The Department of Water, Land and Biodiversity Conservation

Robe township water supply wellfield evaluation

K OSEI-BONSU AND K DENNIS

Report DWLBC 2004/13

Government of South Australia

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FOREWORD

South Australia's natural resources are fundamental to the economic and social well-being of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisims 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 the resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various atresses 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, Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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SI UNITS COMMONLY USED WITHIN TEXT

Name of unit	Symbol	Definition in terms of other metric units	
Millimetre	mm	10^{-3} m	length
Metre	m		length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^{2}	area
Microlitre	µL	10^{-9} m^{3}	volume
Millilitre	mL	10^{-6} m^{3}	volume
Litre	L	10^{-3} m^{3}	volume
Kilolitre	kL	1 m^{3}	volume
Megalitre	ML	10^{3} m^{3}	volume
Gigalitres	GL	10^{6} m^{3}	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g		mass
Kilogram	kg	10^{3} g	Mass

Abbreviations Commonly Used Within Text

Abbreviation		Name	Units of measure
TDS	=	Total Dissolved Solids *(milligrams per litre)*	mg/L
EC	=	Electrical Conductivity *(micro Siemens per centimetre)*	µS/cm
PH	=	Acidity	
δD	=	Hydrogen isotope composition	$^{o}/_{oo}$
CFC	=	Chlorofluorocarbon *(parts per trillion volume)*	pptv
$\delta^{18}O$	=	Oxygen isotope composition	$^{o}/_{oo}$
^{14}C	=	Carbon-14 isotope *(percent modern Carbon)*	pmC
Ppm	=	Parts per million	
Ppb	=	Parts per billion	

1 INTRODUCTION

The groundwater supply provided by the South Australian Water Corporation (SA Water) for the township of Robe is currently from three wells located in confined sand aquifers more than 290 m below ground surface. The purpose of this work was to evaluate existing production wells with regard to their performance and provide recommendations to increase the deployable output and reliability of the wellfield to meet future demand.

In this report the term deployable output of a wellfield is defined as the amount of water the wellfield can produce from existing infrastructure under current operation conditions like construction and conditions of the wells, interference effect from the wells, deepest non-pumping water levels in each production well, pump duties and pump intake depths. While constraints imposed by abstraction licence and water quality issues could also affect the deployable output they were not considered in this work.

The important aspect of the assessment procedure was to establish yield-drawdown behaviour of each well and to identify the lowest non-pumping water levels in each production well at the start of pumping in the months of peak demand. Based on current hydraulic performances of the three wells and hydrogeologic conditions at the site, the deployable output from the existing wellfield during a drought period was estimated. The word drought, as used in this report, is defined on the basis of available water level records in the production wells and it is represented by the lowest water level recorded at a production well at the start of pumping at the beginning of a calendar month. The estimated future deployable output was based on utilising 98% of available drawdown in the wells during drought periods.

This report seeks to provide information useful to the water supply operator. The operator of the wellfield would need to know the amount of water that the wellfield could produce from existing infrastructure under current conditions, and the deployable output during periods of peak demand now and in the near future. The scope of this study was:

- To assess the production capacity of the current wellfield.
- To investigate the potential of the current wellfield to support the proposed peak demand of 59 L/s.
- To provide options to meet demand if the output from the current wellfield is inadequate.

Analysis of historical pumping and water level data from the production wells indicates that the total deployable output from wells Robe TWS 1 and 5 has been reduced by 50% between 1998 and 2001, and the production capacity of Robe TWS 6 has decreased from 20 m/kL/min to about 15 m/kL/min between 2001 and 2002. The loss of capacity in these wells over the years can be attributed to one or more factors that may have acted in various degrees to reduce the deployable output of the wells. These are: fall in groundwater levels as result of intensive pumping from the sand aquifer; well interference effect due to pumping from nearby production wells; and deterioration of the wells, well screen and any gravel packing around the well screens.

The study indicates that:

- The existing wellfield is capable of producing instantaneous yield of about 75 L/s.
- The current peak instantaneous extraction is 70 L/s.

- During periods of drought and high demand a deployable output of ~31.6 L/s could be obtained in the medium term and ~26 L/s in the long term from the existing wellfield.
- An average medium-term deployable output of 34.5 L/s and long-term deployable output of 28.7 L/s could be obtained from the existing wellfield.
- The estimated average medium-term deployable output of 34.5 L/s is almost equal to the current peak day average yield of 33.0 L/s.
- The peak day average yield from the wellfield could be represented as the average medium-term deployable output determined from analysis of well and aquifer data provided.
- The wellfield under current conditions would not be able to produce the average yield of 59 L/s SA Water would need to extract on peak days in the near future.

The potential of increasing the production capacity by expanding the wellfield by adding one production well to the current ones was investigated. The estimated deployable output for all the scenarios investigated for a proposed expanded wellfield of four production wells ranged between 39.0 L/s and 42.1 L/s. This falls short of the anticipated average yield of 59 L/s that is estimated to be required during periods of peak demand in the near future.

The studies have also shown that under drought conditions the deployable output of the wellfield could increase from 31.5 L/s to:

- 47 L/s if Robe TWS 1 is decommissioned and replaced with a new well which is as efficient as Robe TWS 5
- 60 L/s if two new deep wells with their pump intake set at 95 m below ground surface are constructed.

Additional factors not considered in this work and which should be addressed in the short term if SA Water plans to increase capacity by establishing a new well should include:

- A detailed review of any changes in salinity during pumping demand.
- A detailed numerical model assessment of predicted impacts given that in this locality the aquifer is only between 2 to 3 m thick, and it is uncertain what drawdown cone may develop or how far it may extend.
- The establishment of two or three observation wells within reasonable proximity of the pumping wells given that the current regional observation well operated by the Department of Water, Land and Biodiversity Conservation (DWLBC) is 20 km distant.
- Establishment of two or three observation wells will assist SA Water in managing potential risks of well field failure either as a result of too great extractive demand placed on an aquifer only 2–3 m thick or the possible risk of saline water intrusion given the proximity of the town water supply to the coast.
- Consideration should also be given to the installation of a bigger above ground storage tank to buffer demand during peak season.

2 STUDY AREA

Robe, which is about 340 km south east of Adelaide, is a small historic fishing town located on the Limestone Coast in the South East Region of South Australia, Figure 1. The normal population of the town is 1450 people, but because it is a popular summer holiday destination the population can swell to almost ten times its normal size (District Council of Robe, 2003).

Tourism and lobster fishing are the predominant industries of Robe, with the surrounding district involved in the production of wool, beef cattle, lambs, wines and some cereal crops.

The temperature of Robe is shown in Figure 2. The highest daily maximum temperature ranges from 20.4°C in June to 39.6°C in February. The lowest daily minimum temperature varies from -2.8°C in June to 5.2°C in January. The mean daily maximum temperature ranges from 13.6°C in July to 22.5°C in February. The mean daily minimum temperature ranges between 8.1°C in July to 13.7°C in February.

The rainfall of Robe is shown in Figure 3. The highest monthly rainfall at Robe varies between 87.6 mm in November to 217.1 mm in June. The lowest monthly rainfall ranges between 0 mm in the months of December through April, to 32.6 mm in July. The mean monthly rainfall ranges between 18.3 mm in February and 104.5 mm in July.

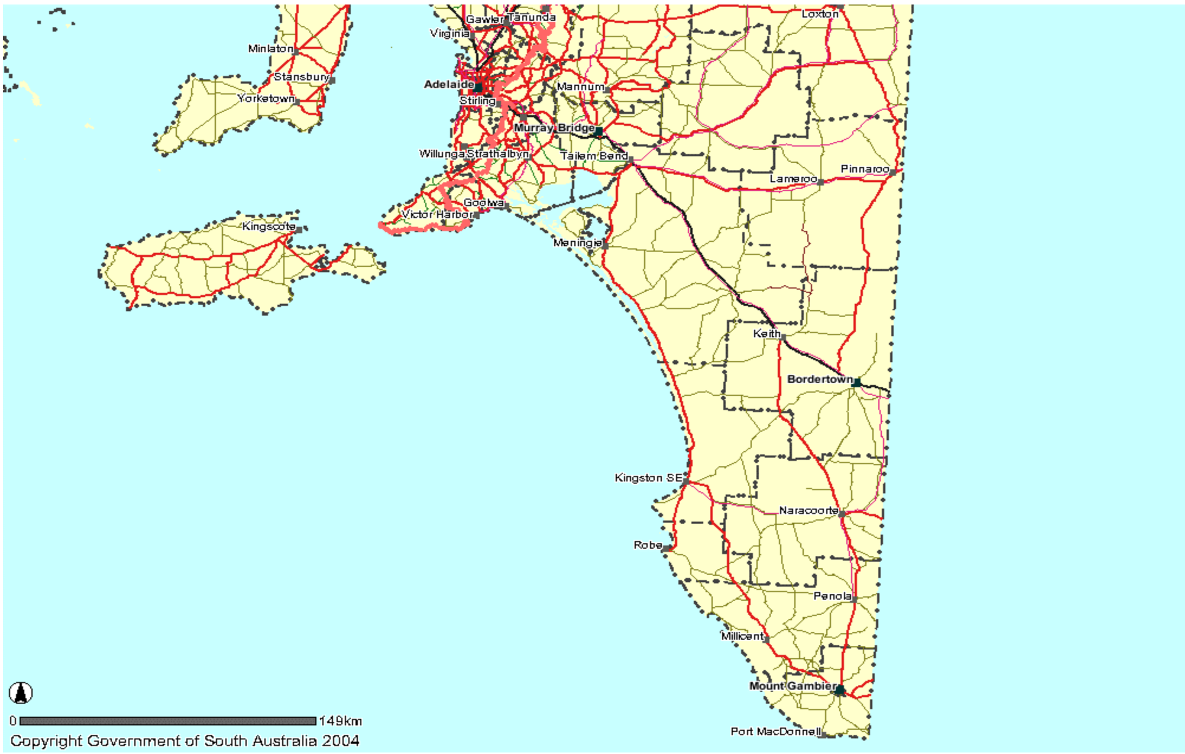

Figure 1. Site location

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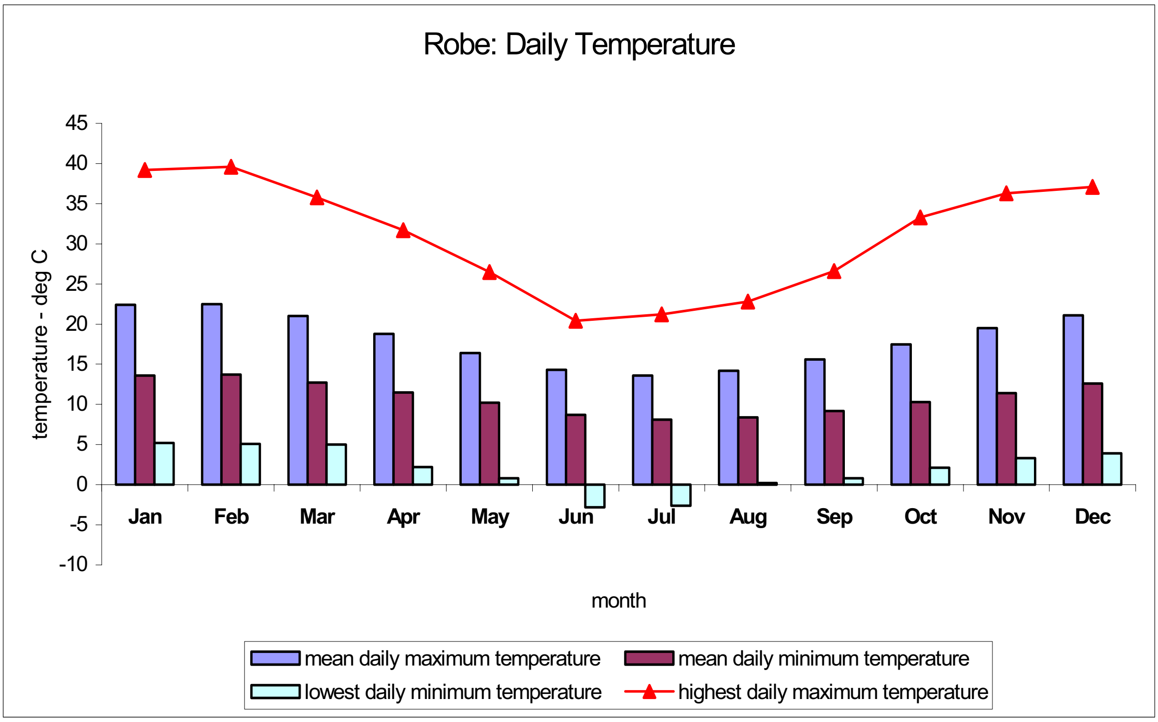


Figure 2. Robe daily temperature

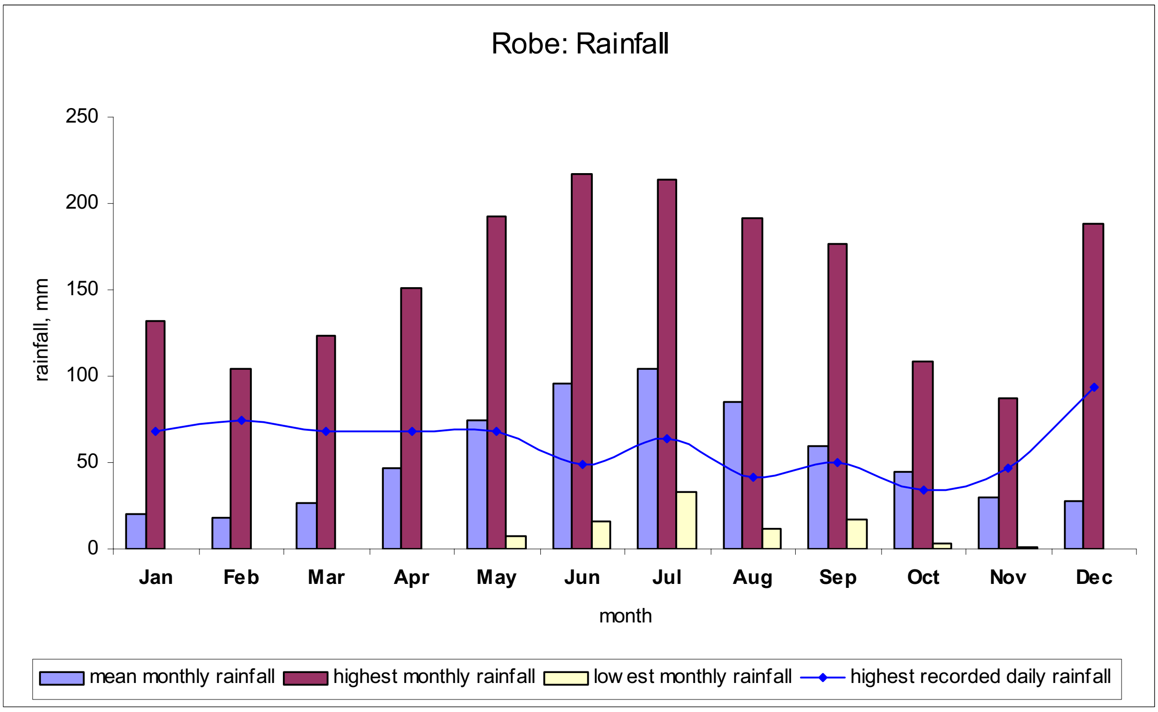


Figure 3. Robe monthly rainfall

3 SITE HYDROGEOLOGY

Hydrogeologic information of the site was obtained through review and analysis of existing well and borehole logs, pumping test results, water level data, and the production history and performance of the Robe Township Water Supply (TWS) wellfield. Data were collected about the type and thickness of geologic materials forming the aquifer system, the occurrence and flow of groundwater, and the quality of the groundwater in the study area. The hydrogeologic information acquired was used in:

- assessing changes in the performance of current production wells
- determining how the wells that constitute the wellfield interact with one another
- estimating the deployable output of an expanded wellfield.

The geological, hydrogeological and groundwater pumping information used in this study was sourced from the State well database (SA_GEODATA), DWLBC (Mount Gambier office) and SA Water (Mount Gambier). The following well information were used in this study: well name, well identification number, well location, date drilled, well depth, well construction, length of casing, well yield, pump settings and historical extraction rates. The hydraulic properties of the aquifer were determined from pump test results.

Hydrogeology of the confined sand aquifer

The hydrogeologic materials underlying the study site consist of a sequence of limestone–sandstone and sand interbedded with marl and clay. There are two main aquifers in the study area — an unconfined limestone–sandstone and confined sand aquifers — separated by marl and carbonaceous clay deposits. The formation logs of selected boreholes are shown in (App. 1). A brief description of the hydrogeology of the confined sand aquifer is reported below.

The sand aquifer system consists of a sequence of non-calcareous quartz sand, interbedded with carbonaceous clay. In and around Robe, the depth to the sand aquifer is more than 290 m below ground surface, and thickness of the sand aquifers ranges between 3 and 4 m. Most wells drilled in the sand aquifer are drilled to depths of up to ~300 m below land surface, and the wells are cased and screened. Data on aquifer hydraulic properties, like transmissivity and storage coefficient, is lacking in the literature. Drillers estimated yield of wells tapping the confined sand aquifer range from less than 0.5 L/s to as high as 100 L/s. Generally, water in the sand aquifer is under confined conditions. Piezometric heads in the confined aquifer in and around Robe stand above ground level and above levels in the overlying unconfined aquifer. In the Kingston-SE, Robe, Beachport and Lucindale areas the confined aquifer wells flow at land surface. Water level maps constructed by Rammers and Stadter (2002; using water level elevations collected between September–October 2001 and March 2002 from observation wells tapping the confined sand aquifer) indicate that groundwater in Robe and surrounding areas generally flows west. Inflow to the confined sand aquifer is by lateral groundwater flow from western Victoria through the South East region of South Australia. Outflow from this aquifer occurs as discharge to the ocean. Groundwater pumping is a more recent form of discharge from this aquifer. The chemistry of water in this aquifer is characterised by low total dissolved solid (TDS) concentration, ranging between 500 and 1000 mg/L.

Figure 4 is a map showing the location of Robe town and nearby observation wells completed in the confined aquifer. Hydrographs of the selected observation wells are shown in Figures 5–12. General groundwater level behaviour reflects seasonal winter-high and summer-low fluctuations in response to seasonal summer pumping demand and winter recovery.

Figure 4. Location of selected observation wells near Robe township

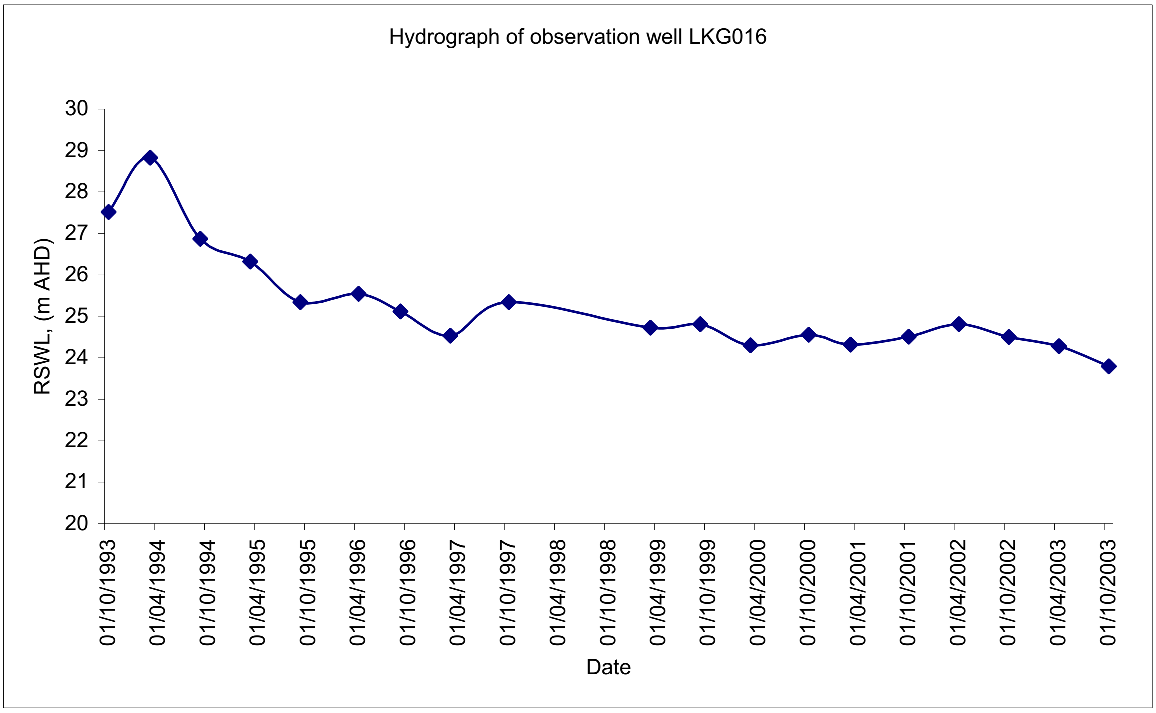


Figure 5. Hydrograph of observation well LKG016

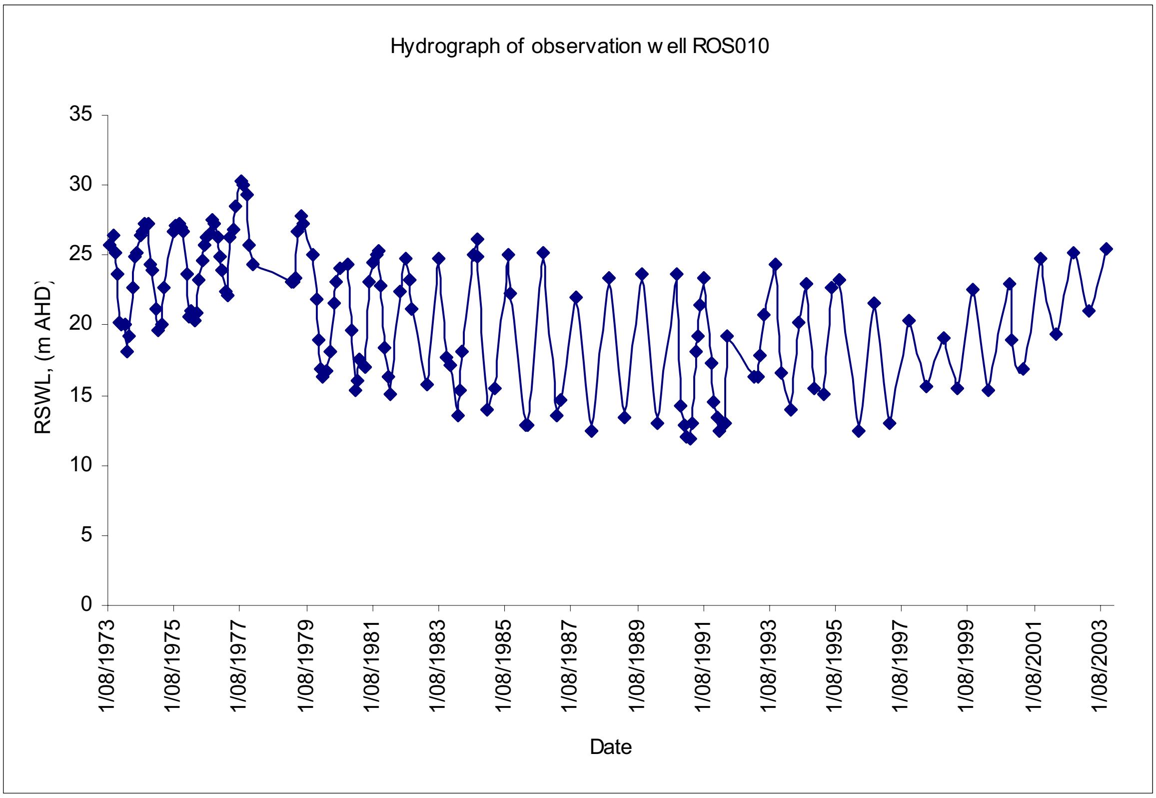


Figure 6. Hydrograph of observation well ROS010

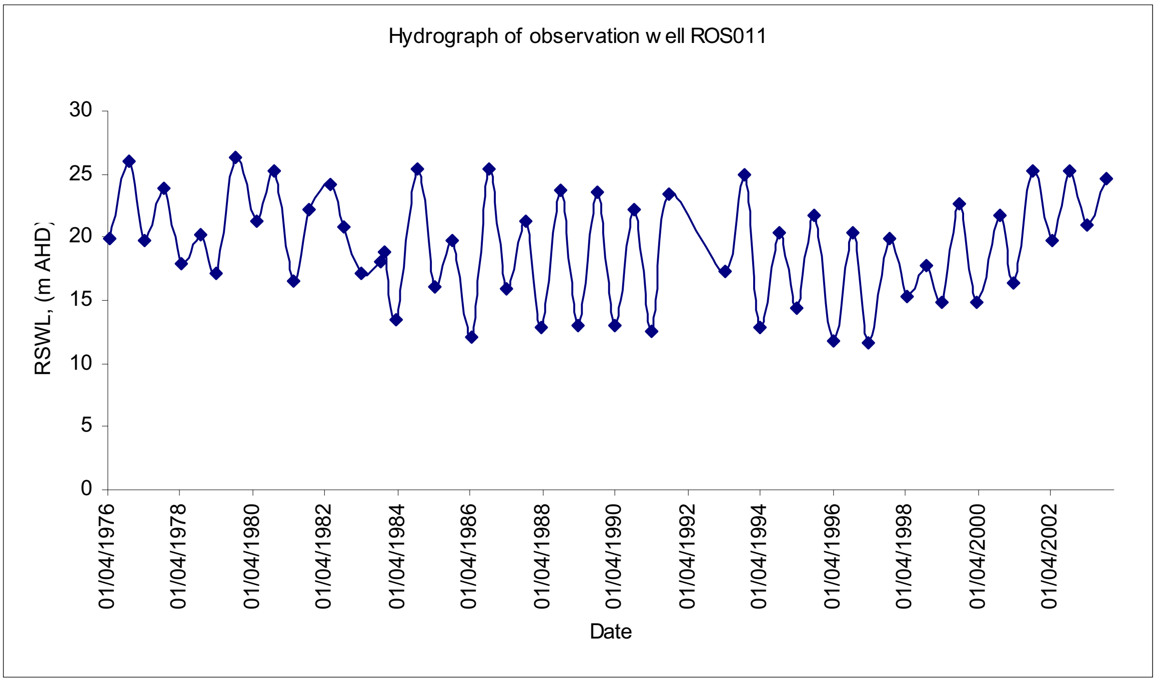


Figure 7. Hydrograph of observation well ROS011

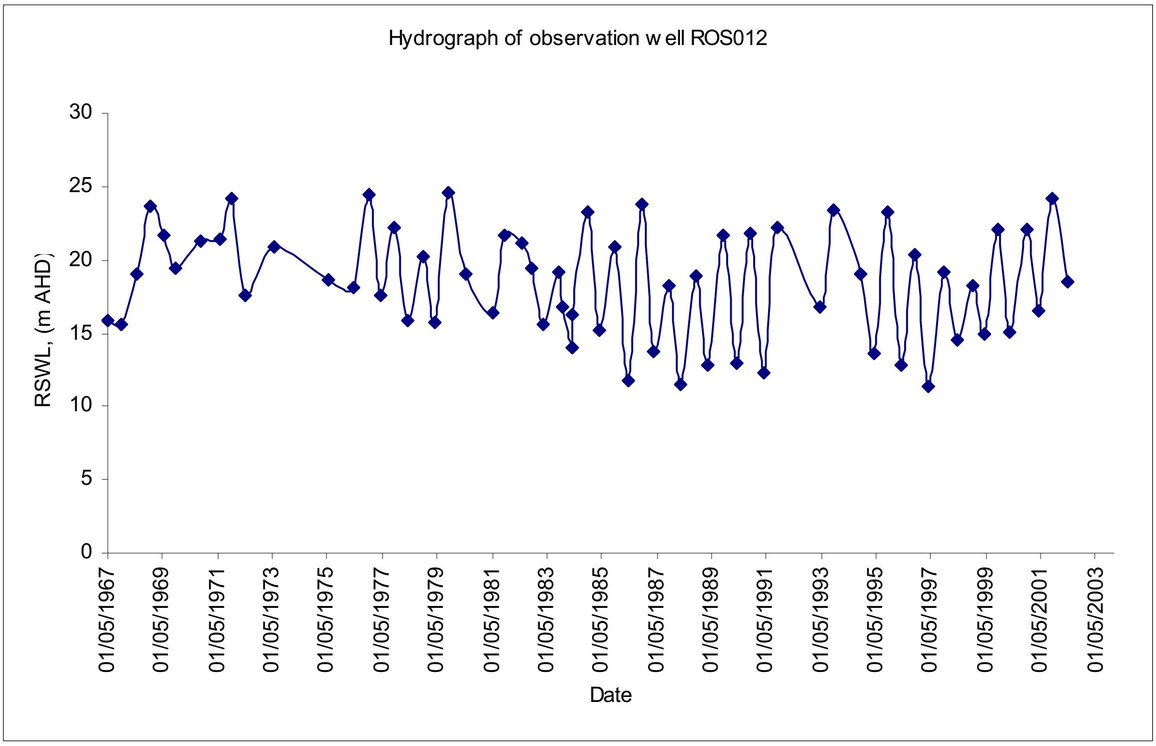


Figure 8. Hydrograph of observation well ROS012

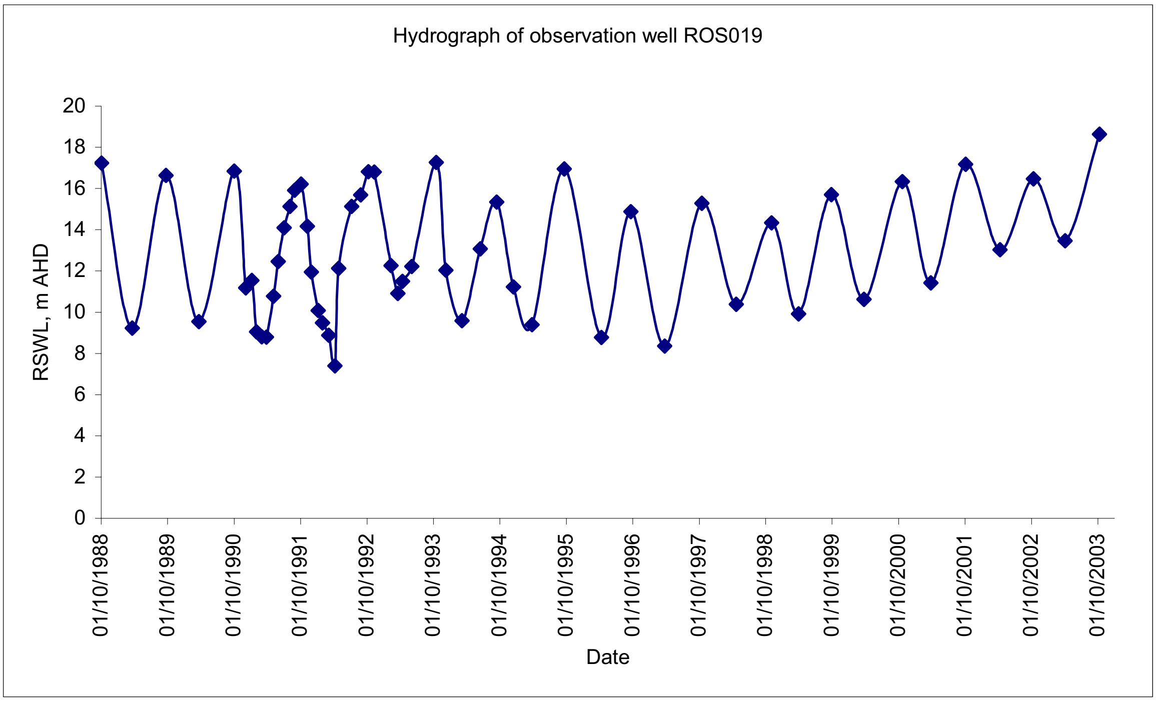


Figure 9. Hydrograph of observation well ROS019

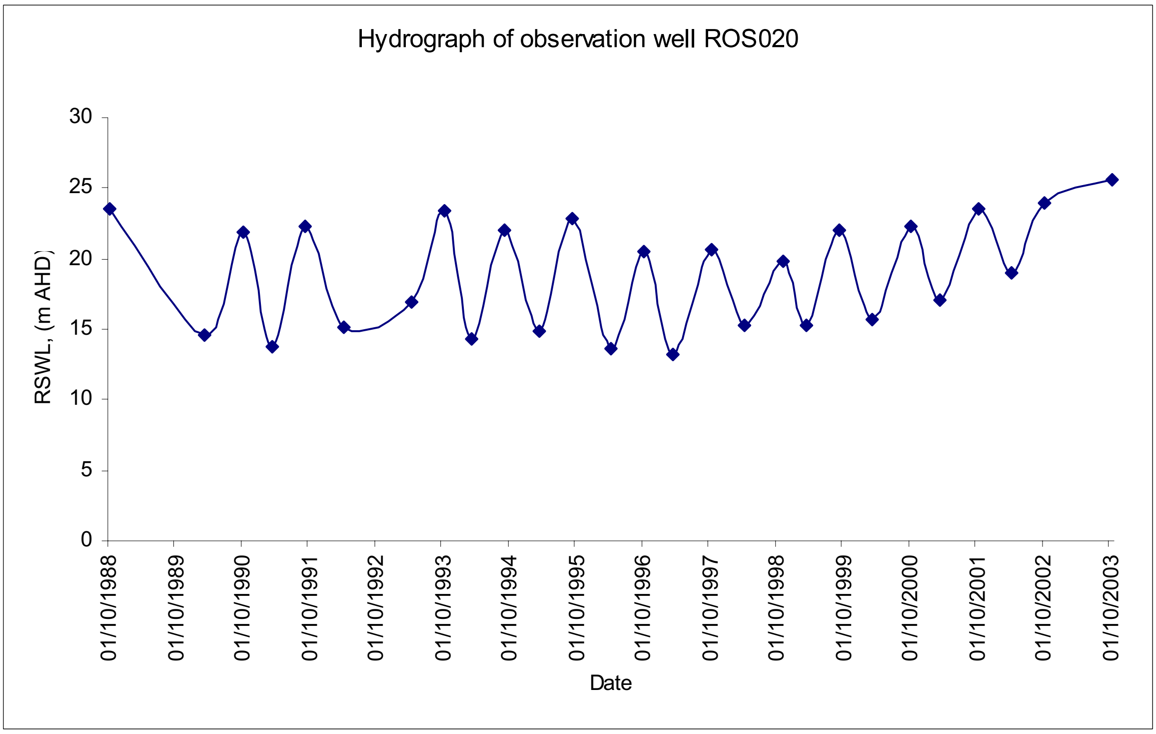


Figure 10. Hydrograph of observation well ROS020

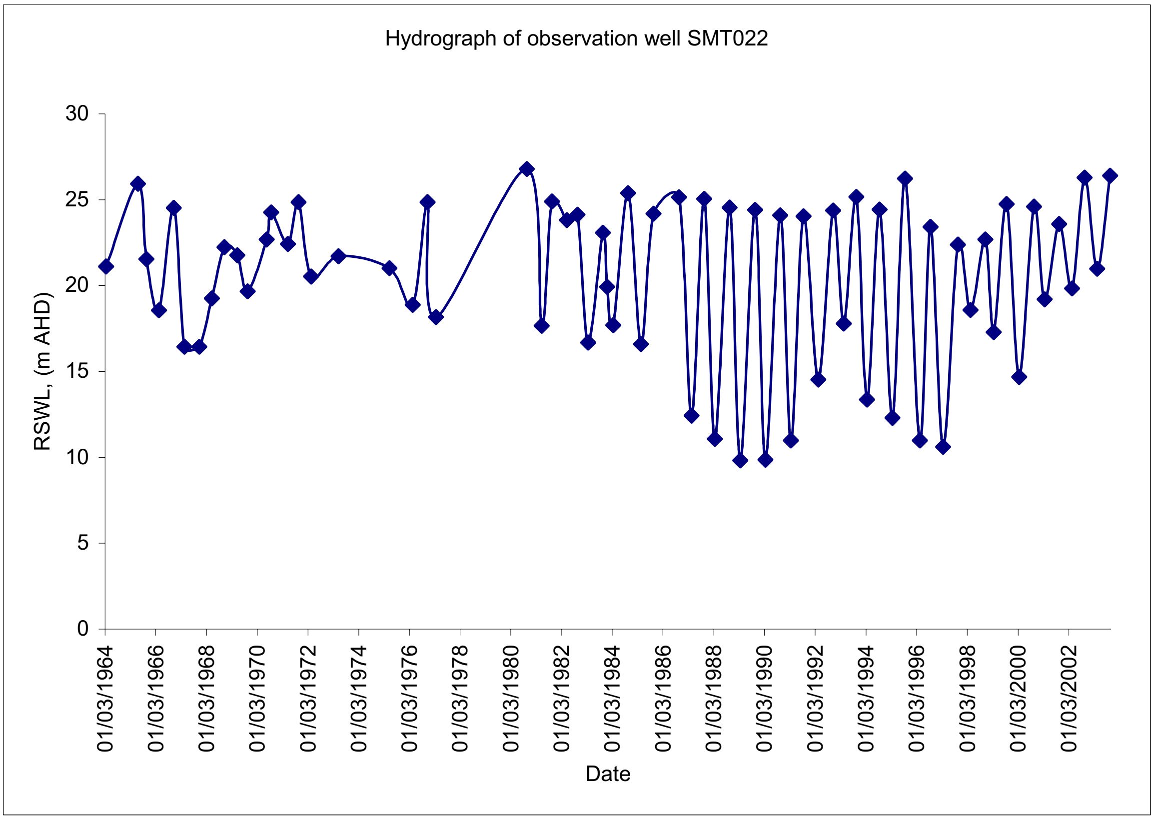


Figure 11. Hydrograph of observation well SMT022

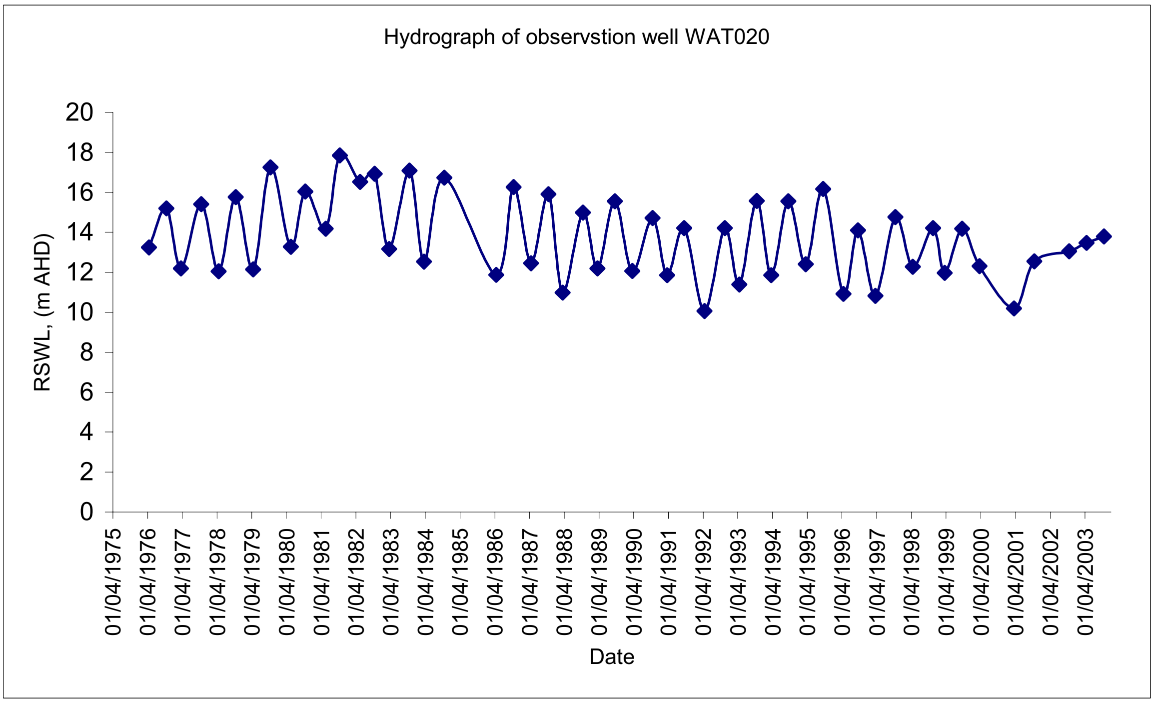


Figure 12. Hydrograph of observation well WAT020

4 ROBE TWS WELLFIELD

Groundwater is the major source of water for domestic, agricultural (irrigation), industrial and recreational (watering of golf courses) use in the South East region of South Australia. In this region of South Australia, groundwater is generally abstracted from the unconfined aquifer. The groundwater resources from the confined sand aquifer have not been developed to a large scale in the South East region due basically to the cost of drilling to deeper depths to tap the sand aquifers. However, the confined aquifer is an important source of water supply to towns in the South East. The largest single user of groundwater from the confined aquifer in the South East is SA Water, which uses the deep confined aquifer as source of water supply for six towns, including Robe.

The Robe TWS wellfield is made up of six wells. These wells are identified as Robe TWS 1 to 6. Currently Robe TWS 1, 5 and 6 (Fig. 13) are the production wells in use. Robe TWS 1 and 5 are configured to operate at the same time whilst Bore 6 comes on line when the level of water in a 136 kL water supply tank falls below ~70% capacity. There is intermittent pumping at the wellfield with the wells pumping 18 h on and 6 h off each day. The operator observations between pumping well stop and start again is ~7 min, and pumping is ~15 min. The peak instantaneous extraction from the wellfield is currently 70 L/s with all bores pumping.

The monthly withdrawal from four production wells is shown in Figures 14–17. In general, there is an overall reduction in the amount of water pumped at Robe TWS 1 and 5 since the beginning of 2000. There is an overall increase in the amount of water extracted from TWS 6 since it was commissioned in 2001. The monthly total groundwater extracted by SA Water from the Robe TWS wellfield ranges between 6319 kL in August 1997 to 74 837 kL in December 1999 (Fig. 18). In December 1999, a total of 21 732 kL was pumped from Robe TWS 2, (which has been decommissioned), 15 894 kL from TWS 5 and 37 211 kL from TWS 1.

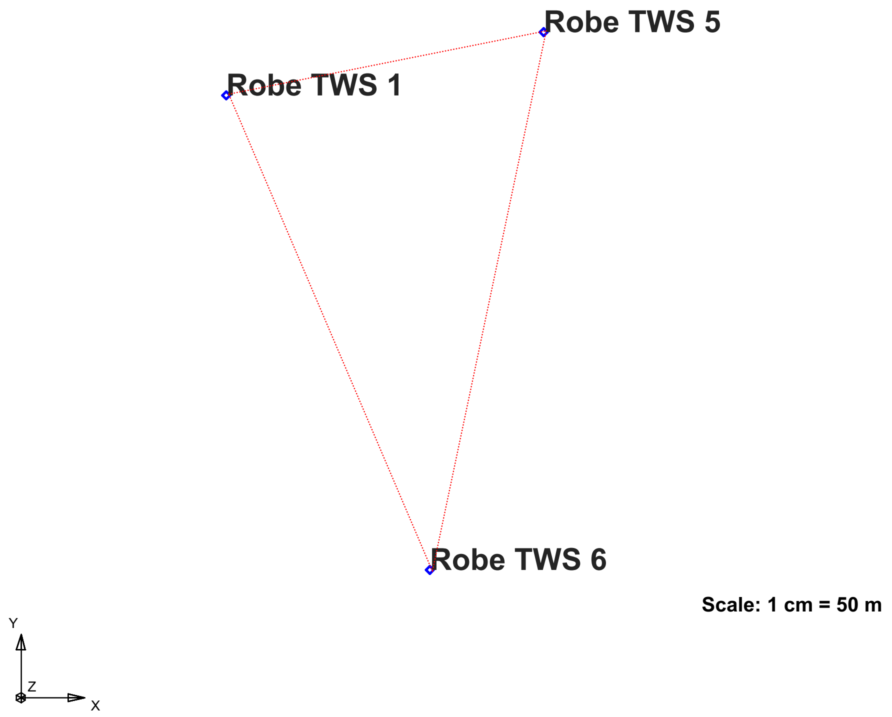


Figure 13. Location of current production wells at Robe TWS wellfield

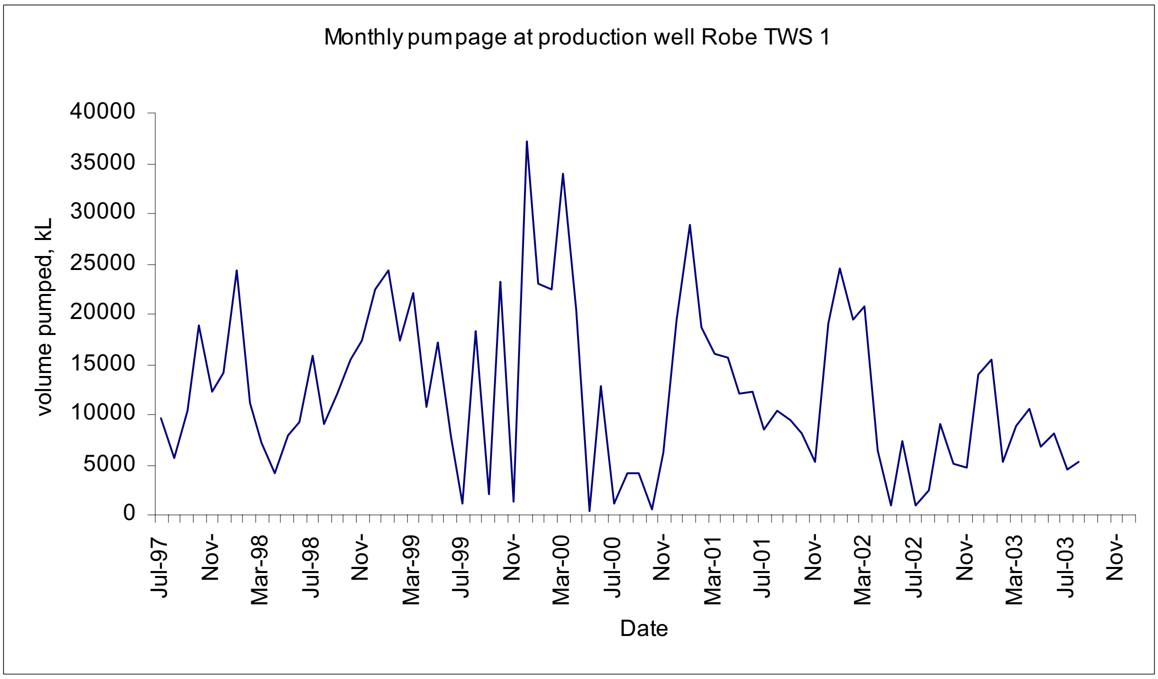


Figure 14. Monthly pumpage at production well Robe TWS 1

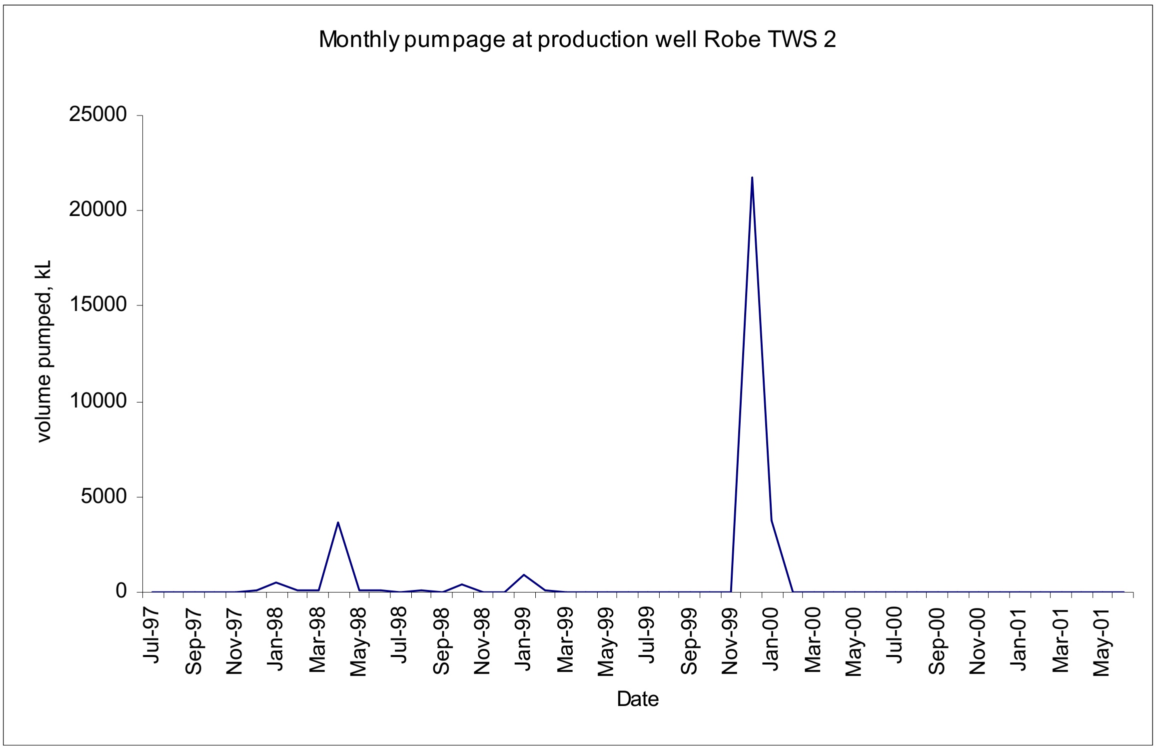


Figure 15. Monthly pumpage at production well Robe TWS 2

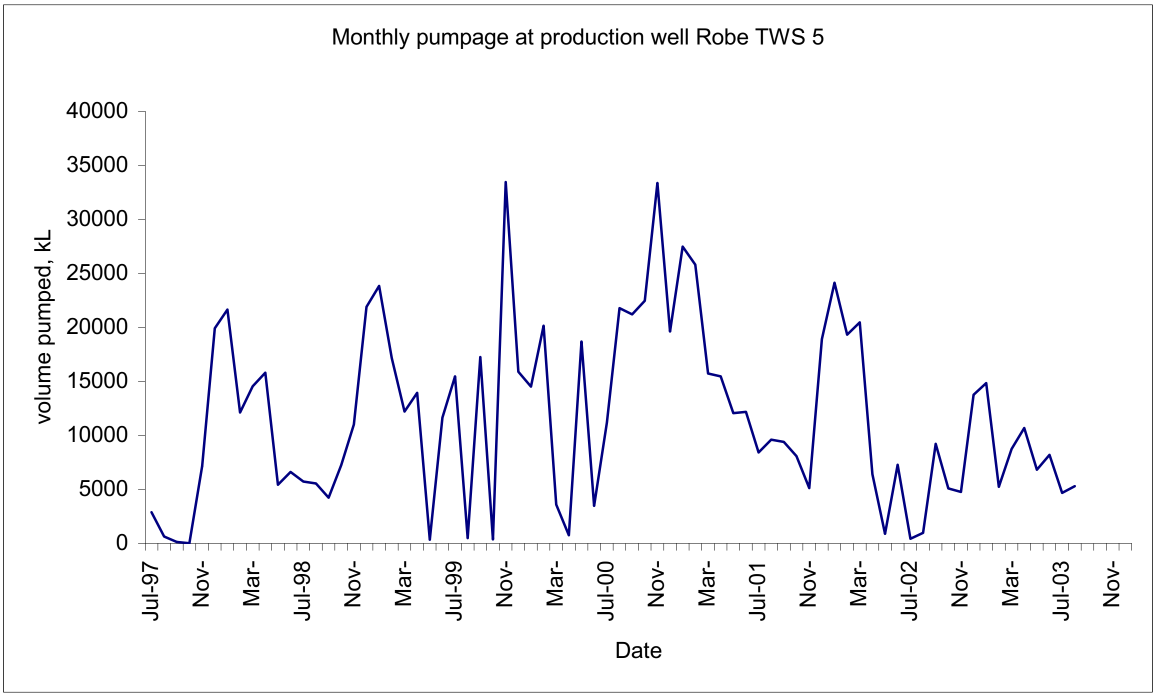


Figure 16. Monthly pumpage at production well Robe TWS 5

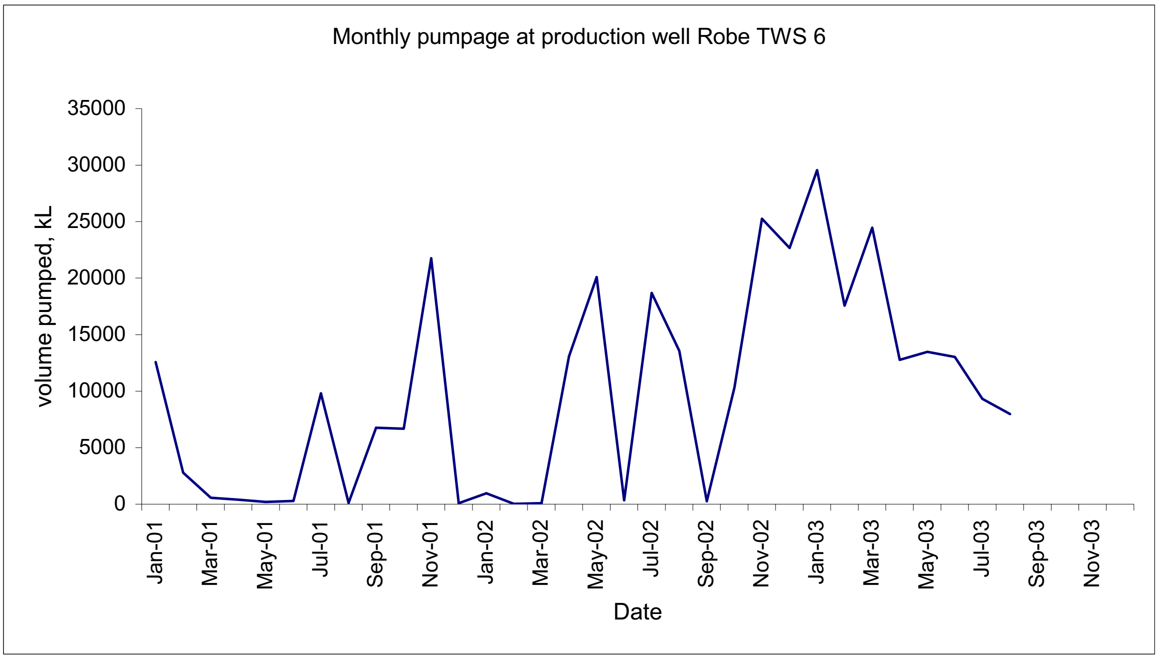


Figure 17. Monthly pumpage at production well Robe TWS 6

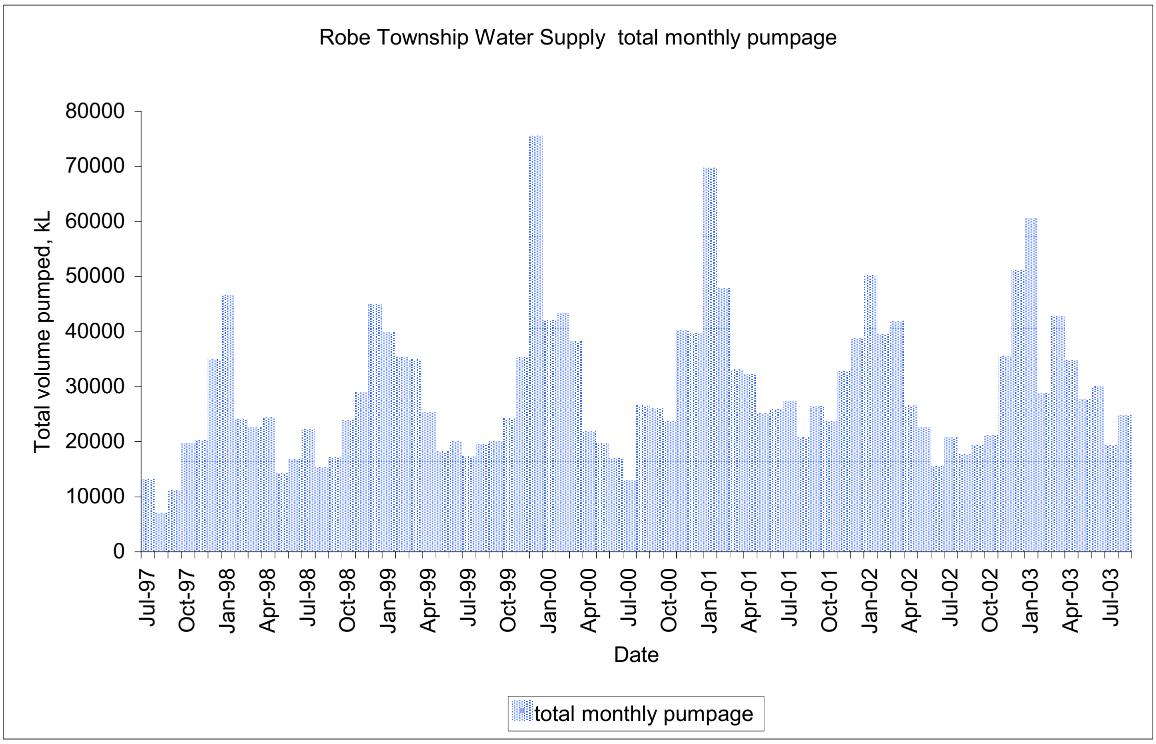


Figure 18. Total monthly pumpage from Robe TWS wellfield

Figure 19 is a plot of ratio of water above pump setting after 30 min of pumping to pumping rate, against time. The pumping rates range between 0.2 and 1.4 kL/min at Robe TWS 1, 1.0–23.3 L/sec at TWS 5 and 18.3–30 L/sec at TWS 6. It should be noted that the graphs shown in Figure 19 are dependent on the standing water level at the beginning of each pumping cycle, however the following statements are valid. From Figure 19 it can be seen that the behaviours of Robe TWS 1 and 5 after 30 min of pumping are almost similar, and between 1998 and 2001 the deployable output or 'production capacity' of Robe TWS 1 and 2 after 30 min of pumping has been reduced by ~57% and 43%, respectively. Between 2001 and 2002, the deployable output or 'production capacity' of Robe TWS 6 has decreased from 20 m/kL/min to <15 m/kL/min.

The causes of the reduction in the deployable output or 'production capacity' of these wells over time may be attributed to one or more of the following potential factors: well interference effect due to pumping from nearby production wells; and deterioration of the wells, well screen and any gravel packing around the screens. It is suggested that:

- Robe TWS 1 and 5 be inspected with video cameras to examine their state of condition and determine the need for rehabilitation.
- Since the wells are more than 290 m deep below ground surface, lowering the pump intake depth (if physically, technically and economically feasible) can increase the production capacities.

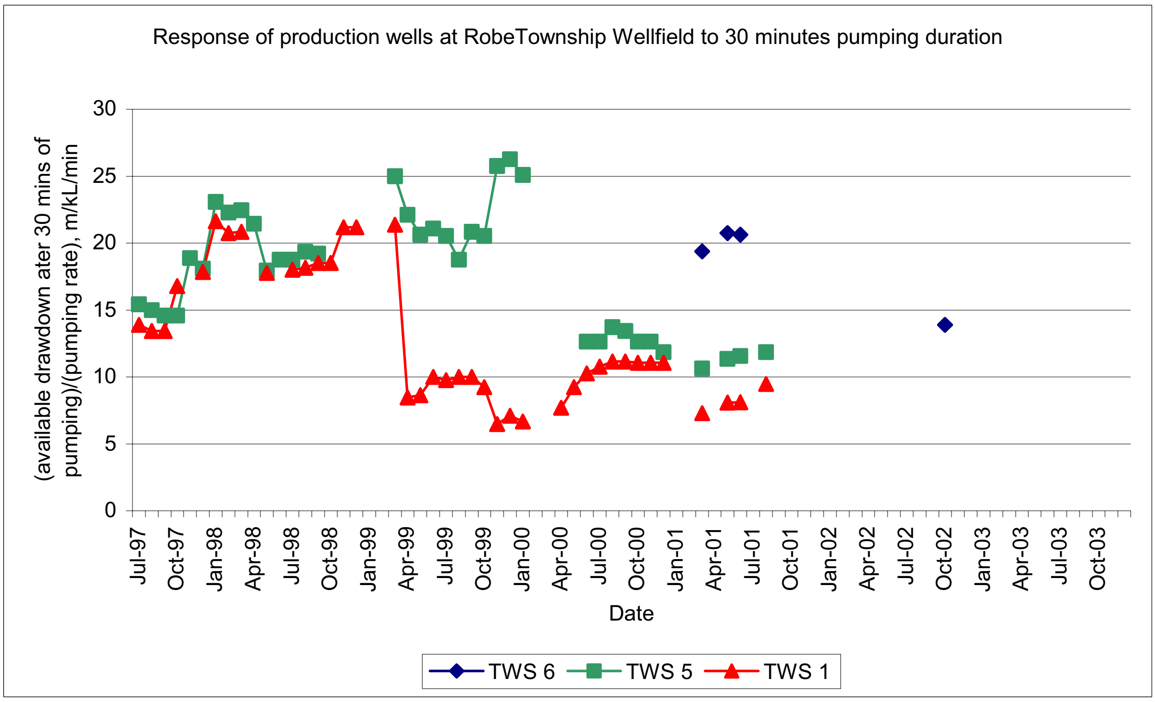


Figure 19. Observed available drawdown after 30 min of pumping of groundwater

5 AQUIFER TESTING AND ANALYSIS

Knowledge of aquifer hydraulic conductivity, storage coefficient, and aquifer and well losses allows quantitative prediction of the hydraulic response of aquifer and well to pumping. These properties can be estimated on a local scale by analysis of data from aquifer tests. The hydraulic properties (transmissivity and storage coefficient) of the sand aquifer were determined from pump test results obtained at Robe TWS1, 5 and 6. Both Hazel (1975) and Theis step-drawdown (Birsoy and Summers 1980) methods of analysis were used. The fit between measured and simulated drawdown was judged by visual inspection of the log-log graph (for Theis method) and semi-log graph (Hazel method) of drawdown as a function of adjusted time since the start of pumping.

Step-drawdown test analysis

As part of this study, pumping test results from three of the existing Robe township water supply wells (Fig. 13) were analysed. The tests included step-drawdown and long-term constant-discharge tests. Both single well and multiple-well (single pumping well and observation wells) tests were carried out. The step-drawdown test result was needed to establish the non-linear well-loss components of drawdown which are independent of time.

The general approach for analysing the aquifer test results was to match the measured drawdown with simulated drawdown using Hazel and Theis step-drawdown test analytical models. In these models the aquifer is assumed homogenous, isotropic and infinite in extent, uniform in thickness and horizontal, and fully confined with no outward or inward vertical leakage. Furthermore, these models assume that the testing well fully penetrates the confined aquifer and the potentiometric surface is horizontal before testing starts. The aquifer in the conceptual model is made up of sand whose thickness and grain size vary from place to place. Since the water level in the sand aquifer in the study area is under artesian conditions and is higher than the water level in the overlying unconfined aquifer, the potential for vertical upward flow from the sand aquifer to the overlying unconfined aquifer exists. Pumping activities in and around the study site would lead to the development of local hydraulic gradients.

In step-drawdown tests the conceptual model assumes that drawdown in a well is related to well and aquifer losses according to the following equation, Hazel (1975):

$$\mathbf{s_w = \textit{b}\log(t)Q + \textit{a}Q + \textit{c}Q^n} \qquad \mathbf{1}$$

where s_w is the total drawdown at the well; $b\log(t)Q$ drawdown related to discharge from the aquifer and meets above assumptions; b is aquifer loss 'constant' and is determined from a semi-logarithm plot of (s_w/Q) versus Q and is equal to $\frac{\Delta s}{Q}$; a is the aquifer loss coefficient defined as $a = b\log(\frac{2.25T}{r^2S})$; cQ^n is drawdown related to well screen losses and well damage; c well loss coefficient; and n is exponent of 1 or greater. Estimates of n ranged from 1.5 to 3.5 in several well applications (Rorabaugh 1953). In this investigation n is given a value of 2.

Single well test at Robe TWS 6

A single well pumping test was conducted at Robe TWS 6 in November 1999. Robe TWS 6 is constructed with 254 mm internal diameter (ID) FRP from 0 to 102.7 m, then 152 mm ID FRP from 102.7 to 281 m, screened with stainless steel material from 285.38 to 288.48 m and then 100 mm ID sump from 288.5 to 293.8 m. The water-bearing zone is sand. Robe TWS 6 flowed under non-pumping conditions when drilled in November 1999. The yield of this well was estimated by the driller at 15 L/s.

A 300-minute 3-stage aquifer test at pumping rates of 10, 20, and 30 L/s was conducted at Robe TWS 6 and drawdown was measured in the production well. Each stage lasted 100 min in duration. The final drawdown at the end of the test was 50.21 m.

The yield-drawdown behaviour of Robe TWS 6 and the transmissivity value for the sand aquifer at Robe TWS 6 were obtained by analysing the pumping test results with the use of Hazel and Theis step-drawdown analytical models. The following well equation describing the response of Robe TWS 6 to the three different pumping rates was obtained by using the Hazel method of analysis.

$$\mathbf{s_w = 4.14log(t)Q + 15.10Q + 2.04Q^2} \qquad \mathbf{2}$$

In this equation the units of s_w is m; time, t, is minutes; and pumping rate, Q, is m^3/min. The hydraulic properties of the aquifer determined at Robe TWS 6 are shown in Figure 20. A well loss coefficient of 2.04 min/m^2 and an aquifer loss coefficient of 15.1 m were obtained at Robe TWS 6. An average aquifer loss constant ($\Delta s/Q$) value obtained from the analysis of Robe TWS 6 pumping test data was 4.14 m/m^3/min, where ($\Delta s/Q$) = ($2.3/4\pi T$) from which average transmissivity (T) value was calculated as 0.04421 m^2/min or 63.66 m^2/d.

Multiple well tests at Robe TWS 5

Aquifer testing using Robe TWS 5 as the pumping well, with Robe TWS 1 and 6 as observation wells (Fig. 13), was conducted in November 2003. Table 1 contains a summary of details of the wells used in this test. The pumping well was drilled in December 1982 and is currently 295 m deep and is cased to a depth of 277.4 m. The construction details of Robe TWS 5 are shown in (App. 2.1). The driller estimated yield for this well at 3.75 L/s. Robe TWS 1 (App. 2.2), which was drilled in February 1969, is 195 m away from Robe TWS 5. Robe TWS 6 is 330 m from Robe TWS 5.

Robe TWS 5 was pumped for 2160 min (36 h). During the first 300 min Robe TWS 5 was pumped at rates of 1037, 1987 and 2938 m^3/d, each stage lasting 100 min. The pumping rate was kept constant at 2938 m^3/d from 300 min after pumping started to the end of pumping. Water levels were measured in Robe TWS 5, 1 and 6 during the test. The Hazel and Theis step-drawdown analytical models were used to establish the yield-drawdown behaviour of Robe TWS 5 and determine the aquifer transmissivity and storage coefficient.

The following well equation describing the yield-drawdown behaviour of Robe TWS 5 was derived on the basis of Hazel method.

$$s_w = 4.09\log(t)Q + 5.75Q + 4.71Q^2 \qquad 3$$

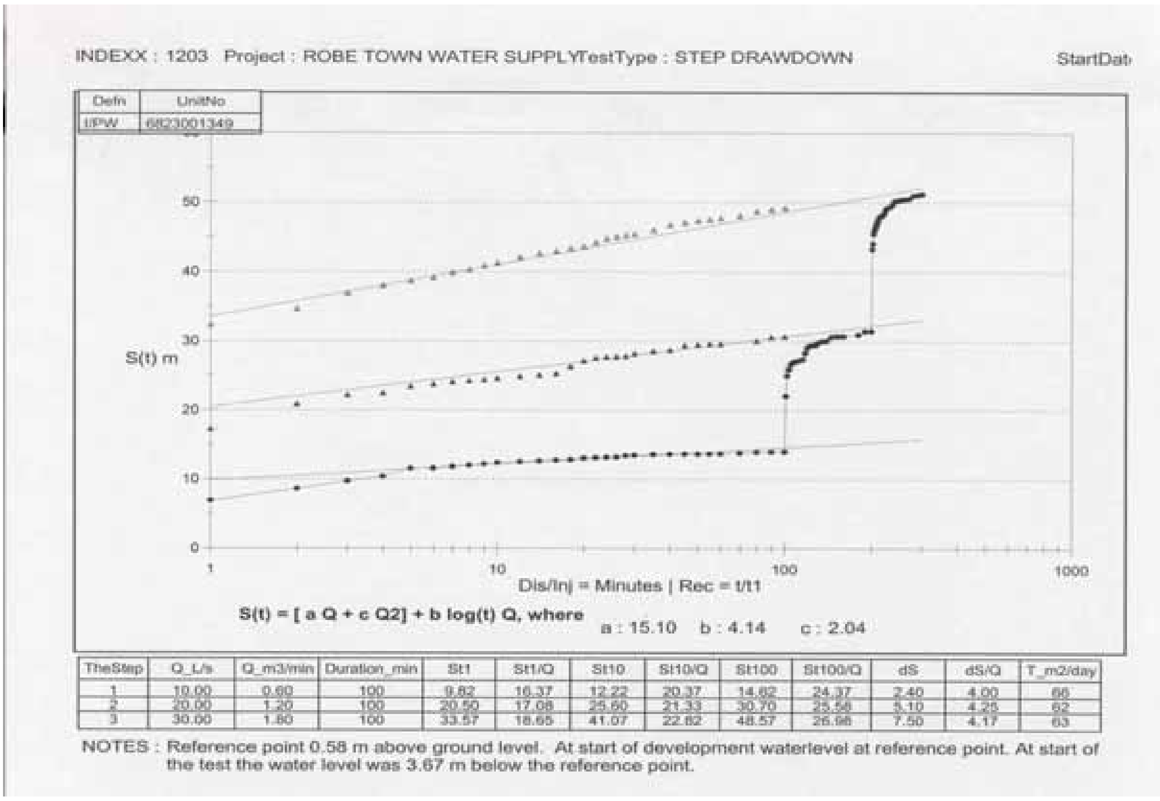
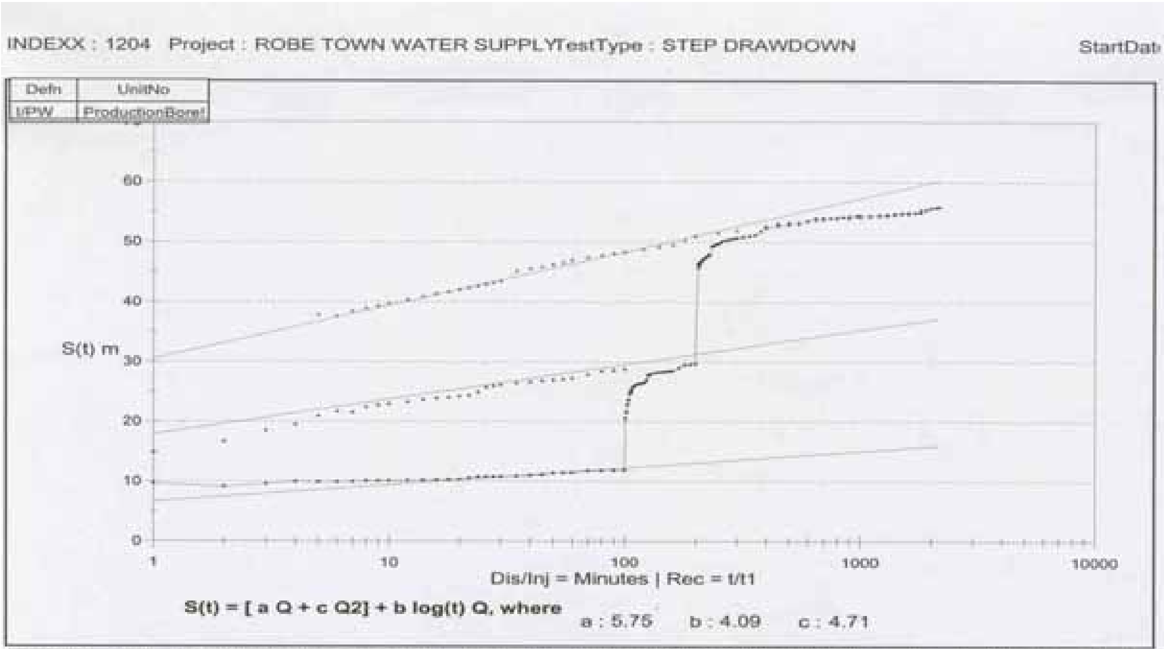


Figure 20. Results of Robe TWS 6 step-drawdown test analysis using Hazel (1975) method

Table 1. Wells used in pumping test at Robe TWS wellfield

Well	Unit no.	Depth (m)	Casing depth (m)	Well diameter (m)	SWL before test (m)	Drawdown at end of test (m)	Land surface elevation (m AHD) *Ground elevation*	*Reference elevation*	Radial distance relative to pumped well (m)
Robe TWS 5	6823-949	295	277	0.113	?	55.81	?	?	-
Robe TWS 1	6823-316	293	?	0.127	?	18.8	2.81	3.27	195
Robe TWS 6	6823-1349	294	286.33	0.100	?	8.9	?	?	330

The aquifer property and yield-drawdown relationship for pumped well Robe TWS 5 are shown in Figure 21. A well loss coefficient of 4.7 min/m^2 and aquifer loss coefficient of 5.75 m was obtained at Robe TWS 5. The average (Δs/Q) value obtained from the analysis of Robe TWS 5 pumping test results was 4.09 m/m^3/min, where (Δs/Q) = (2.3/4πT), from which an average transmissivity T value of 0.04471 m^2/min or 64.39 m^2/d was obtained.



TheStep	Q_L/s	Q_m3/min	Duration_min	St1	St1/Q	St10	St10/Q	St100	St100/Q	dS	dS/Q	T_m2/day
1	12.00	0.72	100	6.65	9.24	9.45	13.13	12.25	17.01	2.80	3.89	68
2	24.00	1.44	100	17.94	12.46	23.74	16.48	29.54	20.51	5.80	4.03	65
3	34.00	2.04	1960	30.54	14.97	39.44	19.33	48.34	23.70	8.90	4.36	60

NOTES :

Figure 21. Results of Robe TWS 5 step-drawdown test analysis using Hazel (1975) method

The transmissivity values obtained at Robe TWS 1, 5 and 6, on the basis of the Theis Step-drawdown method, were 74.1, 63.4 and 81.7 m^2/d, respectively. Table 2 summarises the hydraulic values obtained from the two methods. From Table 2 an average transmissivity value of about 71 m^2/d was calculated. An average storage coefficient value of 5.25x10^{-7} was calculated for the aquifer. It is assumed that these averages represent the local transmissivity and storage coefficient values of the sand aquifer.

From the analysis of the results of the two aquifer tests, it can be seen that whilst the aquifer loss coefficient for laminar flow *(b)* at Robe TWS 5 and 6 is similar, the well loss coefficient for laminar flow (*a*) at Robe TWS 6 is higher than that at TWS 5 and the well loss coefficient for turbulent flow (*c*) at Robe TWS 5 is higher than that at TWS 6 (Figs 20, 21).

Table 2. Aquifer hydraulic values determined from multiple well step-drawdown test data

Well	Unit number	Transmissivity (m^2/d)	Storage coefficient	Method
Robe TWS 5	6823-949	63.40	–	Theis
		64.39*	–	Hazel
Robe TWS 1	6823-316	74.5	5.025×10^{-7}	Theis
Robe TWS 6	6823-1349	81.7	1.0×10^{-5}	Theis

* Details of results using Hazel method is shown in Figure 21.

ESTIMATED DRAWDOWNS AT ROBE TWS 5 AND 6 FROM STEP-DRAWDOWN TEST RESULTS

The pump test results (Figs 20, 21) indicate that the well performances are different at Robe TWS 5 and 6. The results from the step-drawdown test, Hazel and Cooper-Jacob (Cooper and Jacob, 1946) models and the production history of the wellfield were used in an attempt to estimate the deployable output from the existing wellfield under current conditions and any future expansion. The drawdowns at any given point and time in the confined sand aquifer were determined.

A 3-staged approach adopted in estimating the deployable output from the wellfield is outlined below. The first stage involves the calculation of short-, medium- and long-term pumping drawdowns at Robe TWS 5 and 6 for a range of pumping rates using the step-test results and Cooper-Jacob transient flow equation for the confined aquifer. While the short-term drawdowns at Robe TWS 5 and 6 were determined from the step-drawdown test results, the medium- and long-term drawdowns are estimated by extrapolating the short-term values using the following equations based on the Cooper-Jacob equation for non-steady state radial flow in a confined aquifer:

$$\Delta s = 0.183Q/T \qquad 4$$

$$s_a = L\,\Delta s \qquad 5$$

Where Δs is drawdown [m] per log cycle of time [d]; s_a is additional drawdown [m] in the pumping well; [L] is the number of log cycles of time between the end of the first step and the time for which the yield estimate is to be made; Q is the pumping rate [m^3/d]; and T is aquifer transmissivity [m^2/d]. The medium- and long-term drawdowns were estimated by assuming 210 d and 25 y of pumping. The medium-term of 210 d is about 3.5 log cycles between 100 and 3.024×10^5 min. The long-term of 25 y is about 5 log cycles between 100 and 1.3×10^7 min.

The second stage involves the calculation of interference drawdown between the pumping wells. This effect is calculated for a range of extraction rates using the Cooper-Jacob non-steady flow equation for a confined aquifer.

$$s = \frac{0.183Q}{T}\log(\frac{2.25Tt}{r^2 S}) \quad \mathbf{6}$$

where s is the drawdown [m] at one well produced by pumping at a rate Q [m^3/d] from another well; S is the aquifer storage coefficient; r is the distance [m] between the wells; T is the aquifer transmissivity [m^2/d]; and t is time in days.

In stage 3 interference drawdown-pumping rate curves for the wells are plotted from which the deployable output at individual well is estimated from these curves.

Estimated drawdowns at Robe TWS 5

Medium-term drawdown at Robe TWS 5

Table 3 summarises estimated medium-term drawdown at Robe TWS 5 using the step-test results and equations 4 and 5. A transmissivity value of 64 m^2/d was used.

Table 3. Estimated medium-term drawdown at Robe TWS 5 based on step-drawdown data and equations 4 and 5

Pumping rate (m^3/d)	**100-min* drawdown** (m)	**Additional drawdown, s_a, for 210 d** (m)	**Total estimated drawdown, s_w** (m)
1037	11.895	10.38	22.27
1987	29.66	19.89	49.55
2938	50.56	29.40	79.76

* Obtained from step-test data. Additional drawdown, s_a, is calculated from the equation s_a=LΔs; where L is the number of log cycles of time between 100 min and 210 d (= 3.5), and Δs drawdown per log cycle of time.

Using well equation 3, the predicted drawdown at Robe TWS 5 after 210 d of pumping at various pumping rates is summarised in Table 4. The drawdowns shown in Tables 3 and 4 are similar.

Table 4. Predicted medium-term drawdown at Robe TWS 5 based on well equation developed from step-drawdown test data

Q (m^3/min)	**Q** (L/s)	**Predicted drawdown** (m)
0.72	12.0	23.41
1.40	23.0	48.66
2.04	34.0	77.06

* Obtained from step-test data. Additional drawdown, s_a, is calculated from the equation s_a=LΔs; where L is the number of log cycles of time between 100 min and 25 y (= 5), and Δs drawdown per log cycle of time.

LONG-TERM DRAWDOWN AT ROBE TWS 5

The estimated long-term drawdown at Robe TWS 5 is shown in Table 5.

Table 5. Estimated long-term drawdown at Robe TWS 5 based on step-drawdown data and equations 4 and 5

Pumping rate (L/s)	**100-min* drawdown** (m)	**Additional drawdown, s_a, for 25 y** (m)	**Total estimated drawdown, s_w** (m)
12	11.895	14.83	26.72
23	29.66	24.41	58.07
34	50.56	42.00	92.56

Using well equation 3, the predicted long-term drawdown at Robe TWS 5 at various pumping rates is summarised in Table 6. Again the drawdowns shown in Tables 5 and 6 are similar. Figure 22 is a graphical representation of the drawdown-pumping rate relationship at Robe TWS 5.

Table 6. Predicted long-term drawdown at Robe TWS 5 based on well equation developed from step-drawdown test data

Q (m^3/min)	**Q** (L/s)	**Predicted drawdown** (m)
0.72	12.0	27.54
1.40	23.0	58.04
2.04	34.0	90.73

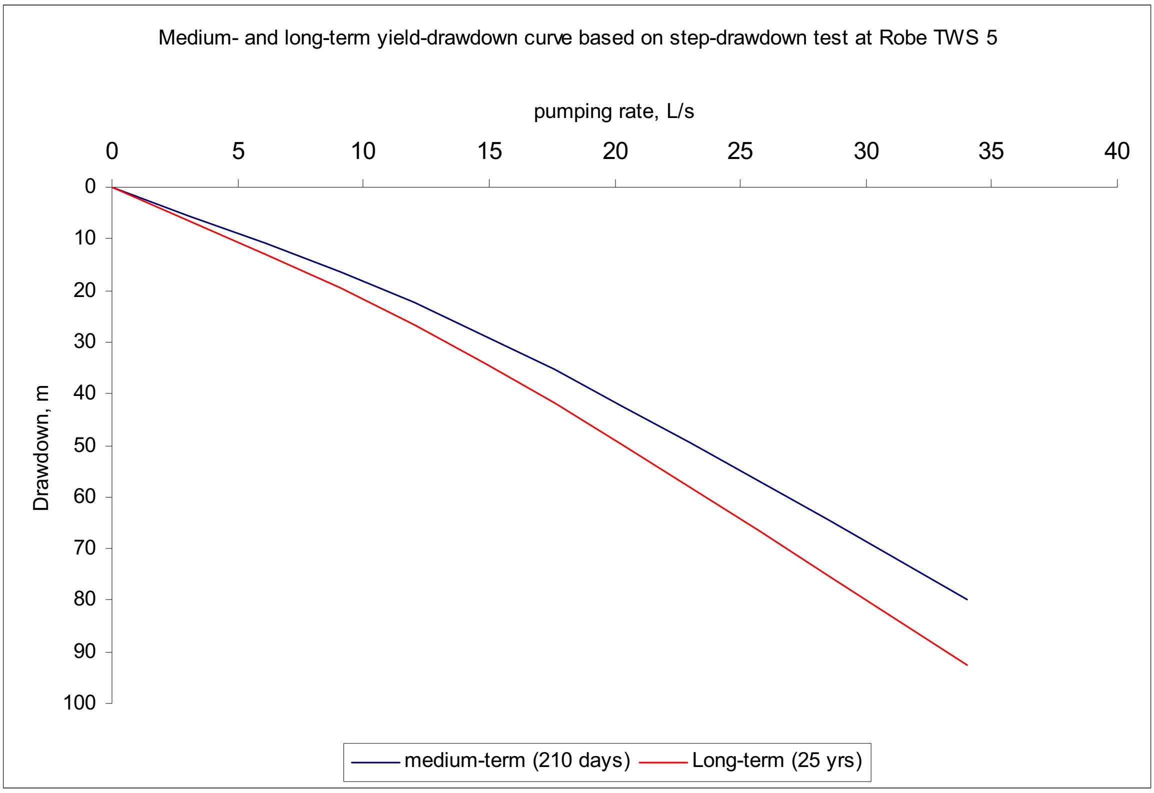


Figure 22. Medium- and long-term discharge-drawdown relationship at Robe TWS 5

Estimated drawdowns at Robe TWS 6

MEDIUM-TERM DRAWDOWN AT ROBE TWS 6

Table 7 summarises estimated medium-term drawdown at Robe TWS 6 using the step-drawdown test results and equations 4 and 5. A transmissivity value of 64 m^2/d obtained at Robe TWS 6 was used.

For comparison, the predicted drawdown at Robe TWS 6 was determined based on equation 2, 210 d of pumping and various abstraction rates (Table 8). The predicted drawdowns compare well with the estimated drawdowns in Table 7.

Table 7. Estimated medium-term drawdown at Robe TWS 6 based on step-drawdown data and equations 4 and 5

Pumping rate (L/s)	**100-min*** **drawdown** (m)	**Additional drawdown, s_a, for 210 d** (m)	**Total estimated drawdown, s_w** (m)
10	14.04	8.65	22.69
20	31.48	17.29	48.77
30	51.21	25.94	77.15

* Obtained from step-test data. Additional drawdown, s_a, is calculated from the equation $s_a=L\Delta s$; where L is the number of log cycles of time between 100 min and 210 d (= 3.5), and Δs drawdown per log cycle of time.

Table 8. Predicted medium-term drawdown at Robe TWS 6 based on well equation 2 developed from step-drawdown test data

Q (m^3/min)	**Q** (L/s)	**Predicted drawdown** (m)
0.6	10.0	23.41
1.2	20.0	48.29
1.8	30.0	74.63

LONG-TERM DRAWDOWN AT ROBE TWS 6

The long-term drawdown at Robe TWS 6 was estimated by extrapolating the step-drawdown test results over 25 y. Table 9 summarise estimated long-term drawdowns at Robe TWS 6 at various pumping rates. The information in Table 9 is based on the step-test result and equations 4 and 5. A transmissivity value of 64 m^2/d was used.

Table 9. Estimated long-term drawdown at Robe TWS 6 based on step-drawdown data and equations 4 and 5

Pumping rate (L/s)	**100-min*** **drawdown** (m)	**Additional drawdown, s_a, for 25 y** (m)	**Total estimated drawdown, s_w** (m)
10	14.04	12.35	26.39
20	31.48	24.71	56.19
30	51.21	37.06	88.27

* Obtained from step-test data. Additional drawdown, s_a, is calculated from the equation $s_a=L\Delta s$; where L is the number of log cycles of time between 100 min and 25 y (= 5), and Δs drawdown per log cycle of time.

Well equation 2 was used to calculate the long-term drawdown at Robe TWS 6. The results are shown in Table 10. The drawdowns in Table 9 compare with drawdowns shown in Table 10. Figure 23 shows the relationship between pumping rate and drawdown at Robe TWS 6.

Table 10. Predicted long-term drawdown at Robe TWS 6 based on well equation developed from step-drawdown test data

Q (m^3/min)	Q (L/s)	**Predicted drawdown** (m)
0.6	10.0	27.47
1.2	20.0	56.42
1.8	30.0	86.83

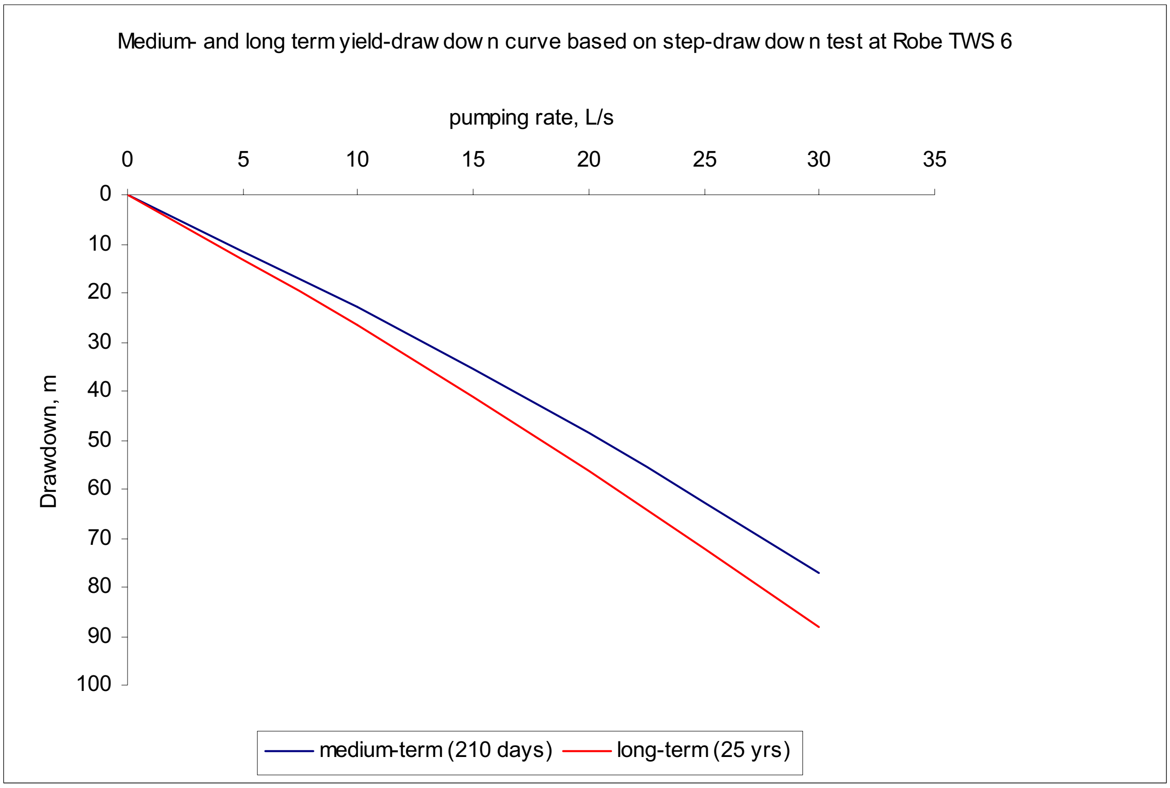


Figure 23. Medium- and long-term discharge-drawdown relationship at Robe TWS 6

6 INTERFERENCE DRAWDOWN AND DEPLOYABLE OUTPUT OF CURRENT WELLFIELD DUE TO CONCURRENT PUMPING FROM ROBE TWS 1, 5 AND 6

Currently Robe TWS 1, 5 and 6 are serving as production wells at Robe TWS wellfield. The distances between the wells are: Robe TWS 6 is 330 m away from TWS 5; Robe TWS 1 is 195 m away from TWS 5; Robe TWS 6 and 1 are 310 m apart. The configuration of the wellfield is shown in Figure 13.

In this investigation 'instantaneous', medium- and long-term yields from the wellfield are investigated. Instantaneous, as used in this report, means a pumping duration of 15 min without interruption. There is an intermittent pumping situation at the wellfield and the pumping cycle is 18 h on, 6 h off each day. Given a pumping scenario of 18 h operation per day for 210 d/y for 25 y, the medium- to long-term yield can be modelled. The potential interference drawdown between the wells is calculated for a range of pumping rates by using the well equations developed from the step-drawdown tests, Cooper-Jacob analytical model (equation 6) and the hydraulic properties of the aquifer that were derived from the pumping test results. The drawdown caused by pumping in the wellfield was estimated by adopting the method proposed by Driscoll (1986). Field data used in estimating the deployable output from individual wells included current pump settings, observed standing water levels and historical behaviour of the production wells.

Estimated instantaneous, medium- and long-term interference drawdown and deployable output

ROBE TWS 1

The pumping rate interference drawdown curves have been estimated for Robe TWS 1 (Fig. 24). These estimations are based on equation 6 since no step-drawdown test was conducted at Robe TWS 1. Transmissivity and storage coefficient at Robe TWS 1 were assigned values of 75 m^2/d and 5.025×10^{-7} respectively. The pump setting at Robe TWS 1 is at 36 m below ground surface. Data obtained from SA Water indicate that, between May 1999 and August 2001, the standing water level at Robe TWS 1 ranges from 2 m above ground surface to 10 m below ground surface (Fig. 25). This means that the water above pump setting (available drawdown) at Robe TWS 1 at the start of pumping ranges between 26 m and 38 m, with an average of 33.65 m (Fig. 26).

Using the minimum available drawdown of 26 m to represent non-pumping water level above the pump setting during drought conditions, the instantaneous, medium-term and long-term yield from Robe TWS 1 is estimated (Fig. 24). The potential instantaneous yield from Robe TWS 1 under drought conditions is estimated at 11.80 L/s. In the medium and long terms the estimated yield from Robe TWS 1 is 5.50 L/s and 4.60 L/s respectively.

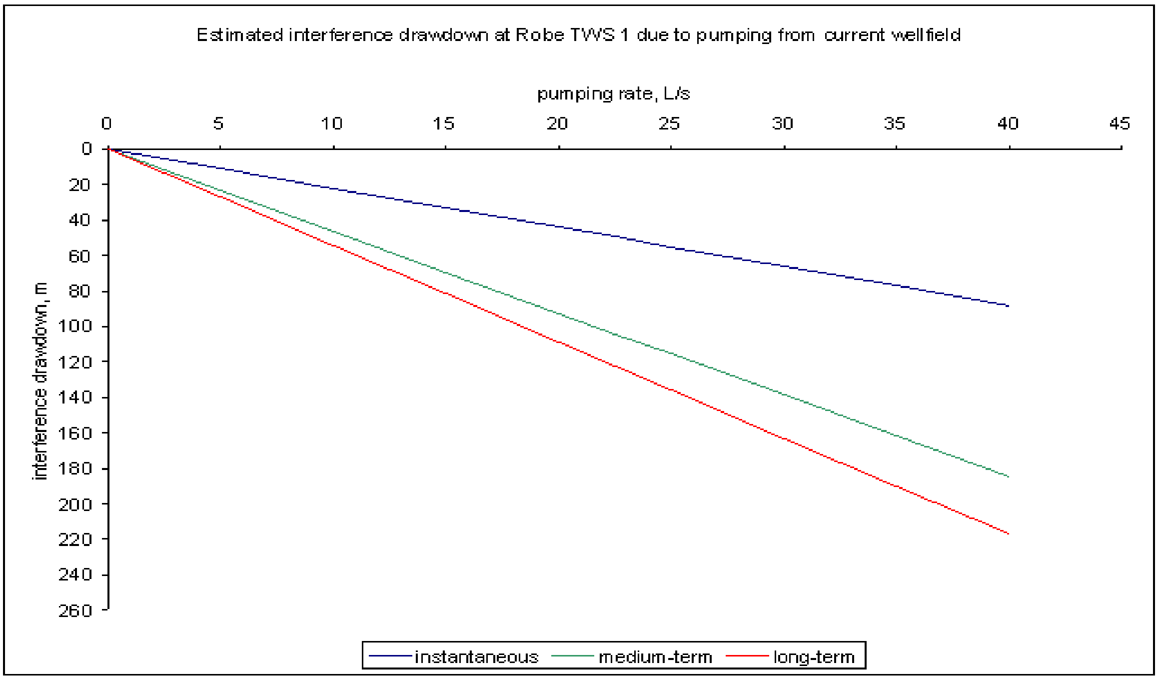


Figure 24. Well interference drawdown at Robe TWS 1 due to concurrent pumping from the production wells in the wellfield

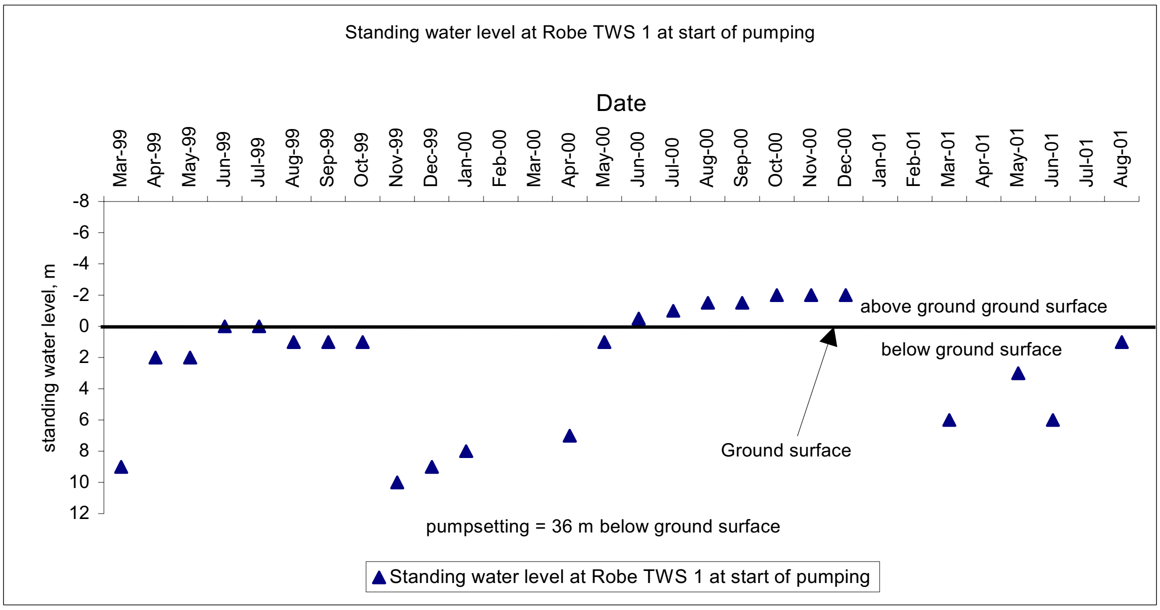


Figure 25. Observed standing water level at Robe TWS 1 at start of pumping

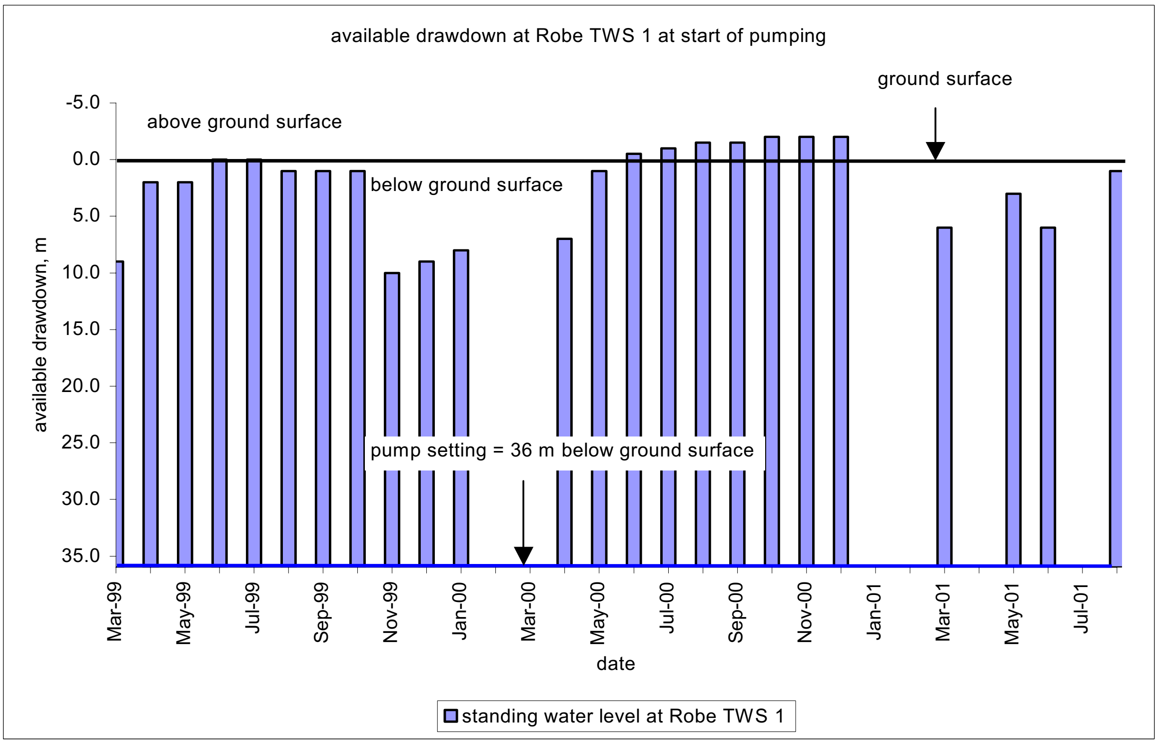


Figure 26. Observed available drawdown at Robe TWS 1 at start of pumping

Using 98% of the available drawdown during drought conditions, estimated instantaneous, medium and long-term deployable outputs of 11.50 L/s, 5.30 L/s and 4.40 L/s, are obtained.

With an average available drawdown of 33.0 m (98% of 33.6 m), Robe TWS 1 has the capacity to produce an average deployable output of 7.3 L/s in the medium term and 6.0 L/s in the long term.

ROBE TWS 5

The pumping rate-interference drawdown curves at Robe TWS 5 have been estimated and are shown in Figure 27. The pump setting at Robe TWS 5 is at 43 m below ground surface. Data obtained from SA Water indicate that between January 2000 and August 2001 the standing water level at Robe TWS 5 varies between 1.5 m below ground surface and 6.5 m below ground surface (Fig. 28). This indicates that the available drawdown at Robe TWS 5 at the start of pumping ranges between 36.5 m and 41.5 m, with a mean value of 39.48 m (Fig. 29).

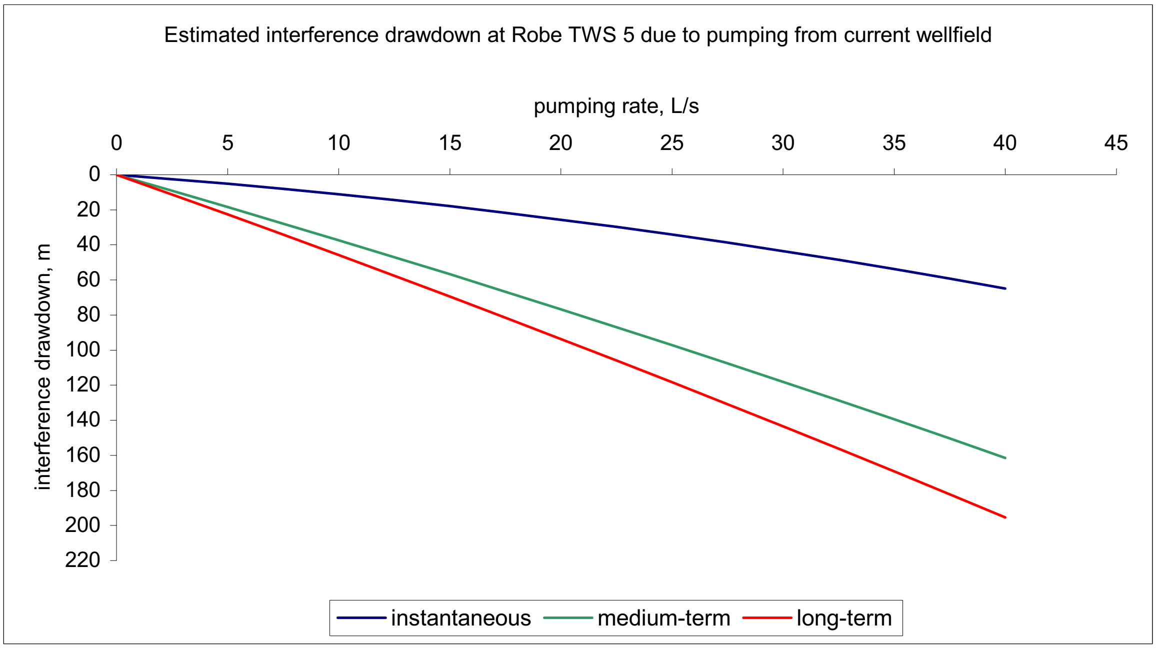


Figure 27. Well interference drawdown at Robe TWS 5 due to concurrent pumping from the production wells in the wellfield

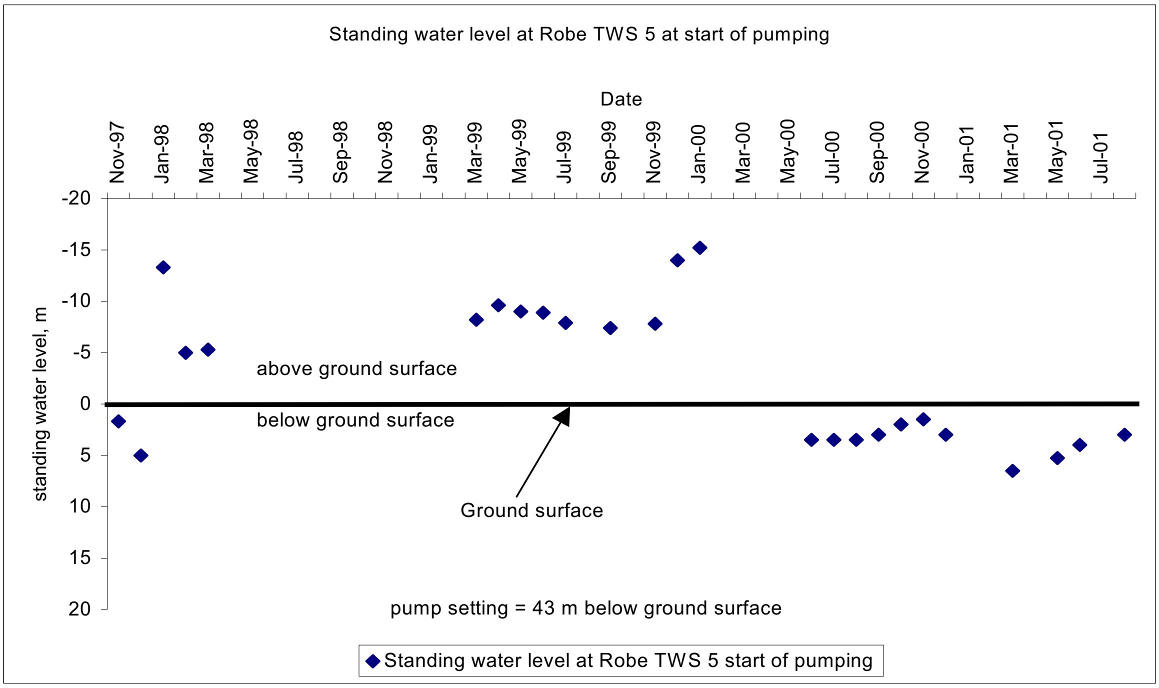


Figure 28. Observed standing water level at Robe TWS 5 at start of pumping

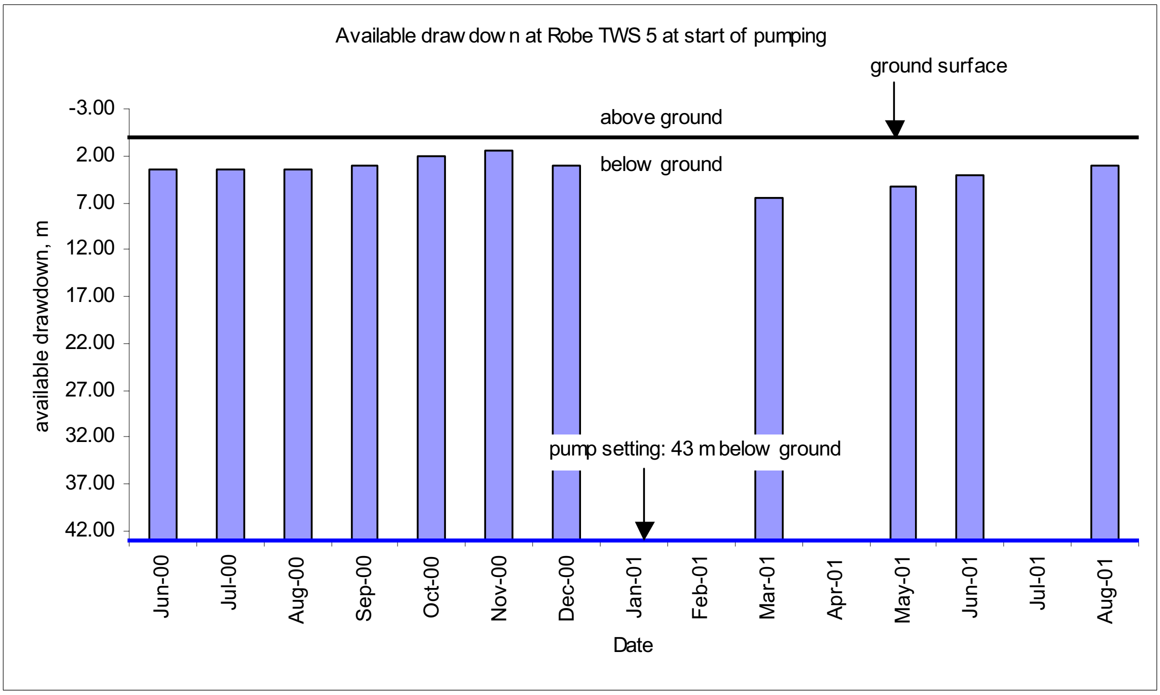


Figure 29. Observed available drawdown at Robe TWS 5 at start of pumping

Using the minimum available drawdown of 36.5 m to represent the drought condition non-pumping groundwater level at Robe TWS 5, the instantaneous, medium-term and long-term yields from Robe TWS 5 are estimated at 26.40 L/s, 9.80 L/s and 8.00 L/s (Fig. 27). If 98% of the available drawdown during drought periods is utilised then the estimated instantaneous, medium- and long-term deployable output from Robe TWS 1 is 25.80 L/s, 9.50 L/s and 7.50 L/s respectively. An average available drawdown of 38.69 m (98% of 39.48 m) means Robe TWS 5 has the capacity to produce an average deployable output of 10.20 L/s in the medium term and 8.40 L/s in the long term.

ROBE TWS 6

The relationship has been estimated between interference drawdown and pumping rate at Robe TWS 6, under a condition of concurrent pumping at Robe TWS 6, 5 and 1 at the same rates (Fig. 30). The pump intake depth at Robe TWS 6 is 74 m below ground surface. Theoretically estimated standing water level at Robe TWS 6 before any pumping takes place at the wellfield ranges between 1.83 m below ground surface and 4.2 m below ground surface, averaging 3.05 m below ground surface (Fig. 31). A water level test, conducted between Christmas and New Year 2003 to check for leaks in the airline tube at Robe TWS 6, indicated a water level of 71 m above pump intake level (i.e. a depth to water level of 3.0 m from ground surface; B Quirke, SA Water, pers. comm., 2004). This observation validates the available drawdowns values used at Robe TWS 6. The available drawdown at Robe TWS 6 at the beginning of any pumping from the wellfield ranges between 69.8 and 72.17 m, with an average of 70.95 m (Fig. 32).

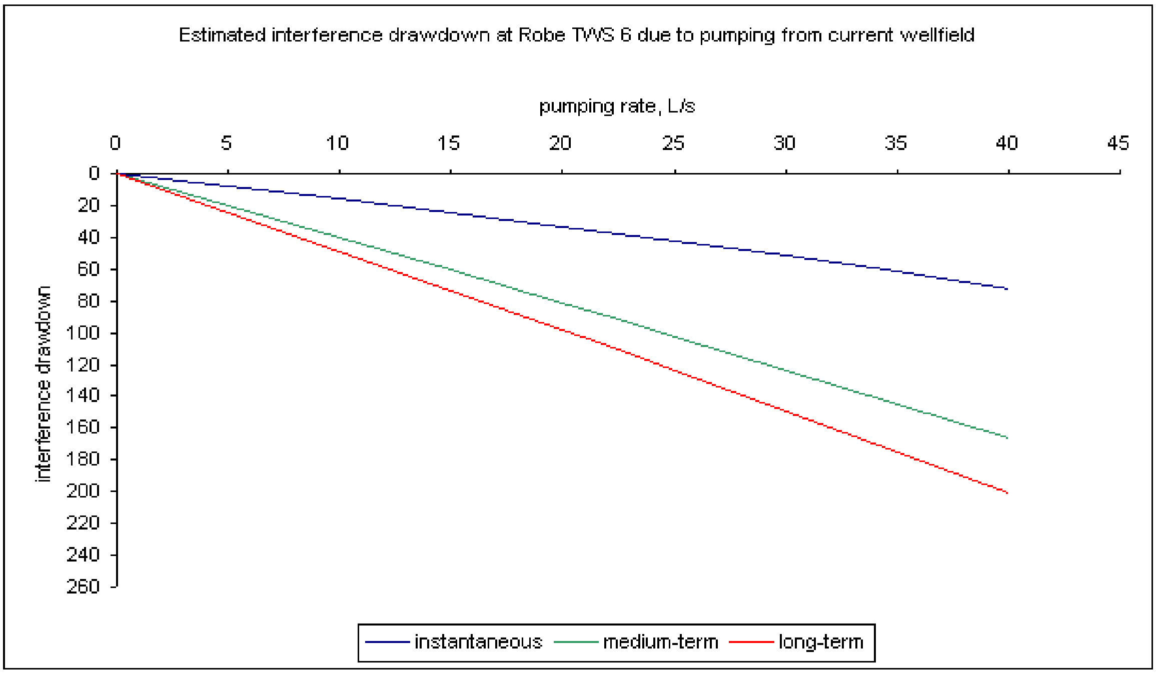


Figure 30. Well interference drawdown at Robe TWS 6 due to concurrent pumping from the production wells in the wellfield

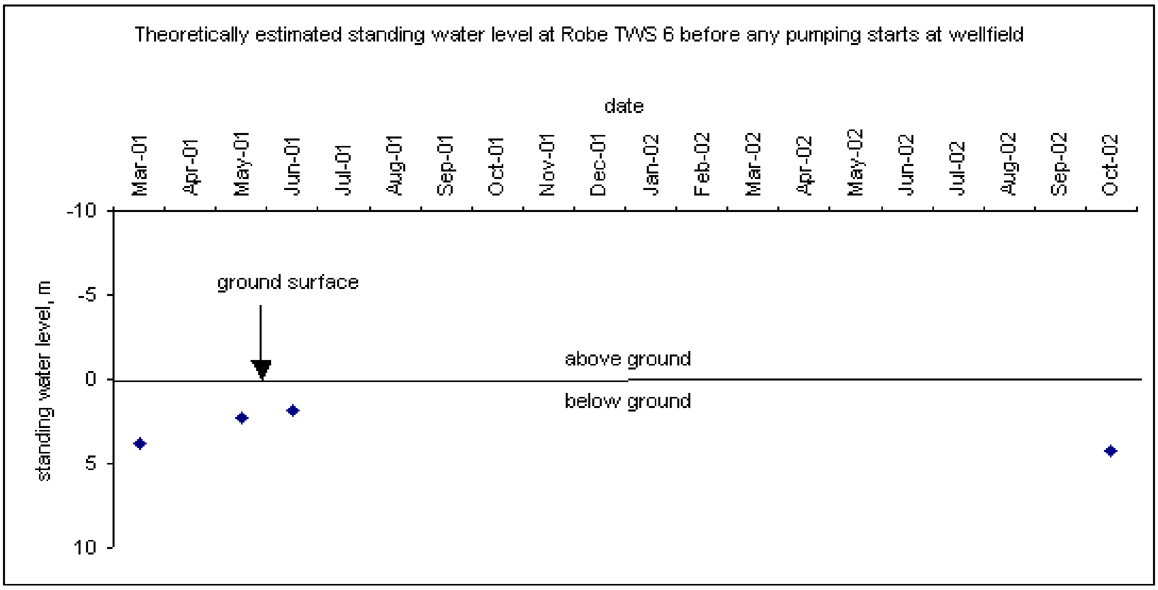


Figure 31. Extrapolated standing water level at Robe TWS 6 at start of pumping

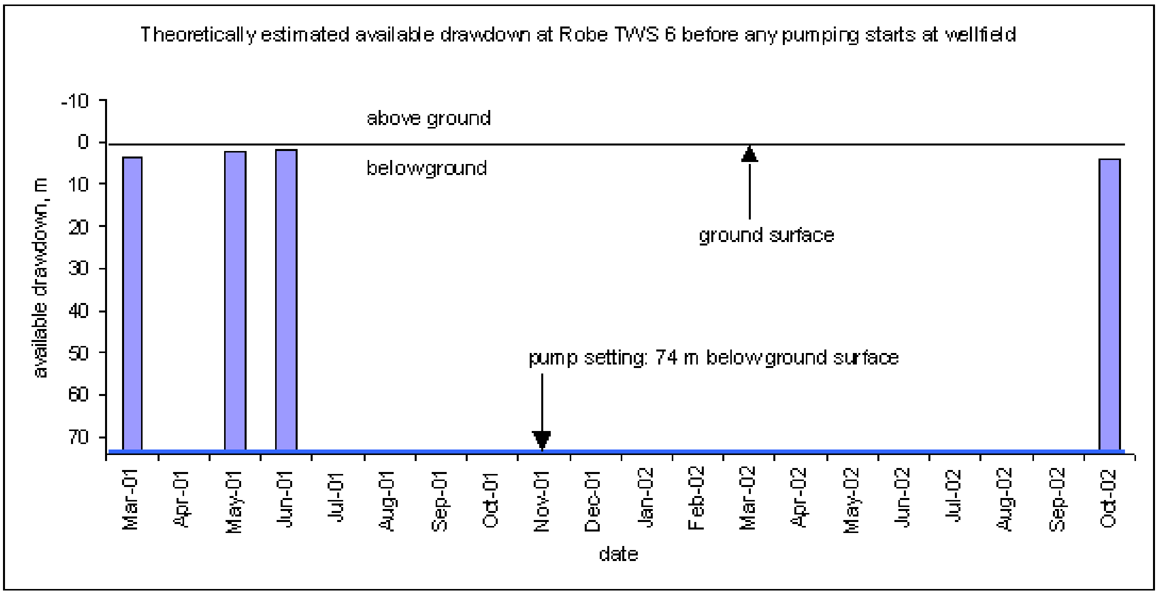


Figure 32. Extrapolated available drawdown at Robe TWS 6 at the start of pumping

The minimum non-pumping available drawdown at Robe TWS 6 is 69.8 m. From this the instantaneous yield of 38.80 L/s, medium-term yield of 17.00 L/s and long-term yield of 14.40 L/s could be obtained at Robe TWS 6 under drought conditions (Fig. 30). A medium-term and long-term average deployable output, estimated at 17.00 L/s and 14.25 L/s respectively, could be extracted at Robe TWS 6 during drought conditions (i.e. available drawdown of 69.53 m — 98% of 70.95 m.

Total instantaneous, medium- and long-term deployable output estimated from existing wellfield

A summary of the estimated deployable output from the current wellfield is provided in Table 11. The values listed were determined on the assumptions that:

- current production wells are pumping at the same rate and at the same time
- intermittent pumping situation exists at the wellfield and the pumping cycle is 18 h on, 6 h off each day
- the pumping duration is 210 d for medium-term and 25 y for the long-term
- 98% of the minimum available drawdown is utilised.

Table 11. Estimated deployable output of current wellfield

Well	Instantaneous	Deployable output (L/s)			
		Medium term		Long term	
		'Drought'	Average	'Drought'	Average
Robe TWS 1	11.50	5.30	7.30	4.40	6.00
Robe TWS 5	25.80	9.50	10.20	7.50	8.40
Robe TWS 6	38.00	16.75	17.00	14.00	14.25
Total	**75.30**	**31.55**	**34.5**	**25.9**	**28.65**

The estimated total deployable output values shown in Table 11 indicate that:

1. The wellfield with existing installation under current conditions is capable of producing an instantaneous yield of about 75.0 L/s. This value is almost the same as the current peak instantaneous extraction of 70.0 L/s.
2. During periods of drought and high demand a deployable output of about 31.6 L/s could be obtained in the medium-term and about 26.0 L/s in the long term.
3. The average medium-term and long-term deployable output is estimated at 34.5 L/s and 28.7 L/s, respectively.
4. The estimated average medium-term deployable output is almost equal to the current peak day average yield of 33 L/s.
5. The wellfield under current conditions would not be able to produce an average yield of 59 L/s, which SA Water is expected to extract on peak days in the near future.

7 INVESTIGATION TO INCREASE THE YIELD TO MEET PROJECTED FUTURE REQUIREMENTS

As seen from Table 11, the estimated combined yield from current production wells (Robe TWS 1, 5, 6) would not be able to provide the expected future demand of 59 L/s on peak days, in both medium and long term. Options available to increase the output from the wellfield in order to meet the anticipated future demand are to either expand the Robe TWS wellfield or decommission any inefficient well and replace it with a new efficient one. The potential of an expanded wellfield is the subject of investigation in the next sections.

Potential impact of additional well on existing wellfield

INTERFERENCE DRAWDOWN AND MEDIUM-TERM DEPLOYABLE DUE TO INTRODUCTION OF AN ADDITIONAL PRODUCTION WELL TO EXISTING WELLFIELD

The aim here was to determine the optimum location for the proposed additional well and the deployable output of the expanded wellfield. Three potential sites (N, S, W) for the location of an additional production well were investigated. These sites were selected on the basis of land availability. The objective was to minimise well interference and maximise wellfield output. It is assumed that conditions (pump intake depth and available drawdown) at the proposed new well are the same as conditions at Robe TWS 6 and that 98% of the minimum available drawdown is utilised. The optimum location of the proposed new well was determined by estimating the medium-term yield of the expanded wellfield.

Proposed new well located in Site 1

In this scenario three potential new production well sites were located at the positions marked as N1, N2 and N3 (Fig. 33). The location of the proposed new production well sites in relation to existing production wells is as follows: at N1 the proposed new well is 400 m away from Robe TWS 1, 310 m away from TWS 5 and 195 m away from TWS 6; at N2 the new well is 290 m away from Robe TWS 1, 100 m away from TWS 5 and 350 m away from TWS 6; at N3 it is 380 m from Robe TWS 1, 200 m from TWS 5 and 390 m from TWS 6. The pumping rate interference drawdown relationships at these locations are shown in Figures 34–36. Table 12 summarises estimated average medium-term deployable output at various locations.

Proposed new well located in Site 2

In this scenario three potential new production well sites are located at the positions marked as S1, S2, and S3 (Fig. 33). The location of the proposed new production well sites in relation to existing production wells are as follows: at S1 the proposed new well is 420 m away from Robe TWS 1, 440 m away from TWS 5 and 100 m away from TWS 6; at S2 it is 500 m away from Robe TWS1, 540 m away from TWS 5 and 200 m away from

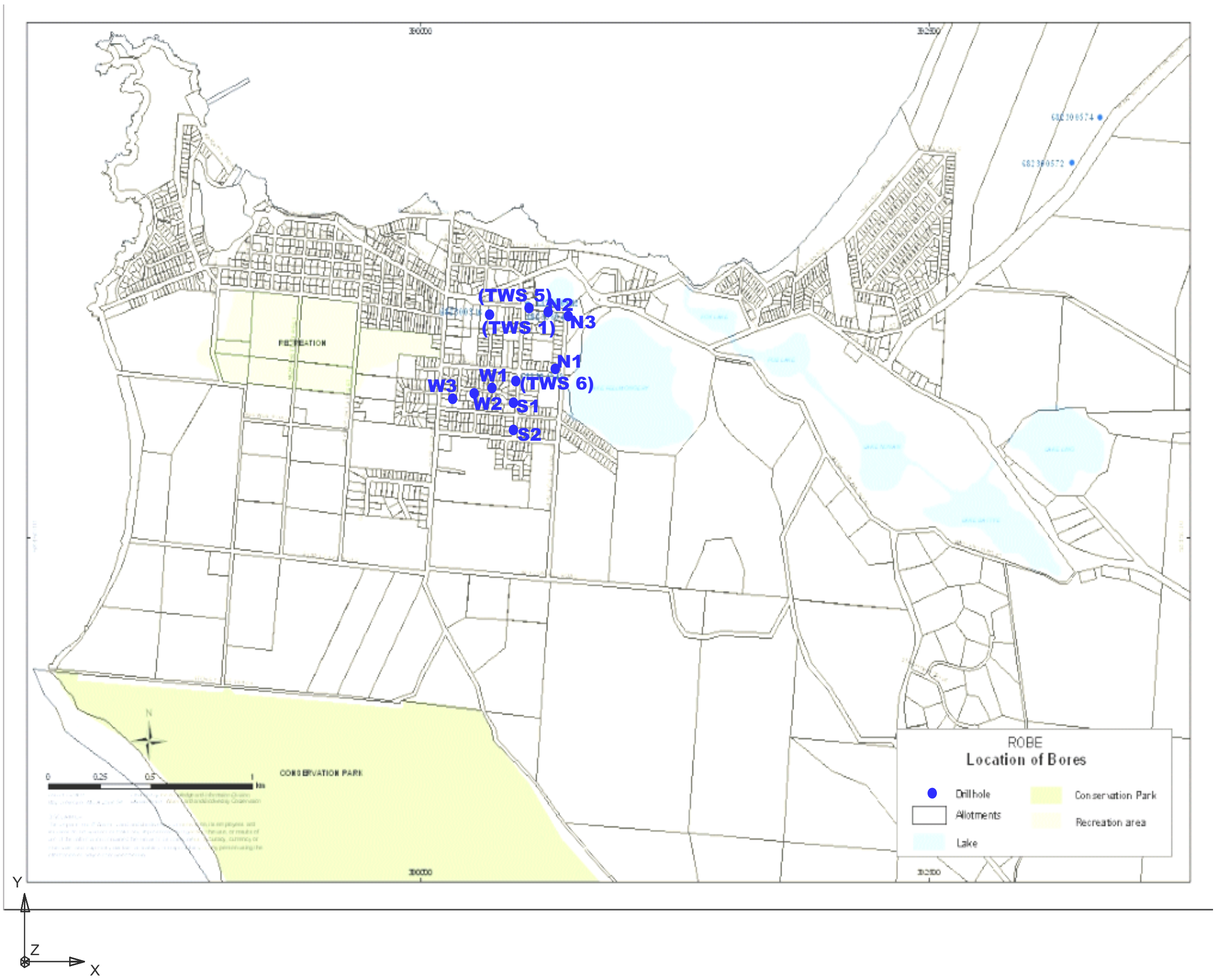


Figure 33. Location of proposed new well in relation to existing wells

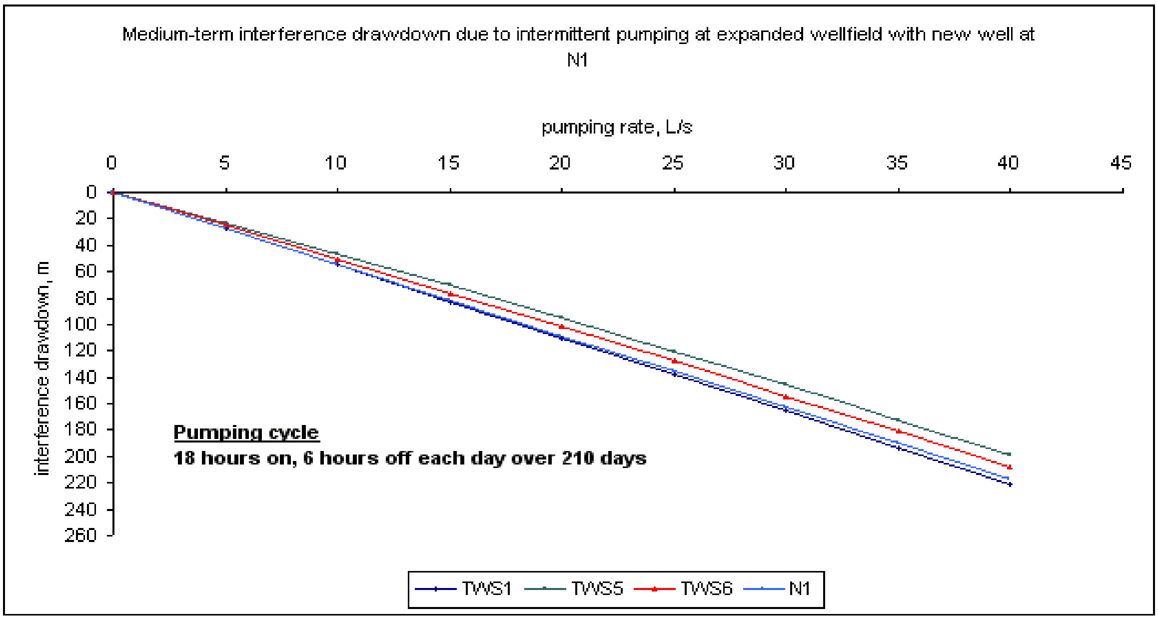


Figure 34. Site 1: Medium-term interference drawdown when proposed new well is positioned at N1

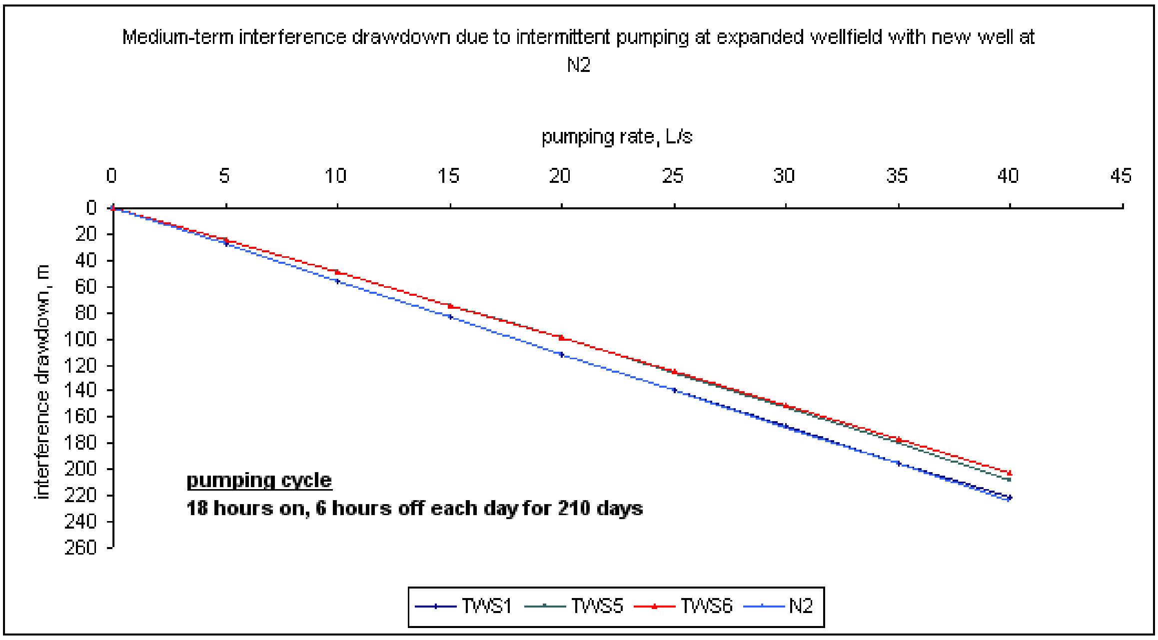


Figure 35. Medium-term interference drawdown when proposed new well is positioned at N2

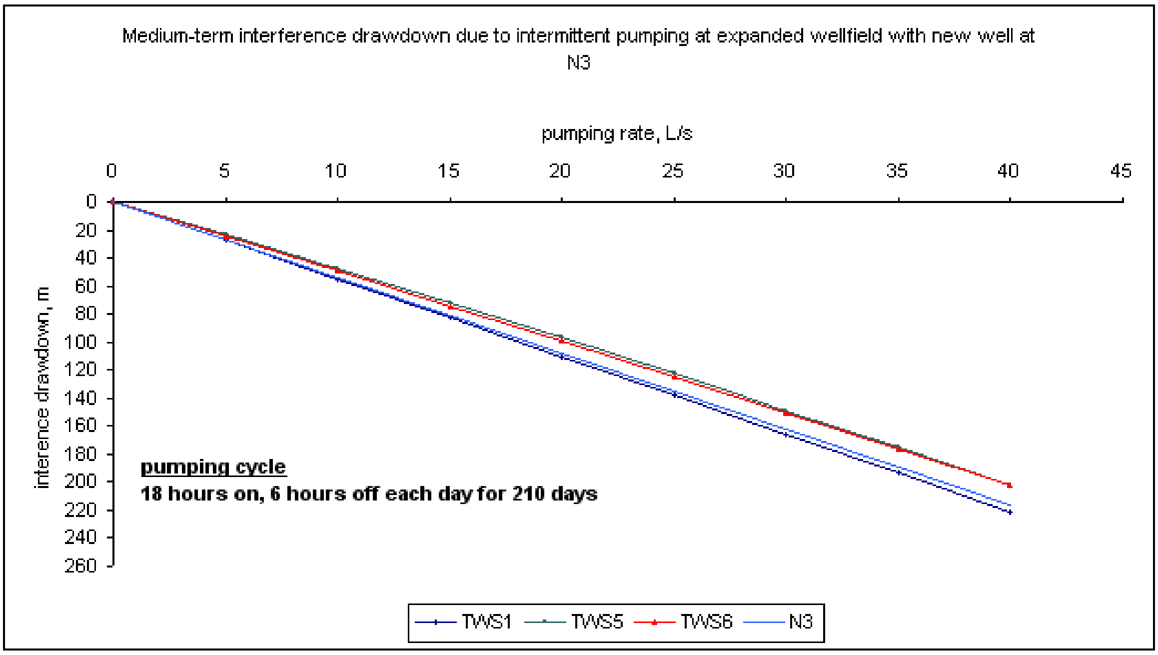


Figure 36. Medium-term interference drawdown when proposed new well is positioned at N3

Table 12. Estimated average medium-term potential yield from expanded wellfield with new well located in Site 1

Well	**Average available drawdown** (m)	**Estimated average medium-term potential yield** (L/s) **Location of new well**		
		N1	N2	**N3**
TWS 1	33.65	6.0	5.8	**6.0**
TWS 5	39.48	8.3	6.8	**8.2**
TWS 6	69.53	13.5	14.0	**14.1**
New well	69.53	12.5	12.4	**13.8**
Total		40.3	39.0	**42.1**

TWS 6; at S3 the new well is located 600 m away from Robe TWS 1, 620 m away from TWS 5 and 300 m away from Robe 6. The pumping rate interference drawdown relationship at these locations are shown in Figures 37–39. Table 13 summarises estimated average medium-term potential yield of the expanded wellfield if the proposed new well is located at Site 2.

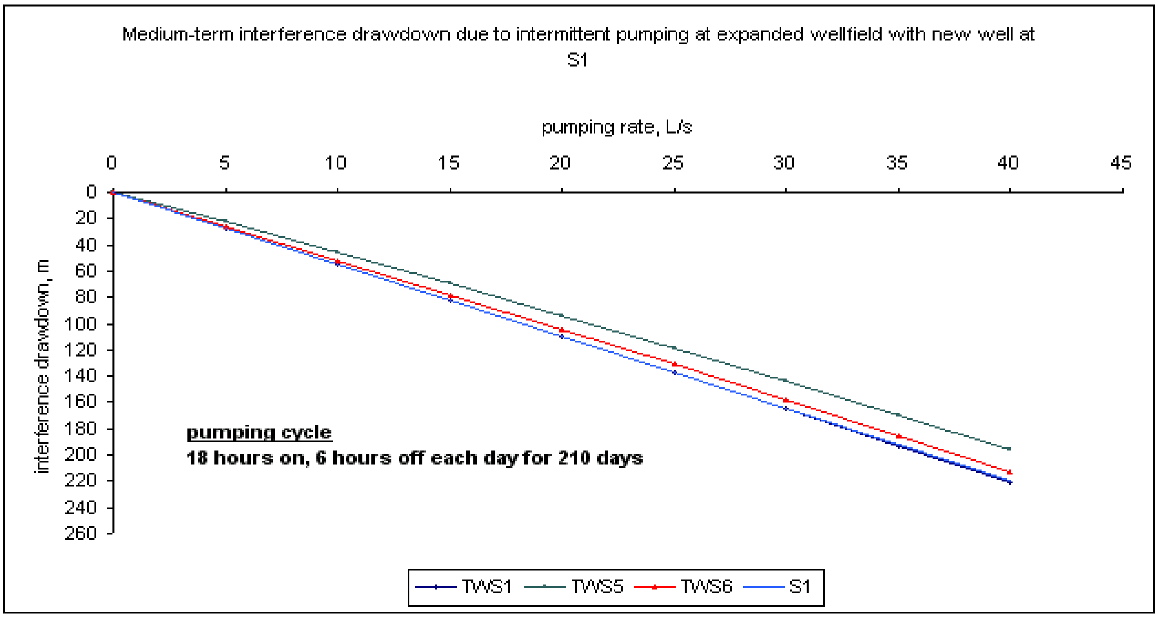


Figure 37. Site 2: Medium-term interference drawdown when proposed new well is positioned at S1

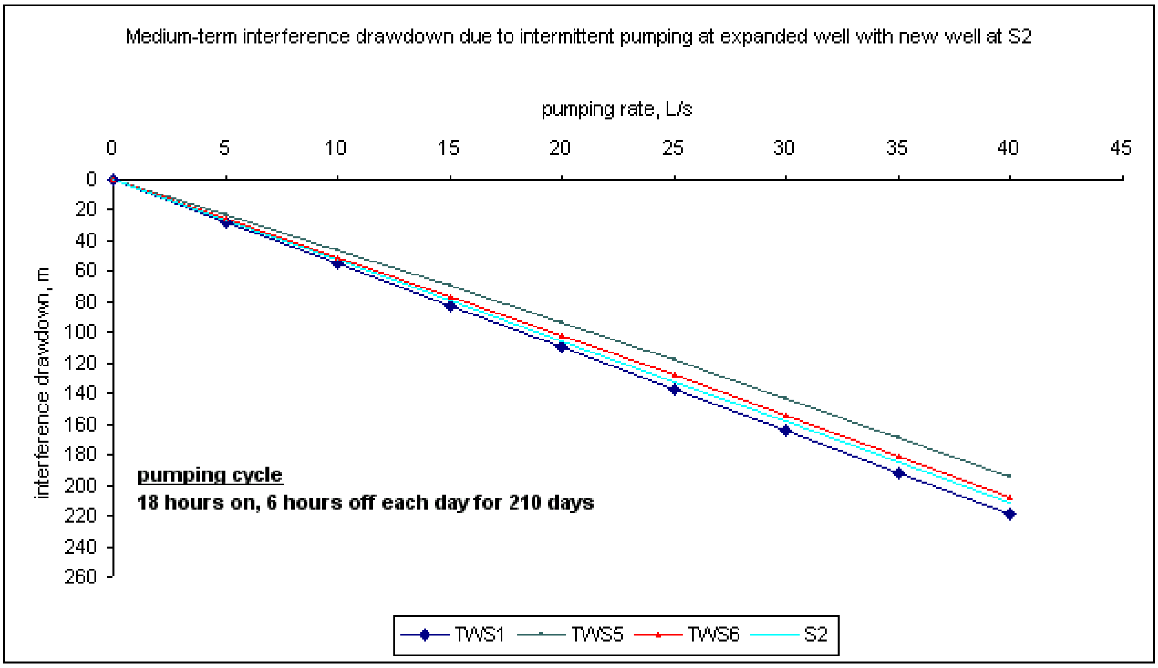


Figure 38. Site 2: Medium-term interference drawdown when proposed new well is positioned at S2

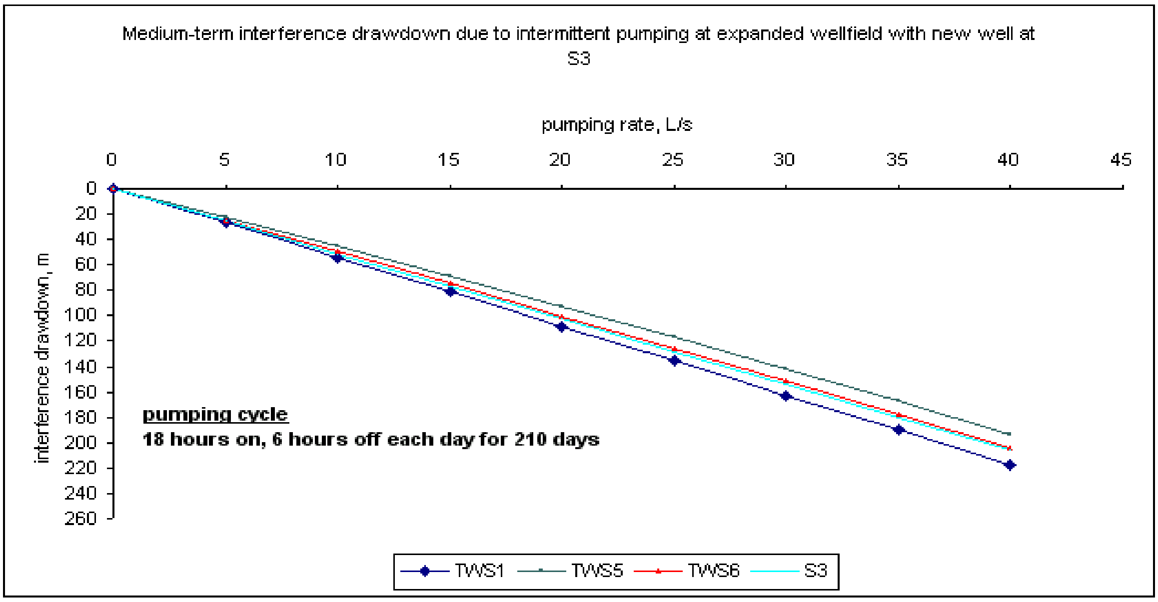


Figure 39. Site 2: Medium-term interference drawdown when proposed new well is positioned at S3

Table 13. Estimated average medium-term deployable output at expanded wellfield with new well located in Site 2

Well	**Average available drawdown** (m)	**Estimated Average medium-term potential yield** (L/s) **Location of new well**		
		S1	S2	S3
TWS 1	33.65	6.2	6.2	6.2
TWS 5	39.48	8.5	8.5	8.5
TWS 6	69.53	13.2	13.6	13.8
New well	69.53	12.4	13.2	13.4
Total		**40.1**	**41.5**	**41.9**

Proposed new well located in Site 3

In this scenario three potential new production well sites are located at the positions marked as W1, W2, and W3 (Fig. 33). The location of the proposed new production well in relation to existing production wells is as follows: at W1 the proposed new well is 320 m away from Robe TWS 1, 400 m away from TWS 5 and 100 m away from TWS 6; at W2 it is 350 m away from Robe TWS 1, 450 m away from TWS 5 and 200 m away from TWS 6; at W3 the new well is 400 m away from Robe TWS 1, 550 m away from TWS 5 and 300 m away from TWS 6. The pumping rate interference drawdown relationships at these locations are shown in Figures 40–42. Table 14 is a summary of estimated average medium-term deployable output.

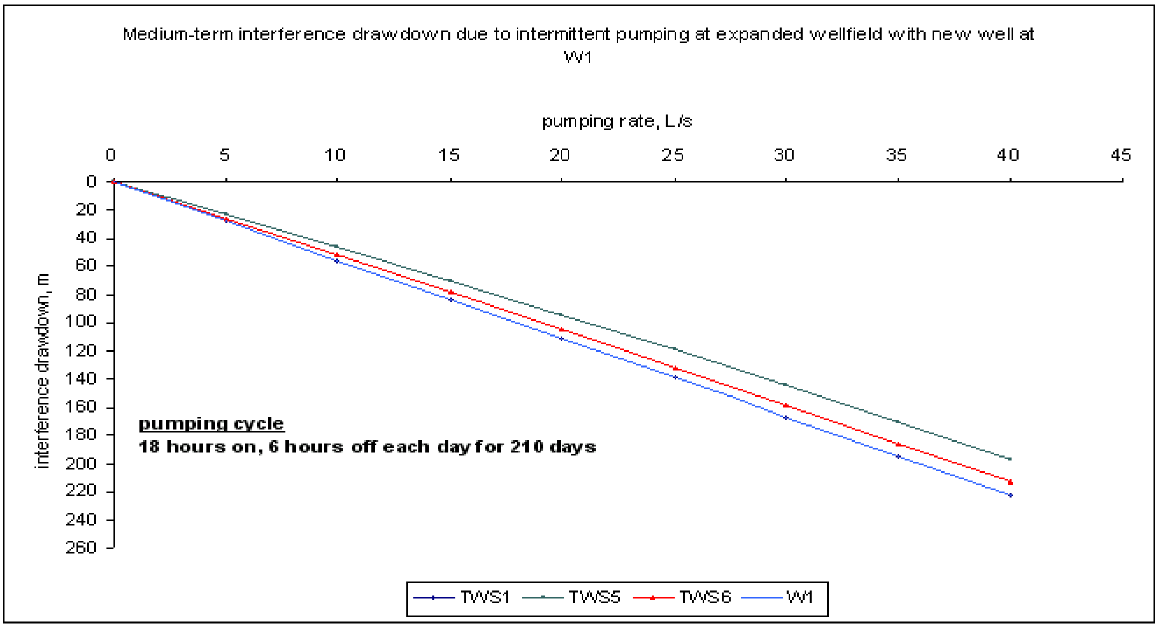


Figure 40. Site 3: Medium-term interference drawdown when proposed new well is positioned at W1

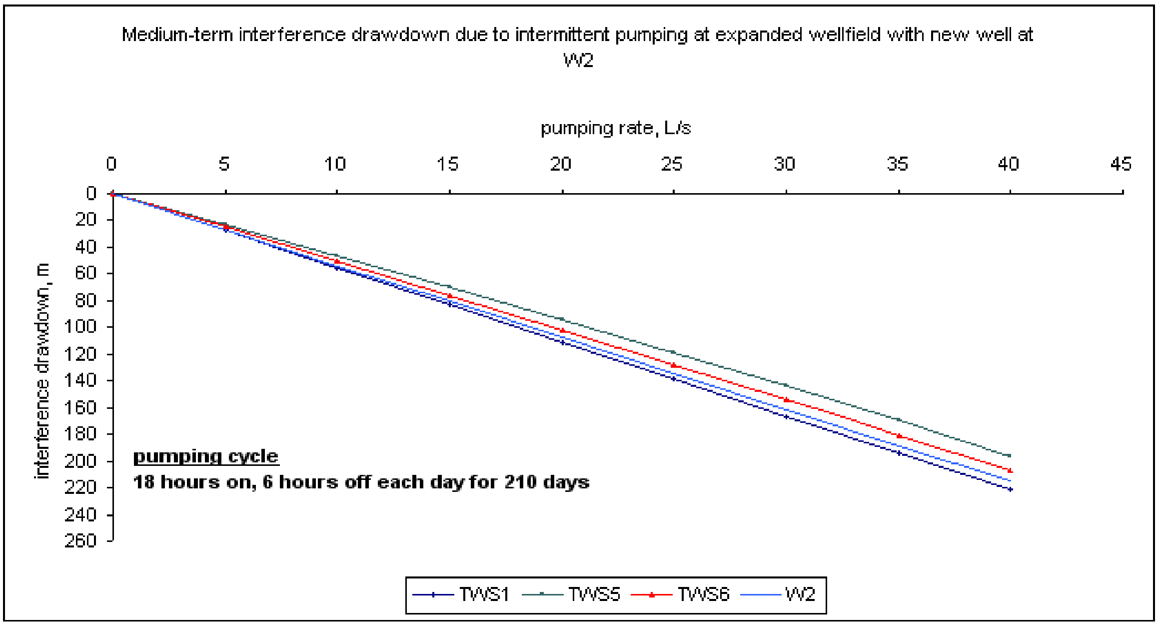


Figure 41. Site 3: Medium-term interference drawdown when proposed new well is positioned at W2

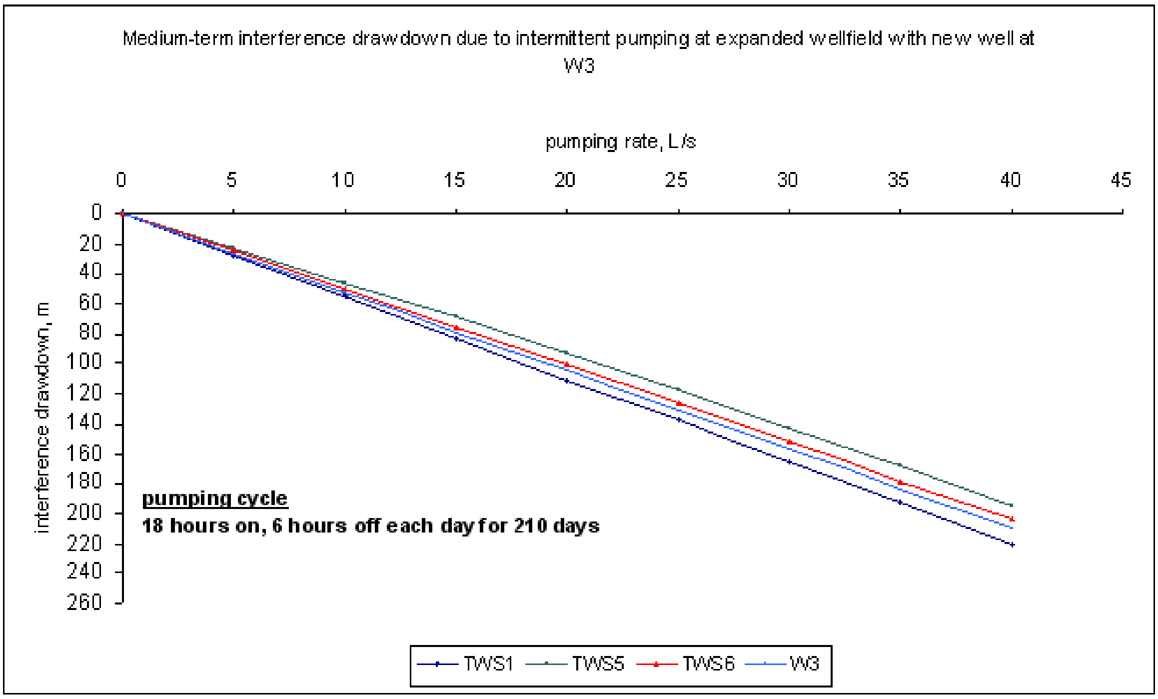


Figure 42. Site 3: Medium-term interference drawdown when proposed new well is positioned at W3

Table 14. Estimated average medium-term deployable output at expanded wellfield with new well located in Site 3

Well	**Average available drawdown** (m)	**Estimated average medium-term potential yield** (L/s)		
		Location of new well		
		W1	W2	W3
TWS 1	33.65	6.0	6.0	6.0
TWS 5	39.48	8.5	8.5	8.6
TWS 6	69.53	13.4	13.5	13.8
New well	69.53	12.4	12.8	13.2
Total		**40.3**	**40.8**	**41.6**

From Tables 12, 13 and 14 it can be seen that the estimated deployable output for all the scenarios investigated for the proposed expanded wellfield would not be enough to meet the anticipated demand of an average of 59 L/s in the near future. A maximum of 42.1 L/s could be obtained if an additional production well is drilled at N3.

8 DEPLOYABLE OUTPUT FOR A CASE WHERE ROBE TWS 1 AND/OR 5 IS DECOMMISSIONED AND REPLACED WITH NEW WELLS

As seen from above, the yield from an expanded wellfield of 4 production wells would not meet the future peak day demand of 59 L/s. Case scenarios in which Robe TWS 1 and/or 5 is decommissioned and replaced with new wells were investigated.

Scenario 1. Robe TWS 1 is decommissioned and replaced with a new one

In this scenario it was assumed that the replacement well would be located close to where the existing TWS 1 is, pump setting is at 74 m below ground surface and the available drawdown is the same as at Robe TWS 6.

If Robe TWS 1 is decommissioned and replaced with a new well at the same site, the yield–interference drawdown relationship for cases where the replacement well is as efficient as Robe TWS 5 and 6 are shown in Figures 43–44, respectively. If the replacement well were as efficient as Robe TWS 5, the estimated deployable output would be 47.2 L/s (Fig. 43). The estimated deployable output from the wellfield, if the replacement well is as efficient as Robe TWS 6, would be 44.3 L/s (Fig. 44).

In Table 15 the estimated deployable output for current, expanded and replaced TWS 1 wellfield are compared. From Table 15 it can be concluded that the deployable output can be maximised if Robe TWS 1 is decommissioned and replaced with a new well. However, even for this scenario the estimated deployable output would not be sufficient to meet the projected future demand on peak days.

Scenario 2. Robe TWS 1 and 5 are decommissioned and replaced with two new wells

An average yield of 20 L/s per well is required from a wellfield of three production wells in order to provide 59 L/s on peak days. The depth to the sand aquifers at the wellfield is more than 290 m and a pumping rate of 20 L/s per well from a wellfield of 3 production wells would cause 82 m drawdown at Robe TWS 6, and 76 m drawdown at both Robe TWS 5 and a replacement well close to the site of Robe TWS 1 (Fig. 43). SA Water needs at least three wells with deeper pump intake depths in order to obtain the projected requirements of 59 L/s during periods of peak demand. Another scenario that was investigated was to decommission both TWS 1 and TWS 5 and replace them with two new wells. It was assumed that the replacement wells would be located close to where TWS 1 and TWS 5 are. In this case the pump settings in both new wells are at 95 m below ground surface. These two new wells are denoted as TWS 1A and TWS 5A in

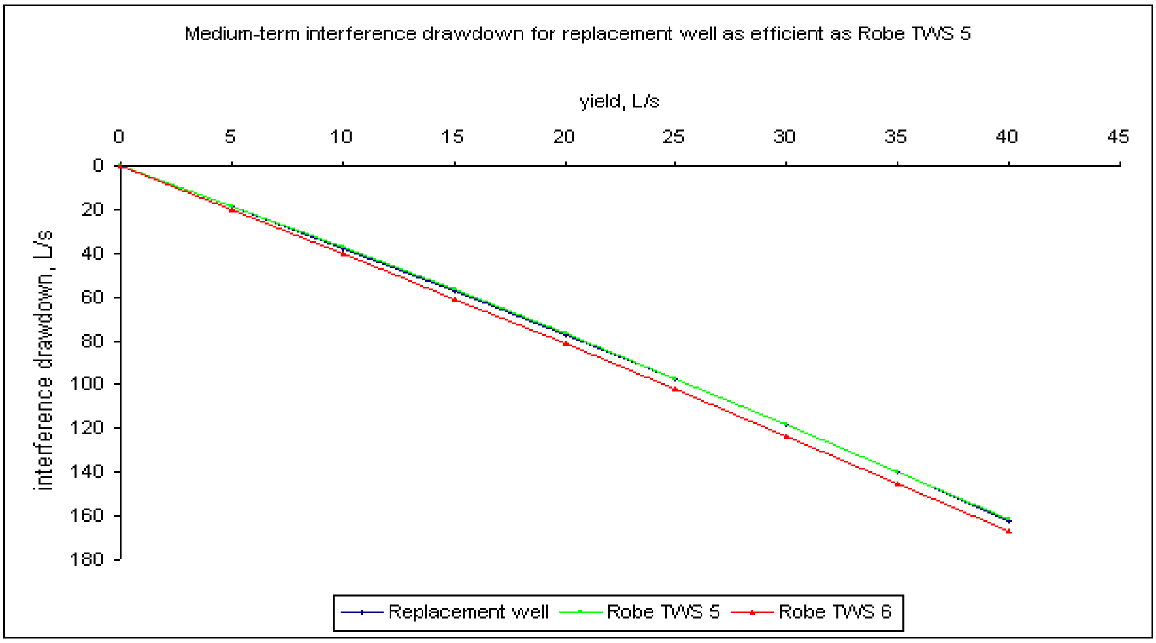


Figure 43. Medium-term interference drawdown for a replacement well as efficient as Robe TWS 5

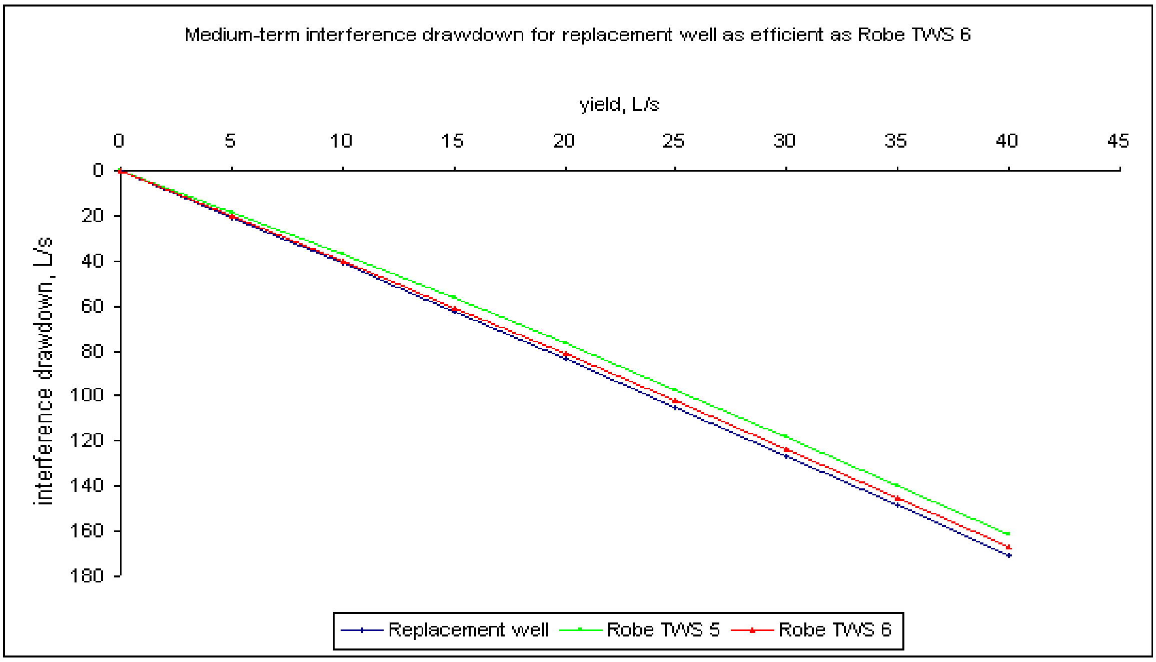


Figure 44. Medium-term interference drawdown for a replacement well as efficient as Robe TWS 6

Table 15. Comparison of deployable output at wellfield under different well installations

Well	Deployable output (L/s)			
	Current wellfield	**Expanded wellfield**	**Robe TWS 1 decommissioned and replaced with a new well which is as efficient as TWS 5**	**Robe TWS 1 decommissioned and is replaced with a new well which is as efficient as TWS 6**
TWS 1	5.30	6.00	–	–
TWS 5	9.50	8.20	9.8	10.50
TWS 6	16.75	14.10	17.2	17.10
New well	–	13.80	18.2	16.70
Total	**31.55**	**42.10**	**45.20**	**44.30**

Table 16 below. The average depth to water level at Robe TWS 1 and 5 during drought periods are 10 m and 7 m below ground surface. Setting the pump intake at 95 m below ground surface means the available drawdowns at TWS 1A and 5A during drought periods would be 85 m and 88 m respectively. A summary of deployable output under this scenario, estimated from Figures 43–44, is provided in Table 16.

From Table 16 it can be seen that the future peak day demand of 59 L/s would be met if Robe TWS 1 and 5 are replaced with two new wells and the pump intake is set at 95 m below ground surface. The pumps should be capable of pumping 25 L/s from a depth of 95 m below ground surface.

Table 16. Wellfield output when both TWS 1 and TWS 5 are replaced with two new wells

Well	**Available drawdown** (m)	Deployable output (L/s)		
		Current wellfield	**Robe TWS 1 and 5 decommissioned and replaced with two new wells which is as efficient as TWS 5**	**Robe TWS 1 and 5 decommissioned and are replaced with two new wells which is as efficient as TWS 6**
TWS 1	33.65	5.30	–	–
TWS 5	39.48	9.50	–	–
TWS 6	69.53	16.75	17.20	17.10
TWS 1A	85.00	–	21.25	20.50
TWS 5A	88.00	–	21.87	23.50
Total		**31.55**	**60.32**	**61.1**

9 CONCLUSION AND RECOMMENDATIONS

The conclusions made in this report are based on the yield-drawdown behaviour of the wells, water level and pumping records of the production wells, construction and present conditions of the wells, pump capacity and pump intake depths, interference effect from the wells and aquifer properties.

Issues that have been addressed in this report include the:

- amount of water that could be produced at the wellfield from existing installations under existing conditions
- deployable output of the wellfield for both average and peak demand conditions.

Analysis of field data indicates that the production capacities at Robe TWS 1 and 5 have been reduced significantly. Between 1998 and 2001 the production capacity of Robe TWS 1 and 2 has been reduced by about 57% and 43%, respectively. These wells require improvement to increase their yield and reliability. It is recommended that, where feasible, appropriate rehabilitation work be done to improve the performance of the wells.

Apart from undertaking the necessary rehabilitation work to improve the efficiency of the wells, lowering the pump intake would also help to increase the production capacities of the wellfield. The pump intake should be lowered if it is physically, technically and economically possible.

Other findings made in this report are as follows:

1. The existing wellfield is capable of producing an instantaneous yield of about 75 L/s. This value is almost the same as the current peak instantaneous extraction of 70 L/s.

2. The average medium-term and long-term deployable output of the existing wellfield was estimated at 34.5 L/s and 28.7 L/s, respectively

3. During periods of drought conditions and high demand, deployable output of about 31.6 L/s could be obtained in the medium term and about 26 L/s in the long term from the existing wellfield.

4. The estimated average medium-term deployable output is almost equal to the current peak day average yield of 33 L/s.

5. The peak day average yield from the wellfield could be estimated from the medium-term deployable output curves, established on the basis of aquifer hydraulic properties and production well performance information and data provided by SA water.

6. The wellfield under current conditions would not be able to produce the average yield of 59 L/s SA Water would need to extract on peak days in the near future.

7. The deployable output of the wellfield could be increased to 42 L/s if the current wellfield is expanded to four wells.

8. The deployable output could be increased to 45.2 L/s if Robe TWS 1 is decommissioned and replaced with a new well with a pump intake at 74 m below ground surface.

9. The deployable output of the wellfield could be increased to 60 L/s if both Robe TWS 1 and 5 are decommissioned and replaced with two new wells at the same sites, with pump settings at 95 m below ground surface.

It can be concluded that SA Water needs at least three wells with pump intake depths deeper than 90 m below ground surface in order to obtain the projected requirements of 59 L/s during periods of peak demand from the wellfield. Since it is physically impossible to lower the pump intake depths at current production wells it is recommended that one of the following options be considered by SA Water in order to meet the projected future demand.

Option 1

Replace both TWS 1 and TWS 5 with two new wells close to the locations of TWS 1 and TWS 5. The pump intake depths at both wells should be set at 95 m below ground surface.

Option 2

Replace Robe TWS 1 with a new well located close to where Robe TWS 1 is and construct an additional well at any of positions marked N3, S2 and W3 (Fig. 33). The pumps settings at the Robe TWS 1 replacement well and the new additional well should be 95 m below ground surface. With this option Robe TWS 5 could be used as a stand-by production well only.

Of these two options, option 2 is highly recommended. SA Water would require a pump capable of pumping 25 L/s from 95 m below ground surface.

10 REFERENCES

Birsoy V.K. and Summers W.K., 1980. Determination of aquifer parameters from step tests and intermittent pumping data. *Ground Water,* 18:137-146.

Cooper, H.H. and Jacob C.E., 1946. A generalised graphical method for evaluating formation constants and summarising well field history. *American Geophysical Union. Transactions,* 27:526-534.

Driscoll, F.G., 1986. *Groundwater and wells.*

Hazel, C.P., 1975. *Groundwater hydraulics.* Lectures presented to the Groundwater School, Australian Water Resources Council, Adelaide, August 1975.

Rammers, N and Stadter F., 2002. South East Prescribed Wells Areas groundwater monitoring status report 2002. *South Australia. Department of Water, Land and Biodiversity Conservation. Report,* DWLBC 2002/10.

District Council of Robe, 2003. District Council of Robe Annual Report, 2002-03. <http://www.robe.sa.gov.au/robecouncil>.

Rorabaugh, M.I., 1953. Graphical and theoretical analysis of step-drawdown test of artesian well. *American Society of Civil Engineers. Proceedings,* 79:362.

www.atlas.sa.gov.au

www.bom.gov.au/climate

11 APPENDIX 1

FORMATION LOGS OF SELECTED WELLS

1.1. Robe TWS 6 formation log

Well name: Robe TWS 6.

Unit No: 6823-1349.

Date drilled: 01/11/1999

Hundred: Waterhouse

Easting: 390465 Northing: 5885684

Formation Log		Material
From (m)	To (m)	
0.00	1.00	Fill
1.00	14.00	Sand and shells
14.00	213.00	Limestone - chert
213.00	234.00	Grey clay/marl
234.00	243.00	Brown clay
243.00	245.00	Sandy clay
245.00	249.00	Brown clay
249.00	250.00	Sand
250.00	280.00	Brown clay
280.00	381.50	Sandy clay
381.50	286.50	Hard brown clay
286.00	289.50	Sand
289.50	293.66	Brown clay

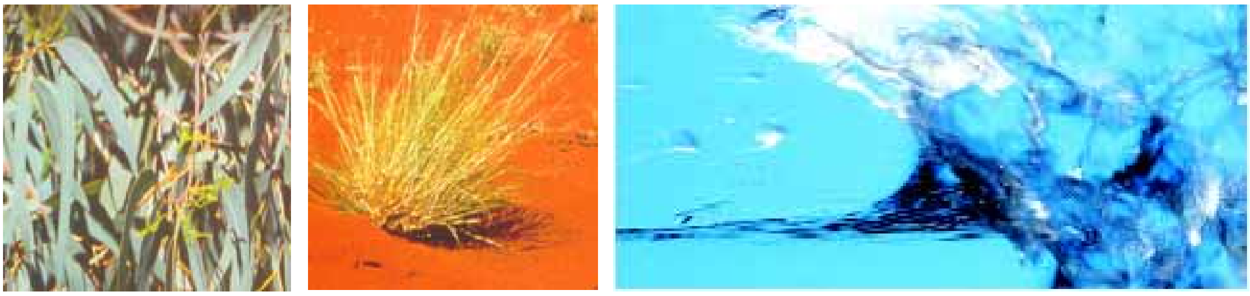
1.2. Well 6823-1416 formation log

Well name: Unit No: 6823-1416. Date drilled: 21/08/2002 Hundred: Waterhouse Easting: 396440 Northing: 5883113		
Formation Log		Material
From (m)	To (m)	
0.00	3.00	Sand
3.00	14.00	Sandstone
14.00	50.00	Limestone

1.3. Well 6923-4204 formation log

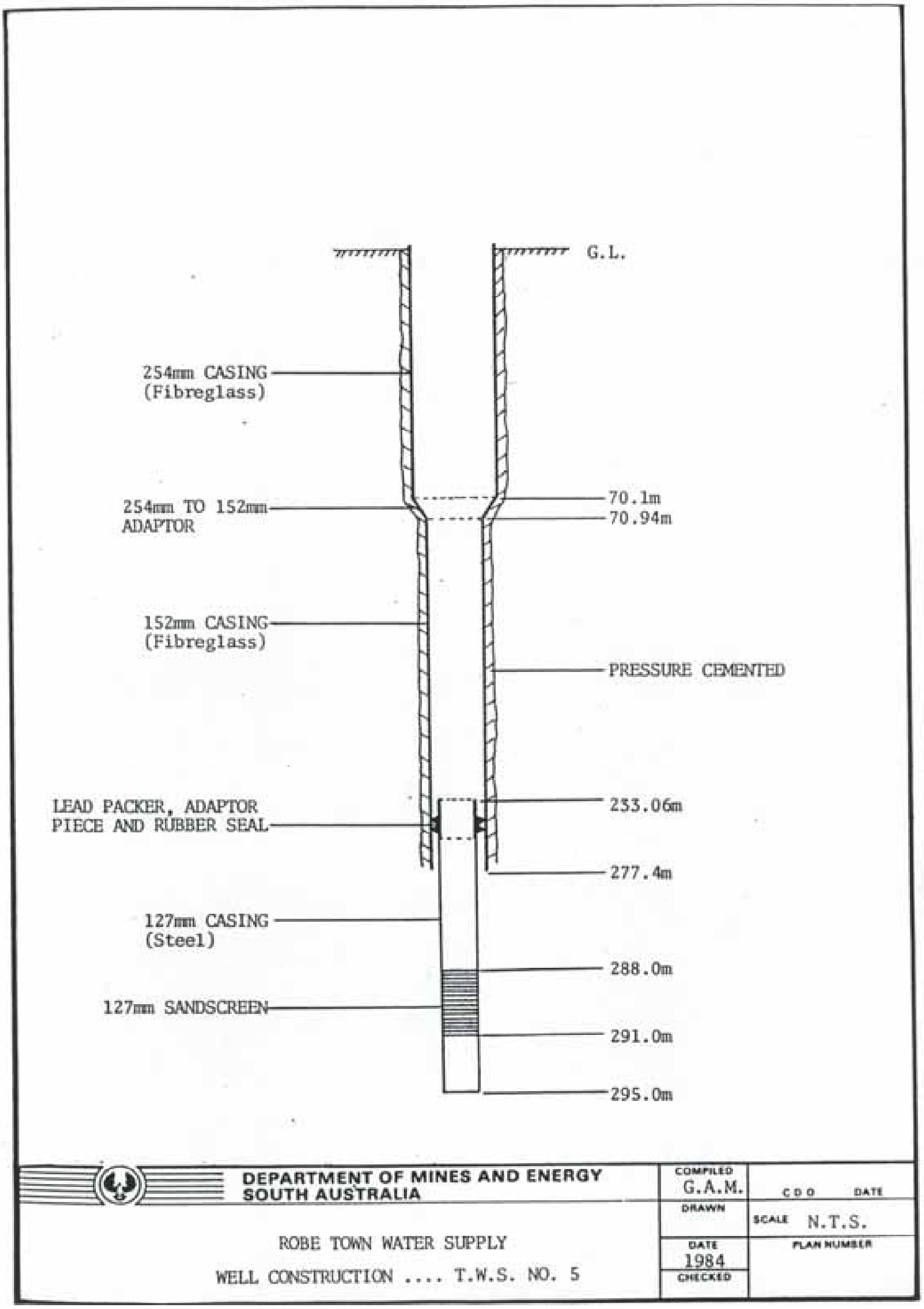
Well name: Unit No: 6923-4204 Date drilled: 21/02/2002 Hundred: Smith Easting: 422755 Northing: 5870118		
Formation Log		Material
From (m)	To (m)	
0.00	4.00	Sandstone
4.00	6.00	Clay
6.00	136.00	Limestone
136.00	196.00	Clay
196	204	Brown sand
204.00	266.00	Brown clay
266.00	246.00	Sand

12 APPENDIX 2



PRODUCTION WELL CONSTRUCTION DETAILS

Robe TWS 5 construction details



Robe TWS 1 construction details