery versus time observed in the Pumped Well, 5(a), and observation wells Obs 2, 5(b), and Obs 3, 5(a), during and after the pumping test. Results of TDS analysis are presented in Table 5.

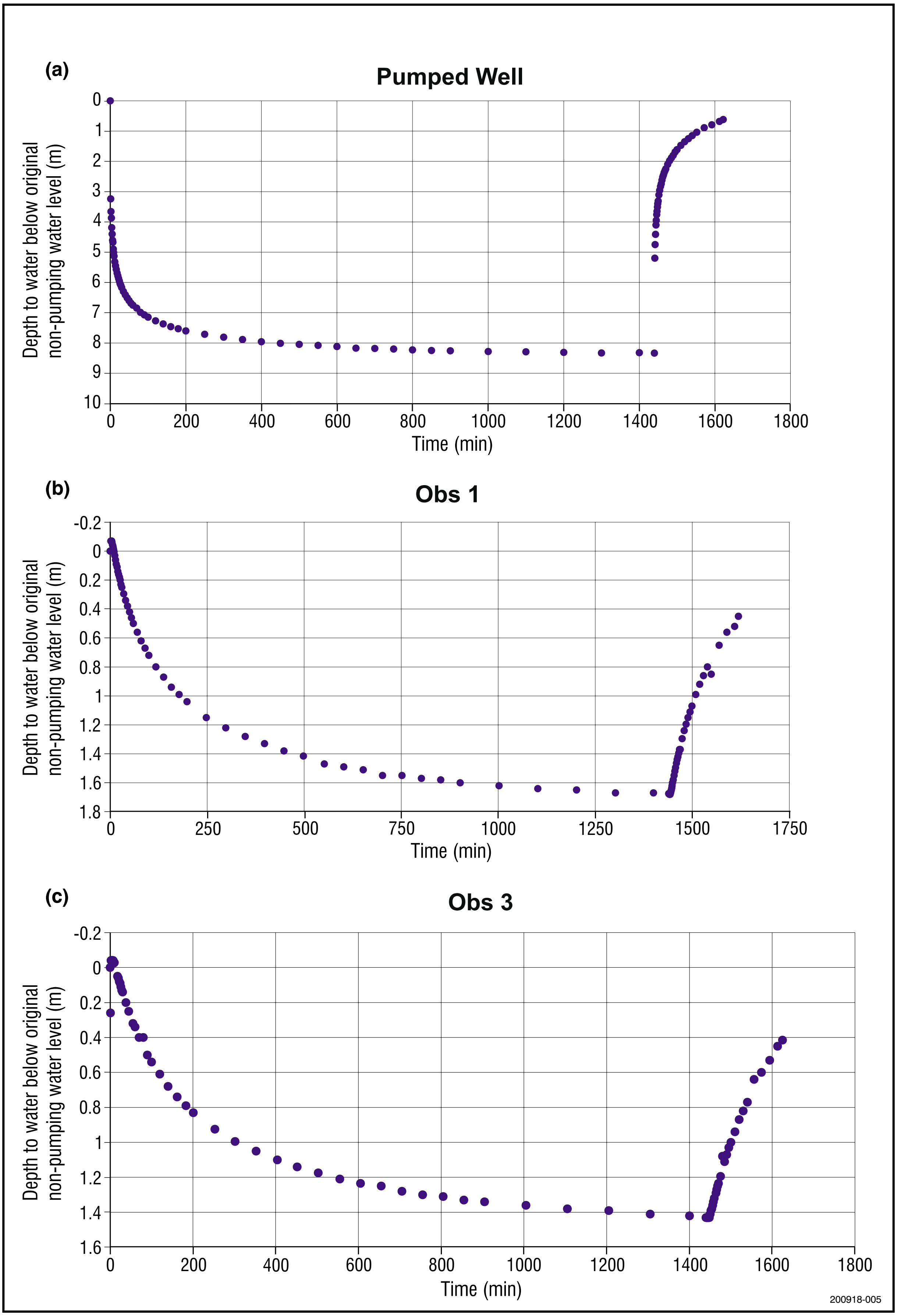

Figure 5 Arithmetic plots of drawdown and recovery versus time

Table 1 Hydrogeological Investigation well details, Kangaroo Flat

Properties	Pumped Well	Obs 2	Obs 3	Obs 4	Obs 5
Unit number	6628-19388	6628-19920	6628-19387	6628-20084	6628-18727
Permit number	47590	48684	44307		42730
Hundred	Mudla Wirra	Mudla Wirra	Mudla Wirra	Mudla Wirra	Mudla Wirra
Section	861	860	860	–	859
Completed	10.02.1999	15.09.1999	16.10.1998	17.02.2000	08.11.1997
Total depth (m)	58	60	58	63	48
Casing to (m)	45	48	45	48	44
Well yield (L/s) measured during drilling	25	22	18	22	10
Meter number	80-ZR5216	80-ZR5214	80-ZR5253	80-ZR5255	No head works
SWL (m) 19.09.2000	19.50	19.42	19.28	20.01	20.56
SWL (m) 27.09.2000 (after 24 h recovery)	21.76	21.78	21.64	22.45	22.67
GPS Easting	284210	284286	284335	284596	285133
GPS Northing	6171846	6171892	6171827	6171828	6171850
Distance from Pumped Well (m)	0	88.84	126.44	386.42	923.01
Average yield during test (L/s)	18.01	–	–	–	–

ANALYSIS AND RESULTS

The drawdown and recovery data obtained from the wells in the T2 aquifer during the 24-hour pumping test were analysed using:

- the Cooper–Jacob straight line semi-log method (Cooper and Jacob, 1946)
- Distance–Drawdown analysis
- the Hantush log–log graphical curve-matching analysis (Hantush, 1964).

The Cooper–Jacob and Distance–Drawdown analysis methods are based on a number of assumptions including; the aquifer is horizontal, isotropic, homogeneous, uniform in thickness, infinite in lateral extent and confined by impermeable beds. It is evident from Figure 5 that vertical leakage occurred through the confining bed during pumping. However, the Cooper–Jacob and Distance–Drawdown methods of aquifer analysis were used for obtaining estimates of the hydraulic conductivity and storativity of the aquifer. By restricting the analyses to suitable segments of the drawdown-time graphs, the effects of the deviations from all of the assumptions stated were minimised.

Cooper–Jacob method

The Cooper–Jacob method is applied in Figure 6, which shows drawdown-time graphs on semi-log scale. Figure 6(a) shows drawdown-time graph for the Pumped Well with straight-line graph segments of 0–200 minutes. Figure 6(b) shows drawdown-time graph for observation well Obs 2 with straight-line graph segments at 30–700 minutes. The linear drawdown segments from these graphs were used in the Cooper–Jacob analyses. The apparent boundary conditions encountered in the

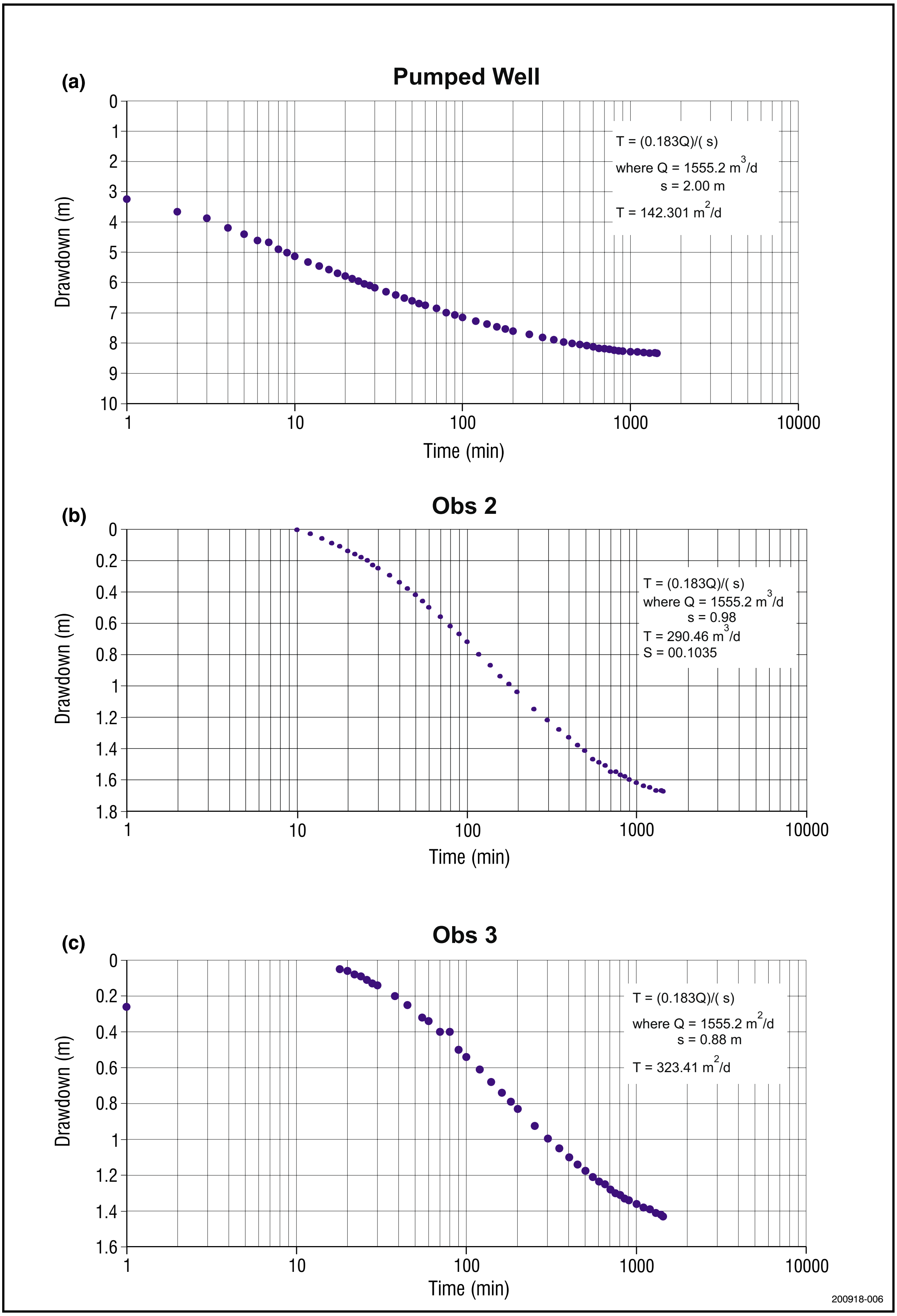

Figure 6 Semi-log plot of drawdown versus time

‘tailing off’ portions of Figure 6 are caused by water entering the pumped aquifer by either vertical leakage across a confining bed or release of water from storage in the confining bed.

The slope of the straight-line segment of Figure 6(a) is $\Delta s = 2.0$ m. Substituting this into the equation $T = (0.183Q) / \Delta s)$ yields a transmissivity value of 142 m^2/d. Figure 6(b) is a plot of drawdown versus time for observation well Obs 2, located 88.84 m away from the pumping well. The slope of the straight-line segment of Figure 6(b) is $\Delta s = 0.98$ m. Substituting this into the equation $T = (0.183Q) / \Delta s)$ yields a transmissivity value of T = 290 m^2/d. The intercept with abscissa $t_0 = 18$ min. Substituting this into equation the $S = 2.25\ Tt_0 / r^2$ yields a storage coefficient value of S = 0.001.

Figure 6(c) is a plot of drawdown versus time for observation well (6628–19387) located 126.44 m away from the pumping well. The slope of the straight-line segment of Figure 6(c) is $\Delta s = 0.88$ m. Substituting this into the equation $T = (0.183Q) / \Delta s)$ yields a transmissivity value of T = 323 m^2/d. The intercept with abscissa $t_0 = 25$ min. Substituting this into the equation $S = 2.25\ Tt_0 / r^2$ yields a storage coefficient value of S = 0.0008.

Table 2 gives a summary of the results of the Cooper–Jacob analyses. The Cooper–Jacob analysis yields an average transmissivity and storativity values of 252 m^2/d and 0.0009, respectively.

Table 2 Summary of results based on semi-log (Cooper–Jacob straight-line) method

Well name	**Bore status**	**Calculated distance from pumping well** (m)	**Observed maximum drawdown** (m)	**Calculated transmissivity** (m^2/d)	**Calculated storage coefficient**
Pumped Well	pumping*	0.00	8.335	142.301	–
Obs 2	observation**	88.84	1.675	290.41	0.001035
Obs 3	observation**	126.44	1.430	323.41	0.000790
Obs 4	observation	386.42	0.150	–	–
Obs 5	observation	923.01	-0.700	–	–

*Influenced by local hydraulic conditions in and near the well (e.g. drawdown in the Pumped Well can be influenced by well losses)

**The differences may be due to aquifer heterogeneity.

Distance–Drawdown method

Observation wells Obs 2, Obs 3 and Obs 4 (located 89 m, 126 m and 386 m away from Pumped Well, respectively) were used in the Distance–Drawdown analysis. The selected time was 500 minutes. Figure 7 shows a plot of drawdown versus distance from the pumping well at 500 minutes. The slope of the straight line is $\Delta s = 2.25$ m and the intercept with the abscissa $r_0 = 400$ m. Substituting these values into the equations $T = (2.3Q) / (2\pi\Delta s)$ and $S = 2.25\ Tt / r_0^2$ yields a transmissivity of 253 m^2/d and storage coefficient of 0.0012. These values compare very well with the averages obtained from the Cooper–Jacob (straight-line) method.

Hantush Method

The Hantush (1964) aquifer test analysis is a curve-matching procedure. The hydraulic properties of the aquifer and the confining bed were determined by

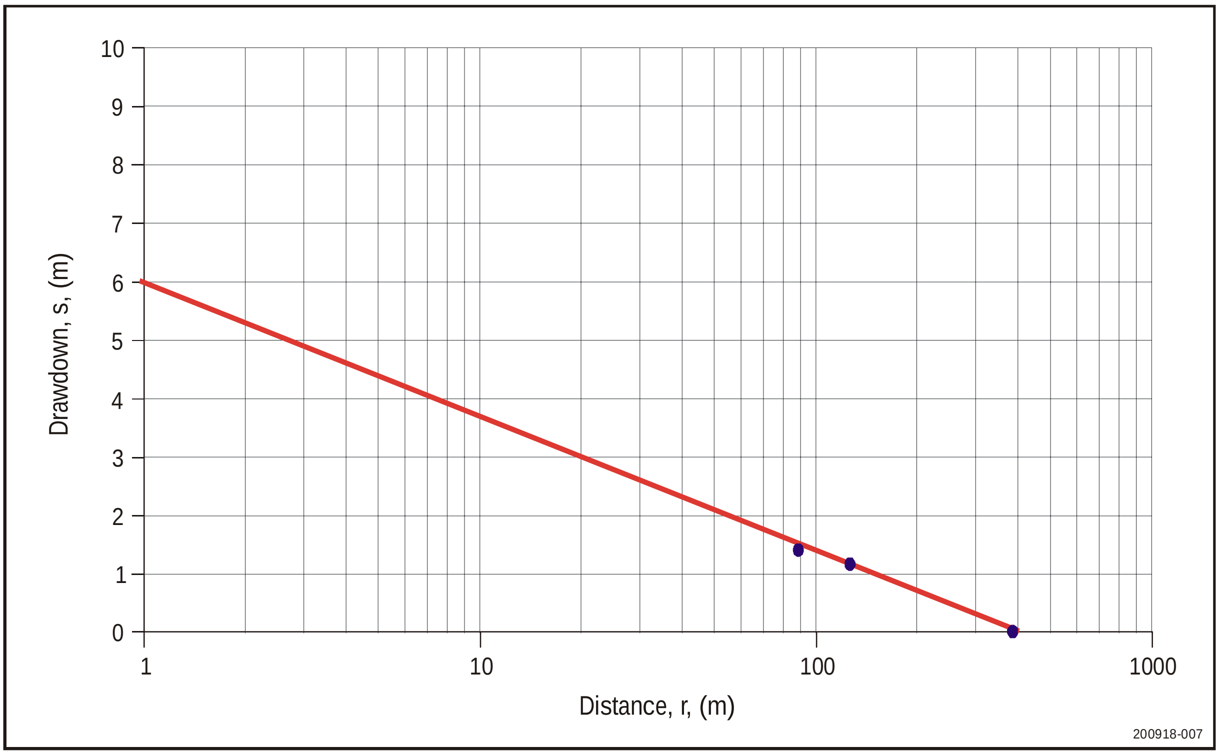

Figure 7 Distance–drawdown plot at t = 500 minutes

matching a log–log plot of drawdown and time data from observation well Obs 2 against a type plot of well function W(u) and u (Fig. 8) as described by Hantush (1964). The hydraulic properties obtained from this analysis are presented in Table 3. From the match point the following values were obtained:

- r/B = 0.3
- calculated transmissivity, T = Q/ ($4\pi\Delta s$) W(u,r/B) = 195 m^2/day
- storage coefficient, S = (4uTt) /r^2 = 0.0015
- leakage coefficient, $K_v/b = T (r/B)^2 / r^2 = 0.002\ d^{-1}$
- The hydraulic resistance of the confining bed is 419 days.

The hydraulic resistance characterises the resistance of the confining bed to vertical flow, either upward or downward. Large values of hydraulic resistance indicate a low leakage rate through the confining bed, while small values of hydraulic resistance indicate a higher leakage rate. A hydraulic resistance value of 419 days suggests a high leakage rate and a highly transmissive confining bed. This indicates a high potential for poor-quality water to move from the overlying Q4 aquifer through the confining bed to the T2 aquifer when the T2 aquifer is being pumped.

Table 3 summarises the hydraulic characteristics of the T2 aquifer and the confining bed determined from the Hantush method. For a thickness of 1 m the vertical hydraulic conductivity is 0.0024 m/d and the leakage coefficient (Kv/b) = 0.0024 d^{-1}.

Table 3 Summary of results based on Hantush method*

r/B	**Radial distance r** (m)	**Thickness of confining bed** (m)	**Vertical hydraulic conductivity of confining bed** (m/d)	**Aquifer transmissivity** (m^2/d)	**Storage coefficient**
0.31335	88.84	1.0	0.0023861	191.8	0.0014581

*Hantush (1964), 'Leaky Confined Partial Penetration Analysis'

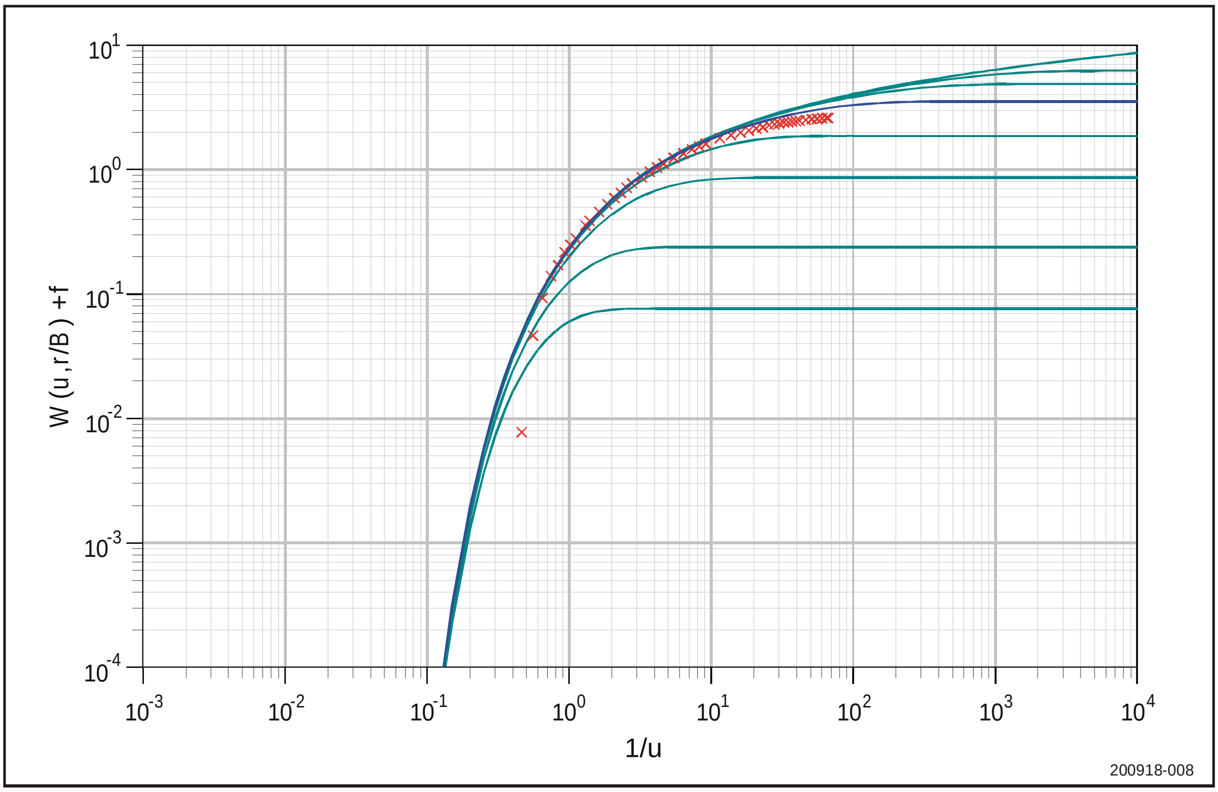

Figure 8 Hantush Leaky Confined Partial Penetration typed curve analysis

Table 4 summarises the hydraulic properties of the aquifer system obtained from the various methods of analysis with average Transmissivity, T = 222 m^2/d and storage coefficient, S = 0.0011.

Table 4 Hydraulic characteristics of the aquifer and confining bed

Method	Transmissivity (m^2d^{-1})	Storage coefficient	Leakage coefficient (d^{-1})
J-C* (Pumping Well)	142.30	–	–
J-C* (Obs 1)	290.41	0.001035	–
J-C* (Obs 2)	323.41	0.000790	–
J-C* (Distance–Drawdown)	253.02	0.001235	–
Recovery (Pumping Well)	132.39	–	–
Recovery (Obs 1)	279.06	–	–
Hantush, 1964 (Obs 1)	191.80	0.001458	0.0023861

* J-C: Jacob-Cooper (1946) straight-line semi-log method.

It should be noted that the different methods produced varying results, due to the assumptions underlying the various methods, which are not always entirely satisfied.

SALINITY CONCENTRATION DURING PUMPING

During the test, the TDS concentration (salinity) of water pumped from the T2 aquifer was measured. The TDS results are presented in Table 5, while Figure 9 shows a graph of TDS versus time on a linear scale. The concentration remains constant during pumping, which shows there is no evidence of leakage from Q4 to T2.

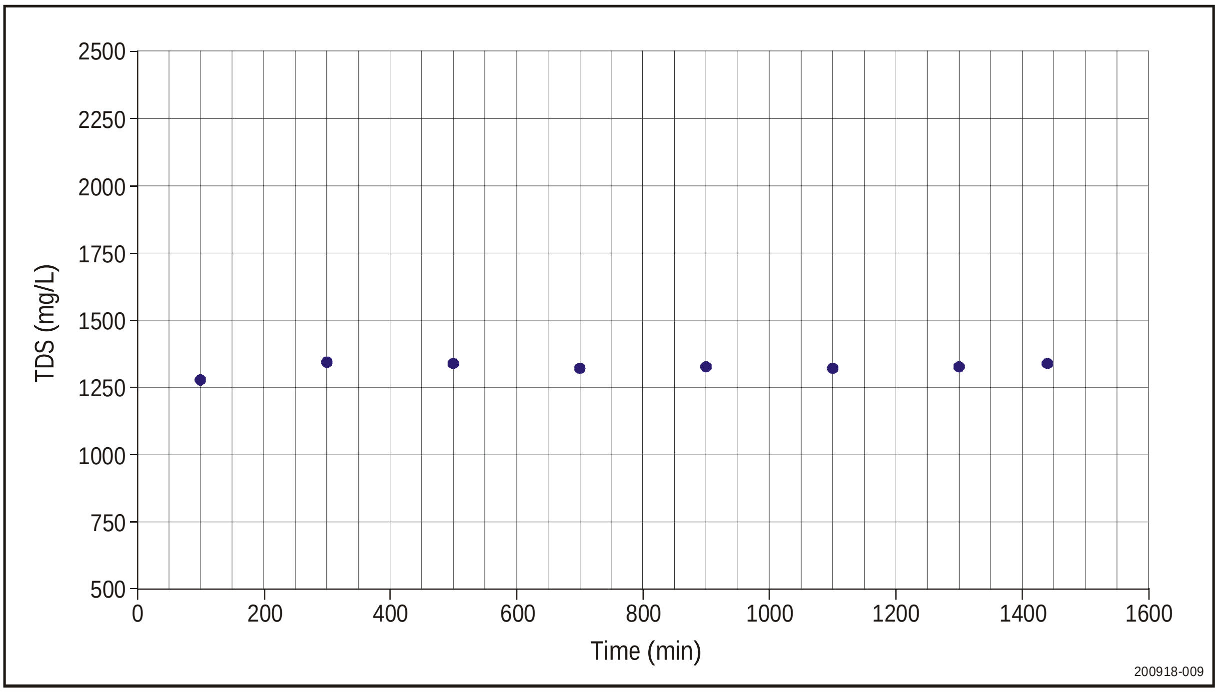

Figure 9 Concentration history of TDS in pumped water versus time, T2 aquifer

Table 5 Observed TDS of pumped water

Time sample taken (min)	**TDS** (mg/L)
0	1434
100	1278
300	1345
500	1340
700	1322
900	1328
1100	1322
1300	1328
1440	1340

CONCLUSIONS

The hydraulic properties of T2 aquifer and the confining bed in the Kangaroo Flat area were determined by using the Cooper–Jacob straight-line method and by matching a log–log plot of drawdown and time data versus type-plot of well function W(u) and u, described by Hantush, 1964.

The Cooper–Jacob semi-log method yielded an average transmissivity value of 250 m^2/d and average storage coefficient of 0.0009. A transmissivity value of 253 m^2/d and storage coefficient value of 0.00124 was obtained from Distance–Drawdown method. Based on the straight-line (semi-log) method of analysis, proposed by Cooper–Jacob, it can be concluded the average transmissivity of T2 aquifer at the study site is 252 m^2/d and the average storage coefficient is 0.001.

Analysis based on the Hantush (1964) curve-matching method gave a transmissivity value of 192 m^2/d, storage coefficient of 0.0015, a leakage coefficient of 0.0024 and a hydraulic resistance between the Q4 and T2 aquifer of 419 days. With a small hydraulic resistance of 419 days between Q4 and T2 aquifers, the likelihood of vertical flow of poor quality water from Q4 to T2 aquifer is high when T2 aquifer is stressed. This is due to the lowering of hydraulic head in T2 aquifer, which would create a higher hydraulic-head difference (driving force), between the two aquifers.

Since groundwater in the overlying Q4 aquifer is of poor quality and the hydraulic resistance of the semi-confining bed is low, control on the location and construction of wells and the withdrawal rate of water are necessary to prevent inflow of poor quality water from external sources. Mathematical modelling would be required for quantitative predictions of the response of the aquifer system to development in the Kangaroo Flat area.

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