CSRO10 – CONSTANT RATE PUMPING TEST

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ANNEXES

1. INTRODUCTION

1.1 Background

Section 3.2 of the main report discusses methods to estimate the radius or zone of interest of a dewatering abstraction and the uncertainties associated with applying the more commonly used approaches to assess the impact of dewatering the Queensferry cutting and South Launch excavation. The uncertainties arise either because there is insufficient information to define some parameters or because there is some doubt as to the applicability of empirical equations. Some equations are simply not applicable, for example because they apply only to radial flow to a circular excavation and/or because they apply only to confined aquifers (groundwater level monitoring indicates that the principal aquifer units in this case are generally semi-confined or unconfined).

Therefore, FCBC undertook a constant rate pumping test (CRT) in the sandstone unit close to Echline Corner in May 2012, with a view of applying the results to the Thiem-Depuit equation (see Section 3.2 of main report). Analysis of the test data would also allow a bulk transmissivity value to be determined and from this an estimated bulk permeability value. In view of the anisotropy of the sandstone unit at Echline (presence of mudstone layers, anisotropy of fractures and therefore flow paths etc), this is likely to be a truer reflection of the permeability of the unit than the values estimated from falling head tests (Section 2.3 of main report).

1.2 Borehole details

A new borehole, CSRO10, was drilled for the purpose of the pumping test. To ensure that a response could be monitored within the same aquifer unit, two observation boreholes: - CSRO11 and CSRO12, were drilled nearby. Borehole details are provided in Table 1.2 below.

Table 1.1 – Borehole Construction Details

	CSRO10 (pump test borehole)	CSRO11	CSRO12
Construction date	12/03/2012	26/03/2012	27/03/2012
Location (NGR)	311427.4 677750.1	311432.1 677749.0	311426.0 677752.4
Ground level (mAOD)	55.727	55.607	55.827
Total depth (mBGL)	15	15	15
Top and bottom of monitored aquifer unit (mBGL)	Sandstone (with thin beds of mudstone) 0.5 – 13.0	Sandstone (with thin beds of mudstone) 0.5 – 14.0	Sandstone (with thin beds of mudstone) 0.6 – 14.8
Monitored interval (mBGL)	2.0 – 13.0	1.5 – 14.0	1.5 – 14.0
Rest water level (mBGL)	2.60	2.02	2.62

Full borehole logs are attached Annex 1. The sandstone under test is overlain by 0.5 – 0.6m of sandy gravelly clay at the abstraction location. Mudstone is found beneath the sandstone.

The drift cover above the sandstone varies in lithology and thickness away from the abstraction borehole. Approximately 60m south south-east of CSRO10, the lithological sequence is very similar (at CSRO03A), yet 40m to the south east of CSRO10, the sandstone is overlain by around 2m of sand (at BHS101). Approximately 60m to the north of the abstraction borehole at S80, the sandstone is found at 4.8 mBGL, overlain by 1m of mudstone and 3.8m of clay. Approximately 40 m to the north-west at S78, the sandstone is overlain by 1m of sand, gravel and gravelly clay. In summary, the borehole logs around the area of the test borehole show that the aquifer and overlying geology are similar but not vertically and laterally homogeneous.

No other abstraction was occurring in the area before or at the time of the pumping test.

2. PUMPING TEST

2.1 Programme of work

The pumping test was preceded by a review of groundwater level data, borehole logs from the test area and permeability test results (falling head tests), which are presented in the main report.

CSRO10, CSRO11 and CSRO12 were developed by airlift and purging in March 2012 to remove accumulated sediment and to improve performance/reduce turbulent head loss.

The test programme was as follows:

28th and 29th May 2012	Pre-test set up
30th May 2012	CSRO10 constant rate pump test
30th – 31st May 2012	CSRO10 recovery test

2.2 Test Design

The previous review of permeability data and aquifer geometry indicated that a pumping rate of around 1 l/s was likely to be the maximum sustainable rate. The test was designed so that the abstraction borehole would be pumped at a constant rate for at least 8 hours, or until a quasi-steady state condition (no significant increase in drawdown) had been achieved.

FCBC's specialist subcontract, WJ Groundwater Ltd, supplied the pumping test equipment including the pump, temporary pipework, electromagnetic flow meter and data logger for the abstraction borehole.

2.3 Test Set-up

A temporary soakaway pit was excavated approximately 250m to the west of CSRO10 for test discharge. This was considered to be sufficiently far away so as to prevent recirculation of groundwater.

The pump was installed as deep as possibly in the borehole. A dip tube was installed alongside the pump in CSRO10 to prevent the monitoring equipment and the pump becoming tangled. On completion of pump installation, pre-test pumping was carried out to check achievable pumping rates. It became apparent that a pumping rate of 1 l/s would not be sustainable. Water levels in the abstraction borehole dropped rapidly and the pump was turned off for 45 minutes so that water levels could recover. The borehole was subsequently tested at lower pumping rates and a rate of approximately 0.13 l/s was selected as the maximum probable sustainable rate.

Water level monitoring instruments (data loggers) were installed in each of the boreholes and three additional boreholes in the surrounding area. Details of the measuring equipment are provided in Table 2.1.

Table 2.1 – Instrumentation and Measuring Equipment

Instrument	Measurement	Further Details	Borehole
Water Level Logger (Schlumberger Water Services – Diver)	Borehole water level (automatic)	10 mH_20 range, accuracy= 0.005m	CSRO11, CSRO12, CSRO03A
Water Level Logger (Schlumberger Water Services – Diver)	Borehole water level (automatic)	50 mH_20 range, accuracy = 0.001m	S80 (piezometer)
Water Level Logger (RuggedTroll)	Borehole water level (automatic)	9 mH_20 range	S78 (standpipe)
Barometric Pressure Logger (Schlumberger Water Services Baro-Diver)	Barometric Pressure at the test site (automatic)	150 cmH_20 range, accuracy = 0.5 cmH_20	CSRO12
Vibrating Wire Transducer	Borehole water level (automatic)	35 mH_20 range, accuracy = 3.5cm	CSRO10
Electric tape dipmeter	Borehole water level (manual)		CSRO10, CSRO11, CSRO12
50mm electromagnetic flowmeter	Discharge rate (l/s)		CSRO10 (abstraction borehole)

A weir tank was requested by DJV for manual discharge measurements. WJ Groundwater Ltd did not provide this on the day but instead installed an in-line mechanical flow meter. Readings from this appeared inaccurate so were disregarded.

After test set-up, water levels were left to recover overnight.

2.4 Monitoring Schedule and Water Level Datum

Electronic water level monitoring commenced at CSRO10, 11 and 12, 25 days prior to the test date and continued until after the test was complete. Electronic water level monitoring was also carried out at S78, S80 and CSRO03A one day prior to the test, continuing until after the test was complete.

During the test, manual water level and flow measurements were scheduled as given in Table 2.2 below.

Monitoring of the test borehole (CSRO10) was undertaken by WJ Groundwater (manual water level dip readings, data logger, and flow recordings). Monitoring of the observation boreholes was undertaken by the DJV.

Table 2.2 – Schedule of water level and discharge measurements

Manual water level and flow meter readings	0 to 10 minutes	30 second intervals
	10 to 20 minutes	1 minute intervals
	20 to 40 minutes	2 minute intervals
	40 to 60 minutes	5 minute intervals
	60 to 120 minutes	10 minute intervals
	120 to 180 minutes	20 minute intervals
	180 minutes to end of test	1 hour intervals
Electronic Water Level	1 minute intervals throughout the test	

Manual water level measurements were made to the top of the borehole casings (dip datum). These had been surveyed prior to the test. Elevation details are provided in Table 2.3 below.

Table 2.3 – Reference point levels

Borehole (BH)	Dip datum	Dip datum elevation (mAOD)
CSRO10	Top of BH casing	56.207
CSRO11	Top of BH casing	55.915
CSRO12	Top of BH casing	56.073

2.5 Test Results

The constant rate test at CSRO10 was carried out on the 30th May 2012 as planned, and recovery of water levels was also monitored over the 30th and 31st May. Figure 2.1 provides a graphical representation of the manual water level and discharge data collected during the test. The water levels have been corrected to mAOD based on the information in Table 2.3 above.

Manual dip and flow data is provided in Annex A2. Logger data is supplied electronically separately from this document.

The test was started at 09:00:00 but the desired pumping rate was not achieved until 1 minute 30 seconds into the test. There were very small fluctuations in pumping rate (0.01 l/s), but overall the target rate of 0.12 l/s was maintained.

At around 45 minutes into the test, there was a marked increase in rate of drawdown. This meant that the test had to be terminated after 3 hours 10 minutes as the water level in the abstraction borehole approached the pump intake depth. Recovery was manually monitored for 70 minutes after the pump was turned off. Data loggers were left to monitor the recovery overnight.

Figure 2.1 – Manual dip and discharge data

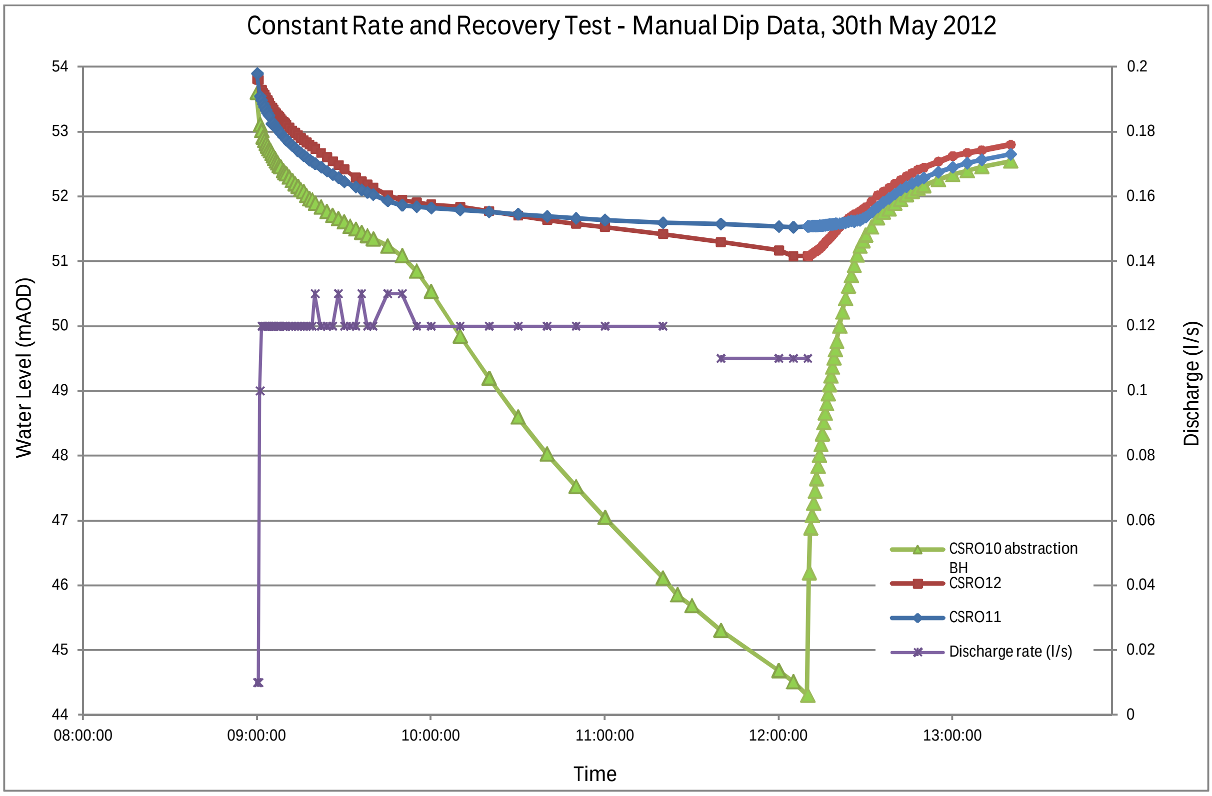
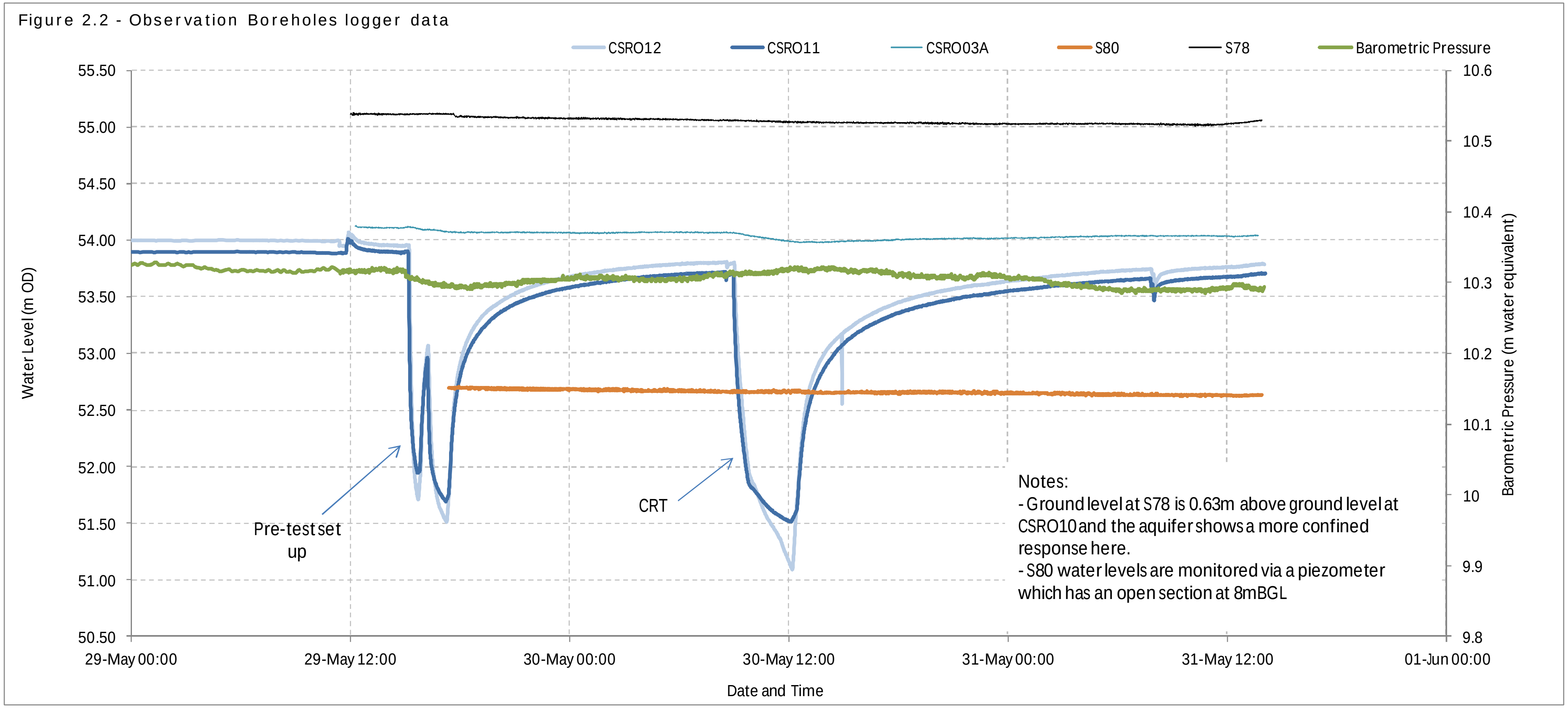


Figure 2.2 shows logger data converted to mAOD for the monitoring boreholes (including extra boreholes not included in the main analysis). The data shows a response at CSRO03A and a gradual decrease in water level at S78, though it is not certain if this is attributable to the pumping test. No response is seen in S80, though water levels in the borehole are measured through a piezometer installed around 8mBGL, as opposed to a standpipe with an open section spanning the sandstone unit.

Figure 2.2 – Observation borehole data



Notes:
- Ground level at S78 is 0.63m above ground level at CSRO10 and the aquifer shows a more confined response here.
- S80 water levels are monitored via a piezometer which has an open section at 8mBGL

3. ANALYSIS OF THE RESULTS

3.1 Preamble

Water levels in the abstraction and observation boreholes failed to approach a quasi-steady state condition during the CRT; indeed the drawdown rate in the production borehole increased markedly 45 minutes into the test. This could be because of a number of reasons but one of the most likely is because water levels have dropped below a more permeable layer within the sandstone unit. This is discussed further in Section 3.8.

Despite this, the test duration was sufficient to allow analysis of the results, although the later-time aquifer responses were not obviously apparent.

Only a thin layer of clay overlies the sandstone at the location of CSRO10 and the rest water level in the sandstone is below the top of the aquifer unit. This means that the aquifer is unconfined and as such the Neuman (1972) curve fitting method of analysis for unsteady state flow is considered suitable.

However, as shown in Section 1.2 the drift cover is laterally and vertically heterogeneous and over the test area there is some clay, and some sand and gravel cover. The Hantush (1960) curve fitting method for a leaky confined aquifer may therefore be more appropriate. The assumptions behind both methods are described in Kruseman and de Ridder (1994).

The data from both CSRO12 (observation borehole 1) and CSRO11 (observation borehole 2) have been analysed using the commonly-used AquiferWin32 software, in which the time drawdown data are used to calculate transmissivity (T) and the aquifer storage coefficient (S).

Transmissivity is the product of the average hydraulic conductivity (K) and the saturated thickness of the aquifer (d). From this, the average hydraulic conductivity has been calculated, using an aquifer thickness of 13.4m (from borehole logs). A summary of the results is given in Section 3.4.

3.2 CSRO10 Constant Rate Test, CSRO12 (Observation borehole 1)

Water levels at CSRO12 showed a clear response to abstraction from CSRO10, with a maximum drawdown of 2.73m. The time-drawdown graph (Figure 3.1) shows the logger data from this borehole over the period of the CRT.

There is a clear reduction in the rate of drawdown at around 50 minutes before the drawdown rate increases again. This coincides with the increase in the rate of drawdown seen in the abstraction borehole.

The Hantush (leaky confined) analysis is shown in Figure 3.2. The Neuman (unconfined) analysis is shown in Figure 3.3.

Figure 3.1 – CSRO12 Time-Drawdown

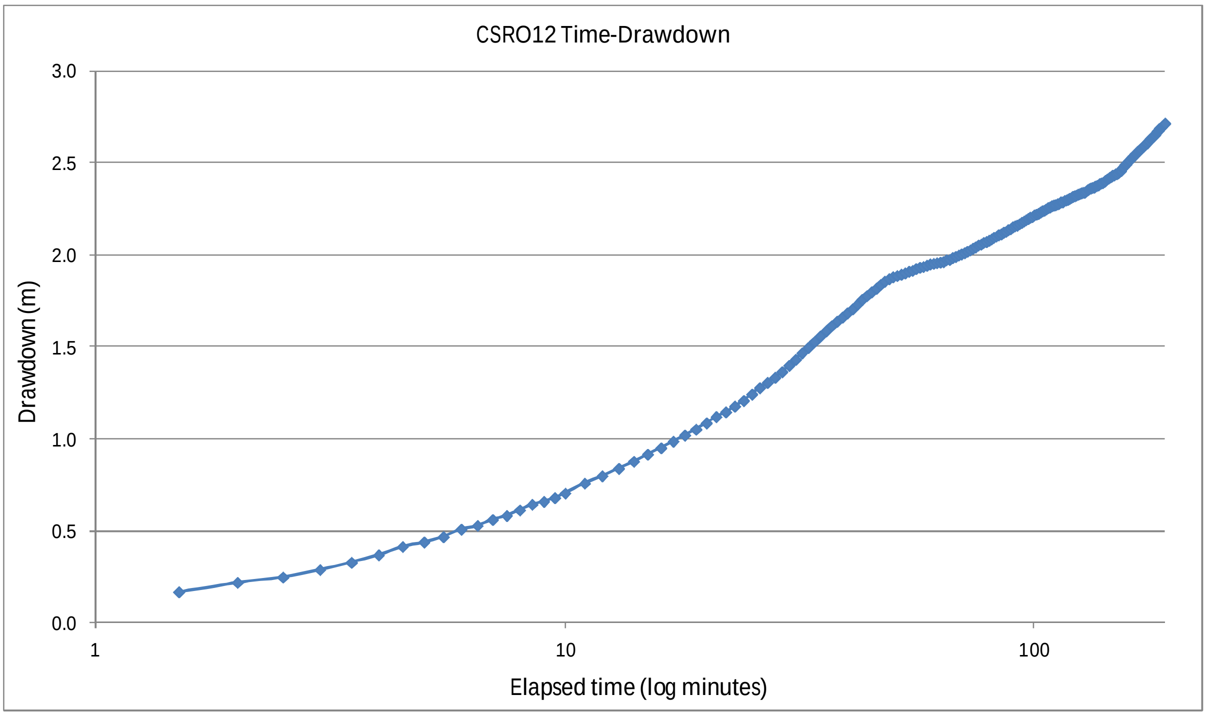


Figure 3.2 – CSRO12 Hantush (1960) analysis

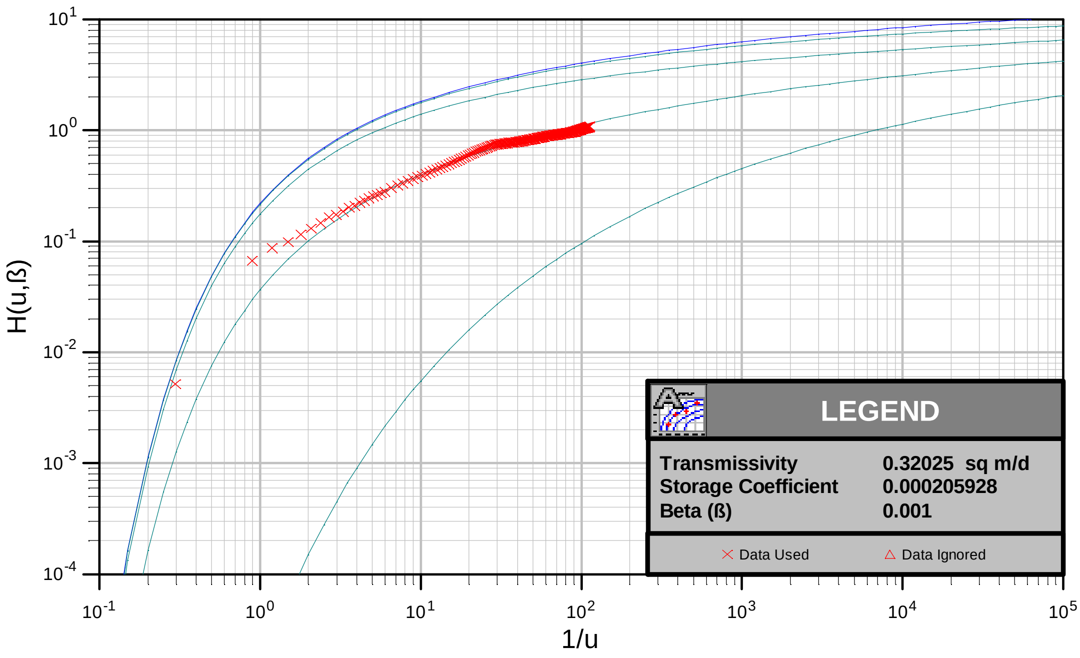
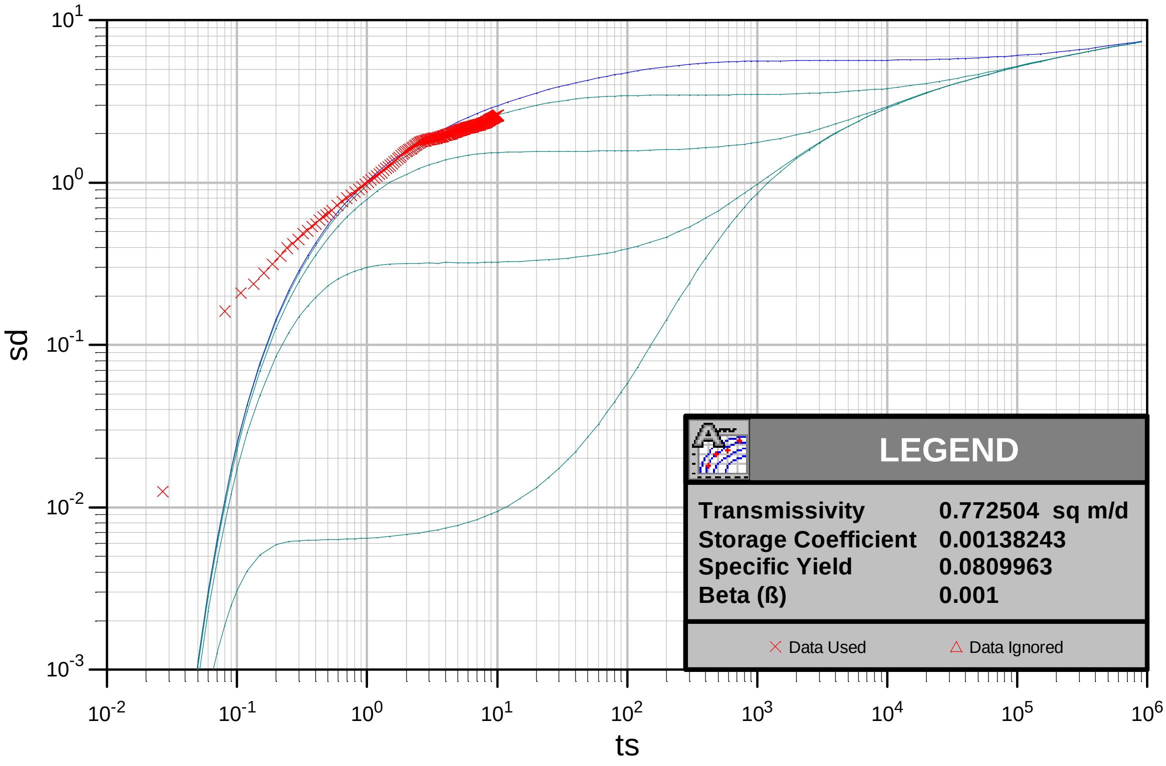


Figure 3.3 – CSRO12 Neuman (1972) analysis



For both analyses, very early time data has been ignored to allow for well storage effects and time taken to establish a constant pumping rate.

The data shows a fairly good fit to the Hantush curve and a less good fit to the Neuman curve.

Unconfined aquifers usually show a ‘s’ shaped curve. Initially the aquifer behaves as a confined aquifer as abstracted water is released from elastic storage, conforming to the Theis curve. The drawdown curve flattens off as dewatering accompanies the falling water table, comparable to leakage. The late time data then steepens again and conforms to the Theis curve as flow in the aquifer becomes largely horizontal.

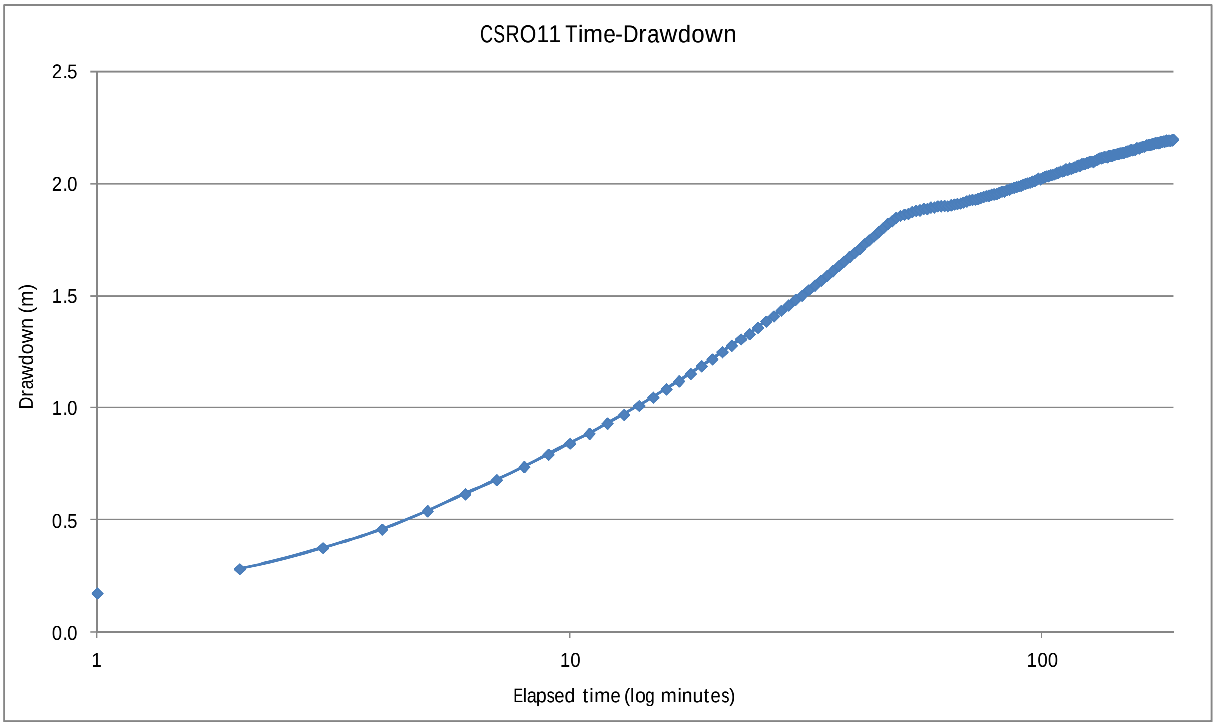
As the test was terminated only three hours after abstraction had commenced it is possible that pumping had not continued long enough for the dewatering response to become very apparent. However, both the Hantush and Newman analyses suggest that leakage had started to occur before the test was curtailed. The beta value (Neuman’s parameter) describes the relationship between vertical and horizontal hydraulic conductivity.

3.3 CSRO10 Constant rate Test, CSRO11 (Observation borehole 2)

Water levels at CSRO11 again showed a clear response to abstraction from CSRO10, with a maximum drawdown of 2.20m. The time-drawdown graph (Figure 3.4) shows the logger data from this borehole over the period of the CRT.

Again, there rate of drawdown decreases at around 50 minutes, coinciding with the increased rate of drawdown seen in the abstraction borehole. Similar to the response in CSRO12, the rate of drawdown decreases at this time before increasing again.

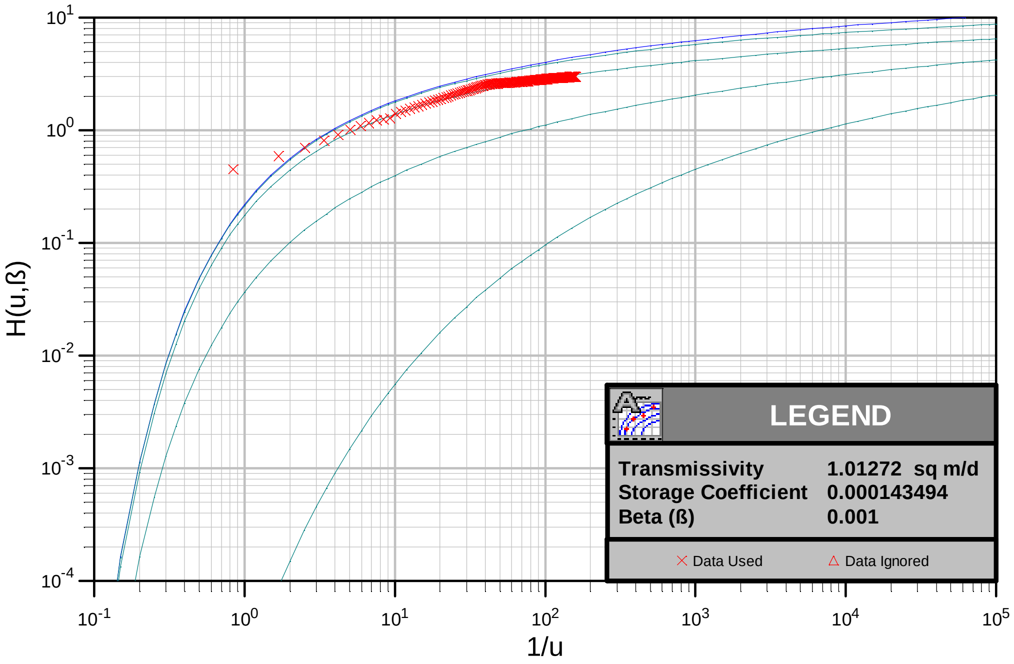
Figure 3.4 - CSRO11 Time - Drawdown



The Hantush (leaky confined) analysis is shown in Figure 3.5. The Neuman (unconfined) analysis is shown in Figure 3.6.

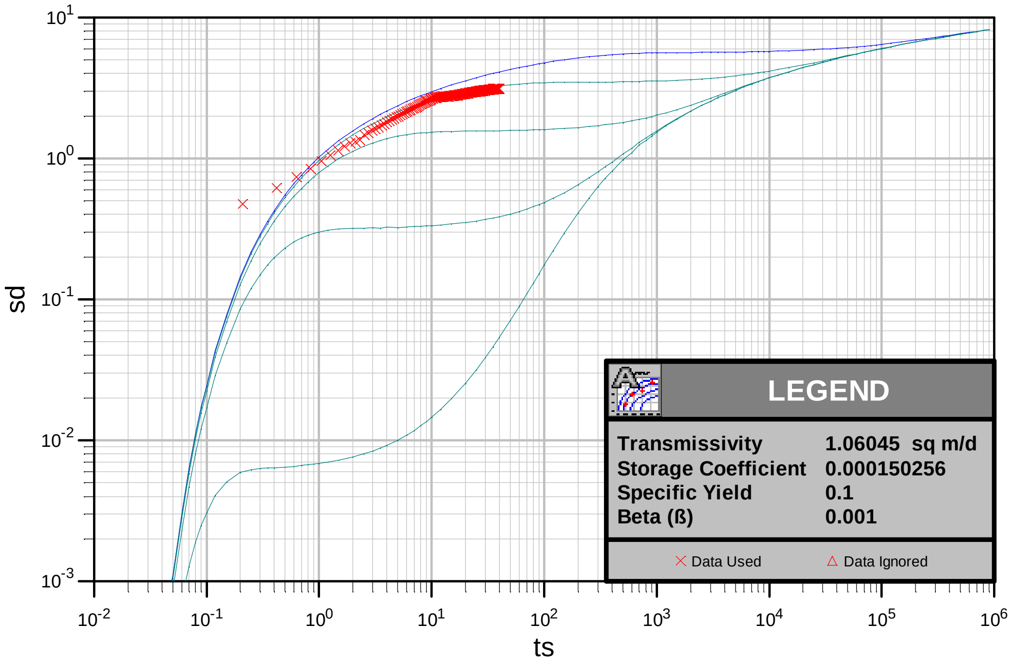
The CSRO11 results and fit of the data to the two analytical curves presented in this report are very similar to those from CSRO12, reflecting both the aquifer conditions and short duration of the test.

Figure 3.5 – CSRO11 Hantush (1960) analysis



Transmissivity	1.01272 sq m/d
Storage Coefficient	0.000143494
Beta (ß)	0.001

Figure 3.6 - CSRO11 Neuman (1972) analysis



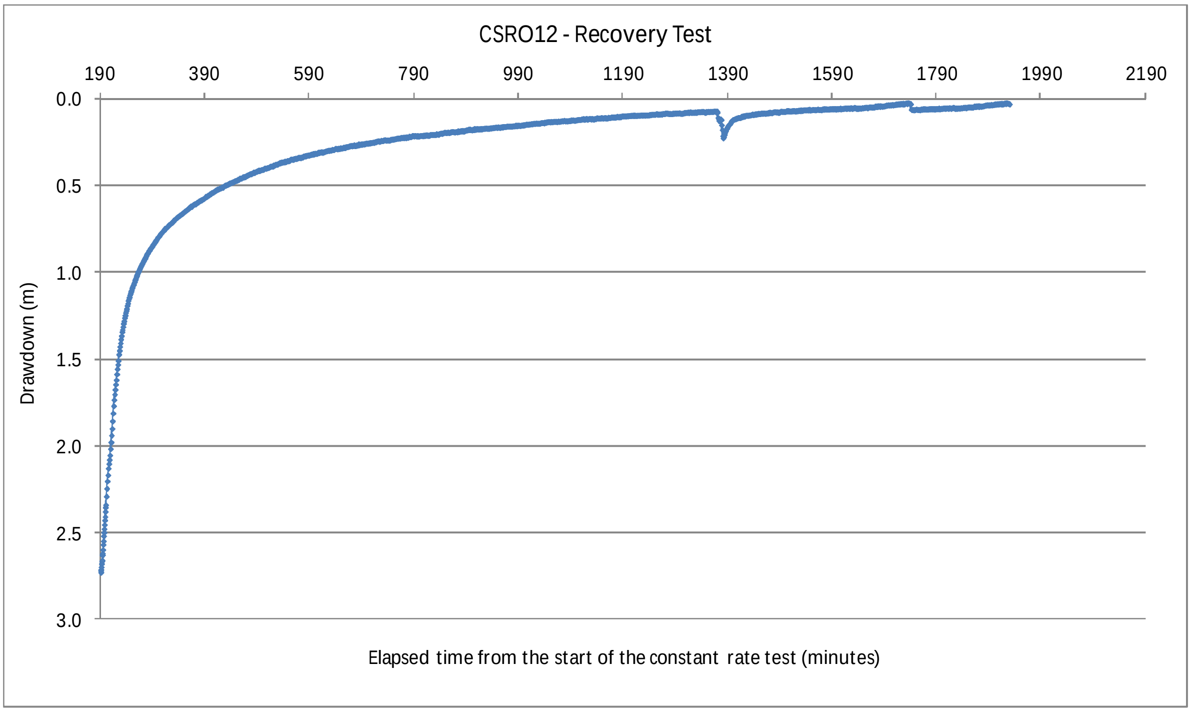
Transmissivity	1.06045 sq m/d
Storage Coefficient	0.000150256
Specific Yield	0.1
Beta (ß)	0.001

3.4 CSRO12 Recovery

The data loggers were left in the monitoring boreholes for over 24 hours after pumping terminated, to record water level recovery (Figure 3.7). Recovery data can be more reliable than pumping test data as there are no impacts due to fluctuations in pumping rate, but analysis only allows determination of transmissivity. Interestingly, Figure 2.1 shows that water level recovery in CSRO12 commenced as soon as the pump in CSRO10 (2m away) was shut down, even though the drawdown was much less than in the pumping borehole, while recovery in CSRO11 commenced later.

At the time of logger removal, the water level had recovered to within 0.03m of the rest water level prior to the CRT.

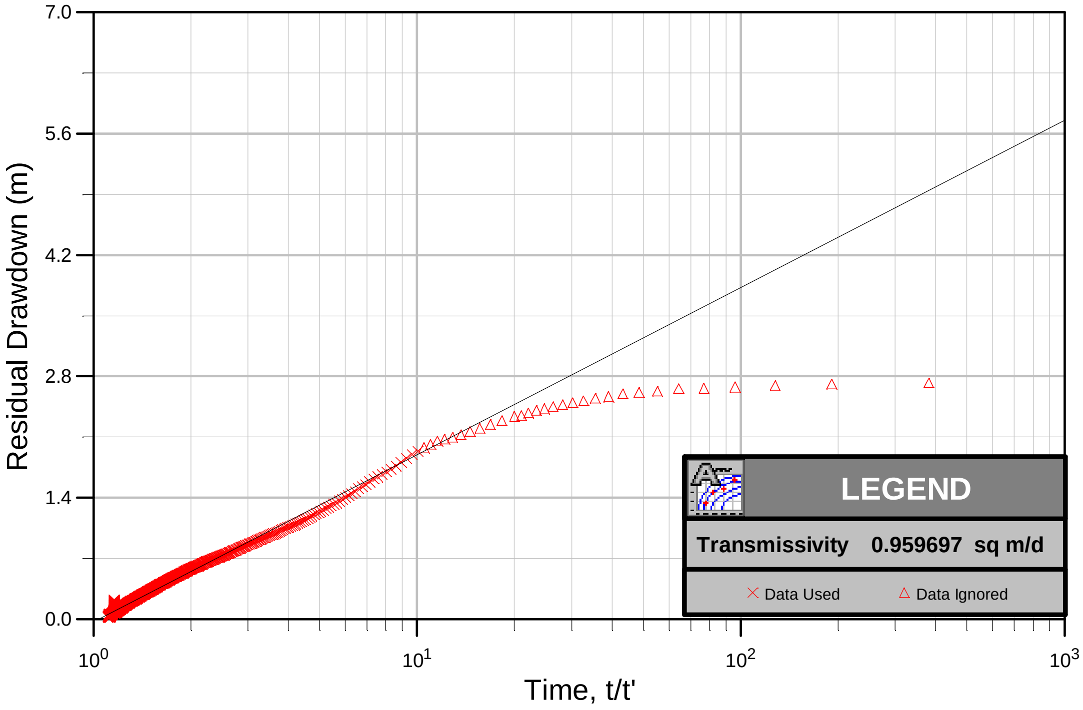
Figure 3.7 – CSRO12 Recovery Test Data



The recovery data shows a much smoother curve. The water level change at 1390 minutes (just over 23 hours) corresponds with the removal of the pump.

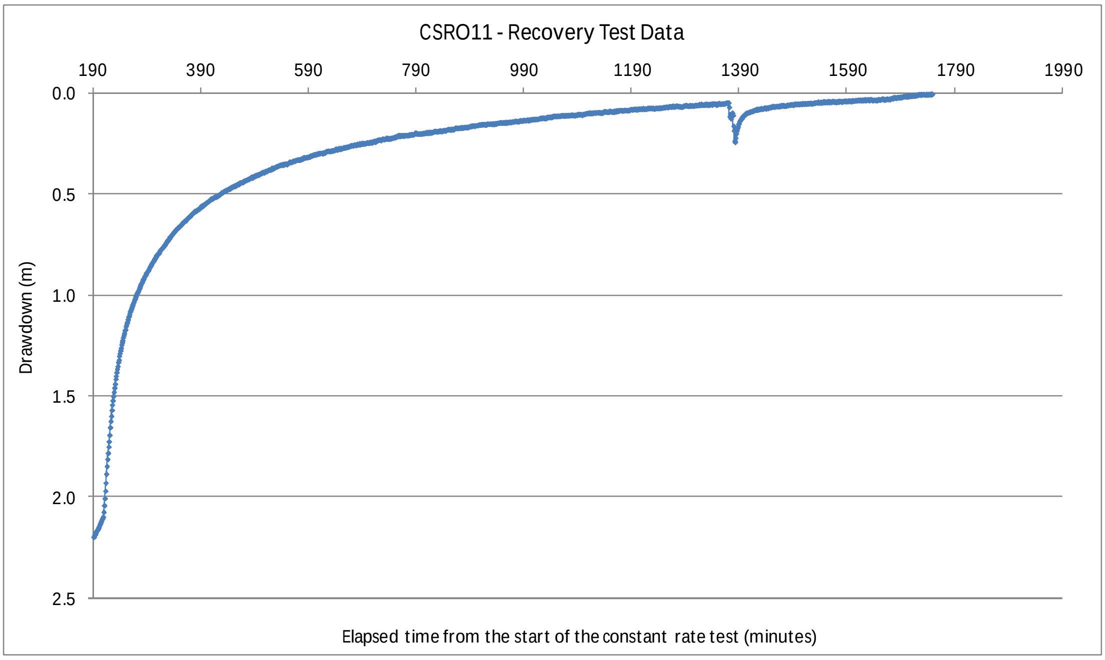
The data was analysed using the Theis (1935) recovery method. This method is applicable to both confined and unconfined aquifers if late time data is used. As such the early time data was set with a weight of 0 and therefore not used in the data optimisation process. The results are presented in Figure 3.8.

Figure 3.8 – CSRO12 Theis (1935)Recovery Analysis



3.5 CSRO11 Recovery

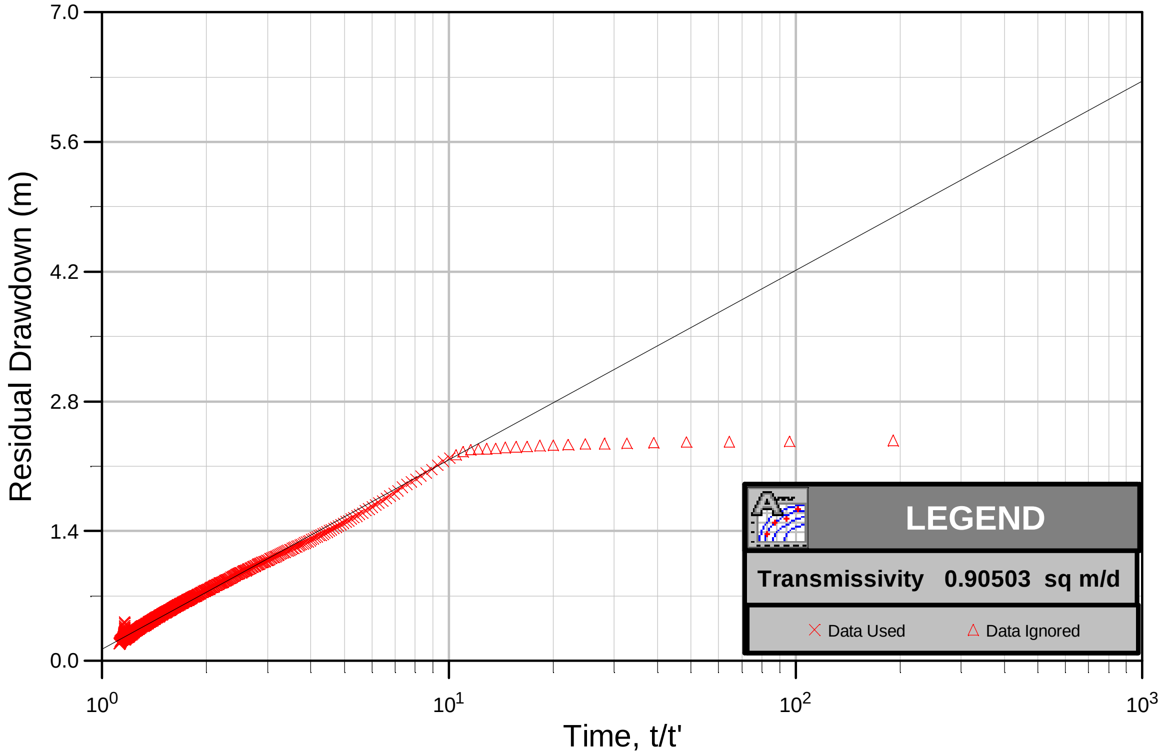
Figure 3.9 – CSRO11 Recovery Test Data



The recovery data for CSRO11 is shown in Figure 3.9. A similar response is seen in CSRO11 and CSRO12.

Results were analysed using the Theis recovery method. Again, early time data has been ignored in the optimisation process.

Figure 3.10 – CSRO11 Theis (1935) Recovery Analysis



3.6 CSRO10 Recovery

Figure 3.11 shows the logger recovery data. The logger was removed from the borehole at the same time as the pump, around 20 hours after the end of the CRT. At this point water levels in the test borehole had recovered to within 0.08m of the rest water level prior to the test.

Figure 3.11 - CSRO10 Recovery Test Data

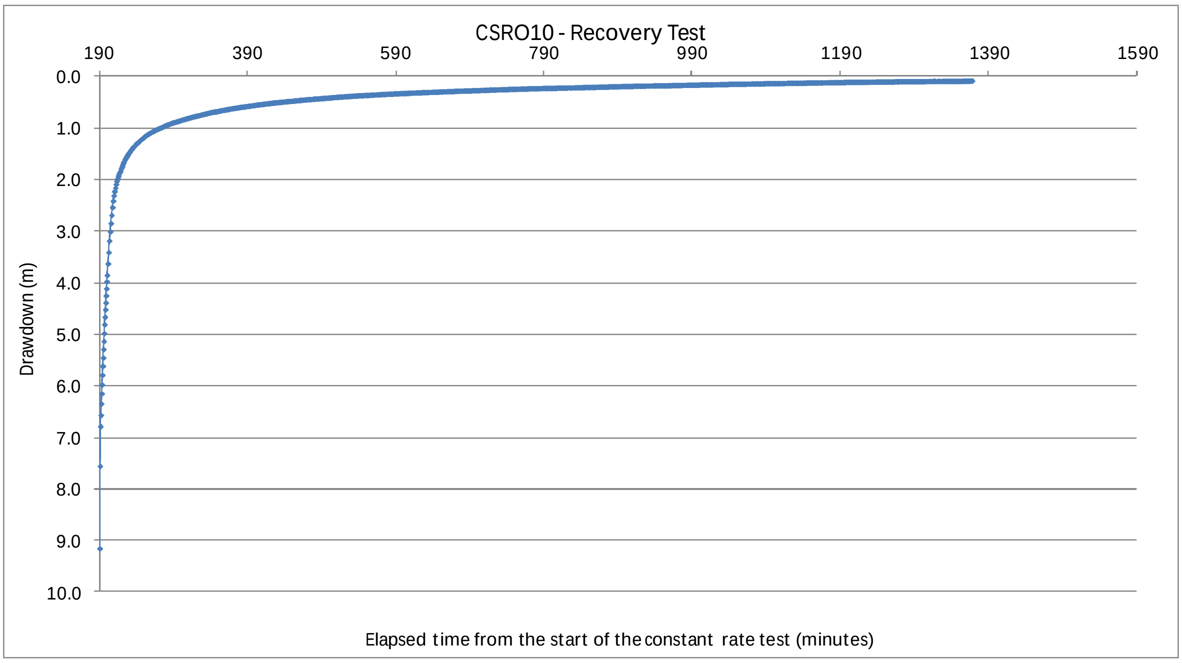
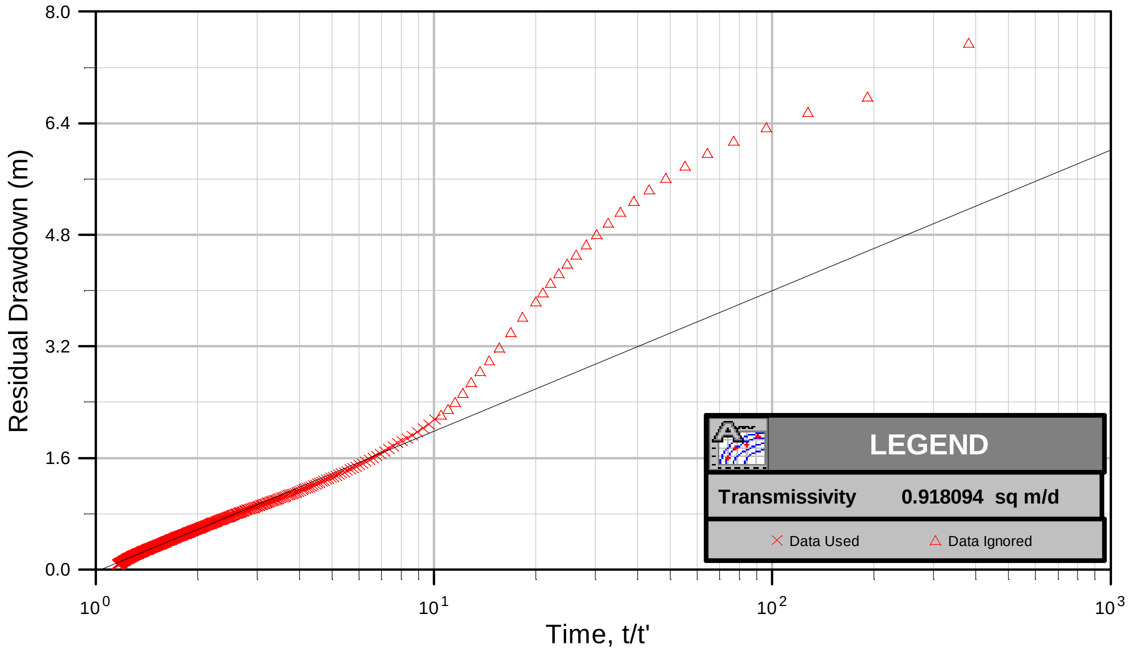


Figure 3.12 shows the Theis (1935) recovery analysis of the abstraction borehole data. Early time data has been ignored as above.

Figure 3.12 - CSRO10 Theis (1935) Recovery Analysis



3.7 Summary of estimated aquifer properties

Table 3.1 shows the estimated aquifer properties derived from the above analyses. Hydraulic conductivity (K) has been calculated from the transmissivity (T) and saturated aquifer thickness (b) using the following equation and converting the units to m/s: -

$$K = T/b$$

Table 3.1 – Summary of estimated aquifer properties

Observation Borehole	Test	Results		
		T (m^2/d)	S	K (m/s)
CSRO12	Hantush (1960) CRT	0.32	2.06E-04	2.77E-07
	Neuman (1972) CRT	0.77	1.38E-03	6.67E-07
	Theis Recovery	0.96	-	8.29E-07
CSRO11	Hantush (1960) CRT	1.01	1.43E-04	8.75E-07
	Neuman (1972) CRT	1.06	1.50E-04	9.16E-07
	Theis Recovery	0.91		7.82E-07
CSRO10	Theis Recovery	0.92		7.93E-07
	Mean	0.85	4.70E-04	7.34E-07

Note: (d) assumed = 13.4m

3.8 Discussion of Results

Mean values of hydraulic conductivity (K) of 7.34 x 10^{-7} m/s and storage coefficient (S) of 4.70 x 10^{-4} were derived from data analysis. Pumping and observation borehole test and recovery data gave very similar K values, although these were one or two orders of magnitude less than those calculated from some of the permeability (falling head and packer) tests of other boreholes in the area. S values ranged from 2.06 x 10^{-4} – 1.38 x 10^{-3}. This range is at least one order of magnitude lower than would be expected for an unconfined aquifer, but may be due at least in part to the very limited aquifer thickness.

The rate of drawdown increased in the abstraction borehole at around 45 minutes into the CRT. At the same time the rate of drawdown in the observation boreholes decreased for a short period before increasing at the same rate as before. As discussed in Section 3.1, this is most likely to be associated with water levels dropping below the base of a more permeable section of the sandstone unit.

The analysis assumes that the aquifer is vertically and laterally homogeneous, isotropic and has infinite areal extent. In reality this is not the case and the sandstone is constrained both laterally and vertically, so it is possible that the increase in drawdown rate is a result of the cone of depression reaching a sandstone unit boundary, although if this was the case, an increase in drawdown rate would also be reflected in the observation boreholes.

The other possibility is that the turbulent head loss component of the drawdown increases below the top few metres of the sandstone, perhaps because the borehole has not been developed sufficiently below this depth. Flow rates are so low that it is considered unlikely that the increase in turbulent head losses is because of the reducing inflow area to the borehole as water levels decrease.

The local transmissivity, a measure of the aquifer's ability to transmit water to the borehole, will have reduced as the aquifer became locally dewatered. The sandstone is only 12.5m thick in CSRO10 and the rest water level is around 1.7m below the top of this. The drawdown after 45 minutes was in the order of 3m or about 30% of the saturated aquifer thickness. However, if the transmissivity reduction was the main reason for the increased drawdown rate, then the rate of increase would be likely to be more gradual.

Analysis of test results indicate a small leakage response due to the unconfined nature of the sandstone unit, although the test had to be curtailed before the delayed yield (unconfined) response could become more apparent.

4. CONCLUSIONS

- A constant rate pumping test was conducted in the sandstone unit close to Echline Corner. This unit comprises sandstone with interbedded mudstones. The aim of the test was to monitor groundwater levels in nearby observation boreholes under steady state conditions to allow the Thiem-Dupuit equation to be used to estimate the radius of influence of the dewatering abstraction. The test also allows bulk aquifer parameters to be determined.

- Pre-test pumping demonstrated that the sustainable pumping rate was extremely low (0.12 l/s; 10.37 m^3/day). Even then, a marked increase in drawdown rate part way through the test meant that the test had to be terminated earlier than planned. Quasi-steady-state pumping conditions were therefore not achieved.

- A short-term reduction in drawdown rate in the observation boreholes roughly coincided with the marked increased rate of drawdown seen in the pumping borehole. This is most likely to be associated with water levels dropping below the base of a more permeable section of the sandstone unit, although it is also possible that there was a step increase in the turbulent head loss component of drawdown.

- The test duration was sufficient to allow analysis of the results, although the later-time aquifer responses were not obviously apparent. Test data was analysed using the Hantush (1960) method for leaky aquifers and Newman (1972) method for unconfined aquifers.

- Mean values of hydraulic conductivity (K) of 7.34×10^{-7} m/s and storage coefficient (S) of 4.70×10^{-4} were derived from data analysis. Pumping and observation borehole test and recovery data gave very similar K values, although these were one or two orders of magnitude less than those calculated from some of the permeability (falling head and packer) tests of other boreholes in the area. S values ranged from 2.06×10^{-4} – 1.38×10^{-3}. This range is at least one order of magnitude lower than would be expected for an unconfined aquifer, but may be due at least in part to the very limited aquifer thickness.

- Analysis of test results indicate a small leakage response due to the unconfined nature of the sandstone unit, although the test had to be curtailed before the delayed yield (unconfined) response could become more apparent.

- The analytical methods assume that the aquifer is vertically and laterally homogeneous, isotropic and has infinite areal extent. In reality, the sandstone unit under test is laterally and vertically constrained, and is likely to be anisotropic in terms of hydrogeological properties due to the presence of interbedded mudstones and fractures. This is borne out by the step change in drawdown rate in the pumping borehole, which is considered most likely to be due to water levels dropping below a more permeable horizon. The local transmissivity, a measure of the aquifer's ability to transmit water to the borehole, will also have reduced as the aquifer became locally dewatered.

- The test demonstrates that the limited thickness and lateral extent of the sandstone unit means that dewatering abstraction rates are likely to be significantly less than those predicted from aquifer properties, particularly after the initial phase of pumping.

5. REFERENCES

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Neuman, S. P. (1972) Theory of flow in unconfined aquifers considering delayed response of the water table. Water Resources Res., Vol. 8, pp. 1031 - 1045

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ANNEX A1

BOREHOLE LOGS

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO10

Project	Client	Logged By
Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Forth Crossing Bridge Constructors	CD/CA

Job No	Date	Ground Level (m)	Co-ordinates	Checked By
107442	11-03-12 12-03-12	55.73	E 311,427.4 N 677,750.1	

SAMPLES & TESTS			Water	STRATA				Instrument Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	
				55.53		0.20	TOPSOIL	
				55.23		0.50	Brown sandy gravelly CLAY with cobbles and boulders notted. (Driller's description)	
			1			(12.50)	Red brown SANDSTONE with thin beds of Mudstone. (Driller's description)	

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Put down by 100mm rotary open hole drilling (DTHH). Standpipe installed.	**15m bgl**
7				

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO10

Project Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Client Forth Crossing Bridge Constructors	Logged By CD/CA

Job No 107442	Date 11-03-12 12-03-12	Ground Level (m) 55.73	Co-ordinates E 311,427.4 N 677,750.1	Checked By

SAMPLES & TESTS			Water	STRATA				Instrument Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	
				42.73		13.00	Red brown SANDSTONE with thin beds of Mudstone. (Driller's description) *(continued)*	
				40.73		(2.00) 15.00	Black MUDSTONE. (Driller's description)	
							End of Hole at 15m bgl.	

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Put down by 100mm rotary open hole drilling (DTHH). Standpipe installed.	**15m bgl**

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

GRONTMIJ BOREHOLE LOG FRC SOUTH PLUS CGI 230512.GPJ AGS3_ALL.GDT 7/6/12

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO11

Project	Client	Logged By
Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Forth Crossing Bridge Constructors	CA

Job No	Date	Ground Level (m)	Co-ordinates	Checked By
107442	26-03-12 26-03-12	55.61	E 311,432.1 N 677,749.0	

SAMPLES & TESTS				STRATA				
Depth	Type No	Test Result	Water	Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	Instrument Backfill
				55.11	☒	(0.50) 0.50	Brown sandy TILL (Driller's description)	
			▼1		⠿	(13.50)	Light orange brown SANDSTONE (Driller's description)	

Groundwater

Strike Depth: (m)	Rising to: (m)	Groundwater Remarks
4		Water Strike

General Remarks
Put down by 100mm rotary open hole drilling (DTHH). Standpipe installed.

Final Depth
15m bgl

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO11

Project	Client	Logged By
Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Forth Crossing Bridge Constructors	CA

Job No	Date	Ground Level (m)	Co-ordinates	Checked By
107442	26-03-12 26-03-12	55.61	E 311,432.1 N 677,749.0	

SAMPLES & TESTS				STRATA					
Depth	Type No	Test Result	Water	Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	Instrument	Backfill
				41.61	⁘	14.00	Light orange brown SANDSTONE (Driller's description) *(continued)*		
				40.61	☰	(1.00) 15.00	Dark brown MUDSTONE (Driller's description)		
							End of Hole at 15m bgl.		

Groundwater
Strike Depth: (m) Rising to: (m) Groundwater Remarks

General Remarks
Put down by 100mm rotary open hole drilling (DTHH). Standpipe installed.

Final Depth
15m bgl

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

GRONTMIJ BOREHOLE LOG FRC SOUTH PLUS CGI 230512.GPJ AGS3_ALL.GDT 7/6/12

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO12

Project	Client	Logged By
Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Forth Crossing Bridge Constructors	CA

Job No	Date	Ground Level (m)	Co-ordinates	Checked By
107442	27-03-12 27-03-12	55.83	E 311,426.0 N 677,752.4	

SAMPLES & TESTS				STRATA					
Depth	Type No	Test Result	Water	Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	Instrument	Backfill
				55.23	☒	(0.60) 0.60	Brown sandy TILL (Driller's description)		
			1		⁙	(14.20)	Light brown and orange SANDSTONE (Driller's description)		

Groundwater		
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks
3.9		Water Strike

General Remarks
Standpipe installed.

Final Depth
15m bgl

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

Sheet 1 of 2

GRONTMIJ BOREHOLE LOG FRC SOUTH PLUS CGI 230512.GPJ AGS3_ALL.GDT 7/6/12

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO12

Project	Client	Logged By
Forth Replacement Crossing - Construction Phase Ground Investigations (Land Phase)	Forth Crossing Bridge Constructors	CA

Job No	Date	Ground Level (m)	Co-ordinates	Checked By
107442	27-03-12 27-03-12	55.83	E 311,426.0 N 677,752.4	

SAMPLES & TESTS			Water	STRATA				Instrument Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	
							Light brown and orange SANDSTONE (Driller's description) *(continued)*	
				41.03		14.80		
				40.83		15.00	Dark brown MUDSTONE (Driller's description)	
							End of Hole at 15m bgl.	

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Standpipe installed.	**15m bgl**

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50

Grontmij

BOREHOLE LOG

BOREHOLE No CSRO03A				
Project Forth Replacement Crossing		Client Forth Crossing Bridge Constructors (CJV)		Logged By RN
Job No 107442S	Date 05-12-11 05-12-11	Ground Level (m m OD) 57.32	Co-ordinates E 311,411.2 N 677,688.7	Checked By

SAMPLES & TESTS

Depth	Type No	Test Result
1.00	D	
2.70-7.00	D	

Water: strike 1 at approx. 0.6

STRATA

Reduced Level	Legend	Depth (Thickness)	DESCRIPTION	Instrument Backfill
57.12		0.20	TOPSOIL (Driller's description)	
56.72		(0.40) 0.60	Brown sandy gravelly CLAY (Driller's description)	
51.82		(4.90) 5.50	Light brown fine to medium grained SANDSTONE (Driller's description)	
		(7.50)	Interbedded grey fine grained SANDSTONE and black MUDSTONE (Driller's description)	

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Standpipe installed.	15m bgl
0.6		Water Strike		

Contractor GT	Method/ Plant Used	All dimensions in metres Scale 1:50 Sheet 1 of 2

Grontmij

BOREHOLE LOG

BOREHOLE No
CSRO03A

Project Forth Replacement Crossing		Client Forth Crossing Bridge Constructors (CJV)		Logged By RN
Job No 107442S	Date 05-12-11 05-12-11	Ground Level (m m OD) 57.32	Co-ordinates E 311,411.2 N 677,688.7	Checked By

SAMPLES & TESTS			Water	STRATA				Instrument	Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION		
				44.32	∴	13.00	Interbedded grey fine grained SANDSTONE and black MUDSTONE (Driller's description) *(continued)*		
14.00	D			42.32	≡	(2.00) 15.00	Black MUDSTONE (Driller's description)		
							End of Hole at 15m bgl.		

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Standpipe installed.	**15m bgl**

Contractor GT

Method/
Plant Used

All dimensions in metres Scale 1:50
Sheet 2 of 2

BOREHOLE LOG

Grontmij

BOREHOLE No	**S78**	
Project Forth Replacement Crossing	Client Forth Crossing Bridge Constructors (CJV)	Logged By GM+CR
Job No 107442S	Date 18-05-09 09-06-09	Ground Level (m m OD) 56.36
Co-ordinates E 311,406.6 N 677,780.2	Checked By	

SAMPLES & TESTS

Depth	Type No	Test Result
0.20	D	
0.50	B	
0.50	D	
0.50	B	
0.50	D	
1.00	B	
1.00	D	
1.00	B	
1.00	D	
3.50	C	
4.00	C	
4.50	C	
5.10	C	
6.75	C	
6.80	C	
8.10	C	
8.20	C	
9.50	C	

Water

STRATA

Reduced Level	Legend	Depth (Thickness)	DESCRIPTION
55.96		(0.40) 0.40	TOPSOIL: Dark brown slightly sandy slightly gravelly clay with many rootlets. Gravel is sub angular to sub rounded fine to coarse of sandstone and dolerite. Sand is fine to coarse.
55.56		(0.40) 0.80	Firm brown slightly gravelly sandy CLAY with silty laminations. Gravel is sub angular fine and coarse of sandstone and various other lithologies. Sand is fine to coarse.
55.36		1.00	Brown very silty very gravelly fine to medium, occasionally coarse SAND. Gravel is sub angular and sub rounded fine to medium of predominantly sandstone.
54.86		(0.50) 1.50	SANDSTONE (Open holed) (Driller's description).
54.65		1.71	Strong brown fine and medium grained SANDSTONE, slightly weathered, recovered non intact.
52.86		(1.79) 3.50	No recovery SANDSTONE (Driller's description).
52.56		3.80	Moderately strong brown fine grained SANDSTONE. Moderately weathered with penetrative iron oxide orange staining. Non intact.
48.86		(3.70) 7.50	Moderately strong grey fine to medium grained SANDSTONE, slightly weathered. Bedding fractures medium to closely spaced, dip 10?, undulating, rough, with patchy iron oxide staining and dark discolouration. 3.90 - 3.90 At 3.80m to 4.05m, fractures sub vertical undulating rough tight clean, intersecting at 90? 4.00 - 4.00 At 4.05m to 4.09m, very weak grey mudstone. 4.10 - 4.10 From 3.94m to 4.03m, non intact 6.00 - 6.00 From 5.96m to 6.06m, non intact 7.40 - 7.40 From 7.40m to 7.50m, non intact
47.96		(0.90) 8.40	Moderately strong thin to thickly bedded grey fine grained SANDSTONE. Fresh. Bedding fractures closely to widely spaced 5? to 15?, undulose and rough, locally infilled with clay. 8.10 - 8.10 From 8.10m to 8.22m, non intact.
		(2.20)	Moderately strong to strong thin to thickly bedded dark brown fine and medium grained SANDSTONE. Fresh. Bedding fractures are very close to widely spaced 5? to 15?, undulose and rough, locally infilled with clay. 9.40 - 9.40 From 9.40m to 9.50m, non intact

Instrument Backfill

Groundwater

Strike Depth: (m)	Rising to: (m)	Groundwater Remarks
4.3		

General Remarks

Hand dug inspection pit 0.50m x 0.50m to 1.00m depth. Soils borehole terminated at 1.00m on possible sandstone bedrock. Permeability test (Falling Head) undertaken at 4.00m. Packer test undertaken at 5.50m. Borehole completed at 13.00m, 50mm standpipe installed to 13.00m slotted from 2.00m to 13.00m finished at ground level with screw cap and gas valve.

Final Depth **13m bgl**

Contractor GMcA+RL

Method/
Plant Used

All dimensions in metres Scale 1:50

BOREHOLE LOG

Grontmij

BOREHOLE No
S78

Project	Client	Logged By
Forth Replacement Crossing	Forth Crossing Bridge Constructors (CJV)	GM+CR

Job No	Date	Ground Level (m m OD)	Co-ordinates	Checked By
107442S	18-05-09 09-06-09	56.36	E 311,406.6 N 677,780.2	

SAMPLES & TESTS

Depth	Type No	Test Result
10.50	C	
11.40	C	
11.50	C	
11.80	C	
12.30	C	
12.75	C	

Water

STRATA

Reduced Level	Legend	Depth (Thickness)	DESCRIPTION
45.76		10.60	Moderately strong to strong thin to thickly bedded dark brown fine and medium grained SANDSTONE. Fresh. Bedding fractures are very close to widely spaced 5? to 15?, undulose and rough, locally infilled with clay. *(continued)*
43.36		(2.40) 13.00	Moderately weak thinly laminated grey MUDSTONE with occasional white sandstone laminae. Unweathered. Bedding fractures are close to extremely closely spaced 5? to 15? planar and stepped, rough and smooth and clean. Fractures dip 70? stepped smooth tight with carbonate coating. 11.30 - 11.30 From 11.29m to 11.35m, non intact 11.60 - 11.60 From 11.66m to 11.72m, non intact 11.94 - 11.94 From 11.94m to 12.48m, non intact. 12.85 - 12.85 From 12.85m to 13.00m, no recovery.
			End of Hole at 13m bgl.

Instrument Backfill

Groundwater		
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks

General Remarks

Hand dug inspection pit 0.50m x 0.50m to 1.00m depth. Soils borehole terminated at 1.00m on possible sandstone bedrock. Permeability test (Falling Head) undertaken at 4.00m. Packer test undertaken at 5.50m. Borehole completed at 13.00m, 50mm standpipe installed to 13.00m slotted from 2.00m to 13.00m finished at ground level with screw cap and gas valve.

Final Depth
13m bgl

Contractor GMcA+RL

Method/
Plant Used

All dimensions in metres Scale 1:50

BOREHOLE LOG

Grontmij	**BOREHOLE LOG**	BOREHOLE No **S80**

Project Forth Replacement Crossing	Client Forth Crossing Bridge Constructors (CJV)	Logged By MB

Job No	Date	Ground Level (m m OD)	Co-ordinates	Checked By
107442S	03-06-09 03-06-09	56.48	E 311,414.0 N 677,807.6	

SAMPLES & TESTS

Depth	Type No	Test Result	Water
4.50	C		
6.45	C		
6.50	C		
			1 (8.05)
8.30	C		

STRATA

Reduced Level	Depth (Thickness)	DESCRIPTION
56.28	0.20	TOPSOIL (Driller's description) (Open holed).
54.78	(1.50) 1.70	Mottled CLAY (Driller's description) (Open holed).
54.23	(0.55) 2.25	Sandy CLAY (Driller's description) (Open holed).
52.68	(1.55) 3.80	Boulder CLAY (Driller's description) (Open holed).
51.98	(0.70) 4.50	MUDSTONE (Driller's description) (Open holed).
51.68	4.80	No recovery. MUDSTONE(Driller's description).
	(6.20)	Moderately strong thinly bedded medium grained brown SANDSTONE slightly weathered with siltstone inclusions. Bedding fractures close to medium spaced dip 10 - 20? planar to undulating rough fresh, tight with occasional very thin clay fill. Joints medium to widely spaced inclined vertical undulating rough weathered iron oxide staining and thin clay fill. 5.00 - 5.00 From 4.75m to 5.05m joints crossing at 45?. 9.00 - 9.00 from 8.90m, clay fill in bedding fractures up to 1cm thick.

Instrument Backfill

Groundwater

Strike Depth: (m)	Rising to: (m)	Groundwater Remarks
8.05		

General Remarks

Hand dug inspection pit 0.50m x 0.50m to 1.20m depth. Borehole completed at 13.25m. Televiewer survey undertaken on 17 June 2009. 19mm standpipe piezometer installed, tip at 8.30m and 50mm standpipe installed at 3.50m slotted from 1.00m to 3.50m.

Final Depth

13.25m bgl

Contractor RL

Method/
Plant Used

All dimensions in metres Scale 1:50

BOREHOLE LOG

BOREHOLE No
S80

Project Forth Replacement Crossing	Client Forth Crossing Bridge Constructors (CJV)		Logged By MB
Job No 107442S	Date 03-06-09 03-06-09	Ground Level (m m OD) 56.48	Co-ordinates E 311,414.0 N 677,807.6	Checked By

SAMPLES & TESTS			Water	STRATA				Instrument	Backfill
Depth	Type No	Test Result		Reduced Level	Legend	Depth (Thickness)	DESCRIPTION		
10.50	C			45.48		11.00	Moderately strong thinly bedded medium grained brown SANDSTONE slightly weathered with siltstone inclusions. Bedding fractures close to medium spaced dip 10 - 20? planar to undulating rough fresh, tight with occasional very thin clay fill. Joints medium to widely spaced inclined vertical undulating rough weathered iron oxide staining and thin clay fill. *(continued)*		
				44.48		(1.00) 12.00	Strong medium grained dark grey SANDSTONE, fresh. 11.63 - 11.63 At 11.63m, bedding fractures dip 8? planar rough fresh tight and clean.		
				44.13		12.35	Strong laminated dark grey calcareous slightly micaceous MUDSTONE fresh with closely spaced calcite laminations. Bedding fractures closely spaced, dip 8 - 10?, undulating, rough, fresh, tight and clean.		
12.93	C			43.23		(0.90) 13.25	Moderately strong thinly laminated black calcareous irony MUDSTONE, fresh. Bedding fractures closely spaced, sub horizontal planar, smooth, fresh, tight and clean. 12.90 - 12.90 From 12.95m, 3 closely spaced sub horizontal laminations of calcite.		
							End of Hole at 13.25m bgl.		

Groundwater			General Remarks	Final Depth
Strike Depth: (m)	Rising to: (m)	Groundwater Remarks	Hand dug inspection pit 0.50m x 0.50m to 1.20m depth. Borehole completed at 13.25m. Televiewer survey undertaken on 17 June 2009. 19mm standpipe piezometer installed, tip at 8.30m and 50mm standpipe installed at 3.50m slotted from 1.00m to 3.50m.	**13.25m bgl**

Contractor RL

Method/
Plant Used

All dimensions in metres Scale 1:50

Sheet 2 of 2

ANNEX A2

TEST DATA (MANUAL OBSERVATIONS)

Project:	Forth Road Crossing	**Test:**	Constant rate test	**Abstraction borehole:**	CSRO10
Date:	30/05/2012	**Weather:**	Overcast, chilly, very fine drizzle at times but mostly dry	**Monitored borehole:**	CSRO10
				Datum:	Top of BH casing
				Datum elevation:	56.207 mAOD

Time	**Elapsed time (mins)**	**Manually dipped water level (mbdat)**	**Water level (mAOD)**	**Drawdown (m)**	**Electromagnetic flow meter reading (l/s)**	**Flow meter reading (m^3)**
09:00:00	0	2.60	53.61	0.00	0.01	1.591
09:00:30	0.5				0.01	1.591
09:01:00	1	3.10	53.11	0.50	0.1	1.595
09:01:30	1.5	3.19	53.02	0.59	0.12	1.597
09:02:00	2	3.29	52.92	0.69	0.12	1.5
09:02:30	2.5	3.34	52.87	0.74	0.12	1.512
09:03:00	3	3.39	52.82	0.79	0.12	1.514
09:03:30	3.5	3.43	52.78	0.83	0.12	1.505
09:04:00	4	3.47	52.74	0.87	0.12	1.515
09:04:30	4.5	3.50	52.71	0.90	0.12	1.515
09:05:00	5	3.54	52.67	0.94	0.12	1.515
09:05:30	5.5	3.58	52.63	0.98	0.12	1.515
09:06:00	6	3.62	52.59	1.02	0.12	1.515
09:06:30	6.5	3.66	52.55	1.06	0.12	1.515
09:07:00	7	3.69	52.52	1.09	0.12	1.515
09:07:30	7.5	3.73	52.48	1.13	0.12	1.515
09:08:00	8	3.75	52.46	1.15	0.12	1.515
09:08:30	8.5					
09:09:00	9	3.81	52.40	1.21	0.12	
09:09:30	9.5	3.84	52.37	1.24	0.12	
09:10:00	10	3.86	52.35	1.26	0.12	
09:11:00	11	3.91	52.30	1.31	0.12	
09:12:00	12	3.96	52.25	1.36	0.12	
09:13:00	13	4.01	52.20	1.41	0.12	1.526
09:14:00	14	4.05	52.16	1.45	0.12	1.521
09:15:00	15	4.10	52.11	1.50	0.12	1.524
09:16:00	16	4.13	52.08	1.53	0.12	1.531
09:17:00	17	4.19	52.02	1.59	0.12	1.533
09:18:00	18	4.24	51.97	1.64	0.12	1.549
09:19:00	19	4.26	51.95	1.66	0.12	1.542
09:20:00	20	4.31	51.90	1.71	0.13	1.427
09:22:00	22	4.37	51.84	1.77	0.12	1.555
09:24:00	24	4.44	51.77	1.84	0.12	1.577
09:26:00	26	4.50	51.71	1.90	0.12	1.573
09:28:00	28	4.55	51.66	1.95	0.13	1.882
09:30:00	30	4.60	51.61	2.00	0.12	1.691
09:32:00	32	4.67	51.54	2.07	0.12	1.602
09:34:00	34	4.71	51.50	2.11	0.12	1.617
09:36:00	36	4.76	51.45	2.16	0.13	1.625
09:38:00	38	4.81	51.40	2.21	0.12	1.624
09:40:00	40	4.86	51.35	2.26	0.12	1.633
09:45:00	45	4.97	51.24	2.37	0.13	1.755
09:50:00	50	5.12	51.09	2.52	0.13	1.881
09:55:00	55	5.36	50.85	2.76	0.12	1.703
10:00:00	60	5.67	50.54	3.07	0.12	1.722
10:10:00	70	6.36	49.85	3.76	0.12	1.766
10:20:00	80	7.01	49.20	4.41	0.12	2.811
10:30:00	90	7.61	48.60	5.01	0.12	2.859
10:40:00	100	8.18	48.03	5.58	0.12	2.999
10:50:00	110	8.68	47.53	6.08	0.12	2.925
11:00:00	120	9.16	47.05	6.56	0.12	2.061
11:20:00	140	10.09	46.12	7.49	0.12	2.032
11:25:00	145	10.35	45.86	7.75		
11:30:00	150	10.52	45.69	7.92		
11:40:00	160	10.90	45.31	8.30	0.11	2.101
12:00:00	180	11.52	44.69	8.92	0.11	2.261
12:05:00	185	11.69	44.52	9.09	0.11	
12:10:00	190	11.90	44.31	9.30	0.11	
12:10:00	0	11.90	44.31	9.30	**Start of recovery**	
12:10:30	0.5	10.01	46.20	7.41		
12:11:00	1	9.32	46.89	6.72		
12:11:30	1.5	9.13	47.08	6.53		
12:12:00	2	8.94	47.27	6.34		
12:12:30	2.5	8.75	47.46	6.15		
12:13:00	3	8.56	47.65	5.96		
12:13:30	3.5	8.37	47.84	5.77		
12:14:00	4	8.20	48.01	5.60		
12:14:30	4.5	8.03	48.18	5.43		
12:15:00	5	7.87	48.34	5.27		
12:15:30	5.5	7.70	48.51	5.10		
12:16:00	6	7.55	48.66	4.95		
12:16:30	6.5	7.40	48.81	4.80		
12:17:00	7	7.25	48.96	4.65		
12:17:30	7.5	7.11	49.10	4.51		

12:18:00	8	6.98	49.23	4.38
12:18:30	8.5	6.84	49.37	4.24
12:19:00	9	6.70	49.51	4.10
12:19:30	9.5	6.57	49.64	3.97
12:20:00	10	6.44	49.77	3.84
12:21:00	11	6.21	50.00	3.61
12:22:00	12	5.99	50.22	3.39
12:23:00	13	5.78	50.43	3.18
12:24:00	14	5.59	50.62	2.99
12:25:00	15	5.43	50.78	2.83
12:26:00	16	5.27	50.94	2.67
12:27:00	17	5.11	51.10	2.51
12:28:00	18	4.97	51.24	2.37
12:29:00	19	4.89	51.32	2.29
12:30:00	20	4.80	51.41	2.20
12:32:00	22	4.68	51.53	2.08
12:34:00	24	4.54	51.67	1.94
12:36:00	26	4.45	51.76	1.85
12:38:00	28	4.40	51.81	1.80
12:40:00	30	4.31	51.90	1.71
12:42:00	32	4.25	51.96	1.65
12:44:00	34	4.18	52.03	1.58
12:46:00	36	4.13	52.08	1.53
12:48:00	38	4.08	52.13	1.48
12:50:00	40	4.04	52.17	1.44
12:55:00	45	3.95	52.26	1.35
13:00:00	50	3.87	52.34	1.27
13:05:00	55	3.81	52.40	1.21
13:10:00	60	3.75	52.46	1.15
13:20:00	70	3.66	52.55	1.06

Project:	Forth Road Crossing	**Test:**	Constant rate test	**Abstraction borehole:**	CSRO10
Date:	30/05/2012	**Weather:**	Overcast, chilly, very fine drizzle at times but mostly dry	**Monitored borehole:**	Obs 2 (CSRO11)

Datum:	Top of BH casing	
Datum elevation:	55.915	mAOD

Time	Elapsed time (mins)	Manually dipped water level (mbdat)	Water level (mAOD)	Drawdown (m)	
09:00:00	0	2.020	53.895	0.000	
09:00:30	0.5				
09:01:00	1	2.373	53.542	0.353	
09:01:30	1.5	2.431	53.484	0.411	
09:02:00	2	2.492	53.423	0.472	
09:02:30	2.5	2.533	53.382	0.513	
09:03:00	3	2.583	53.332	0.563	
09:03:30	3.5	2.625	53.290	0.605	
09:04:00	4	2.668	53.247	0.648	
09:04:30	4.5				
09:05:00	5	2.797	53.118	0.777	
09:05:30	5.5	2.782	53.133	0.762	
09:06:00	6	2.826	53.089	0.806	
09:06:30	6.5	2.854	53.061	0.834	
09:07:00	7	2.882	53.033	0.862	
09:07:30	7.5	2.912	53.003	0.892	
09:08:00	8	2.940	52.975	0.920	
09:08:30	8.5				
09:09:00	9	2.992	52.923	0.972	
09:09:30	9.5	3.015	52.900	0.995	
09:10:00	10	3.043	52.872	1.023	
09:11:00	11	3.086	52.829	1.066	
09:12:00	12	3.128	52.787	1.108	
09:13:00	13	3.167	52.748	1.147	
09:14:00	14	3.210	52.705	1.190	
09:15:00	15	3.246	52.669	1.226	
09:16:00	16	3.286	52.629	1.266	
09:17:00	17	3.317	52.598	1.297	
09:18:00	18	3.353	52.562	1.333	
09:19:00	19	3.385	52.530	1.365	
09:20:00	20	3.408	52.507	1.388	
09:22:00	22	3.465	52.450	1.445	
09:24:00	24	3.525	52.390	1.505	
09:26:00	26	3.576	52.339	1.556	
09:28:00	28	3.626	52.289	1.606	
09:30:00	30	3.688	52.227	1.668	
09:32:00	32				
09:34:00	34	3.769	52.146	1.749	
09:36:00	36	3.812	52.103	1.792	
09:38:00	38	3.853	52.062	1.833	
09:40:00	40	3.888	52.027	1.868	
09:45:00	45	3.983	51.932	1.963	
09:50:00	50	4.051	51.864	2.031	
09:55:00	55	4.076	51.839	2.056	
10:00:00	60	4.093	51.822	2.073	
10:10:00	70	4.122	51.793	2.102	
10:20:00	80	4.156	51.759	2.136	
10:30:00	90	4.190	51.725	2.170	
10:40:00	100	4.222	51.693	2.202	
10:50:00	110	4.252	51.663	2.232	
11:00:00	120	4.279	51.636	2.259	
11:20:00	140	4.321	51.594	2.301	
11:40:00	160	4.340	51.575	2.320	
12:00:00	180	4.380	51.535	2.360	
12:05:00	185	4.390	51.525	2.370	
12:10:00	190	4.378	51.537	2.358	
12:10:00	0	4.378	51.537	2.358	**Start of recovery**
12:10:30	0.5	4.375	51.540	2.355	
12:11:00	1	4.374	51.541	2.354	
12:11:30	1.5	4.372	51.543	2.352	
12:12:00	2	4.372	51.543	2.352	
12:12:30	2.5	4.372	51.543	2.352	
12:13:00	3	4.373	51.542	2.353	
12:13:30	3.5	4.372	51.543	2.352	
12:14:00	4	4.368	51.547	2.348	
12:14:30	4.5	4.365	51.550	2.345	
12:15:00	5	4.365	51.550	2.345	
12:15:30	5.5	4.362	51.553	2.342	
12:16:00	6	4.359	51.556	2.339	
12:16:30	6.5	4.355	51.560	2.335	
12:17:00	7	4.352	51.563	2.332	
12:17:30	7.5	4.345	51.570	2.325	
12:18:00	8	4.345	51.570	2.325	
12:18:30	8.5	4.345	51.570	2.325	

12:19:00	9	4.340	51.575	2.320
12:19:30	9.5	4.339	51.576	2.319
12:20:00	10	4.335	51.580	2.315
12:21:00	11	4.334	51.581	2.314
12:22:00	12	4.325	51.590	2.305
12:23:00	13	4.320	51.595	2.300
12:24:00	14	4.305	51.610	2.285
12:25:00	15	4.292	51.623	2.272
12:26:00	16	4.301	51.614	2.281
12:27:00	17	4.285	51.630	2.265
12:28:00	18	4.280	51.635	2.260
12:29:00	19	4.255	51.660	2.235
12:30:00	20	4.234	51.681	2.214
12:32:00	22	4.160	51.755	2.140
12:34:00	24	4.080	51.835	2.060
12:36:00	26	4.005	51.910	1.985
12:38:00	28	3.946	51.969	1.926
12:40:00	30	3.880	52.035	1.860
12:42:00	32	3.815	52.100	1.795
12:44:00	34	3.764	52.151	1.744
12:46:00	36	3.714	52.201	1.694
12:48:00	38	3.671	52.244	1.651
12:50:00	40	3.632	52.283	1.612
12:55:00	45	3.542	52.373	1.522
13:00:00	50	3.466	52.449	1.446
13:05:00	55	3.402	52.513	1.382
13:10:00	60	3.351	52.564	1.331
13:20:00	70	3.264	52.651	1.244

Project:	Forth Road Crossing	**Test:**	Constant rate test	**Abstraction borehole:**	CSRO10	
Date:	30/05/2012	**Weather:**	Overcast, chilly, very fine drizzle at times but mostly dry	**Monitored borehole:**	Obs 1 (CSRO12)	
				Datum:	Top of BH casing	
				Datum elevation:	56.073	mAOD

Time	**Elapsed time (mins)**	**Manually dipped water level (mbdat)**	**Water level (mAOD)**	**Drawdown (m)**	
09:00:00	0	2.262	53.811	0.000	
09:00:30	0.5	2.275	53.798	0.013	
09:01:00	1				
09:01:30	1.5	2.430	53.643	0.168	
09:02:00	2	2.480	53.593	0.218	
09:02:30	2.5	2.510	53.563	0.248	
09:03:00	3	2.550	53.523	0.288	
09:03:30	3.5	2.590	53.483	0.328	
09:04:00	4	2.630	53.443	0.368	
09:04:30	4.5	2.675	53.398	0.413	
09:05:00	5	2.700	53.373	0.438	
09:05:30	5.5	2.730	53.343	0.468	
09:06:00	6	2.770	53.303	0.508	
09:06:30	6.5	2.790	53.283	0.528	
09:07:00	7	2.823	53.250	0.561	
09:07:30	7.5	2.845	53.228	0.583	
09:08:00	8	2.875	53.198	0.613	
09:08:30	8.5	2.905	53.168	0.643	
09:09:00	9	2.922	53.151	0.660	
09:09:30	9.5	2.942	53.131	0.680	
09:10:00	10	2.967	53.106	0.705	
09:11:00	11	3.014	53.059	0.752	
09:12:00	12	3.055	53.018	0.793	
09:13:00	13	3.091	52.982	0.829	
09:14:00	14	3.128	52.945	0.866	
09:15:00	15	3.171	52.902	0.909	
09:16:00	16	3.206	52.867	0.944	
09:17:00	17	3.240	52.833	0.978	
09:18:00	18	3.275	52.798	1.013	
09:19:00	19	3.303	52.770	1.041	
09:20:00	20	3.340	52.733	1.078	
09:22:00	22	3.402	52.671	1.140	
09:24:00	24	3.465	52.608	1.203	
09:26:00	26	3.530	52.543	1.268	
09:28:00	28	3.590	52.483	1.328	
09:30:00	30	3.653	52.420	1.391	
09:32:00	32				
09:34:00	34	3.783	52.290	1.521	
09:36:00	36	3.840	52.233	1.578	
09:38:00	38	3.890	52.183	1.628	
09:40:00	40	3.935	52.138	1.673	
09:45:00	45	4.052	52.021	1.790	
09:50:00	50	4.129	51.944	1.867	
09:55:00	55	4.166	51.907	1.904	
10:00:00	60	4.198	51.875	1.936	
10:10:00	70	4.235	51.838	1.973	
10:20:00	80	4.298	51.775	2.036	
10:30:00	90	4.370	51.703	2.108	
10:40:00	100	4.435	51.638	2.173	
10:50:00	110	4.496	51.577	2.234	
11:00:00	120	4.545	51.528	2.283	
11:20:00	140	4.651	51.422	2.389	
11:40:00	160	4.776	51.297	2.514	
12:00:00	180	4.905	51.168	2.643	
12:05:00	185	4.995	51.078	2.733	
12:10:00	190	4.995	51.078	2.733	
12:10:00	0	4.99	51.08	2.73	**Start of recovery**
12:10:30	0.5	4.99	51.08	2.73	
12:11:00	1	4.98	51.10	2.71	
12:11:30	1.5	4.96	51.11	2.70	
12:12:00	2	4.94	51.13	2.68	
12:12:30	2.5	4.93	51.15	2.66	
12:13:00	3	4.92	51.15	2.66	
12:13:30	3.5	4.89	51.18	2.63	
12:14:00	4	4.88	51.19	2.62	
12:14:30	4.5	4.86	51.21	2.60	
12:15:00	5	4.83	51.24	2.57	
12:15:30	5.5	4.81	51.26	2.55	
12:16:00	6	4.78	51.29	2.52	
12:16:30	6.5	4.76	51.31	2.50	
12:17:00	7	4.74	51.33	2.48	
12:17:30	7.5	4.72	51.36	2.45	
12:18:00	8	4.69	51.38	2.43	
12:18:30	8.5	4.67	51.40	2.41	
12:19:00	9	4.64	51.43	2.38	
12:19:30	9.5	4.62	51.46	2.35	
12:20:00	10	4.59	51.48	2.33	

12:21:00	11	4.54	51.53	2.28
12:22:00	12	4.49	51.59	2.22
12:23:00	13	4.45	51.62	2.19
12:24:00	14	4.42	51.66	2.15
12:25:00	15	4.38	51.69	2.12
12:26:00	16	4.35	51.72	2.09
12:27:00	17	4.33	51.74	2.07
12:28:00	18	4.31	51.77	2.04
12:29:00	19	4.27	51.80	2.01
12:30:00	20	4.24	51.83	1.98
12:32:00	22	4.15	51.92	1.89
12:34:00	24	4.06	52.01	1.80
12:36:00	26	4.00	52.07	1.74
12:38:00	28	3.94	52.13	1.68
12:40:00	30	3.88	52.20	1.61
12:42:00	32	3.82	52.25	1.56
12:44:00	34	3.76	52.31	1.50
12:46:00	36	3.71	52.36	1.45
12:48:00	38	3.66	52.41	1.40
12:50:00	40	3.63	52.44	1.37
12:55:00	45	3.54	52.54	1.27
13:00:00	50	3.45	52.62	1.19
13:05:00	55	3.40	52.67	1.14
13:10:00	60	3.36	52.71	1.10
13:20:00	70	3.28	52.80	1.01