Yield Test Report

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FINAL YIELD TESTING ANANLYSIS OF THREE BOREHOLES AT BULHOEK FARM, SWARTRUGGENS IN THE NORTHWEST PROVINCE

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DEFENITIONS & ABREVIATIONS

Abbreviation/ Term	Definition
Aquifer	An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (fractured rock, gravel, sand, or silt) from which groundwater can be usefully extracted by use of a borehole.
BH	Borehole
CFU	Colony forming unit is an estimate of viable bacterial or fungal numbers
Confined	A confined aquifer is bordered at the top and sometimes at the bottom by confining beds (layers of impermeable materials such as clay which impede the movement of water into and out of the aquifer).
Draw down	The difference between the rest water level and the water level during an abstraction or recovery period.
Mbgl	Meters below ground level
mamsl	Meters above mean sea level
Recovery	The way in which water replenish in a borehole under natural hydraulic pressure.
Storativity	The aquifer storativity, S, is defined as the change in water volume per unit aquifer area, A (m^2), per unit change in head.
Transmissivity	The rate at which groundwater flows horizontally in an aquifer. Measured in m^2/d
Unconfined	Unconfined aquifers are also called water table aquifers, because their upper boundary is the water table.
Yield test	A scientific test performed on a borehole in order to determine the safe and sustainable yield as well as aquifer parameters.

INTRODUCTION

Tucana Solutions was appointed by *Enviroworks* to perform long term pump and recovery tests on 3 identified boreholes at Bulhoek operations in the Swartruggens area in the Northwest Province.

According to the Groundwater Harvest Potential Map of the Republic of South Africa (DWAF 1996) the average yield of successful boreholes in the Swartruggens Area vary between 0.8 and 1.5l/s.

The area is situated on a minor aquifer system.

GENERAL SCOPE

AQUIFER TESTING

The procedure that is followed in order to determine the aquifer parameters and the long term sustainable yield of the borehole are described below. The different portions of the test involve:

- Calibration test
- Constant discharge test
- Recovery monitoring

CALIBRATION TEST

This type of test involves the determination of the actual rate of inflow into the borehole from the surrounding geological formations. It is achieved by abstracting water at a higher rate than it is replenished. Eventually it is only the water that enters the borehole from the aquifer that is abstracted. If this rate of abstraction is measured, it represents the rate at which the water enters the borehole from the aquifer, i.e., the actual yield of the aquifer.

The normal duration of a calibration test is 60 minutes. After the termination of the calibration test, enough time is allowed for the water level to recover at least 95%.

CONSTANT RATE DISCHARGE TEST

The constant discharge test is used to

- determine an aquifer's hydraulic parameters like transmissivity and storativity (if an observation well exists)

- compile a conceptual model of the aquifer's hydraulic scenario, for example the presence of impermeable or recharge boundaries.

The test involves monitoring the drawdown in the borehole while the abstraction rate is constant over the duration of the test. A description of the various methods used to analyse the data obtained from constant discharge tests can be found in Kruseman and De Ridder (1991). The duration of the constant rate test may be determined by the information and level of reliability required (Weaver, 1993).

The type of test and its duration shall be selected to suit the level of reliability required, which is a function of the water user's dependence on the borehole(s) and of the consequences (usually financial) of borehole failure (SANS 10299-4). Thus, a borehole for the watering of livestock needs a much shorter duration of test than a borehole for the irrigation of apple orchards or one that supplies an entire factory. In general, the test will run for about eight hours for boreholes to be equipped with hand, solar or wind driven pumps, and for forty-eight to seventy-two hours for boreholes to be equipped with electricity or diesel driven pumps, which are to be operated on a daily basis.

RECOVERY TEST

The results gained from the recovery test are used to determine the aquifer parameters and to determine how rapidly the water level recovers and whether the storativity values vary throughout the aquifer (Driscoll, 1986). The recovery test is done after a calibration test, step-drawdown test or a constant discharge test (or both), as required by the project geohydrologist. (SANS 10299-4)

It can also give an indication of the extent of the aquifer, or the extent and connectiveness of fractures. At the end of the pumping test (constant discharge test or step-drawdown test (or both)), switch off the pump and immediately start collecting residual drawdown readings at the relevant time intervals, until,

1. the water level recovers to less than 5 % of the total drawdown during the constant discharge test, or

2. at least three readings taken in succession are identical, or

3. a time equal to the total time taken for the constant discharge test has elapsed.

In order to establish whether the aquifer has been significantly dewatered during the constant discharge test, and in order to accurately apply the recovery test data for estimating sustainable borehole yields, it may be preferable to monitor recovery water levels for at least the same duration as the constant discharge test.

Recovery Test Method (Kirchner, 1991): This method involves calculating the maximum number of hours a borehole should be pumped each day at the tested rate, and it is based on the time it takes for the water level in a pumped borehole to return to the original rest water level (prior to pumping). Borehole water level measurements during the recovery period following a constant discharge pump test are plotted on semi-log graph paper against the time since pumping began (t), divided by the time since pumping was stopped (t').

The following formula is then used to determine the maximum number of hours (h) a borehole should be pumped for each day, at the pumping rate of the preceding test:

$h = 24 - (24/x)$

where: x = the x-axis intercept of the residual drawdown versus recovery plot (t/t') on semilog graph paper after a constant discharge pumping test. Residual drawdown is the water level in a borehole after pumping was terminated.

Extrapolations may also produce a t/t' value which is less than one, which gives a negative yield recommendation using the abovementioned equation. Under these circumstances it does not necessarily mean that the borehole cannot yield anything at all on a sustainable basis. Rather it indicates that partial dewatering of the aquifer took place during the constant discharge test, or that the aquifer is bounded by formations with relatively low permeabilities. While these may be good reasons to be cautious in recommending a long-term abstraction rate, they are not reasons to abandon the borehole altogether. In cases where rapid recovery occurs due to leakage from overlying material or variations in storativity, relatively high t/t' values may be obtained. This results in the calculation of large yield values. Since the extent of storage in these horizons is not taken into account, the sustainability of these yields would be uncertain.

It is also necessary to examine the assumption that recovery time is related to the preceding pumping rate. Does a borehole that was pumped at a low rate, relative to its potential, require just as long to recover than if it was pumped at a higher rate? If a low rate was selected, a low-pressure gradient would be induced in the fractures, which would limit the rate of replenishment from the surrounding matrix. Consequently, similar t/t' intercept values may be obtained irrespective of the preceding pumping rate.

The implication is that a much lower yield value would be calculated relative to that which would have been calculated from a high pumping rate recovery test. The application of this method should possibly be restricted to tests where the pumping rate is close to the borehole's capacity and where the recovery is complete.

LOCATION

The maps below indicate location of the boreholes that was tested.

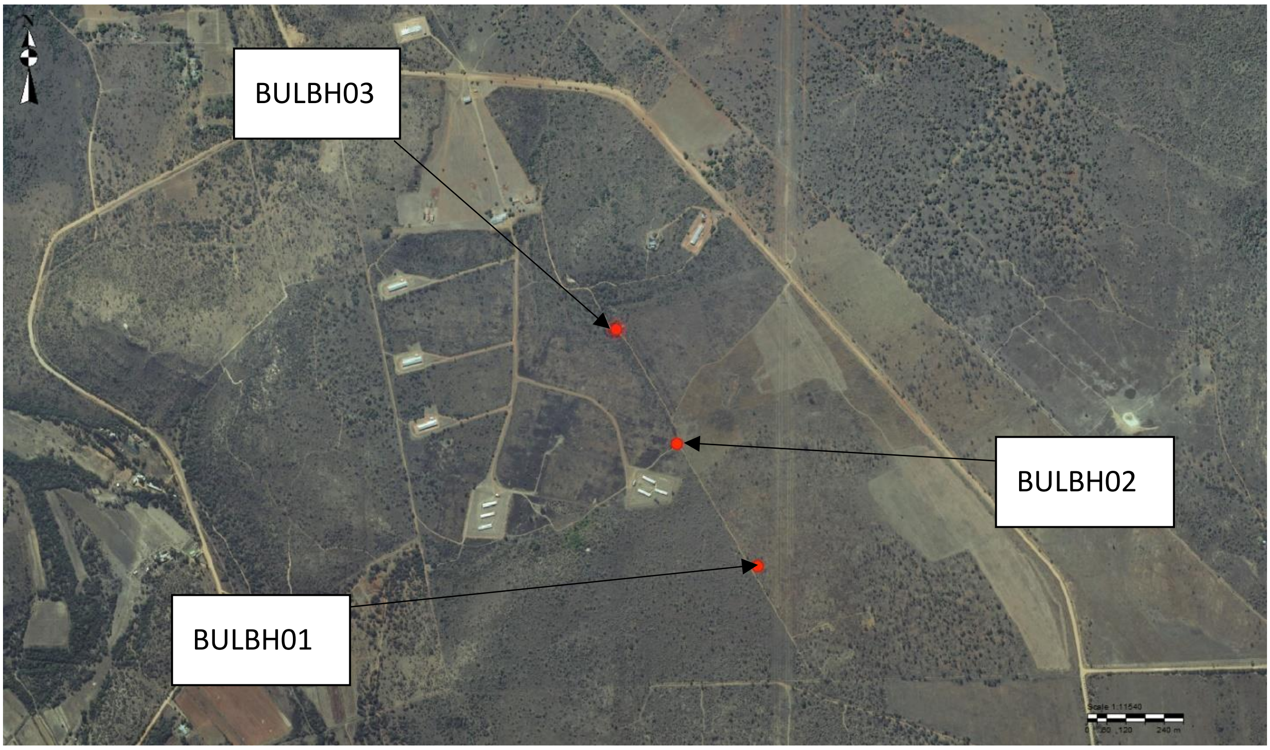


Figure 1: Location of boreholes at the Bulhoek operations

The details of the boreholes that was tested are summarised in the table below;

Name	Lat	Long	Static Water Level(mbgl)	BH Depth (mbgl)	Comments
BULBH01	-25.590748	26.906845	37.2	100+	1.5kW/ SVM70/20 pump @73m
BULBH02	-25.587362	26.914383	26.5	57.8	1.5kW/ SVM55/20 pump @ 43m
BULBH03	-32.309369	24.540708	29.7	55.2	2.2kW pump @ 50m

Table 1: Borehole Details

PUMP TEST ANALYSIS – BULBH01

The following data was recorded:

Start date of test: 12/10/2021

Borehole Depth: 100+m below ground level

Water level: 37.2 m below ground level

Test pump intake: 93 m below ground level

Available draw down (to pump): 55.8 m

Abstraction rate: 1.39 l/s

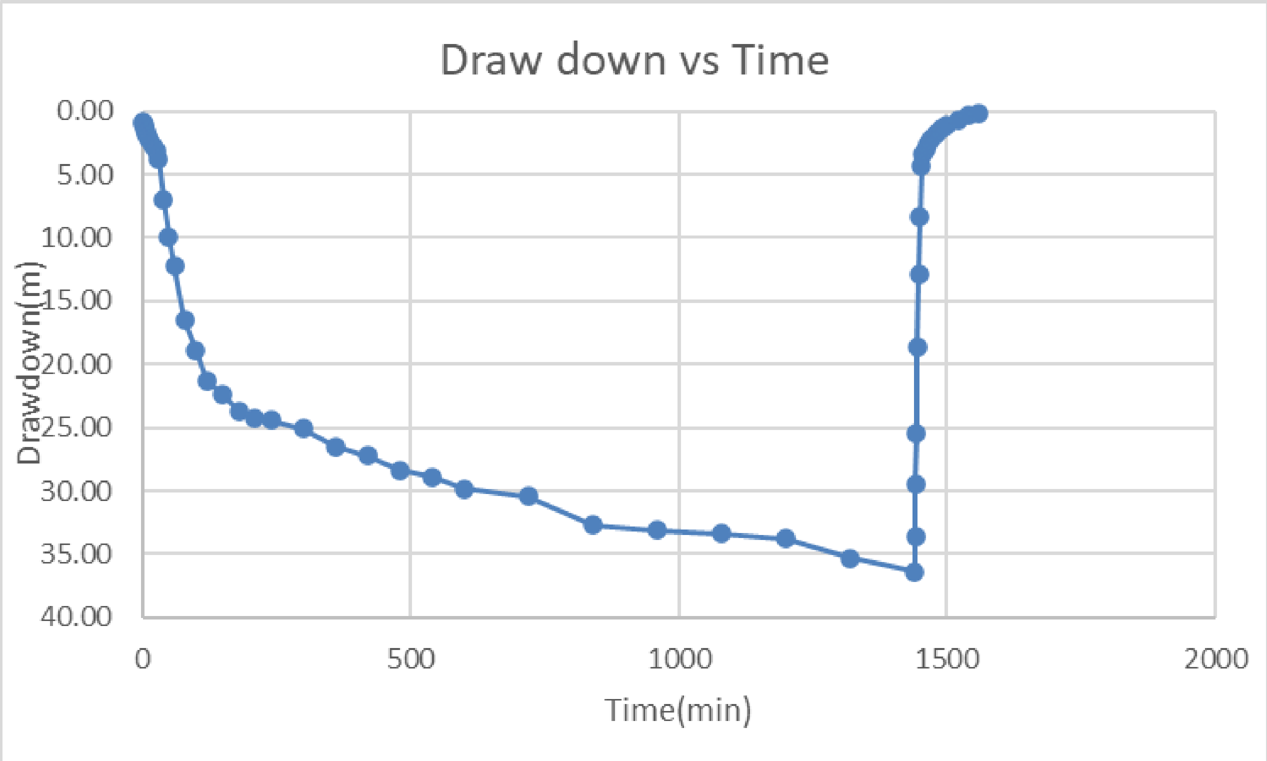


Figure 2: Draw down versus time (Pump & Recovery Data)-BULBH01

CONSTANT RATE PUMP AND RECOVERY TEST CONSTANT RATE TEST

After the calibration test and recovery an average abstraction rate of 1.39 l/s was selected for the long-term test pumping. The final draw down after 24 hours was 36.4 m. The transmissivity as calculated by the Cooper-Jacob method is 8.5 m^2/d.

RECOVERY

During the recovery monitoring the water level recovered to 37.36 mbgl (99 % recovery) within 20 min, which indicate average recovery. According to the recovery data a transmissivity of 8.8 m^2/d could be estimated.

SAFE YIELD ESTIMATION

The safe yield was estimated on the basis of the constant yield test. According to the FC method calculations the sustainable yield for BULBH01 is 0.63 l/s (2 268 l/hr) on a 24-hr pump cycle. A total of 54 432 litres per day is available at the above-mentioned rate and duty cycle.

The recommended depth of the pump intake is 80 meters below ground level and the dynamic water level is 62 mbgl.

WATER QUALITY

No water samples were collected.

PUMP TEST ANALYSIS – BULBH02

The following data was recorded:

Start date of test: 06/10/2021

Borehole Depth: 57.8m below ground level

Water level: 26.5 m below ground level

Test pump intake: 50 m below ground level

Available draw down (to pump): 23.5 m

Abstraction rate: 0.5 l/s

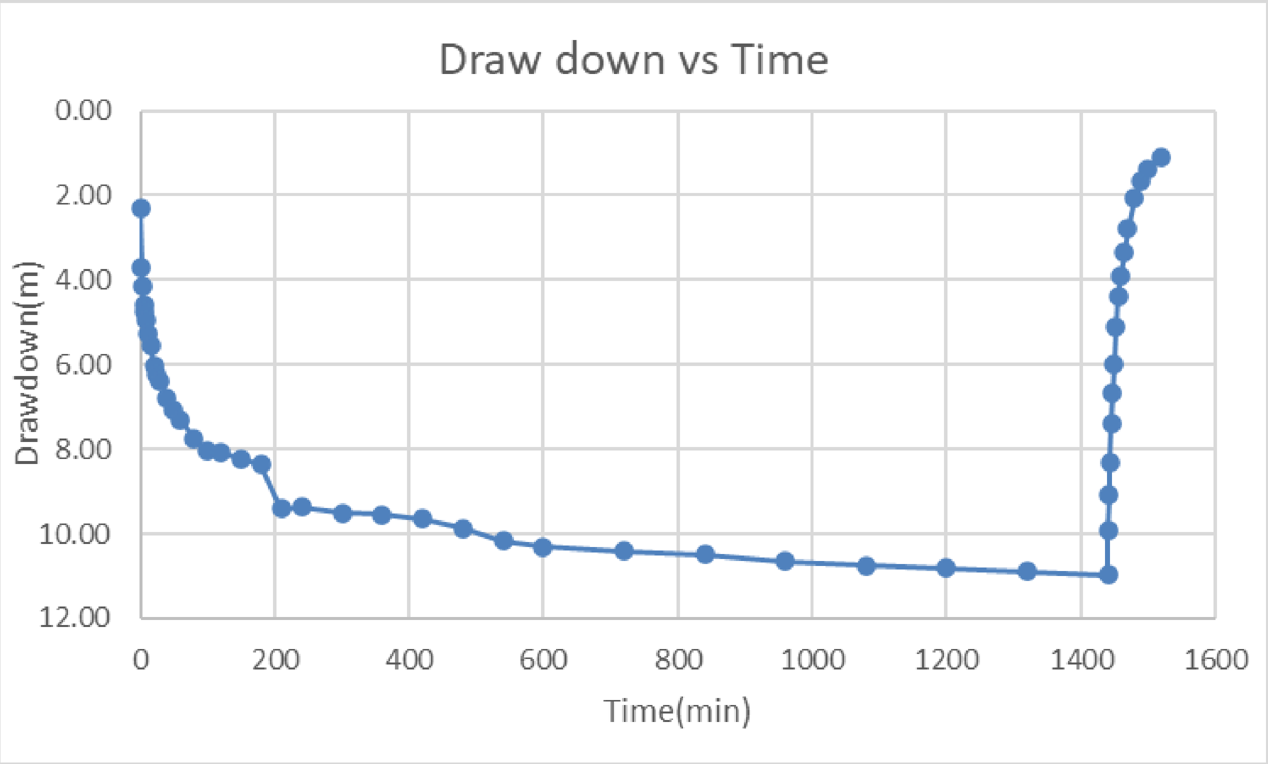


Figure 3: Draw down versus time (Pump & Recovery Data)- BULBH02

CONSTANT RATE PUMP AND RECOVERY TEST CONSTANT RATE TEST

After the calibration test and recovery an average abstraction rate of 0.5 l/s was selected for the long-term test pumping. The final draw down after 24 hours was 10.97 m. The calculated transmissivity is 3 m^2/d.

RECOVERY

During the recovery monitoring the water level recovered to 27.59 mbgl (95 % recovery) within 1.33 hours, which indicate average/good recovery. According to the recovery data a transmissivity of 2.5 m^2/d could be estimated.

SAFE YIELD ESTIMATION

The safe yield was estimated on the basis of the constant yield test. According to the FC method calculations the sustainable yield for BULBH02 is 0.24 l/s (864 l/hr) on an 24-hr pump cycle. A total of 20 736 litres per day is available at the above-mentioned rate and duty cycle.

The recommended depth of the pump intake is 50 meters below ground level and the dynamic water level of 37 mbgl should not be exceeded.

WATER QUALITY

No water sample was requested.

PUMP TEST ANALYSIS – BULBH03

The following data was recorded:

Start date of test: 13/10/2021

Borehole Depth: 55.2m below ground level

Water level: 29.7 m below ground level

Test pump intake: 48 m below ground level

Available draw down (to pump): 18.3 m

Abstraction rate: 2.33 l/s

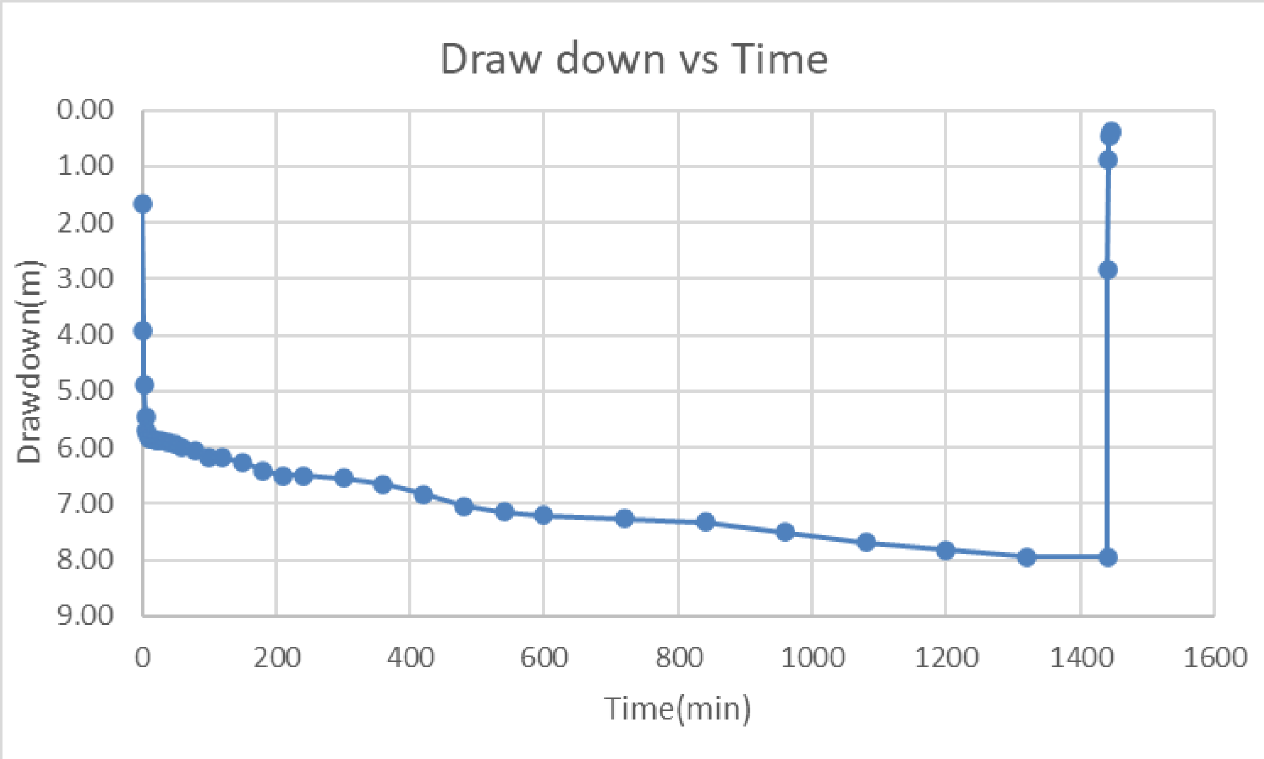


Figure 4: Draw down versus time (Pump & Recovery Data)-BULBH03

CONSTANT RATE PUMP AND RECOVERY TEST CONSTANT RATE TEST

After the calibration test and recovery an average abstraction rate of 2.23 l/s was selected for the long-term test pumping. The final draw down after 24 hours was 7.94 m. The calculated transmissivity is 20.9 m^2/d.

RECOVERY

During the recovery monitoring the water level recovered to 30.09 mbgl (99 % recovery) within 7 min, which indicate rapid recovery. According to the recovery data a transmissivity of 28.1 m^2/d could be estimated.

SAFE YIELD ESTIMATION

The safe yield was estimated on the basis of the constant yield test. According to the FC method calculations the sustainable yield for BULBH03 is 0.85 l/s (3060 l/hr) on an 24hr pump cycle. A total of 73 440 litres per day is available at the above-mentioned rate and duty cycle.

The recommended depth of the pump intake is 50 meters below ground level and the dynamic water level of 37 mbgl should not be exceeded.

WATER QUALITY

No water sample was requested

CONCLUSIONS & RECOMMENDATIONS

It must be noted that the boreholes were tested separately from any other boreholes therefore no calculations or estimation can be made on the effect of simultaneous abstraction from boreholes.

The combined effect of the abstraction of groundwater from the aquifer as well as the seasonal influence of rainfall recharge and other external factors on the aquifer must be monitored in the long term to determine such impacts on these boreholes. The abstraction management must be optimised with these influences in mind. Management and monitoring of the borehole are absolutely crucial in order to develop the resource sustainably.

For water level monitoring purposes, it is recommended that a 32mm HDPE pipe be strapped to the riser main to allow access with a dip meter.

The daily pump cycle, as recommended must not be exceeded and adequate controls must be installed to prevent "dry running" or over stressing of the aquifer.

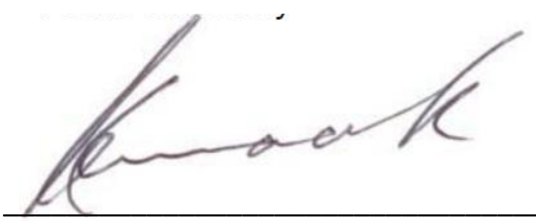
It is recommended that timers as well as water level probes be installed with the correct size pump to yield the recommended rate at the outlet.

The boreholes should be secured from objects or contamination entering at ground level. Based on the results of the analysis of the pump test data and the stated uncertainties the following abstraction rates can be recommended.

Name	Lat	Long	Pump Rate (l/s)	Duty Cycle (hrs pumped/hrs rest)	Available Volume (m^3/d)
BULBH01	-25.590748	26.906845	0.63	24/0	54.43
BULBH02	-25.587362	26.914383	0.24	24/0	20.74
BULBH03	-32.309369	24.540708	0.85	24/0	73.44
Total					148.61

Table 2: Management Recommendations

For proper management, water level monitoring must be implemented and recorded on a monthly basis. An automatic water level logger is recommended for this purpose.



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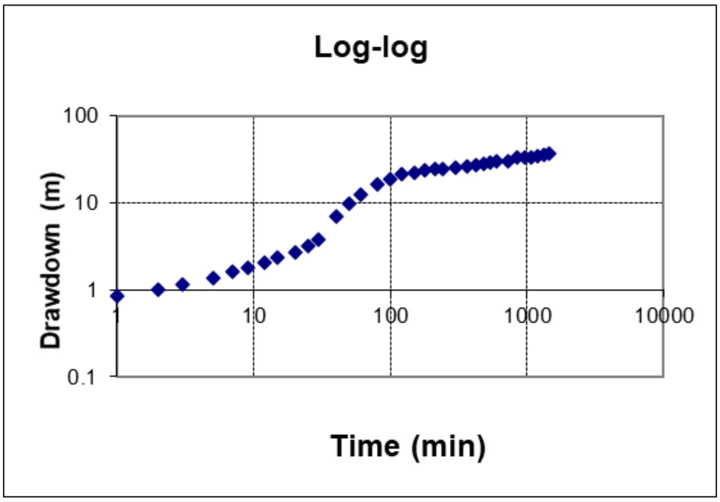
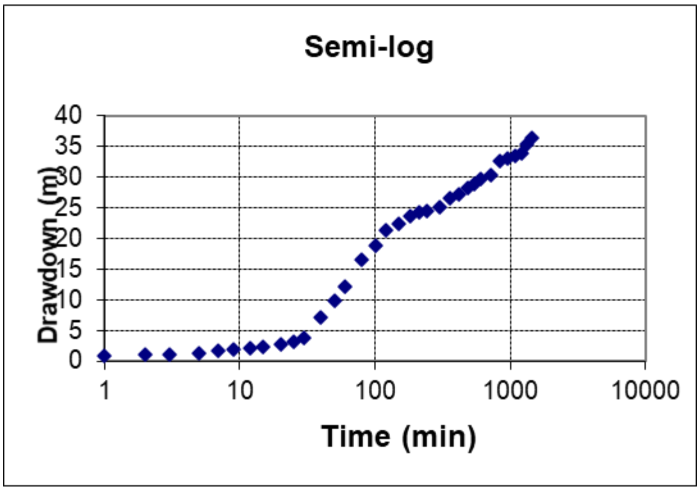
Appendix A

BULBH01

Summary	Main	BULBH1					
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)	Late T (m^2/d)	S	AD used
☑	Basic FC	0.23	0.16	6	1.2	2.20E-03	25.0
☐	Advanced FC			6	1.2	1.00E-03	25.0
☑	FC inflection point	0.52	0.31				24.8
☑	Cooper-Jacob	0.75	0.49		8.5	7.87E-06	25.0
☐	FC Non-Linear	2.49	2.20		34.0	5.06E-03	25.0
☑	Barker	1.04	1.63	K_f = 100	S_s =	2.11E-04	25.0
	Average Q_sust (l/s)	0.63	0.34	b = 0.20	Fractal dimension n =	2.00	

Recommended abstraction rate (L/s)	0.63	for 24 hours per day





Raw Test Data

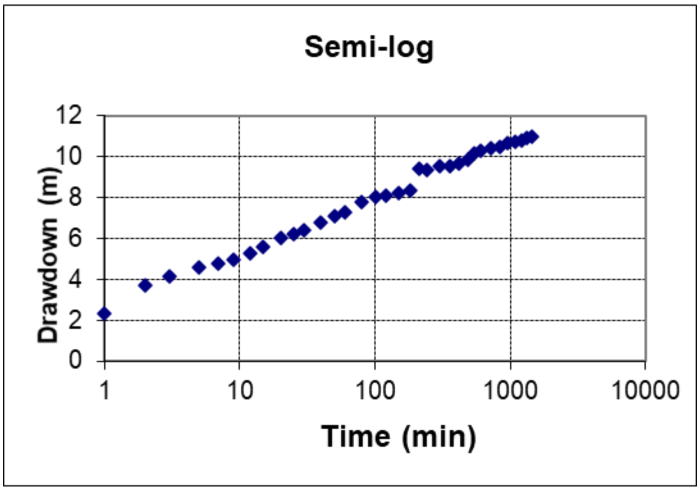
Time(s)	WL(mbgl)
0	37.20
1	38.04
2	38.21
3	38.34
5	38.57
7	38.82
9	39.00
12	39.25
15	39.56
20	39.92
25	40.35
30	40.97
40	44.26
50	47.12
60	49.43
80	53.70

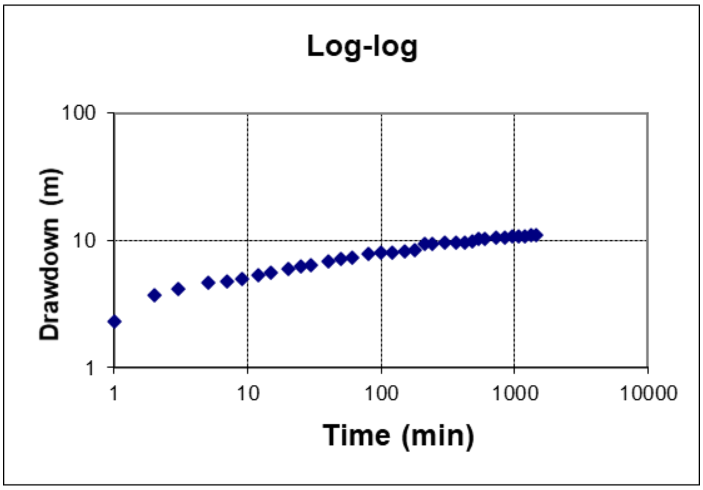
100	56.07
120	58.47
150	59.61
180	60.91
210	61.42
240	61.64
300	62.31
360	63.68
420	64.45
480	65.53
540	66.08
600	67.00
720	67.60
840	69.89
960	70.29
1080	70.56
1200	70.98
1320	72.47
1440	73.60
1441	70.85
1442	66.61
1443	62.59
1445	55.77
1447	50.11
1449	45.55
1452	41.56
1455	40.60
1460	40.16
1465	39.76
1470	39.44
1480	38.95
1490	38.58
1500	38.31
1520	37.88
1540	37.58
1560	37.36

BULBH02

Summary	Main	KBBH02						
Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)	S	AD used
☐	Basic FC	0.22	0.13	3		1.7	9.90E-04	20.0
☐	Advanced FC			3		1.7	1.00E-03	20.0
☑	FC inflection point	0.21	0.09					9.6
☑	Cooper-Jacob	0.28	0.18			3.0	4.90E-04	20.0
☐	FC Non-Linear							20.0
☑	Barker	0.25	0.16	K_f =	192	S_s =	2.11E-04	20.0
	Average Q_sust (l/s)	0.24	0.04	b =	0.04	Fractal dimension n =	1.91	

Recommended abstraction rate (L/s)	0.24	for 24 hours per day





Time(s)	(m above logger)
0	21.51
1	19.20
2	17.81
3	17.37
5	16.91
7	16.77
9	16.55
12	16.25
15	15.95
20	15.49
25	15.29
30	15.12
40	14.71
50	14.43
60	14.20
80	13.75
100	13.46
120	13.43
150	13.28
180	13.15

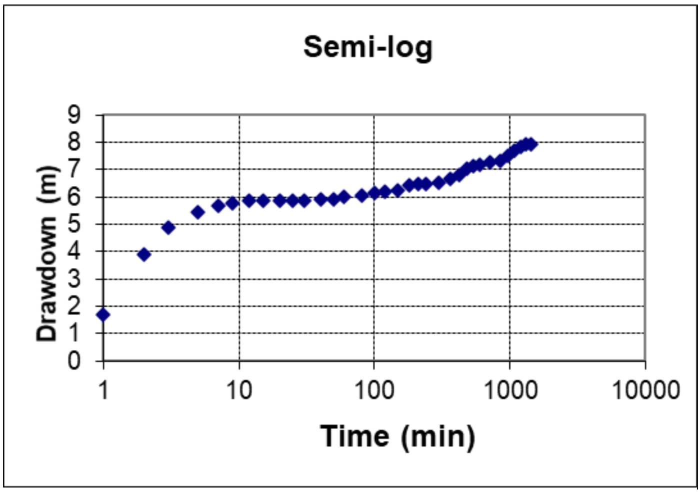
210	12.10
240	12.15
300	12.00
360	11.97
420	11.87
480	11.64
540	11.34
600	11.20
720	11.09
840	11.02
960	10.85
1080	10.76
1200	10.70
1320	10.62
1440	10.54
1441	11.58
1442	12.42
1443	13.19
1445	14.12
1447	14.85
1449	15.52
1452	16.40
1455	17.13
1460	17.61
1465	18.17
1470	18.72
1480	19.43
1490	19.85
1500	20.12
1520	20.42

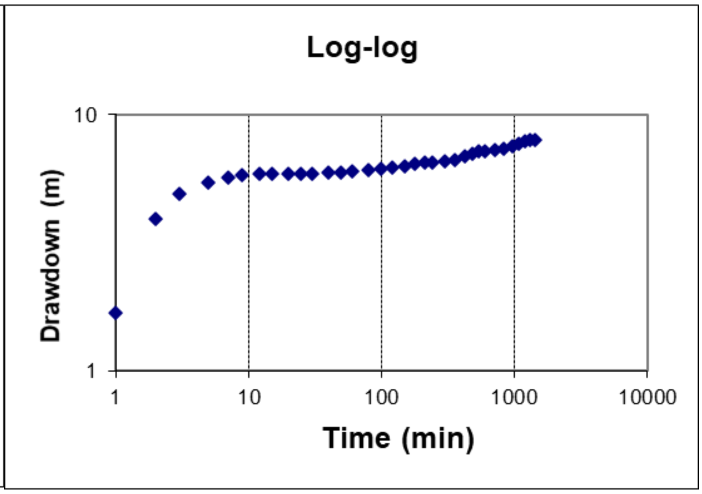
BULBH03

Summary | Main | **BULBH03**

Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)		S	AD used
☑	**Basic FC**	0.68	0.37	72		12.3		1.10E-03	9.0
☐	**Advanced FC**			72		12.3		1.00E-03	9.0
☑	**FC inflection point**	1.01	0.39						6.6
☑	**Cooper-Jacob**	0.83	0.53			20.9		1.16E-03	9.0
☐	**FC Non-Linear**								9.0
☑	**Barker**	0.90	0.63	K_f =	198		S_s =	2.12E-04	9.0
	Average Q_sust (l/s)	**0.85**	**0.14**	b =	0.09	Fractal dimension n =		2.04	

Recommended abstraction rate (L/s)	**0.85**	for 24 hours per day





Time(s)	(m above logger)
0	16.30
1	14.62
2	12.39
3	11.41
5	10.85
7	10.61
9	10.52
12	10.45
15	10.44
20	10.42
25	10.43
30	10.41
40	10.39
50	10.37
60	10.29
80	10.24
100	10.13
120	10.12

150	10.04
180	9.89
210	9.80
240	9.80
300	9.76
360	9.65
420	9.47
480	9.26
540	9.15
600	9.10
720	9.04
840	8.97
960	8.79
1080	8.62
1200	8.47
1320	8.36
1440	8.36
1441	13.45
1442	15.41
1443	15.82
1445	15.90
1447	15.91