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Appendix I
Stage 1 groundwater monitoring bore pumping tests

Aquifer Testing Report
Stage 1 Groundwater Monitoring Wells

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GROUNDWATER PROJECT

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1.0 INTRODUCTION

QGC Pty. Limited ('QGC') - a BG Group business ('BG') is developing an integrated Liquefied Natural Gas (LNG) project in Queensland, Australia. The Queensland Curtis LNG Project ('QCLNG') involves the extraction of coal seam gas (CSG) from deep coal beds in the Surat Basin in South East Queensland from which LNG will be produced for export from a port in Gladstone. In extracting CSG, substantial quantities of associated water must also be extracted.

QGC wishes to implement a comprehensive groundwater monitoring program for the Gas Field Component of the QGLNG Project to ensure that any impacts from the project on the groundwater resources in the region are identified and quantified. The groundwater monitoring program will fulfil the statutory, management and environmental requirements for groundwater monitoring.

1.1 Groundwater Monitoring Plan

A major part of QGC's groundwater monitoring program for the Project is the Groundwater Monitoring Plan (GWMP), which was developed in 2009 and 2010 and was submitted to the Federal Government (as an appendix to the Stage 1 Water Monitoring and Management Plan) in April 2011. The GWMP is prepared as a working tool to provide monitoring programs for the upstream portion of the QCLNG project and the related reporting requirements. The GWMP is also prepared to satisfy both state and federal government conditions, such as Condition C6 within the Project's Environmental Authority (PEN100020207), and serves as a base for the required Coal Seam Gas Water Monitoring and Management Plan as required in The Department of Sustainability, Environment, Water, Population and Communities (SEWPAC) conditions released in October 2010.

To acceptably monitor the potential impacts to the quality of groundwater and levels caused by CSG activities, groundwater monitoring bores are required across the Project area. Monitoring bores are needed primarily within each of QGC's operational areas, but also up gradient and down gradient of project activities where the drawdown in an aquifer is predicted to exceed the set trigger thresholds and outside of the predicted impact areas to monitor for background conditions. Monitoring will be required across the range of hydrogeological formations present in the Project area. There are three classes of infrastructure proposed for groundwater monitoring: privately owned bores, vibrating wire piezometers, and multilevel nested well systems (the latter purpose drilled monitoring bores for both water quality and water level sampling).

1.2 This Report

In mid-2010 the QGC Subsurface Development team, in association with the Water Group, instigated Stage 1a of the GWMP drilling program. This involved the drilling and construction of 8 shallow groundwater monitoring bores targeting the Gubberamunda and Springbok aquifers (i.e. the main aquifers located above the Walloon Coal Measures (WCM) that are the target of CSG development), at 4 locations across QGC's central and southern development areas. In early to mid-2011, the Stage 1a drilling program was extended to cover a further 5 monitoring bores in the central and northern development areas, again targeting the Gubberamunda and Springbok aquifers. The further 5 bores are known as Stage 1b of the drilling program. Figure 1 presents the location of the Stage 1 monitoring bores.

Following drilling of the 13 Stage 1 shallow monitoring bores, the bores were subjected to an aquifer pumping test program in order to collect information regarding aquifer permeabilities, response to pumping, and groundwater quality. This report documents the findings of that Stage 1 aquifer testing program.

2.0 HYDROGEOLOGICAL SETTING

2.1 Surat Basin Geological Setting

The Surat Basin is a large intracratonic basin of Mesozoic age covering approximately 300,000km2 of southeastern Queensland and northern New South Wales. The basin forms part of the larger Great Australian Basin (Green et al, 1997), and interfingers westward across the Nebine Ridge with the Eromanga Basin, and eastward across the Kumbarilla Ridge with the Clarence-Moreton Basin (Exon, 1976). Basement blocks consisting of the Central West Fold Belt and the New England Fold Belt limit the basin to the south, while in the north the basin has been eroded and unconformably overlies Triassic and Permian sediments of the Bowen Basin.

The Surat Basin contains up to 2,500m of sedimentary rocks deposited during the Latest Triassic to Early Cretaceous periods. The Latest Triassic to Earliest Cretaceous succession in the basin consists of five fining-upwards sedimentary cycles dominated by fluviolacustrine deposits (Exon, 1976; Exon and Burger, 1981; Day et al, 1983). The lower part of each cycle typically comprises coarse-grained mature sandstone, grading up into more labile sandstone and siltstone, with mostly siltstone, mudstone and coal in the upper part. In the Cretaceous, inundation of the land through an increase in sea level led to deposition of predominantly coastal plain and shallow marine sediments in two cycles.

Structurally the Surat Basin is relatively simple, with the area of maximum deposition, the Mimosa Syncline, overlying the thickest Permian-Triassic rocks in the Taroom Trough of the underlying Bowen Basin (Day et al., 1983). Major faulting within the basin predominantly mirrors basinal boundary faults of the underlying Bowen Basin. There is substantial folding across the basin, which is due to compaction and draping, as well as some rejuvenation of older pre-Jurassic structures and faults. Formations outcrop along the northern erosional boundary and dip gently to the south and southwest at less than 5°.

2.2 Shallow Aquifers

The Stage 1 drilling program targets the main aquifers that lie above the Walloon Coal Measures in QGC's tenements, those being the Springbok and Gubberamunda Sandstones. The Springbok and Gubberamunda Sandstones are separated by the Westbourne Formation aquitard.

2.2.1 Springbok Sandstone

The Springbok Sandstone is of late-middle Jurassic age, and sits unconformably on top of the WCM. The unit occurs in small channel/valley structures eroded into the uppermost WCM layers, including the coal seams. It is generally lithologically homogenous with feldspathic and lithic sandstones, interbedded carbonaceous siltstones, interbedded mudstone, tuffs, and occasional thin coals. The sandstones display an overall fining upward character, which are fine to coarse grained and found commonly with calcareous cement (calcite) although some areas are friable and display porosity and permeability. Clays, and clay matrix-fill to the sand grains, are common in the typical Springbok Sandstone section, and are likely due to the volcanic sediment sourcing of the material.

The thickness of the Springbok Sandstone typically ranges between 50 to 150 m. The depositional environment is believed to be low energy fluvial with gradual infilling with overbank and mire sediments as accommodation space decreased. Sediment sources differ with volcanic lithics and feldspathic rich sediments from the north and east and quartz rich sediments from the south (Green et al. 1997).

Available data suggests that the Springbok aquifer is not widely used within QGC tenements, especially in the Southern and Central Development Areas (SDA and CDA), and there is minimal use in the vicinity of the Northern Development Area (NDA). This is primarily due to the presence of the shallower Gubberamunda Sandstone aquifer which typically is both better yielding and contains fresher groundwater in the QGC tenements.

2.2.2 Westbourne Formation

The Late Jurassic Westbourne Formation is conformable with the underlying Springbok Sandstone. It comprises interbedded with shales, mudstones, siltstones, and fine grained sandstones, with occasional thin coal seams. Sandstones in the section are similar to the Springbok Sandstone and could be deposition source related. Thickness of the Westbourne Formation increases to the east up to 200 m. This formation is interpreted to be deposited in a lacustrine (lake environment) environment with deltaic influences. The unit typically forms an effective aquitard separating the Springbok and Gubberamunda Sandstones.

The contact with the Springbok Sandstone is transitional as the Springbok-Westbourne units represent a single fining upwards sequence.

2.2.3 Gubberamunda Sandstone

Conformably overlying the Westbourne Formation is the Gubberamunda Sandstone of late Jurassic age. This sandstone unit consists of medium to coarse grained, poorly sorted, un-cemented, quartz rich sandstones interbedded with fine grained sandstone, siltstone and shale, with occasional conglomeritic layers. Thickness of the Gubberamunda Sandstone increases towards to the south, up to 300 m. Deposition is a high energy, fluvial influenced, mixed continental and shallow marine environment. It includes numerous high permeability lenses and bands which are exploited for their water resources.

The Gubberamunda Sandstone is exposed at the surface across the NDA, and outcrops/subcrops in the CDA and SDA.

The Gubberamunda Sandstone is widely utilised in the CDA and NDA for stock and domestic purposes, where it commonly forms the shallowest aquifer.

2.2.4 Other Shallow Formations

There are several other shallow formations identified regionally as important aquifers, although these for the most part do not occur on QGC tenements or are too shallow (and therefore have limited saturation) to be considered important aquifers.

The Cretaceous-aged Mooga Sandstone, which lies shallower in the Surat sequence than the Gubberamunda Sandstone and is separated from it by the Orallo Sandstone, is utilised to the west of QGC operations for stock and domestic purposes, and also in the southern part of the Woleebee Creek area of the NDA. The Mooga Sandstone outcrops across the NDA, and subcrops in the CDA (see Glossary) and SDA.

Quaternary Alluvium Aquifers and Tertiary sediments are also identified regionally as important aquifers. These typically comprise the surficial unconfined and unconsolidated aquifers associated with the major drainage systems. Directly east of the SDA, the most prevalent Quaternary aquifer is the Condamine River Alluvium (CRA), which is a highly developed and exploited water resource in the region. A great number of extraction bores exist in the CRA, used for multiple purposes such as for stock and domestic uses, irrigation, industrial, and town supply supplies. The Condamine River Alluvium overlies the Surat Basin formations unconformably in some areas, lying in direct contact with many of the aquifers and aquitards of the Surat Basin sequence. Very little CRA is identified on QGC tenements, with only the Harry and Broadwater blocks within the southeastern-most SDA having CRA mapped on them.

3.0 AQUIFER TESTING

3.1 Program Purpose

Concurrent with the Stage 1b drilling program, a groundwater pumping test program was instigated for the Stage 1 monitoring bores. The pumping test program had several purposes:

1. To allow estimates of aquifer hydraulic properties (transmissivity, hydraulic conductivity) to be calculated, to inform various groundwater studies both underway and being planned (e.g. Gen 3 model);
2. To assess aquifer response to pumping to gain a qualitative understanding of aquifer behaviour (e.g. identify leakage or boundaries);
3. To allow groundwater quality sampling to satisfy the 6-monthly sampling commitments of the GWMP; and
4. To allow groundwater quality sampling for a range of parameters (including isotopes) to provide data for various groundwater studies being undertaken.

3.2 Program Overview

The aquifer testing program was undertaken by TCL International Australia Pty Ltd (TCL Drilling) under the supervision of a QGC hydrogeologist at all times.

The aquifer testing program involved:

1. A multi-rate step test, typically 3 x 30 minute steps, to assess well efficiency and identify a target rate for a longer term constant rate test;
2. A constant rate pumping test typically of 8 hours duration, to allow estimates of aquifer hydraulic properties to be calculated and to assess aquifer response to pumping to gain a qualitative understanding of aquifer behaviour; and
3. A monitored recovery test to 95% of the pre-pumping water level, to allow estimates of aquifer hydraulic properties to be calculated to further gain a qualitative understanding of aquifer behaviour.

A range of Grundfos electro-submersible pumps were used for the testing program, based on the specifics of the well being tested (e.g. well yield, static water level and pumping water level). Pumping rates ranged from 0.2 to 5 L/s (the minimum and maximum that could be achieved using the range of available pumps) and were measured using an in-line electronic flow meter and controlled using a mechanical choke valve on the discharge line.

Field parameters (EC, pH, temperature, and gas in air concentrations at the wellhead and water discharge) were monitored using calibrated equipment at regular intervals during the step test and constant rate test by the supervising QGC hydrogeologist.

Table 3 presents a summary of the aquifer testing program. As shown on Table 3, several tests were abandoned due to insufficient yields from the wells, i.e. the permeability of the formation being tested was too low to accomplish a meaningful pumping test at the lowest possible flow rate of the available equipment (0.2 L/s).

3.3 Results

Aquifer test data were analysed quantitatively by a QGC hydrogeologist using a range of published solutions. Additionally, a QGC reservoir engineer analysed the data using standard well testing software (Saphir).

Table 3: Stage 1 Monitoring Bore Aquifer Testing Program

Well Name	Target	Multi-Rate Test Flowrates (L/s)	Multi-Rate Test Duration (mins)	Constant Rate Test Flowrate (L/s)	Constant Rate Test Duration (mins)
Berwyndale South GW1	Gubberamunda Sandstone	1.5 / 3 / 4.5	30 / 30 / 30	5	480
Berwyndale South GW2	Springbok Sandstone (mid)	0.3 / 0.75 / 1	30 / 30 / 30	0.9	480
Lauren GW1	Gubberamunda Sandstone	0.4 / 0.8 / 1.2	30 / 30 / 30	1	480
Lauren GW2	Springbok Sandstone (lower)	0.3 / 0.75 / 1.2	30 / 30 / 30	0.7	480
Kenya East GW1	Gubberamunda Sandstone	0.3 / 0.6 / 0.9 1.5 / 3 / 3.8	30 / 30 / 30 30 / 30 / 30	4.5	660
Kenya East GW2	Springbok Sandstone (mid)	0.55 / 0.75 / 1	30 / 30 / 30	1	480
Poppy GW1	Springbok Sandstone (mid)	0.18 / 0.3	30 / 30	0.2	70
Poppy GW2	Springbok Sandstone (lower)	0.2 / 0.4 / 0.6	30 / 30 / 30	0.4	480
Woleebee Creek GW1	Gubberamunda Sandstone	0.4 / 0.6	30 / 30	0.45	480
Woleebee Creek GW2	Springbok Sandstone (lower)	-	-	0.9	49
Bellevue GW2	Springbok Sandstone (lower)	0.7 / 0.9	11 / 10	-	-
Kenya East GW3	Gubberamunda Sandstone	0.3 / 0.8 / 1.4	30 / 30 / 30	0.5	326
Kenya East GW4	Springbok Sandstone (lower)	0.3 / 0.6 / 0.9	30 / 30 / 30	0.3	480

Notes:
1. Two multi-rate tests were undertaken at Kenya GW1 due to using a smaller pump on the first test that was not capable of achieving the desired flow rates.
2. Poppy GW1, Woleebee Creek GW1 and GW2, and Bellevue GW2 tests were of limited duration due to pumping water levels reaching pump installation depth during those tests, i.e. insufficient formation yield to complete tests.
3. Kenya East GW3 constant rate test was halted early due to stabilisation of pumping water level.
4. ‘Mid’ and ‘Lower’ Springbok Sandstone are denoted based on QGC’s Springbok Characterisation Study

For the hydrogeological analysis, constant rate test data and recovery test data were analysed using the Cooper-Jacob and Theis Recovery semi-log straight-line methods (Krusemann and de Ridder, 1970) to yield estimates of aquifer transmissivity and therefore horizontal hydraulic conductivity. Mid-time data were analysed for straight-line fitting, i.e. after the influence of well storage effects (typically after 5-10 mins of pumping) but before the influence of aquifer boundaries (typically between 20 and 100 mins). It is considered that this methodology yields aquifer parameters for the aquifer immediately adjacent the well but not necessarily for a more regional analysis. Curve-fitting methods were not used as these are not appropriate for tests with pumped-well data only. Appendix A presents a graphical summary of the semi-log hydrogeological analysis.

For the reservoir engineering analysis, the constant rate drawdown and recovery data were analysed using the Ecrin Saphir Version 4.20 (Saphir) software package. This package uses Derivative Analysis (Bourdet et al., 1989) to compute derivatives from the drawdown or recovery data by numerical differentiation. Where possible, the recovery data were analysed in preference to the constant rate drawdown data to provide a smoother dataset that avoided some of the fluctuations in measured drawdown associated with poor pump control. Appendix B presents the graphical results of the Saphir analysis.

Data were also analysed qualitatively for indications of leakage or aquifer boundary effects. Negative boundaries in the data can be interpreted as pinching or thinning out of permeable aquifers, reductions in hydraulic conductivity away from the pumping well, or geological fault-related barriers. Similarly, recharge boundaries can be interpreted as thickening of permeable aquifers or increases in hydraulic conductivity away from the pumping well, or geological faults conducive to groundwater flow. Leakage is likely to be derived from strata above or below the particular sand package screened by the pumping well. Over the relatively short duration of these pumping tests however, leakage if it occurs is likely to be solely derived from the formation containing the pumped aquifer, rather than a different (aquitard) formation above or below the formation which contains the pumped sand unit.

Table 4 presents a summary of the aquifer testing data analysis using the hydrogeological straight line methods. Table 5 presents a summary of the aquifer testing data analysis using the reservoir engineering software.

Table 6 presents an overall summary of calculated permeability data.

3.4 Discussion

In general, the aquifer testing highlighted that the Gubberamunda aquifer is up to an order of magnitude more permeable than the Springbok aquifer, with horizontal hydraulic conductivity estimates ranging from 0.02 to 8.3 m/day in the Gubberamunda (geometric mean of 0.5 m/day) and 0.003 to 0.1 m/day in the Springbok (geometric mean of 0.03 m/day). Additionally, the middle Springbok aquifer may be generally more permeable than the lower Springbok aquifer, although this conclusion is founded on somewhat limited data as only two tests were undertaken in the middle Springbok. Several tests in the Springbok aquifer had to be halted due to insufficient formation yield to maintain a constant pumping rate, which qualitatively confirms the very low permeability findings of the quantitative permeability analysis. The Gubberamunda aquifer appears to show quite a bit of variability in permeability, with Kh estimates ranging over two orders of magnitude.

Most of the tests were subject to boundary conditions or leakage influencing the drawdown curves. In the Gubberamunda aquifer, two of the five tests showed discharge boundaries and one test showed a sharp recharge boundary. These boundaries may be related to faulting or facies changes. No leakage was detected in the Gubberamunda tests. In the Springbok aquifer, four of the seven tests detected leakage, which is likely to be derived from Springbok Formation strata immediately above or below the pumped sand unit.

Table 4: Stage 1 Monitoring Bore Aquifer Testing Program Results (hydrogeological analysis)

Aquifer	Well Name	Transmissivity (m^2/day)			Boundary / Leakage Effects	Indicative Horizontal Hydraulic Conductivity Kh (m/day)[1]
		Cooper-Jacob	Theis (recovery)	Cooper-Jacob (recovery)		
Gubberamunda Sandstone	Berwyndale South GW1	80	88	81	Mild discharge boundary from 100 mins	8.3
	Lauren GW1	0.8	1.0	0.9	Sharp recharge boundary from 20 mins	0.05
	Kenya East GW1	42	42	45	None	2.3
	Woleebee Creek GW1	0.8	0.3	0.3	Discharge boundary from 10 mins	0.02
	Kenya East GW3	26	21	26	None	1.2
Springbok Sandstone	Berwyndale South GW2	0.8	0.7	0.8	Recharge boundary and/or leakage from 60 mins	0.08
	Lauren GW2	1.3	1.3	1.3	Recharge boundary and/or leakage from 20 mins	0.1
	Kenya East GW2	1.1	0..9	0.9	Recharge boundary and/or leakage from 20 mins	0.04
	Poppy GW1	0.1	Insufficient recovery for analysis		Sharp discharge boundary from 20 mins	0.01
	Poppy GW2	0.3	0.2	0.3	Discharge boundary from 100 mins	0.03
	Woleebee Creek GW2	0.06	Insufficient recovery for analysis		None	0.003
	Kenya East GW4	0.7	0.7	0.7	Recharge boundary and/or leakage from 20 mins	0.05
	Bellevue GW2	0.2	Insufficient recovery for analysis		None	0.01

Notes: 1. Indicative horizontal hydraulic conductivity = geometric mean aquifer transmissivity from the three straight-line methods divided by aquifer thickness taken from petrophysical log interpretation of the screened sand package thickness

Table 5: Stage 1 Monitoring Bore Aquifer Testing Program Results (reservoir engineering analysis)

Aquifer	**Well Name**	**Transmissivity (m^2/day)**		**Indicative Horizontal Hydraulic Conductivity Kh (m/day)[1]**	
		Geometric mean hydrogeological analysis (see Table 4)	**Saphir Result**	**Hydrogeological analysis (see Table 4)**	**Saphir**
Gubberamunda Sandstone	Berwyndale South GW1	83	102	8.3	10.2
	Lauren GW1	0.8	2.6	0.05	0.1
	Kenya East GW1	42	38	2.3	2.4
	Woleebee Creek GW1	0.5	2.0	0.02	0.1
	Kenya East GW3	26	Data unsuitable for analysis – poor flow control in early time and poor recovery curve		
Springbok Sandstone	Berwyndale South GW2	0.8	0.7	0.08	0.1
	Lauren GW2	1.3	3.7	0.1	0.3
	Kenya East GW2	1.0	2.3	0.04	0.1
	Poppy GW1	0.1	Data unsuitable for analysis – insufficient formation yield		
	Poppy GW2	0.3	Data unsuitable for analysis – unstable drawdown		
	Woleebee Creek GW2	0.06	Data unsuitable for analysis – insufficient formation yield		
	Kenya East GW4	0.7	Data unsuitable for analysis – unstable drawdown		
	Bellevue GW2	0.2	Data unsuitable for analysis – insufficient formation yield		

Notes: 1. Indicative horizontal hydraulic conductivity = geometric mean aquifer transmissivity from the Saphir model divided by aquifer thickness taken from petrophysical log interpretation of the screened sand package thickness

Table 6: Summary of Permeability Estimates

Aquifer	Geometric Mean T (m^2/day)	Geometric Mean Kh (m/day)	Max Kh (m/day)	Min Kh (m/day)
Gubberamunda	8.1	0.5	8.3	0.02
Springbok (all tests)	0.34	0.03	0.10	0.003
Springbok (upper, 1 test)	0.10	0.01	0.01	0.01
Springbok (mid, 2 tests)	0.86	0.06	0.08	0.04
Springbok (lower, 5 tests)	0.30	0.02	0.10	0.003

The Saphir reservoir engineering software package produce transmissivity estimates very close to those produced by the standard hydrogeological analysis. However, the Saphir software was only able to analyse 7 of the 13 tests, as the software requires a complete dataset that is more or less without imperfections. Whereas an experienced hydrogeologist using traditional semi-log straight line analyses can identify data to ignore and focus their analysis on only the 'good' data, the Saphir package cannot make a distinction between good and bad data and only analyse the 'good' part of the drawdown or recovery curves. Three of the seven Saphir analyses showed the data was best fit using a single bounding fault model (two in the Gubberamunda [Berwyndale South GW1 and Lauren GW1] and one in the Springbok [Kenya East GW2]). These correspond with aquifer boundaries seen in the semi-log analysis.

4.0 WATER QUALITY SAMPLING

4.1 Overview

Water quality sampling, to satisfy QGC's commitments under the GWMP, was undertaken by Leeder Consulting Pty Ltd, again under the supervision of a QGC hydrogeologist. The sampling program was undertaken concurrent with the aquifer testing program.

Typically, the QGC hydrogeologist would calculate a purge volume based on 3 wet well volumes, and once this had been achieved during the constant rate pumping test, Leeder would be mobilised to site to conduct the sampling whilst the constant rate test was still underway.

Where it was not possible to purge three well volumes due to very low aquifer yields (Poppy GW1 and Bellevue GW2), sampling was undertaken after the well had effectively been purged dry and allowed to recover sufficiently to run the pump again to collect the sample. At Woleebee Creek GW2, sampling was not undertaken as the well was not pumped 'dry' due to the pump installation depth being a significant height above the bottom of the well, and the well did not recover suitably to run the pump again and take a sample.

Samples were analysed by Leeder (or their sub-contracted laboratories) for a range of parameters:

- pH
- Total Dissolved Solids (TDS)
- Major Ions (Sodium, Calcium, Magnesium, Potassium, Chloride, Sulphate, Carbonate and Bicarbonate)

- Selected minor ions and other parameters not reported here (as per the GWMP).

4.2 Results

Table 5 presents a summary of the groundwater quality (pH, TDS and major ions) data from the Stage 1 monitoring well sampling program.

Table 5: Stage 1 Monitoring Bore Groundwater Chemistry Laboratory Results

Aquifer	Well Name	pH	TDS (mg/L)	Cations (mg/L)				Anions (mg/L)			
				Na	Ca	Mg	K	Cl	SO_4	CO_3	HCO_3
Gubberamunda Sandstone	Berwyndale South GW1	8.6	820	280	1.7	0.11	1	120	1	24	549
	Lauren GW1	8.8	870	330	1.2	0.14	0.98	75	5	24	781
	Kenya East GW1	8.1	2,600	950	9.3	12	2	1,500	2	<0.6	305
	Wolleebee Creek GW1	8.8	850	310	1.6	0.11	0.9	210	<1	36	488
	Kenya East GW3	8.6	850	300	0.92	0.42	0.96	56	16	24	720
Springbok Sandstone	Berwyndale South GW2	8.9	1,200	470	1.9	0.14	1.2	350	3	24	708
	Lauren GW2	8.6	1,400	440	2.2	0.13	1.7	280	4	12	781
	Kenya East GW2	8.7	1,100	410	1.2	0.16	0.99	170	8	18	866
	Poppy GW1	11.9	6,400	1,700	2.2	<0.05	44	1,900	31	198	<1.2
	Poppy GW2	8.7	2,000	710	7.3	0.32	2.2	950	3	20	427
	Wolleebee Creek GW2	Well not sampled – insufficient purge volume									
	Kenya East GW4	8.5	1,200	440	2	0.18	1.4	140	1	30	976
	Bellevue GW2	9.2	2,800	850	8	0.97	13	970	7	60	732

Note: CO_3 and HCO_3 have been converted from laboratory values reported as $CaCO_3$

4.3 Discussion

Groundwater pH generally ranges between 8 and 9 in both the Gubberamunda and Springbok aquifers (i.e. slightly alkaline). An elevated value of 11.9 is recorded at Poppy GW1 (upper Springbok) which is presumed to be a result of insufficient well development and purging prior to sampling, which has failed to remove groundwater which has come into contact with the cement grout used to isolate the annulus of the well. The cement contamination theory is supported by high sulphate and carbonate in the Poppy GW1 sample with respect to both other ions and other sampled wells.

Groundwater salinity is somewhat variable, ranging from 820 to 2,700 mg/L TDS in the Gubberamunda aquifer (average of 1,200 mg/L, skewed by one result of 2,700 mg/L compared to four results between 800 and 900 mg/L), and 1,200 to 2,800 mg/L TDS in the Springbok aquifer (average of 1,600 mg/L, ignoring Poppy GW1). In general, it can be concluded that the Springbok aquifer is 1.5 to 2 times more saline than the Gubberamunda aquifer. There does not appear to be any significant correlation between permeability (refer Section 3.3) and salinity on a well-by-well basis, however it is noted that the Gubberamunda aquifer in general is both more permeable and less saline than the Springbok aquifer, suggesting slower rates of groundwater movement in the less permeable Springbok aquifer results in increased groundwater salinity.

To analyse the chemical processes taking place and further characterise the aquifers based on groundwater chemistry, the groundwater quality data was plotted in a Piper plot, as shown in Figure 2. This analysis shows that in general, cation concentration ratios are very similar across both aquifers and all wells, and dominated by sodium. However, bicarbonate and chloride anion concentration ratios vary significantly across the sample group. The Gubberamunda samples plot close together, showing bicarbonate domination, however the Springbok aquifer shows significant variability. Since chloride is conservative but bicarbonate is not, the relative increase or decrease in bicarbonate through chemical processes is driving this variability.

Bicarbonate in the Gubberamunda is likely to be sourced from atmospheric or soil carbon dioxide dissolution, since the aquifer is relatively shallow and close to recharge zones where the sampled wells are located. A plot of bicarbonate versus depth of well for the Springbok is shown in Figure 3 and indicates that bicarbonate concentration increases with depth, suggesting that Springbok groundwater is acquiring bicarbonate with increased residence time after recharge, assuming that shallower aquifer intersections are closer to the basin edge recharge zones. Possible sources of bicarbonate include dissolution (weathering) of calcite or albite (a feldspar), and/or methanogenesis, and/or bacterial sulphate reduction. Methanogenesis is a significant possibility for bicarbonate enrichment as the Springbok formation contains significant coal deposits and is also known to contain methane gas in appreciable quantities. This is supported by the high relative bicarbonate concentrations in the Walloon Coal Measures methane reservoir (Figure 4). Mixing with water from the Walloon Coal Measures is also a possible source of bicarbonate enrichment in the Springbok. Bacterial sulphate reduction is also considered likely as a source of bicarbonate, as the water sampling program has indicated very low sulphate concentrations across all aquifers.

The results of this groundwater sampling program match those reported in previous groundwater chemistry studies undertaken by QGC, including that reported under Appendix 2 of the GWMP.

5.0 CONCLUSIONS

The following summarises the findings of the Stage 1 aquifer testing program:

- In general, the aquifer testing highlighted that the Gubberamunda aquifer is up to an order of magnitude more permeable than the Springbok aquifer.
- Horizontal hydraulic conductivity estimates range from 0.02 to 8.3 m/day in the Gubberamunda aquifer (geometric mean of 0.5 m/day) and 0.003 to 0.1 m/day in the Springbok aquifer (geometric mean of 0.03 m/day).
- The middle Springbok aquifer may be generally more permeable than the lower Springbok aquifer.
- The Gubberamunda aquifer appears to show quite a bit of variability in permeability, with Kh estimates ranging over two orders of magnitude.
- Most of the tests were subject to boundary conditions influencing the drawdown curves (either negative or recharge); these boundaries may be related to faulting or facies changes.
- No leakage was detected in the Gubberamunda tests. Four of the seven Springbok tests detected leakage, which is likely to be derived from Springbok Formation strata immediately above or below the pumped sand unit. Where leakage wasn't detected, it is likely due to the aquifer tests not being run for sufficient enough time due to early halting of the test.

The following summaries the findings of the Stage 1 groundwater sampling program:

- Groundwater pH generally ranges between 8 and 9 in both the Gubberamunda and Springbok aquifers (i.e. slightly alkaline).
- Groundwater salinity is somewhat variable, ranging from 820 to 2,700 mg/L TDS in the Gubberamunda aquifer and 1,100 to 2,800 mg/L TDS in the Springbok aquifer. In general, it can be concluded that the Springbok aquifer is 1.5 to 2 times more saline than the Gubberamunda aquifer.
- Groundwaters are either sodium-chloride or sodium-chloride-bicarbonate or sodium-bicarbonate types.
- Cation concentration ratios are very similar across both aquifers and all wells, and dominated by sodium.
- The Gubberamunda aquifer shows bicarbonate anion domination, however the Springbok aquifer shows significant variability between bicarbonate and chloride domination.
- Bicarbonate concentration in the Springbok increases with aquifer depth of burial, suggesting that Springbok groundwater is acquiring bicarbonate with increased residence time after recharge.
- Possible methods of bicarbonate enrichment in the Springbok include water/rock interactions, methanogenesis, sulphate reduction, or mixing with deeper high-bicarbonate Walloon groundwater. It is possible that all four mechanisms contribute to Springbok bicarbonate concentrations.

FIGURES

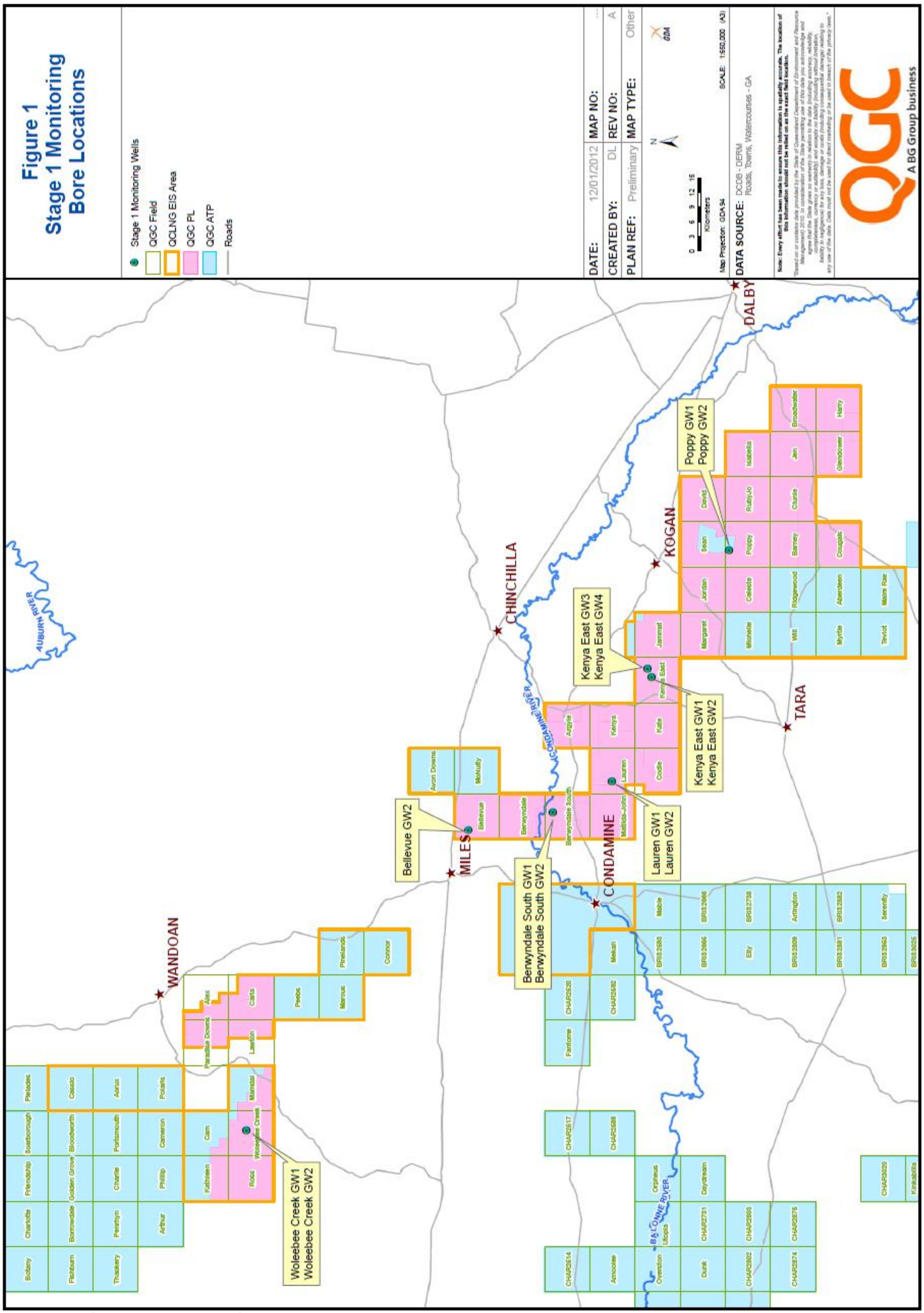


Figure 1 – Locality Plan

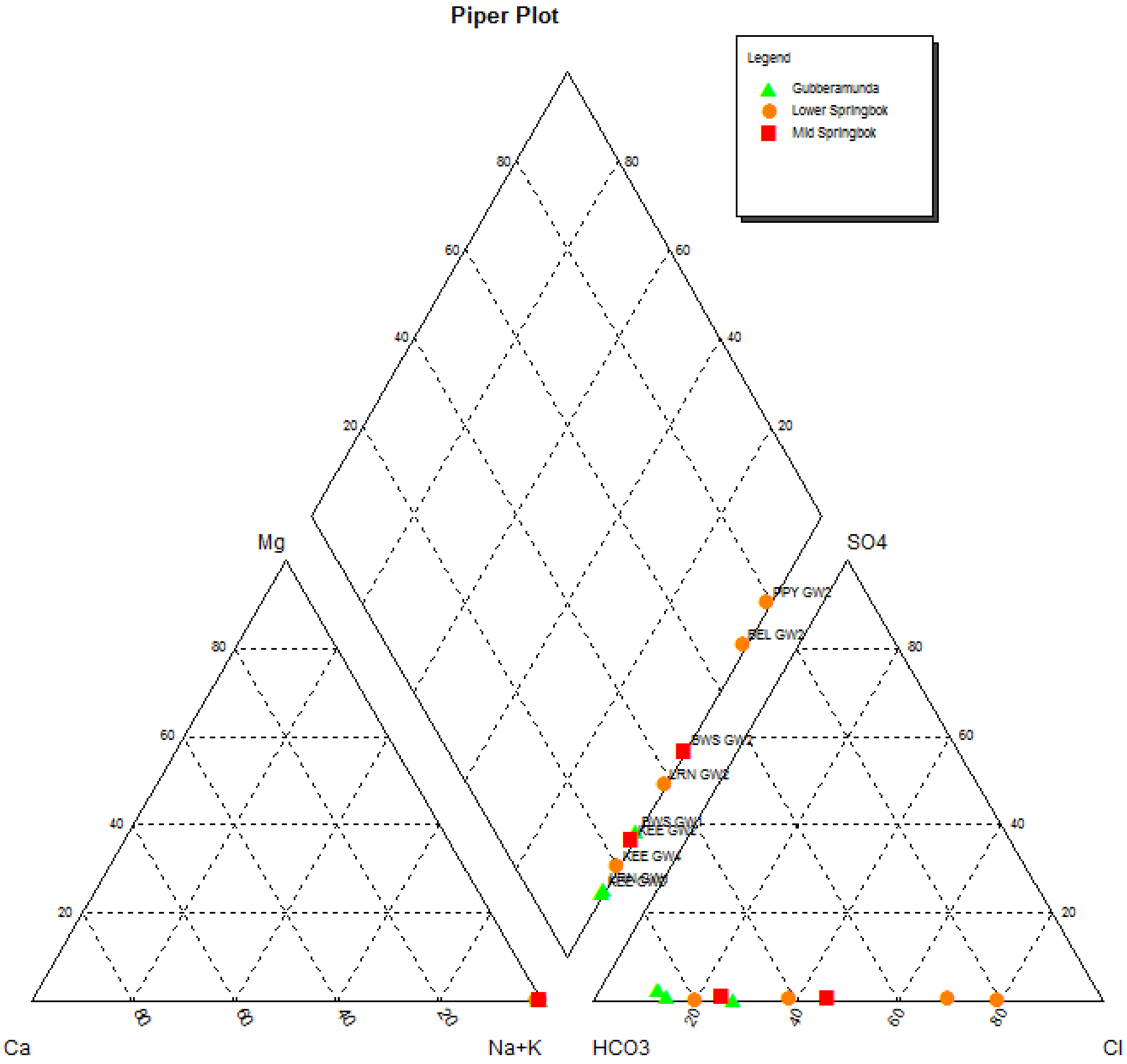


Figure 2 – Piper Plot

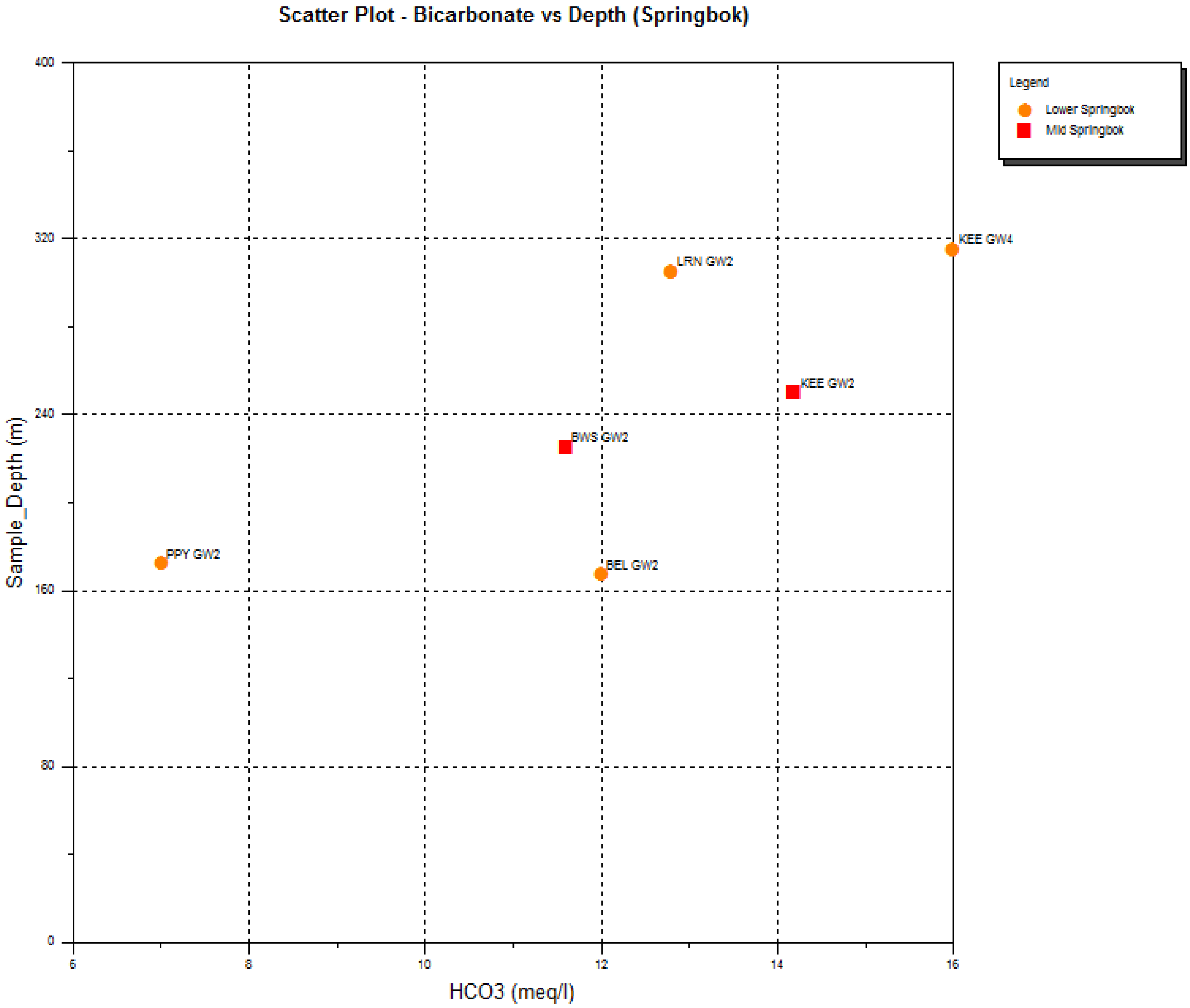


Figure 3 – Bicarbonate versus Depth

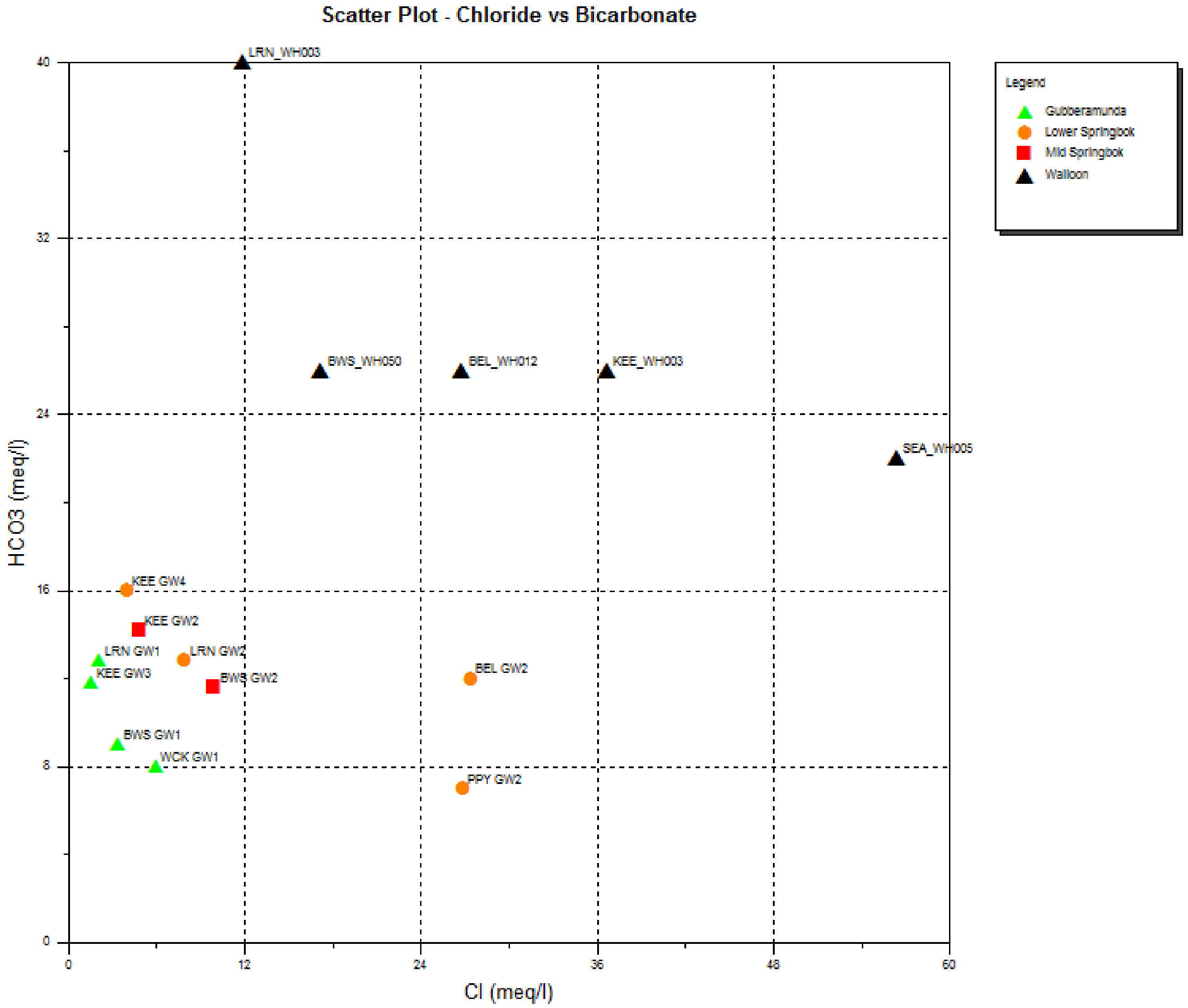
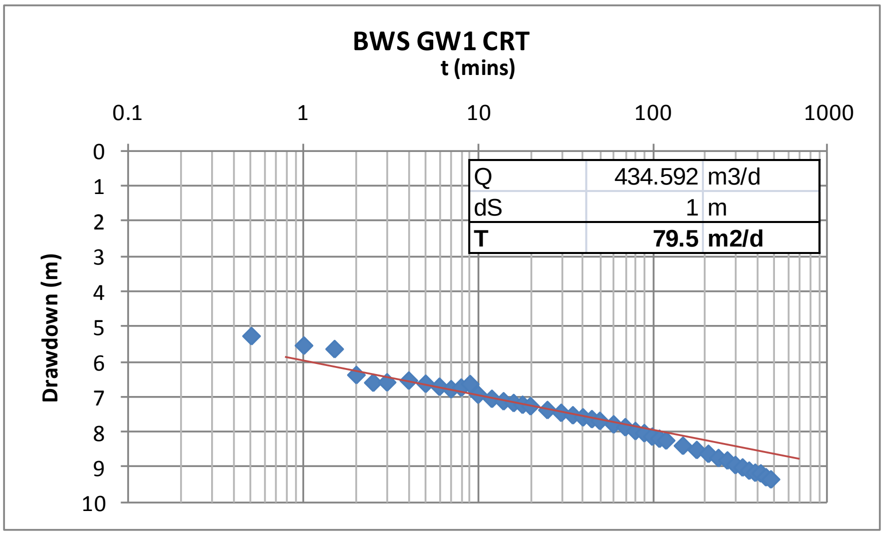


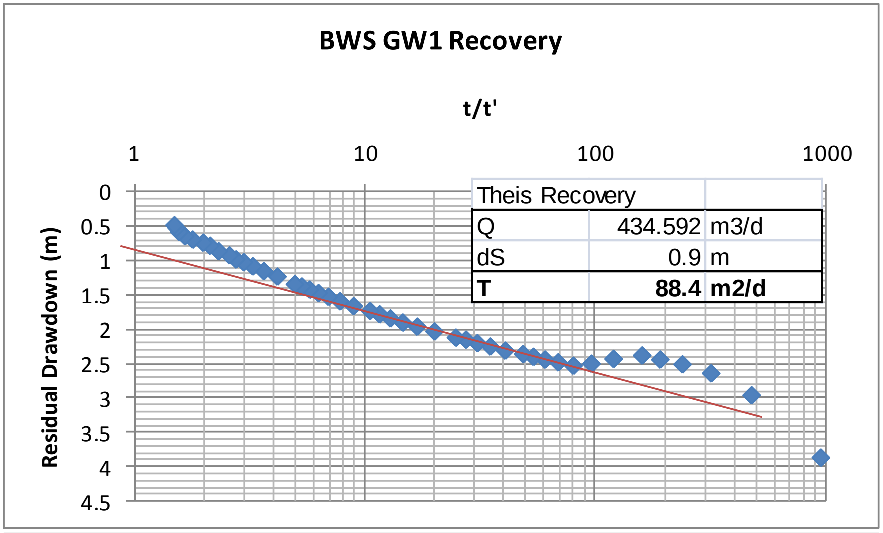
Figure 4 – Chloride versus Bicarbonate

APPENDIX A – SEMI-LOG STRAIGHT LINE ANALYSIS

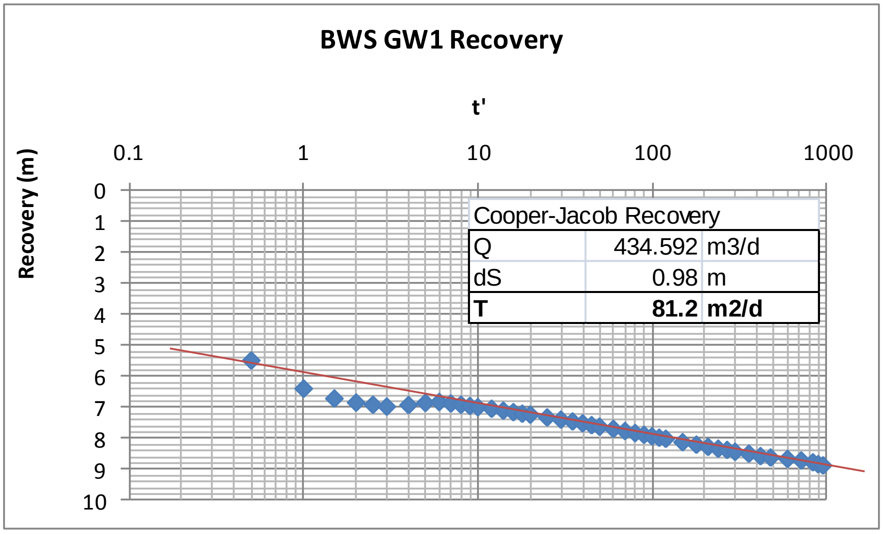
Gubberamunda Sandstone


BWS GW1 CRT

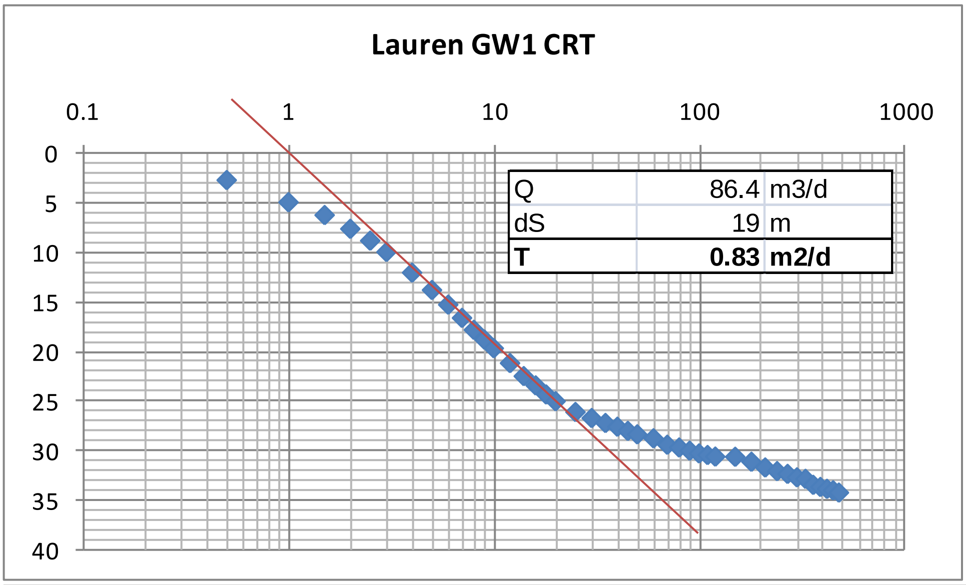
Q	434.592	m3/d
dS	1	m
T	**79.5**	**m2/d**


BWS GW1 Recovery

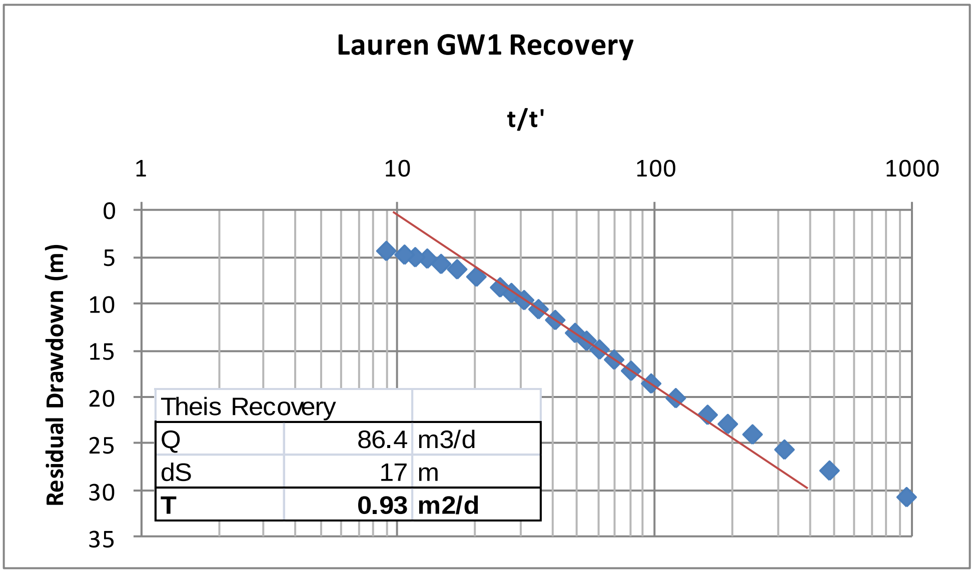
Theis Recovery		
Q	434.592	m3/d
dS	0.9	m
T	**88.4**	**m2/d**


BWS GW1 Recovery

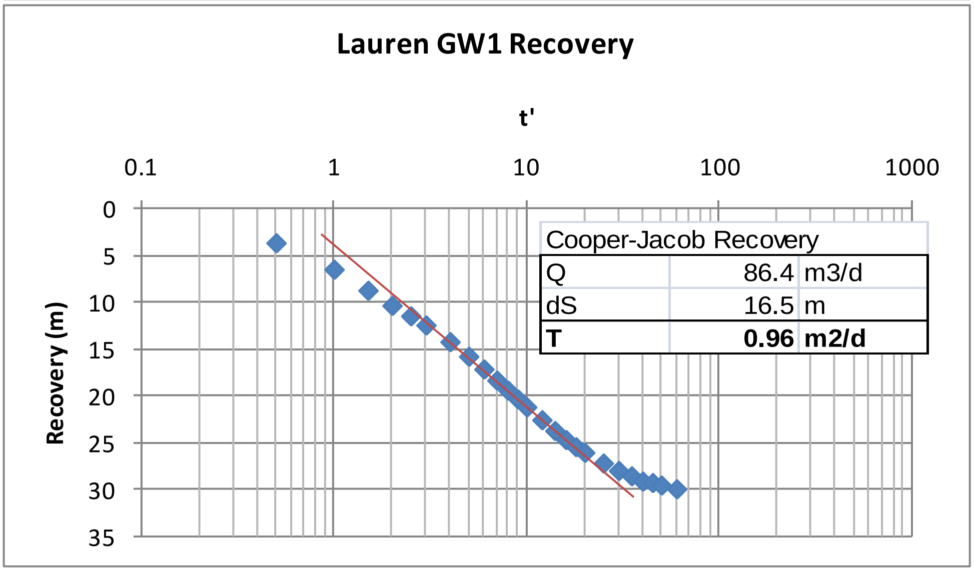
Cooper-Jacob Recovery		
Q	434.592	m3/d
dS	0.98	m
T	**81.2**	**m2/d**


Lauren GW1 CRT

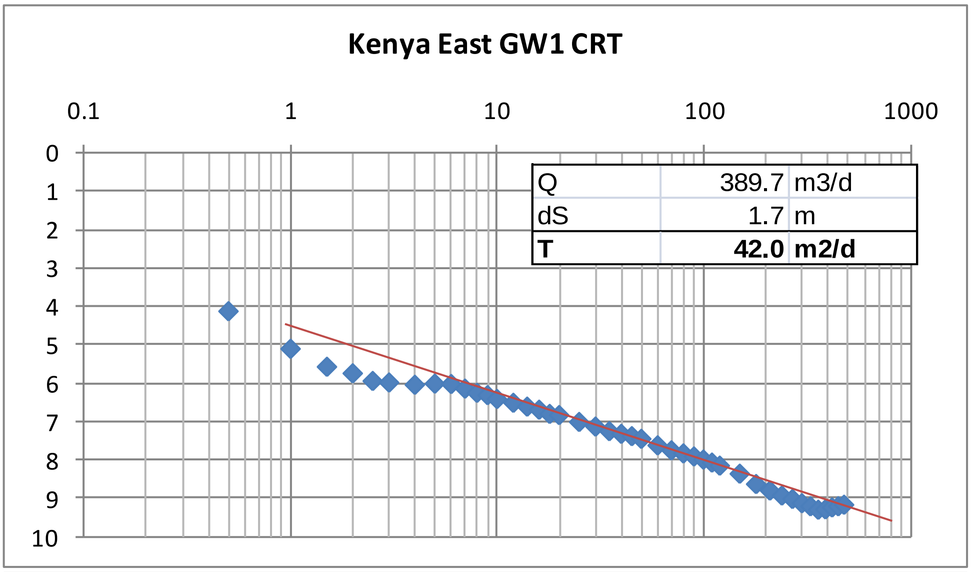
Q	86.4	m3/d
dS	19	m
T	**0.83**	**m2/d**

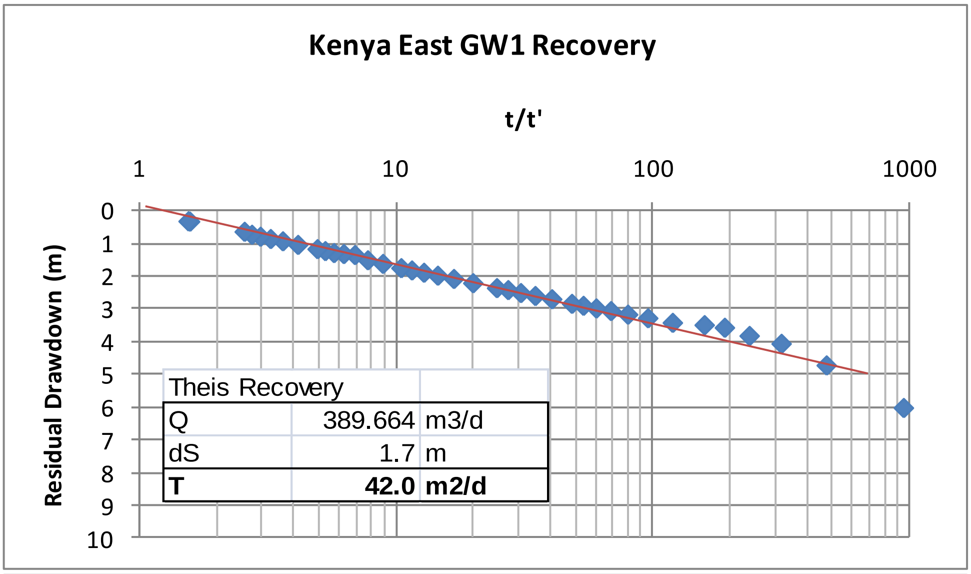

Lauren GW1 Recovery

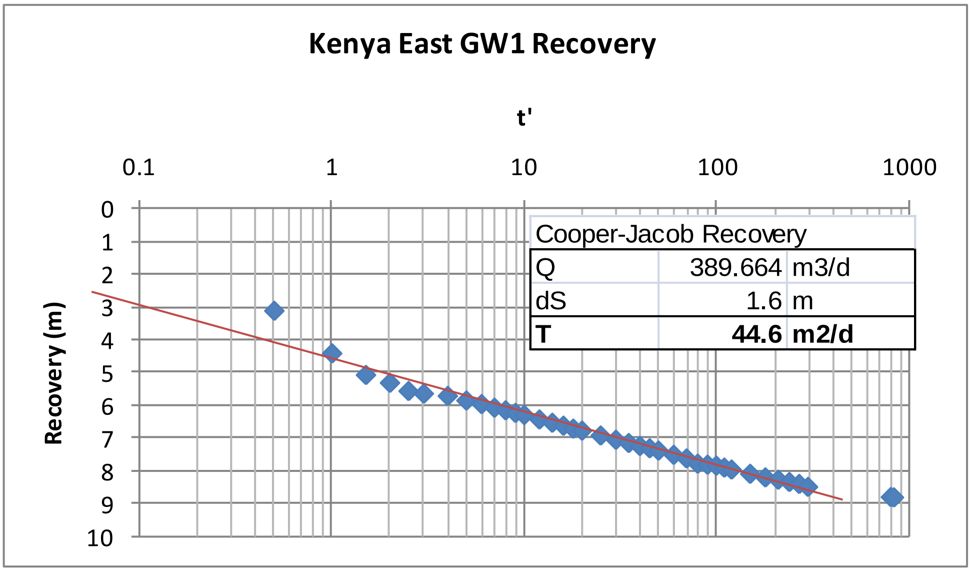
Theis Recovery		
Q	86.4	m3/d
dS	17	m
T	**0.93**	**m2/d**

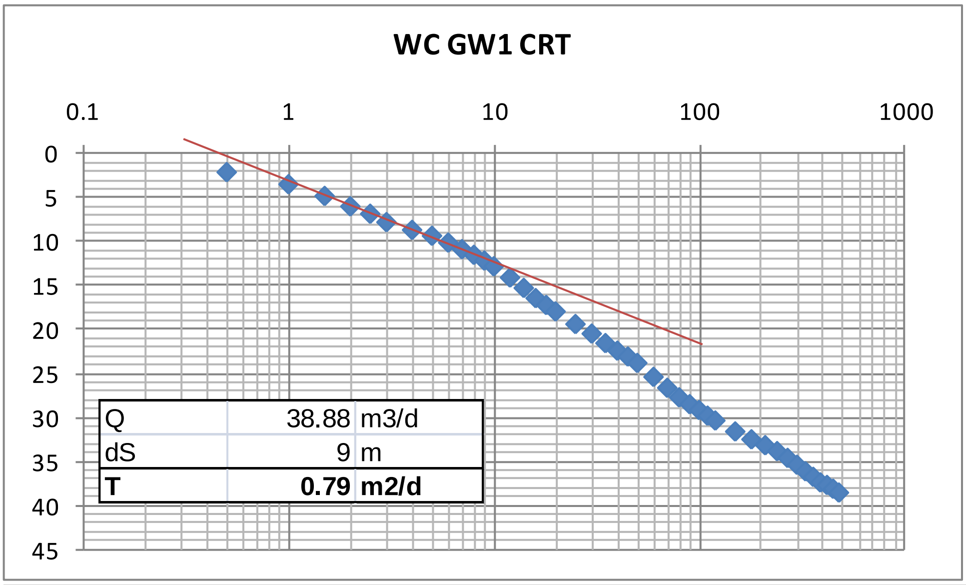

Lauren GW1 Recovery

Cooper-Jacob Recovery		
Q	86.4	m3/d
dS	16.5	m
T	**0.96**	**m2/d**


Kenya East GW1 CRT

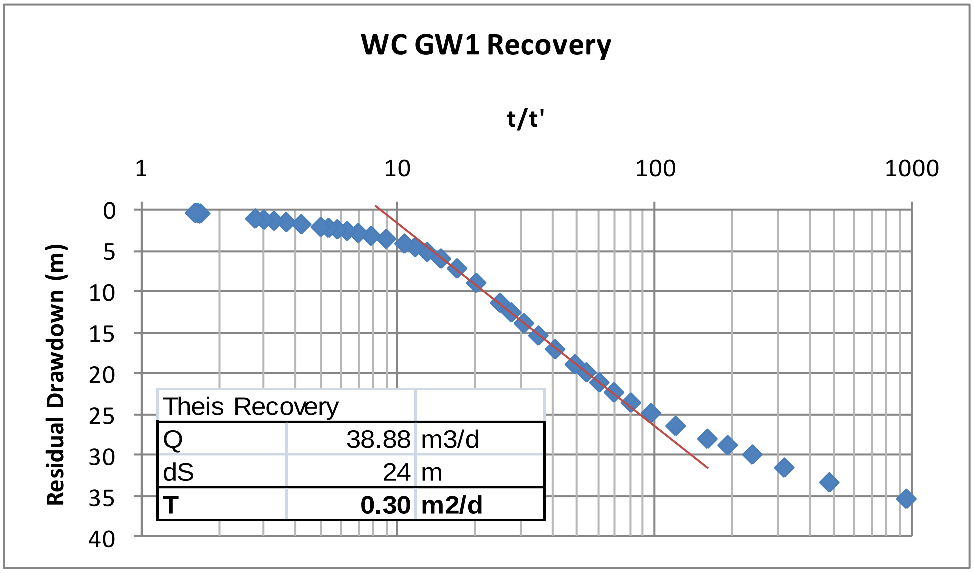

Kenya East GW1 Recovery


Kenya East GW1 Recovery



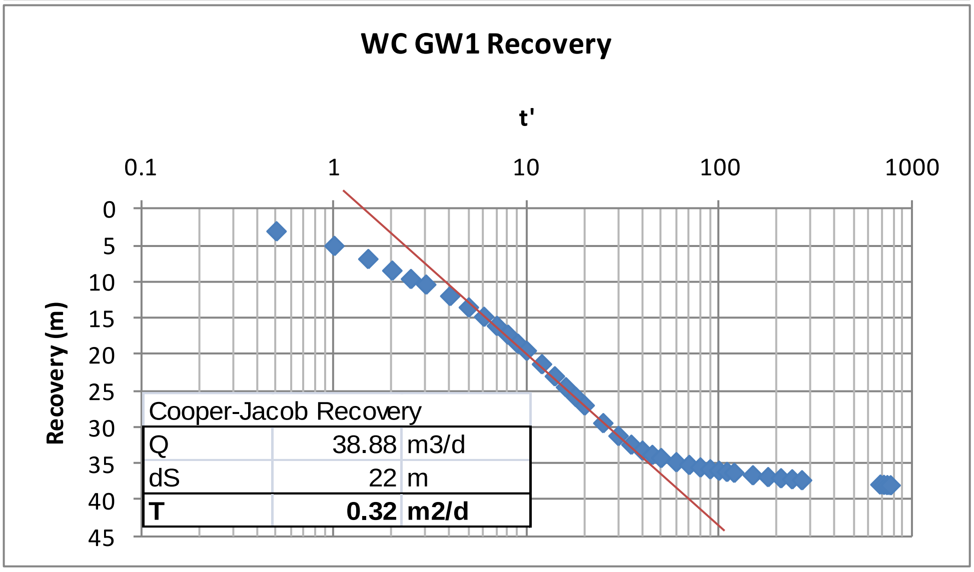
WC GW1 CRT

Q	38.88	m3/d
dS	9	m
T	**0.79**	**m2/d**



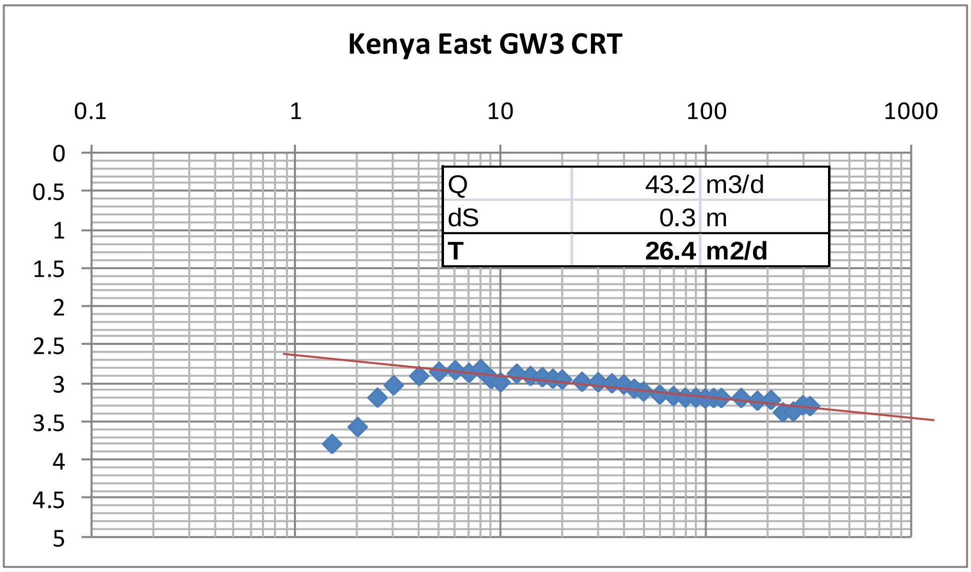
WC GW1 Recovery

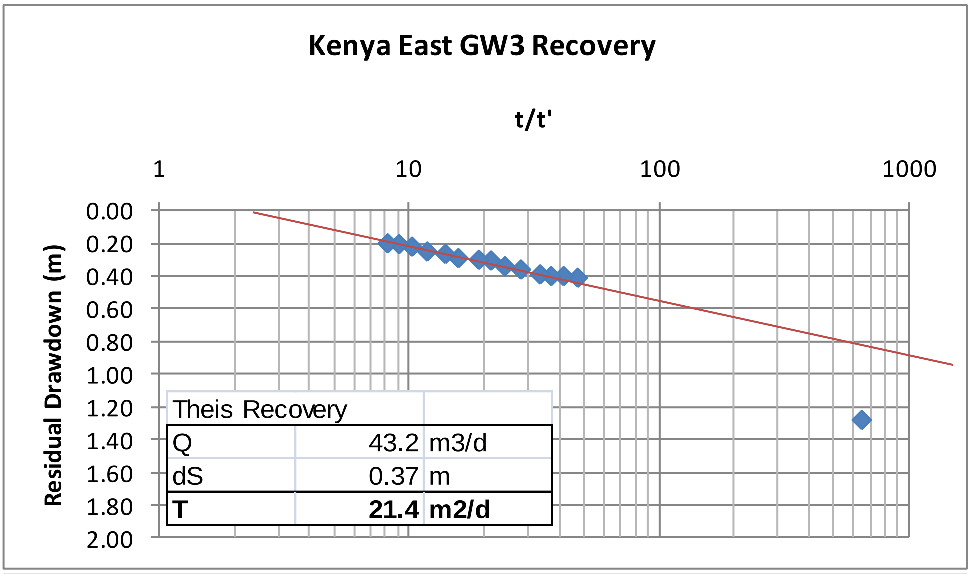
Theis Recovery		
Q	38.88	m3/d
dS	24	m
T	**0.30**	**m2/d**

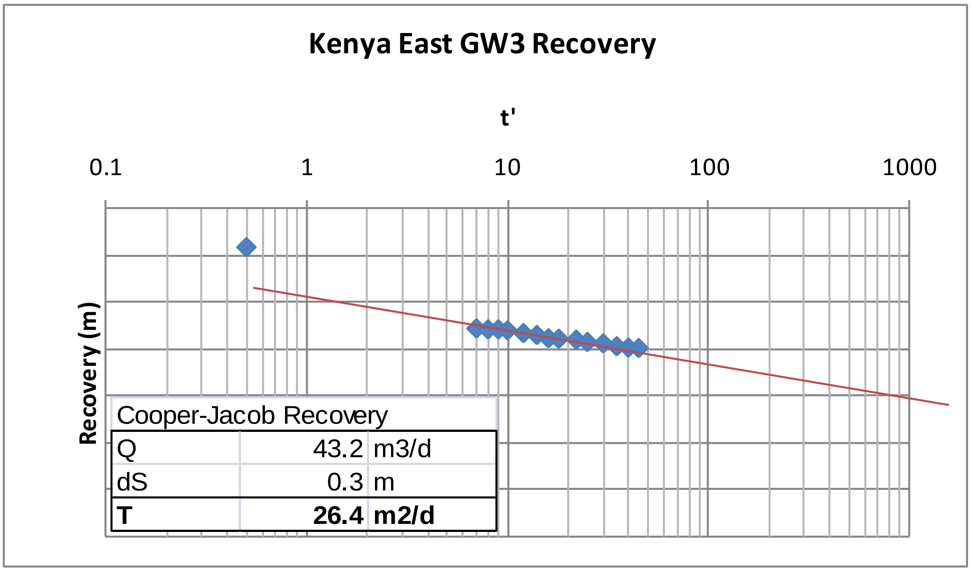


WC GW1 Recovery

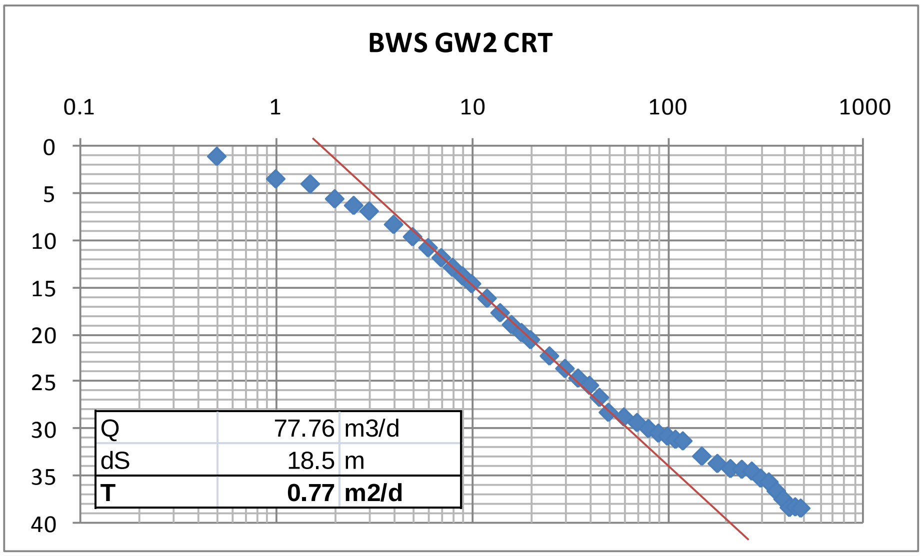
Cooper-Jacob Recovery		
Q	38.88	m3/d
dS	22	m
T	**0.32**	**m2/d**


Kenya East GW3 CRT
0.1
1
10
100
1000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Q 43.2 m3/d
dS 0.3 m
T 26.4 m2/d

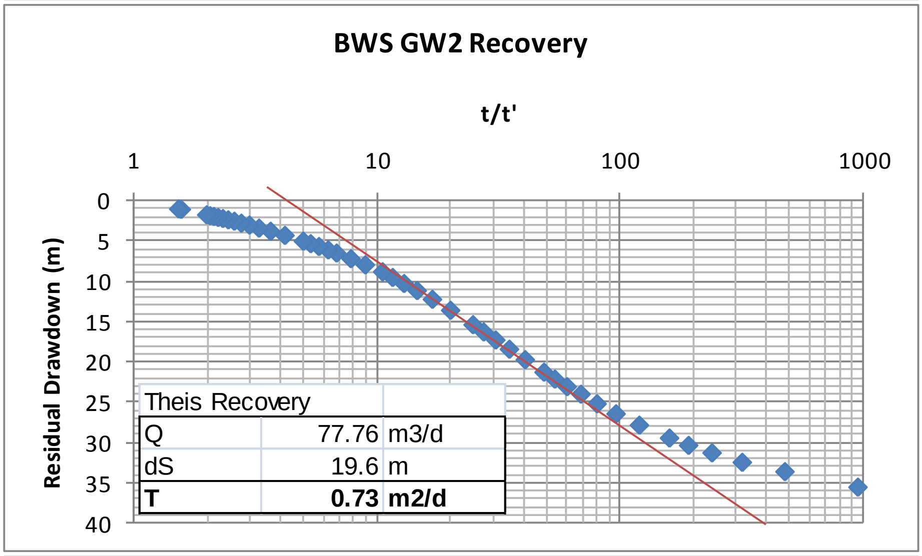

Kenya East GW3 Recovery
t/t'
1
10
100
1000
Residual Drawdown (m)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Theis Recovery
Q 43.2 m3/d
dS 0.37 m
T 21.4 m2/d


Kenya East GW3 Recovery
t'
0.1
1
10
100
1000
Recovery (m)
Cooper-Jacob Recovery
Q 43.2 m3/d
dS 0.3 m
T 26.4 m2/d

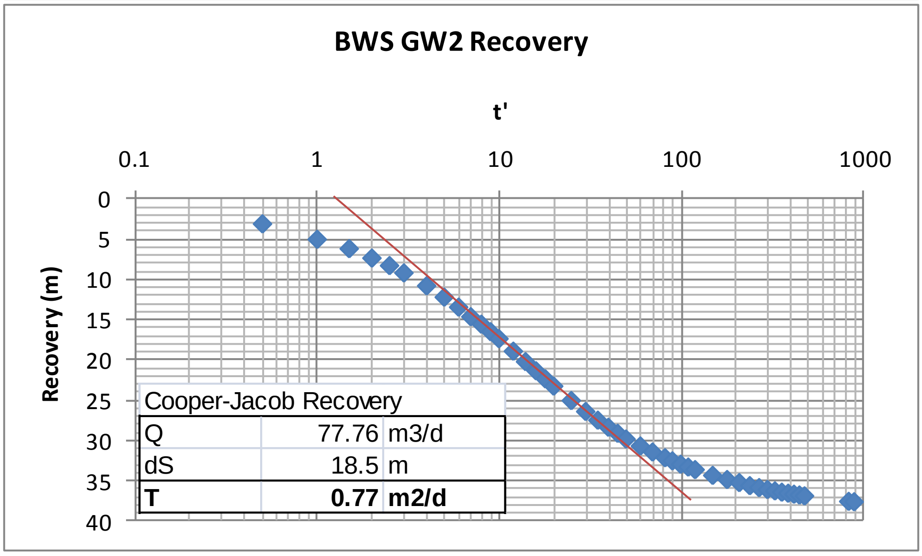
Springbok Sandstone



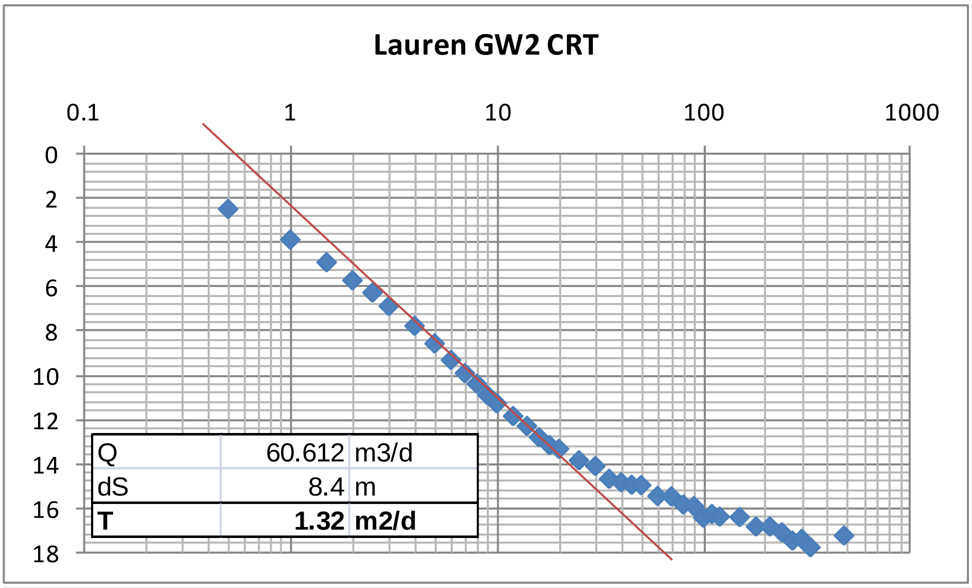
Q	77.76	m3/d
dS	18.5	m
T	**0.77**	**m2/d**



Theis Recovery		
Q	77.76	m3/d
dS	19.6	m
T	**0.73**	**m2/d**

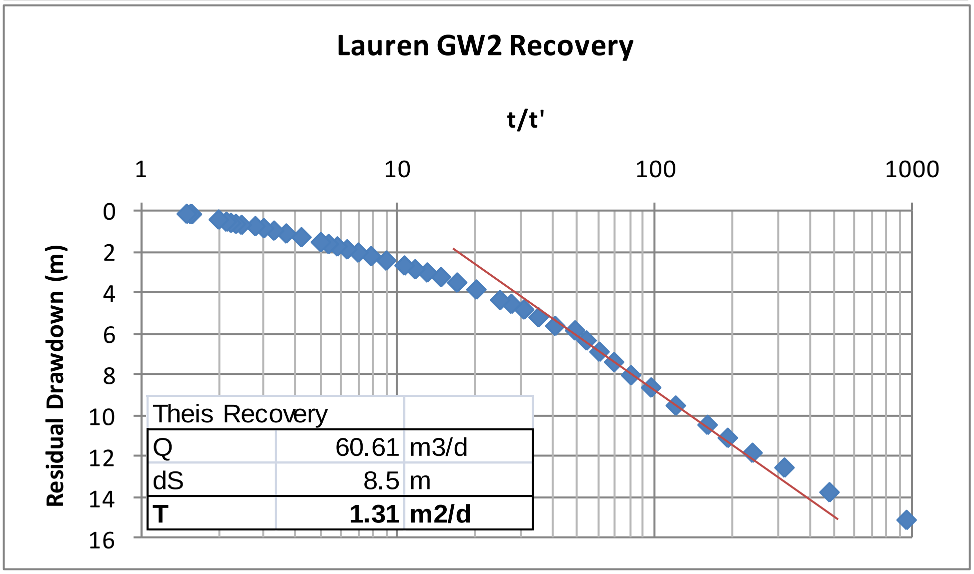


Cooper-Jacob Recovery		
Q	77.76	m3/d
dS	18.5	m
T	**0.77**	**m2/d**



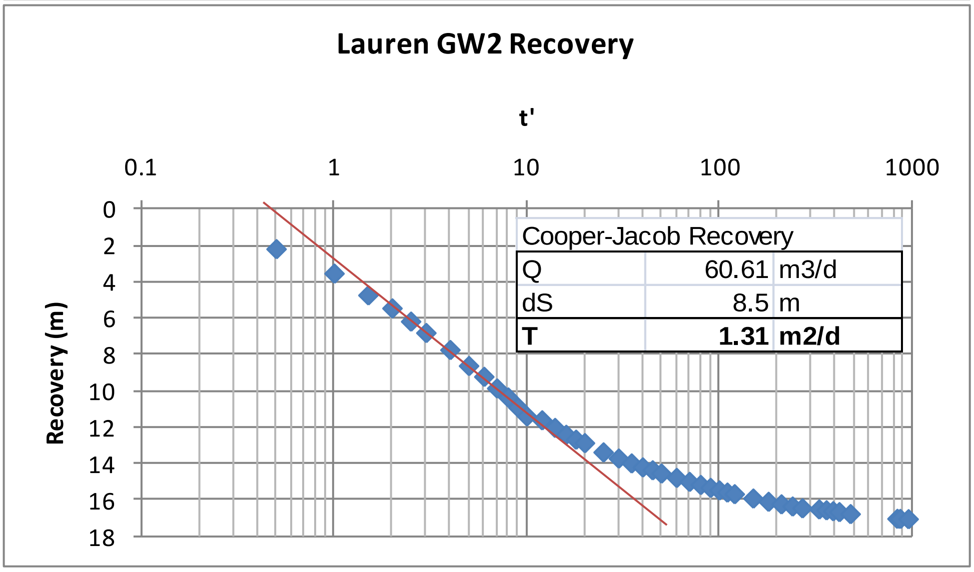
Lauren GW2 CRT

Q	60.612	m3/d
dS	8.4	m
T	**1.32**	**m2/d**



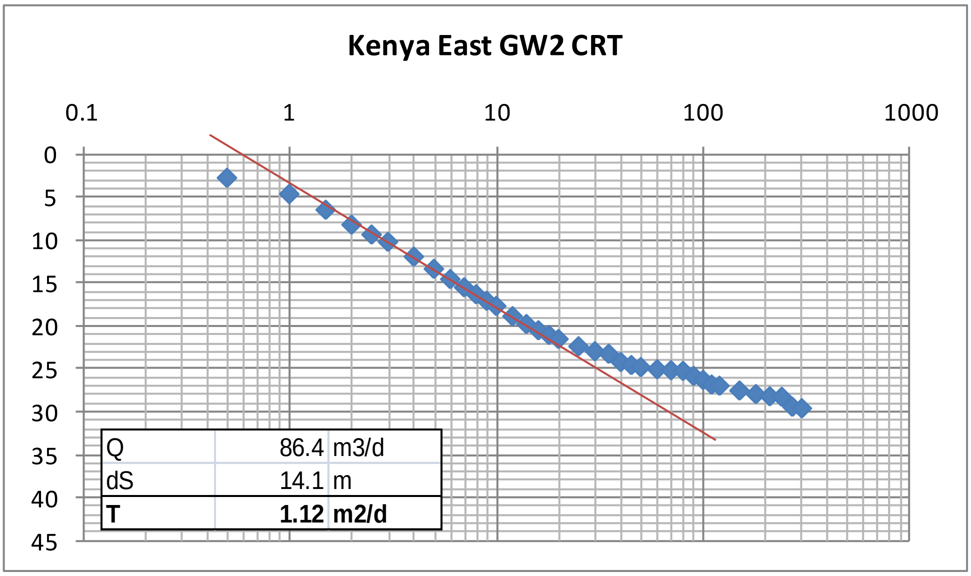
Lauren GW2 Recovery

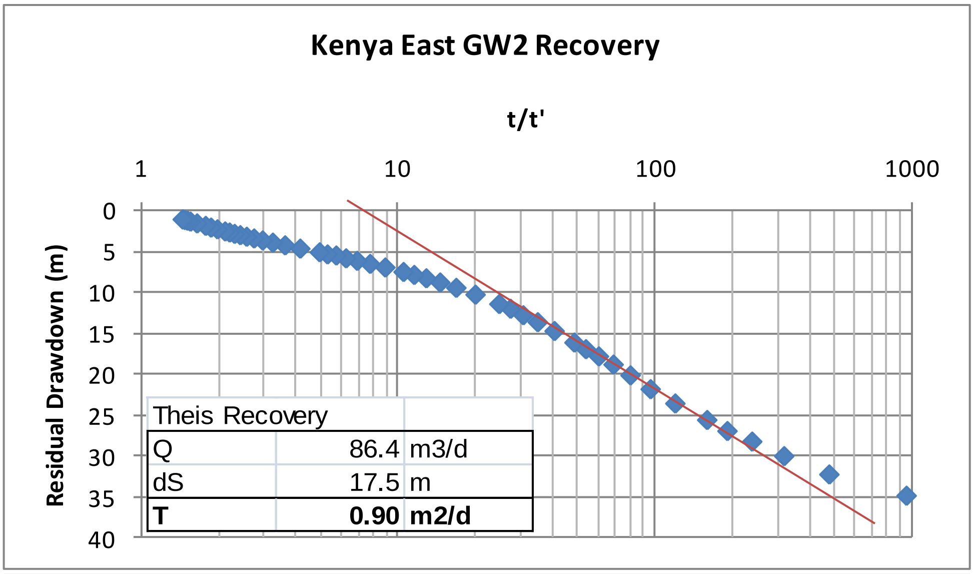
Theis Recovery		
Q	60.61	m3/d
dS	8.5	m
T	**1.31**	**m2/d**

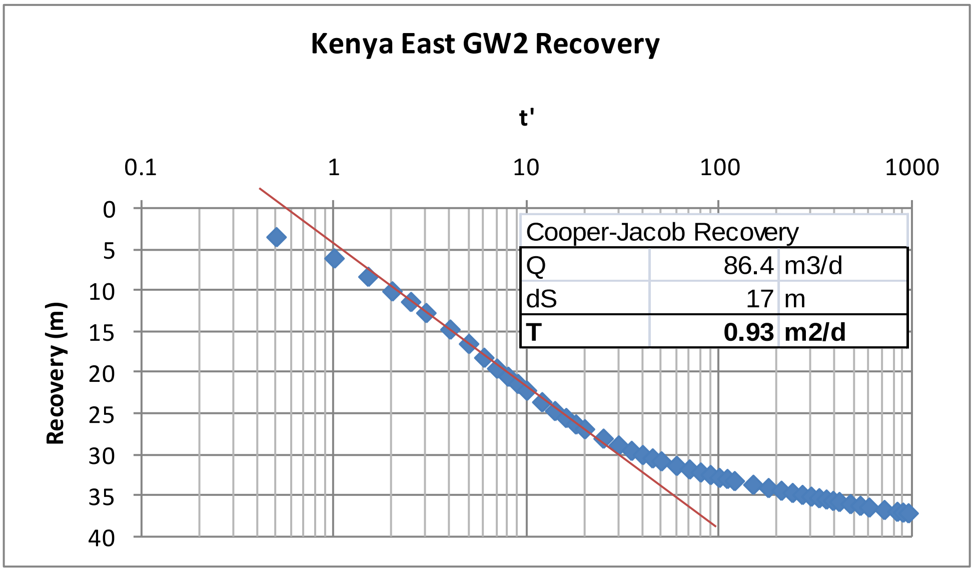


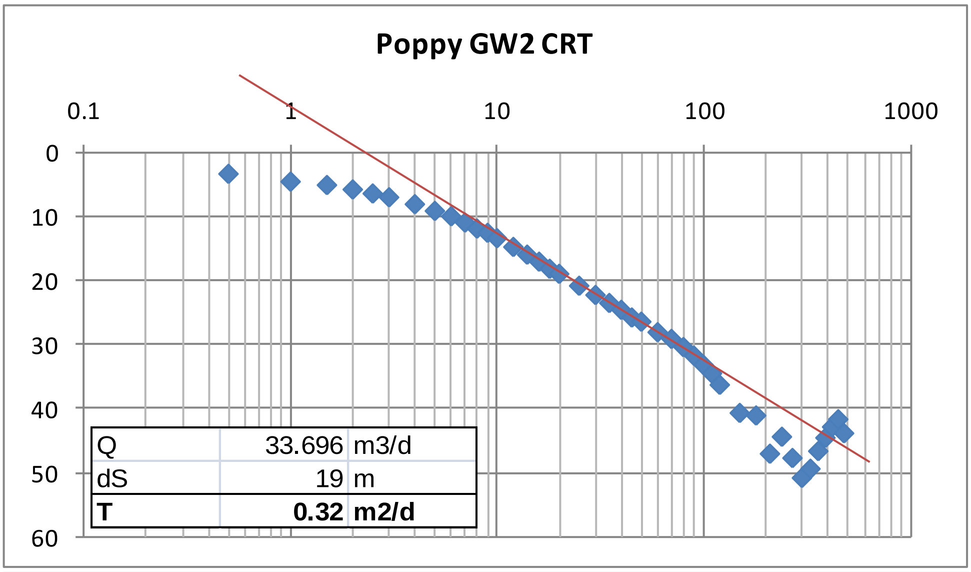
Lauren GW2 Recovery

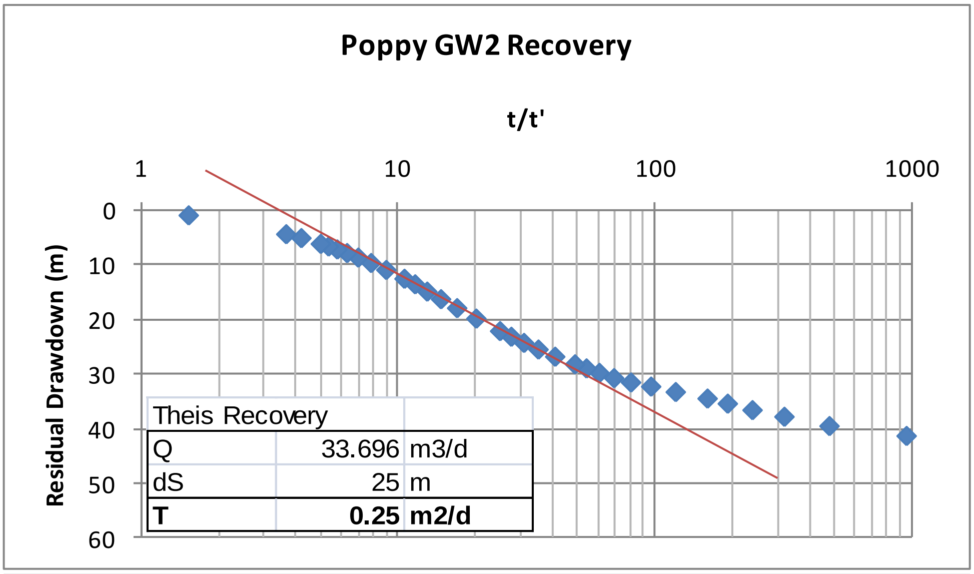
Cooper-Jacob Recovery		
Q	60.61	m3/d
dS	8.5	m
T	**1.31**	**m2/d**

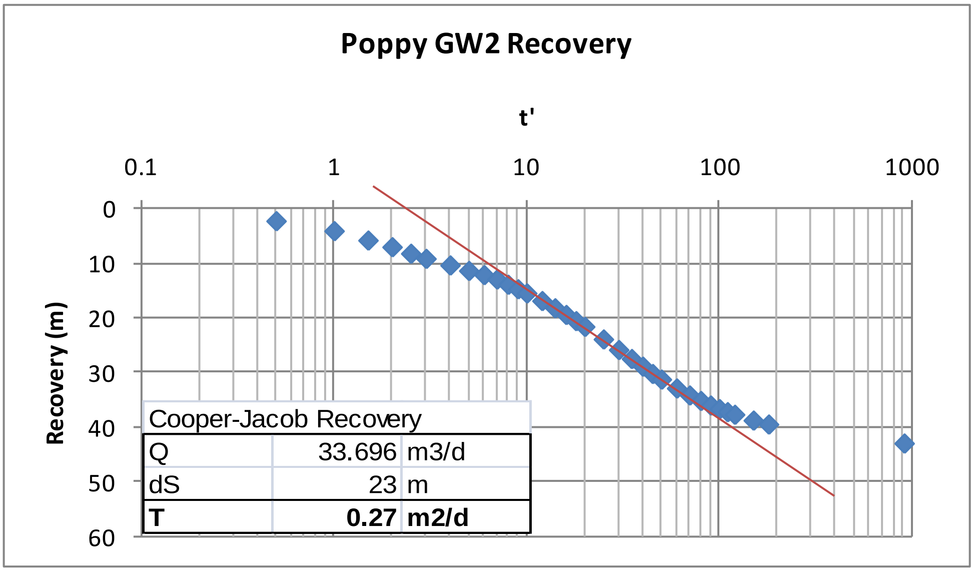

Kenya East GW2 CRT
0.1
1
10
100
1000
0
5
10
15
20
25
30
35
40
45
Q 86.4 m3/d
dS 14.1 m
T 1.12 m2/d

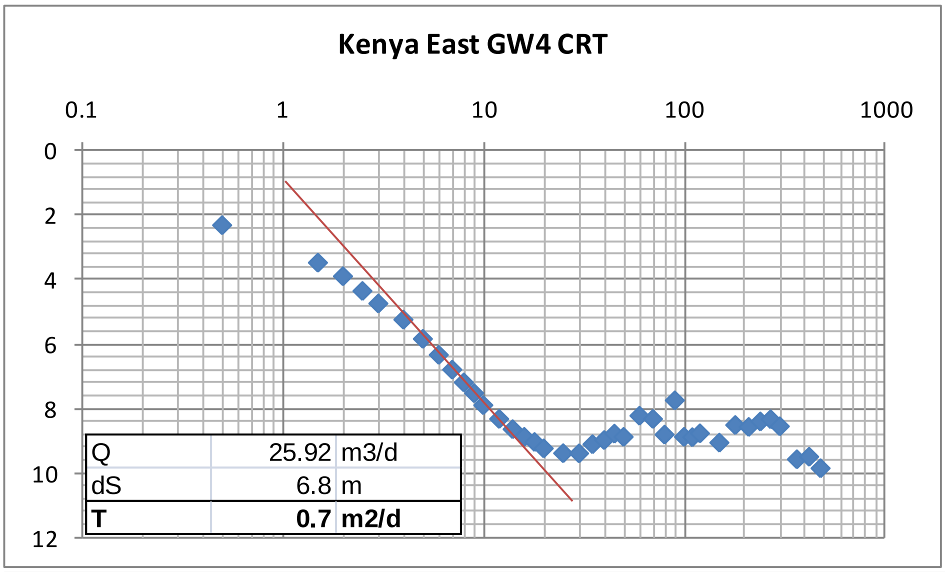

Kenya East GW2 Recovery
t/t'
1
10
100
1000
Residual Drawdown (m)
0
5
10
15
20
25
30
35
40
Theis Recovery
Q 86.4 m3/d
dS 17.5 m
T 0.90 m2/d


Kenya East GW2 Recovery
t'
0.1
1
10
100
1000
Recovery (m)
0
5
10
15
20
25
30
35
40
Cooper-Jacob Recovery
Q 86.4 m3/d
dS 17 m
T 0.93 m2/d

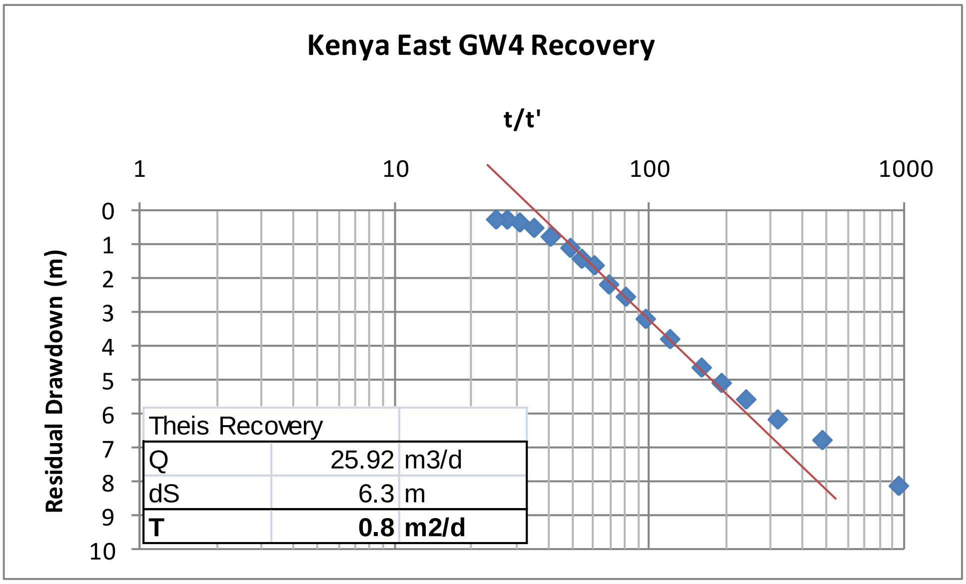

Poppy GW2 CRT
0.1
1
10
100
1000
0
10
20
30
40
50
60
Q 33.696 m3/d
dS 19 m
T 0.32 m2/d


Poppy GW2 Recovery
t/t'
1
10
100
1000
Residual Drawdown (m)
0
10
20
30
40
50
60
Theis Recovery
Q 33.696 m3/d
dS 25 m
T 0.25 m2/d


Poppy GW2 Recovery
t'
0.1
1
10
100
1000
Recovery (m)
0
10
20
30
40
50
60
Cooper-Jacob Recovery
Q 33.696 m3/d
dS 23 m
T 0.27 m2/d

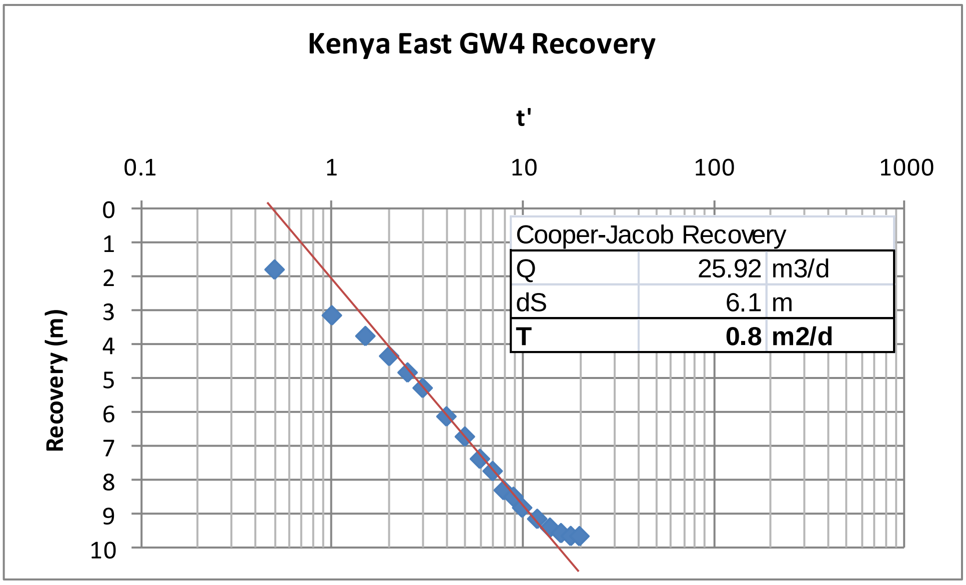


Q	25.92	m3/d
dS	6.8	m
T	**0.7**	**m2/d**



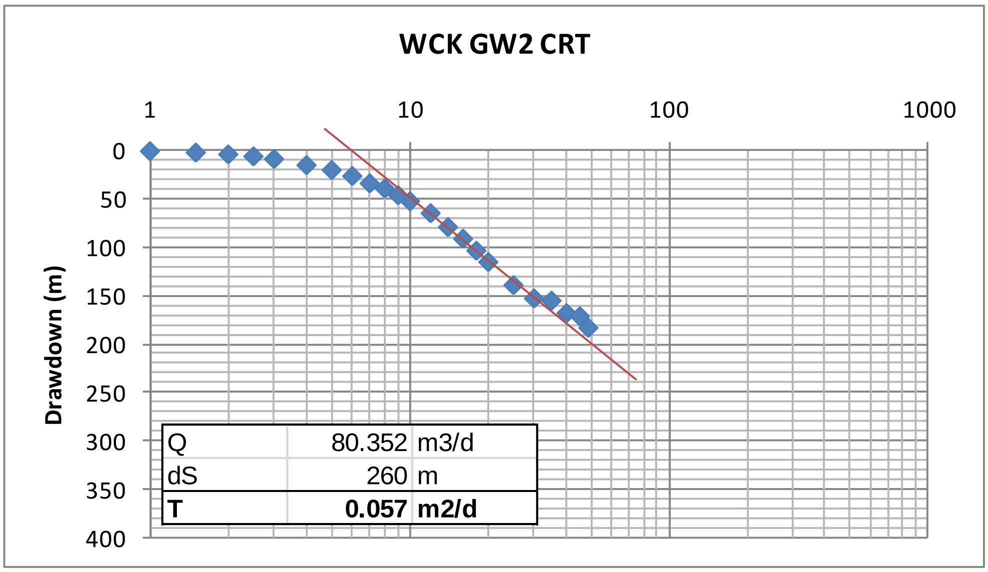
Theis Recovery

Q	25.92	m3/d
dS	6.3	m
T	**0.8**	**m2/d**

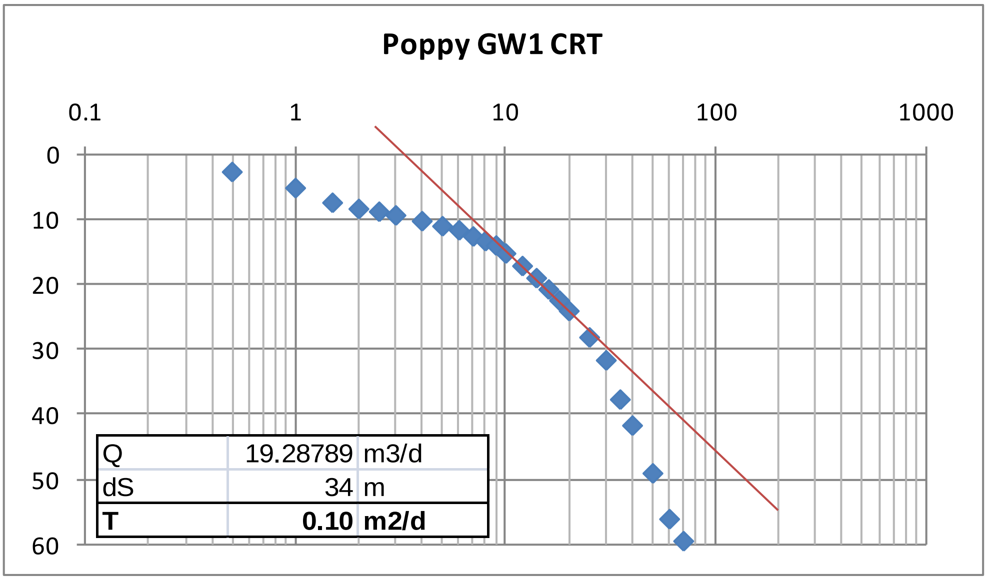


Cooper-Jacob Recovery

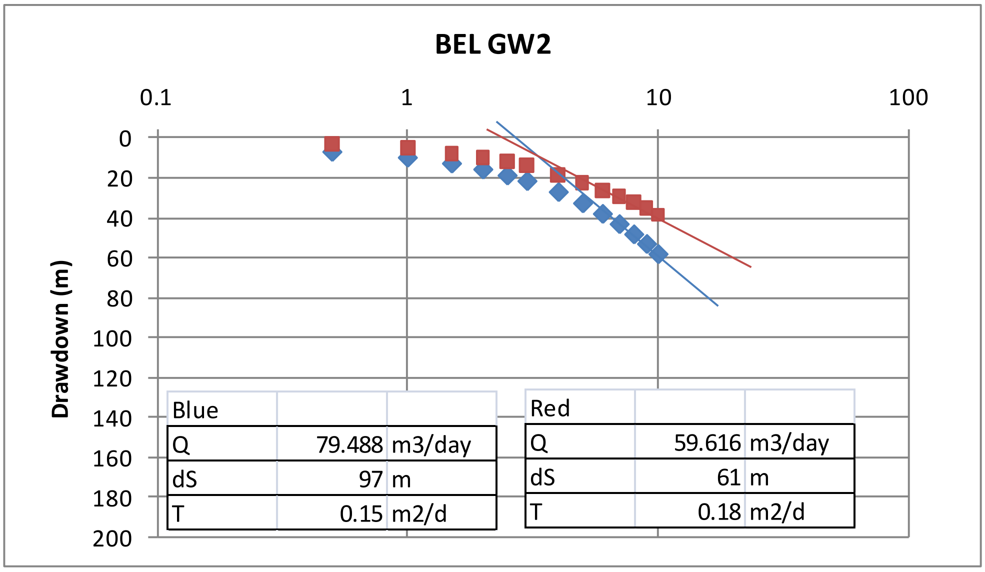
Q	25.92	m3/d
dS	6.1	m
T	**0.8**	**m2/d**



Q	80.352	m3/d
dS	260	m
T	**0.057**	**m2/d**



Q	19.28789	m3/d
dS	34	m
T	**0.10**	**m2/d**

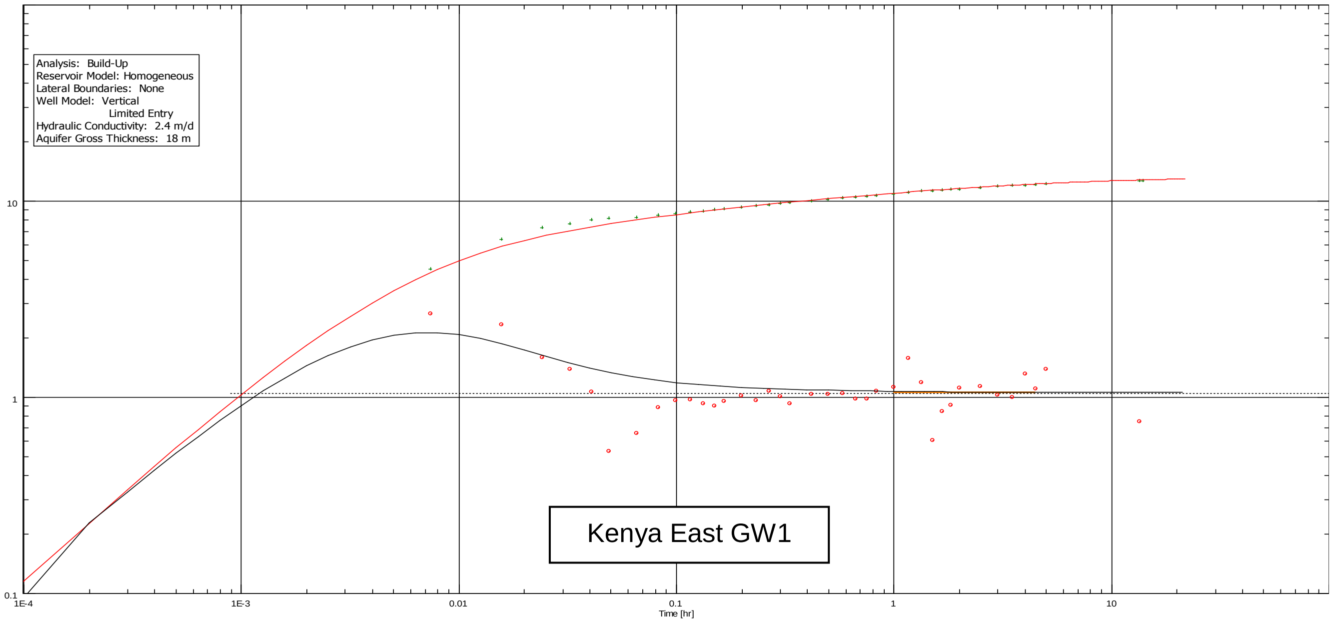


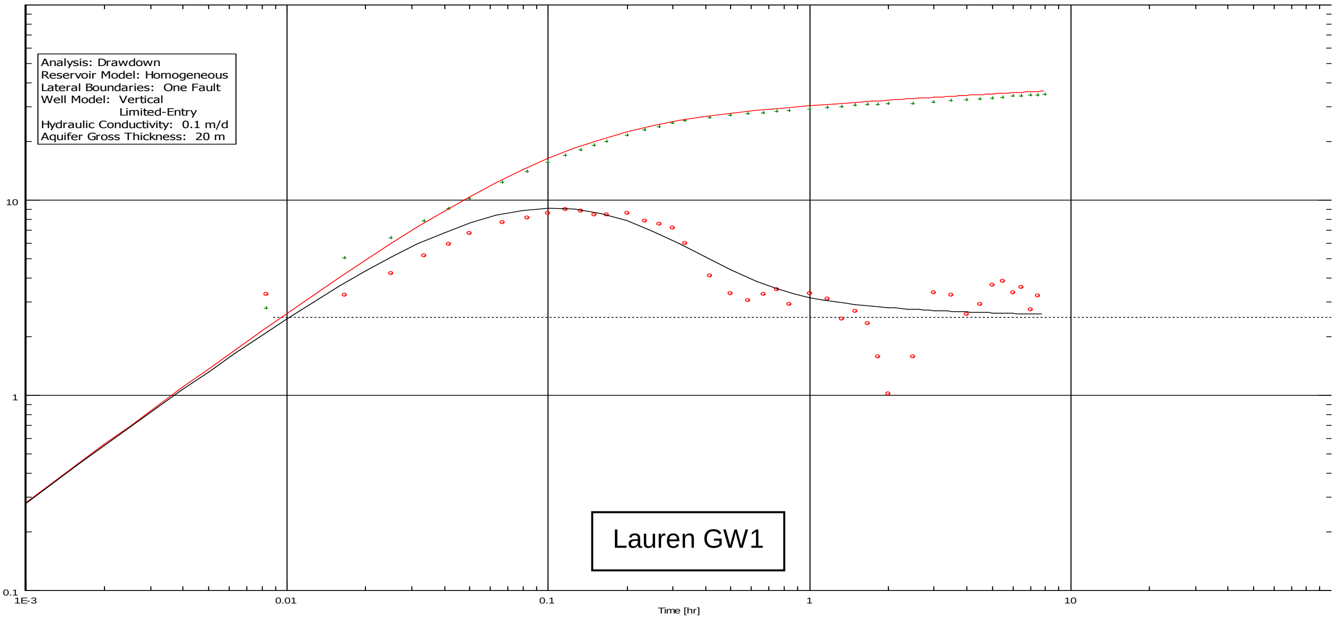
Blue		
Q	79.488	m3/day
dS	97	m
T	0.15	m2/d

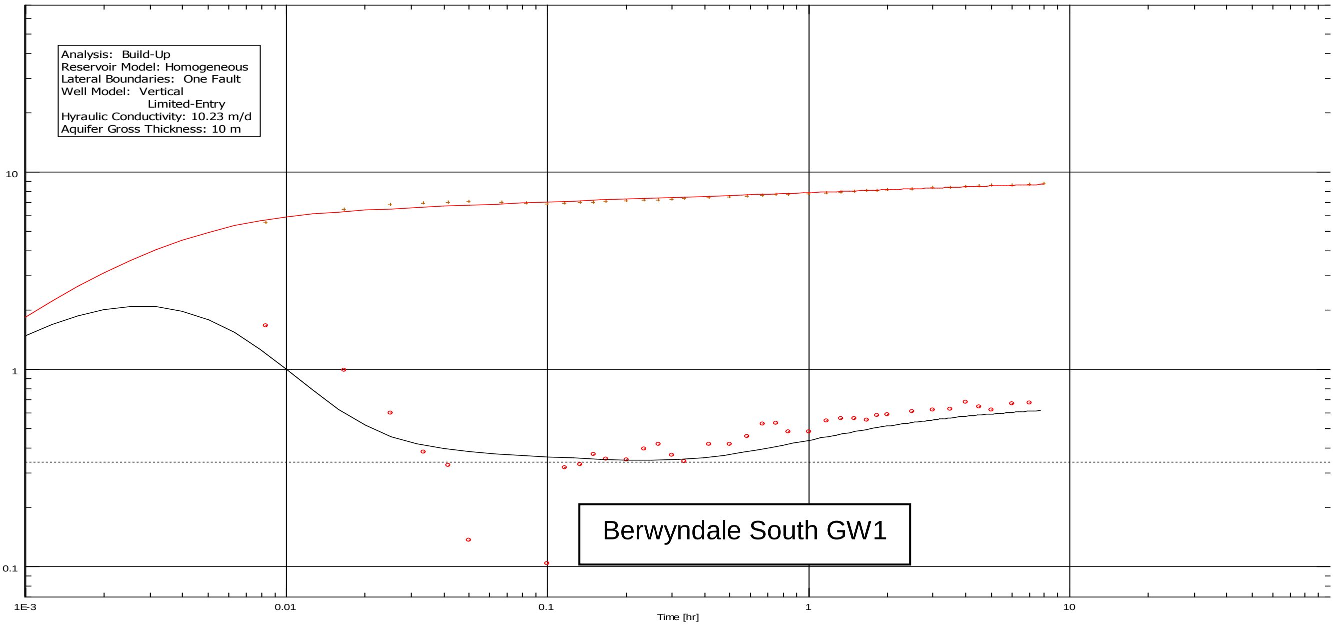
Red		
Q	59.616	m3/day
dS	61	m
T	0.18	m2/d

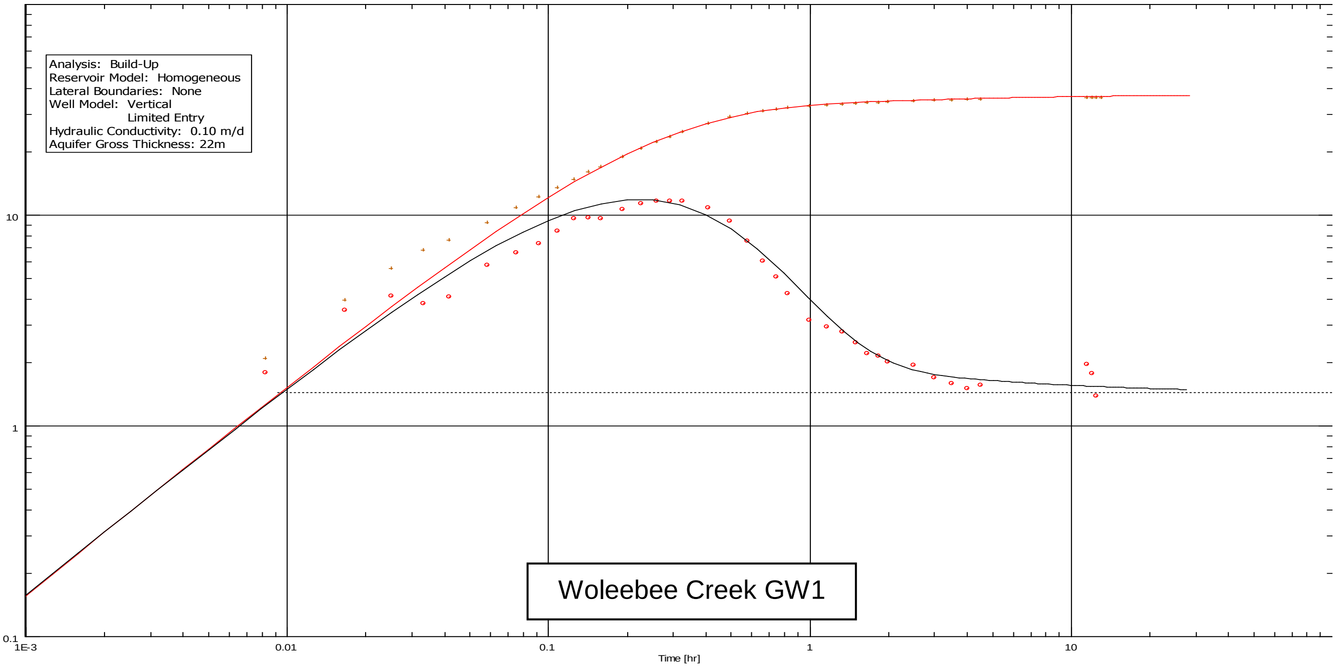
APPENDIX B – SAPHIR ANALYSIS

Gubberamunda Sandstone

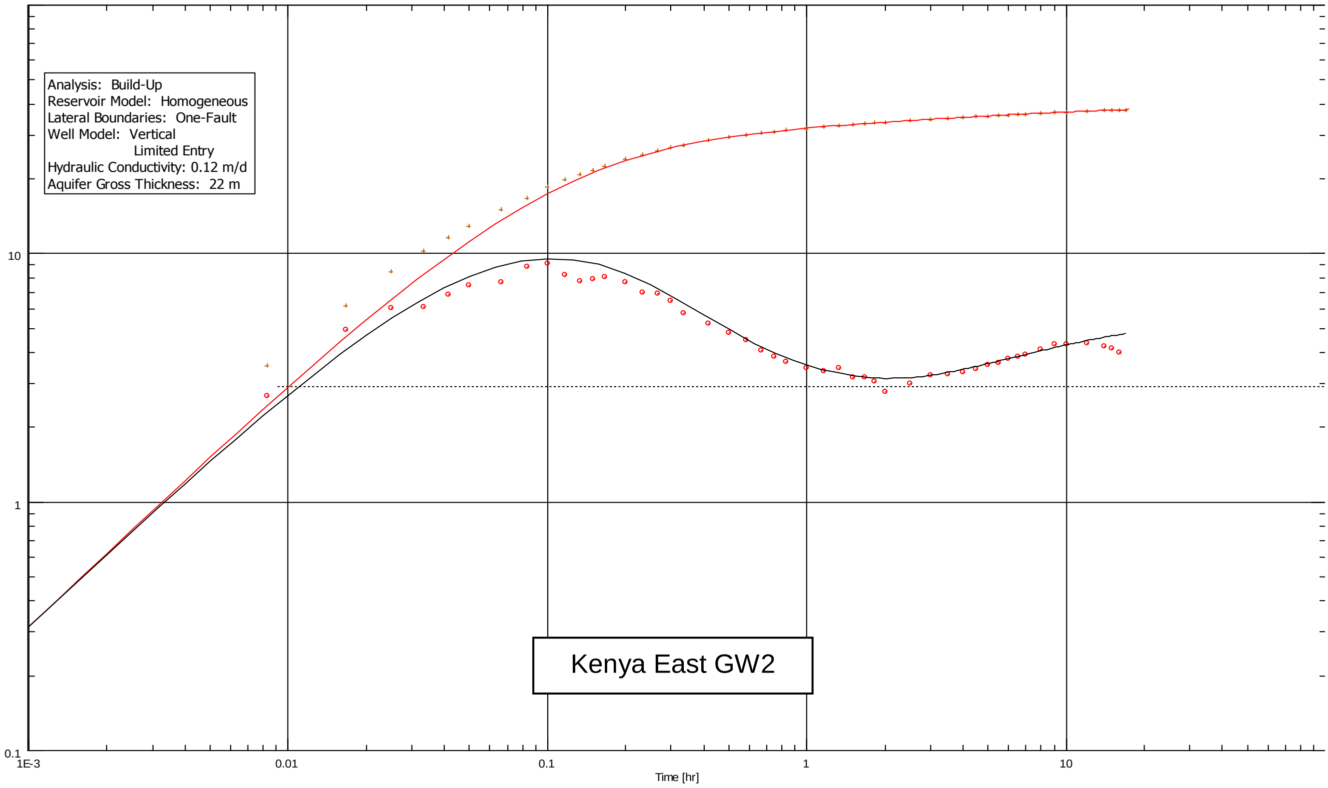


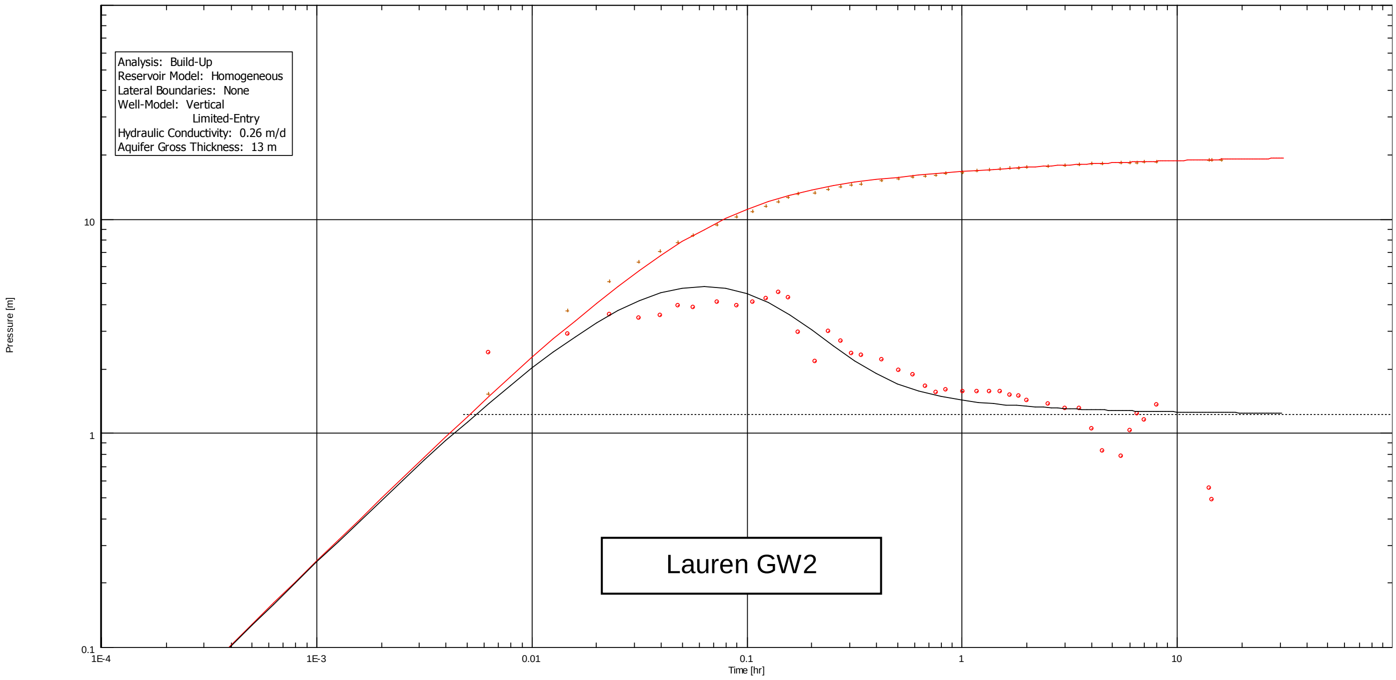


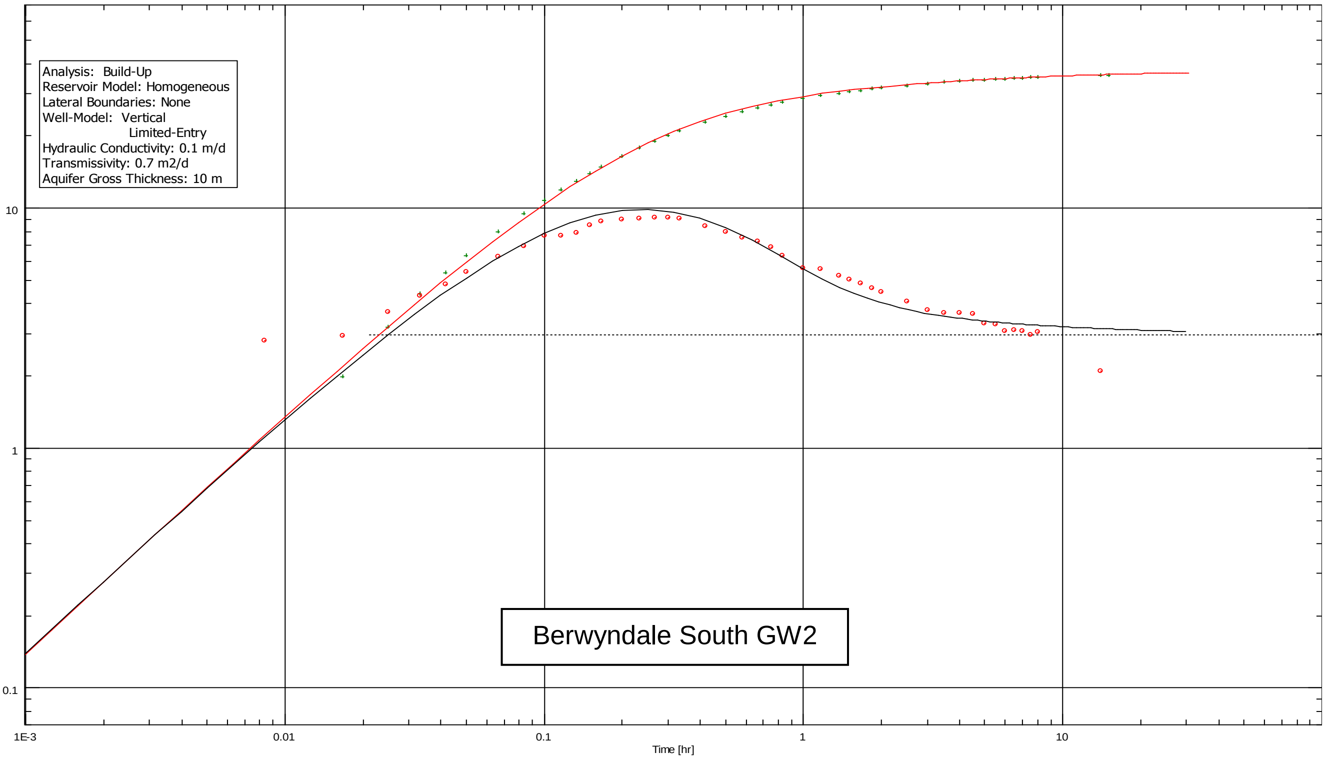

Analysis: Build-Up
Reservoir Model: Homogeneous
Lateral Boundaries: One Fault
Well Model: Vertical
Limited-Entry
Hyraulic Conductivity: 10.23 m/d
Aquifer Gross Thickness: 10 m
Berwyndale South GW1
10
1
0.1
1E-3
0.01
0.1
1
10
Time [hr]


Analysis: Build-Up
Reservoir Model: Homogeneous
Lateral Boundaries: None
Well Model: Vertical
Limited Entry
Hydraulic Conductivity: 0.10 m/d
Aquifer Gross Thickness: 22m
Woleebee Creek GW1
10
1
0.1
1E-3
0.01
0.1
1
10
Time [hr]

Springbok Sandstone






Analysis: Build-Up
Reservoir Model: Homogeneous
Lateral Boundaries: None
Well-Model: Vertical
Limited-Entry
Hydraulic Conductivity: 0.1 m/d
Transmissivity: 0.7 m2/d
Aquifer Gross Thickness: 10 m
Berwyndale South GW2
10
1
0.1
1E-3
0.01
0.1
1
10
Time [hr]