A303 – Amesbury to Berwick Down

Stonehenge Area Pumping Test 2018

Interpretative Report

AECOM, Mace, WSP

HE551506-AMW-EWE-SW-GN-000-ZZ-RP-EN-0001

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List of Outstanding Issues and Information

Outstanding issue/info.	Section/Paragraph	Responsibility	Action

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1 Introduction

1.1 Purpose of this report

1.1.1 This report presents the results and interpretation of the pumping tests carried out on three boreholes to the south of the A303 at Stonehenge Down, Stonehenge Bottom and Coneybury Hill between 7th June and 3rd August 2018. These tests were carried out under a Section 32 consent from the Environment Agency as part of the ongoing investigation into the proposed A303 Amesbury to Berwick Down. The aim of the tests was to characterise the Chalk aquifer hydraulic parameters and groundwater quality at different sites and over a range of prevailing groundwater conditions to provide local detail for the on-going design of the Scheme.

1.1.2 This work complements previous pumping tests, groundwater monitoring in the area and other aspects of the ground investigations carried out for the scheme. The implications of the pumping test results with respect to the A303 Amesbury to Berwick Down Environmental Statement and Groundwater Risk Assessment are set out in a separate report (Implications of 2018 Ground Investigations to the Groundwater Risk Assessment, HE551506-AMW-EWE-SW-GN-000-ZZ-RP-EN-0102).

1.2 Previous studies

1.2.1 As part of an earlier investigation for the proposed tunnel along the A303, Balfour Beatty Major Projects appointed WJ Groundwater Limited to conduct pumping tests on two boreholes: W148 in the dry valley at Stonehenge Bottom and W137 in the interfluve at Stonehenge Down about 650 m to the west. The two boreholes were tested during a period of high groundwater levels, in November 2002, and a period of low groundwater levels, in September 2004.

1.2.2 A series of reports present the findings of the tests:

- WJ Groundwater Limited, January 2003. Pumping Test Factual Report. A303 Stonehenge Improvements. Balfour Beatty Major Projects.
- WJ Groundwater Limited, February 2003. Pumping Test Interpretation. A303 Stonehenge Improvements. Balfour Beatty Major Projects.
- WJ Groundwater Limited, October 2004. Summer Pumping Test Factual Report. A303 Stonehenge Improvements. Balfour Beatty Costain JV.
- WJ Groundwater Limited, December 2004. Summer Pumping Test Interpretation. A303 Stonehenge Improvements. Balfour Beatty Costain JV.
- Balfour Beatty-Costain JV, February 2005. Review of Results from Summer 2004 Pumping Tests. In association with Halcrow Gifford.

1.3 Scope of the study

1.3.1 Three pumping test boreholes and associated observation boreholes were drilled in 2018. The test boreholes were located to cover three different regimes – interfluve (W623 on Coneybury Hill), dry valley (W617 in Stonehenge Bottom) and phosphatic chalk (W601on Stonehenge Down). The locations of the three new boreholes are shown on Drawing 1 in Appendix A. These boreholes, previous boreholes (W137 and W148) and the West Amesbury Spring are shown in their geological context in Drawing 2.

1.3.2 The locations of two of the 2018 test boreholes are broadly equivalent to the previous ones, representing both Stonehenge Down (W601 and W137) and Stonehenge Bottom (W617 and W148). Borehole W617 is however approximately 75 m west of W148 and therefore at the western margin of the dry valley compared to the previous test location at W148 on the eastern side.

1.3.3 The additional location at Coneybury Hill (W623) was selected to investigate the interfluve which separates Stonehenge Bottom from the River Avon and to test the validity of the conclusion from previous investigations that the interfluve is a low permeability area potentially impeding groundwater flow to the River Avon.

1.3.4 This report summarises the site settings, borehole construction and the pumping test programme. At each of the three boreholes a step test, 7 day constant rate test and recovery test were completed. The results are interpreted using time- drawdown and distance-drawdown methods to derive values transmissivity and storage coefficient. Water quality samples were collected during testing and compared across sites and over the duration of testing.

1.3.5 The implications of the pumping test results with respect to the A303 Amesbury to Berwick Down Environmental Statement and Groundwater Risk Assessment are set out in a separate report (Implications of 2018 Ground Investigations to the Groundwater Risk Assessment, HE551506-AMW-EWE-SW-GN-000-ZZ-RP-EN-xxxx. P01 January 2019).

2 Summary of site settings

2.1 Topography and Drainage

2.1.1 The topography of the area consists of low relief, gently sloping Chalk downland. The ground levels at Stonehenge Bottom are around 80 m AOD while levels at Coneybury Hill reach around 115 m AOD.

2.1.2 The area presents a network of shallow dry valleys and shallower dry tributary swales. The valley of interest for this project is Stonehenge Bottom, which runs north to south and crosses the proposed A303 tunnel route.

2.1.3 The two main surface water bodies within the area are the River Avon and the River Till which both flow in a southerly direction through Amesbury and

Winterbourne Stoke respectively. The River Till is predominantly groundwater-fed and in its upper reaches north of Berwick St James it flows as a winterbourne on an intermittent basis.

2.2 Land Designations

2.2.1 The pumping test sites are surrounded by three sites of Special Scientific Interest (SSSI): the River Avon approximately 1.5 km to the southeast, the River Till approximately 4 km to the west and Salisbury Plain about 2.5 km to the north. The River Avon and the River Till are also designated as Special Areas of Conservation (SAC).

2.2.2 There are three Source Protection Zone (SPZs) for public drinking water supply borehole abstractions within 5 km of the pumping test area:

- One abstraction is located north of Amesbury at Durrington;
- One is located north east of Amesbury at Bulford
- The other abstraction is located south of Amesbury, near Little Durnford and its SPZ2 and SPZ3 extend just to the south of Amesbury
- There are 23 active licensed abstractions located within 5 km of the pumping test area which are all understood to abstract from the Chalk aquifer. There are eight Private Water Supplies (PWS) registered with Wiltshire Council within 5 km of the pumping test area. Details of the abstraction licences and PWS are presented in Chapter 11 of the Environmental Statement (Highways England, October 2018). The location of the licensed abstractions and the PWS are presented on Drawing 1.

2.3 Geology

2.3.1 The study area is underlain by the White Chalk, an Upper Cretaceous succession of the Chalk group, including the Newhaven and Seaford Chalk Formations. The majority of the Chalk outcrop is the Seaford Chalk with a north-east south-west trending outcrop of Newhaven Chalk present in the area between the Avenue and Normanton Down, and an outcrop on Coneybury Hill. The underlying Lewes Nodular Chalk outcrops at Berwick St James in the Till valley, and from Upper to Lower Woodford in the Avon valley (Drawing 2).

2.3.2 The Seaford Chalk is approximately 60 m thick in the area while the Newhaven Chalk is reported to be approximately 10m thick. Investigation in the study area has also identified distinct deposits of Phosphatic Chalk within both the Seaford and Newhaven Chalk Formations of limited lateral extent particularly on the western side of the Stonehenge Bottom valley. The Phosphatic Chalk is described as a variably, and often weakly, cemented brown sandy Chalk with pelletal phosphatic grains.

2.3.3 The area of interest is located within the wider Wessex Basin, which comprises a series of broadly east-west trending anticlines and synclines plunging toward the east. Due to this the Chalk strata are folded and dip to the north east and to the south or south east.

2.3.4 The superficial deposits within the study area typically comprise alluvium, sands and gravels, localised river terrace deposits, and head deposits, which are largely remobilised weathered Chalk material deposited as a result of periglacial processes.

2.3.5 The dry valleys contain head deposits, comprising clay, silt, sand and gravel, overlying the Chalk. The river valleys of the Avon and Till contain alluvial and terrace gravel deposits, as well as head deposits of gravel. The site investigation revealed that the thickness of the head deposits is less than 3 m. Borehole R620 in Stonehenge Bottom and near W617 proved a thickness of 2.70 m. Superficial Head deposits of clay with flints are located on a number of hill tops.

2.3.6 The geology of the study area is described in more detail in Chapter 10 Geology and Soils of the Environmental Statement (Highways England, October 2018).

2.4 Hydrogeology

Aquifer and Groundwater Flow

2.4.1 The White Chalk bedrock in the region is classified by the Environment Agency as a Principal Aquifer.

2.4.2 The Chalk is a dual porosity medium with groundwater flow principally through fractures and fissures, resulting in rapid groundwater movement. The majority of aquifer storage is derived from secondary porosity within these fractures. A strong topographical control on aquifer transmissivity is evident with high transmissivity values occurring within valleys decreasing towards the interfluves.

2.4.3 The superficial deposits present in the study area are classified by the Environment Agency as Secondary Aquifers:

- The Secondary A aquifers are associated with the alluvial and terrace gravel deposits, and gravelly head deposits, which provide groundwater that flows to the River Avon and River Till. These are permeable layers with a moderate to high primary permeability and which are capable of supporting water supplies at a local rather than strategic scale, and in some cases form an important source of baseflow to rivers.
- The Secondary B aquifers are associated with sand and clay deposits located on hill tops. These are predominantly lower permeability layers that may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These aquifers are not crossed by the proposed scheme.
- The Secondary (undifferentiated) aquifers are associated with the cohesive head deposits (comprising clay, silt, sand and gravel) present across the study area. These aquifers are defined where it has not been possible to provide an A or B category.

2.4.4 The Chalk in the study area generally is of an unconfined nature, being at outcrop and with limited cover from secondary aquifers that are not considered to be confining.

2.4.5 Groundwater levels in the Chalk are controlled by recharge from rainfall infiltration and by natural discharge to the rivers Avon and Till, as well as groundwater abstractions. Available monitoring data shows that groundwater levels in the Chalk aquifer respond rapidly to recharge events at the surface due to a low storage capacity. Significant changes in groundwater level can occur over short periods of time with rapid rises in excess of 10m occurring over approximately one month as seen, for example, in the Environment Agency observation borehole at Berwick Down (Drawing 3).

2.4.6 Seasonal fluctuations in the groundwater level tend to be less in the dry valleys (between 8m and 10m), than below the topographical divides (about 15m) as the storage capacity is usually greater beneath dry valley systems, than in the interfluve areas. Boreholes located close to the active rivers in the groundwater discharge regions show a limited seasonal fluctuation (about 2m).

2.4.7 Regionally groundwater in the Chalk aquifer flows in a generally southerly direction with flow at high groundwater levels converging towards the River Till in the west of the study area and towards the River Avon in the east of the study area, creating a groundwater divide between the two rivers (Drawing 3). The groundwater discharges naturally as baseflow to the Rivers Avon and Till.

Aquifer Properties derived from previous studies

2.4.8 The pumping tests in the Chalk aquifer were carried out close to the route alignment in 2002 (winter) and 2004 (summer) and indicated transmissivity values of 1,250 m^2/d (summer) - 2,650 m^2/d (winter) for the dry valley, and 430 m^2/d (summer) – 880 m^2/d (winter) in the interfluve area. In both tests the transmissivity at W148 was about three times that measured in W137 (Drawing 2). This supports the concept that transmissivity is typically greater beneath the dry valleys compared to the interfluve areas, as preferential groundwater flow zones beneath dry valleys result in the enhanced development of fissuring within the Chalk. In both locations the transmissivity in the winter was more than twice the transmissivity in the summer, demonstrating the high hydraulic conductivity of the response zone. The ranges of aquifer parameters derived from these tests are summarised in Table 2-1.

Table 2-1 Aquifer parameters derived from previous pumping tests

	November 2002 (high groundwater levels)	**September 2004 (low groundwater levels)**
W148 Stonehenge Bottom (dry valley)	*Transmissivity (m^2/day)* Range: 1,400 – 5,510 Mean: 2,653 (n=19) *Storage coefficient* Range: 0.015 – 0.34 Mean: 0.11 (n=5)	*Transmissivity (m^2/day)* Range: 1,400 – 5,510 Mean: 2,653 (n=19) *Storage coefficient* Range: 0.015 – 0.34 Mean: 0.0056 (n=6)
W137 Stonehenge Down (interfluve)	*Transmissivity (m^2/day)* Range: 108 – 2,142 Mean: 880 (n=26) *Storage coefficient* Range: 5×10^{-5} – 0.18 Mean: 0.02 (n=10)	*Transmissivity (m^2/day)* Range: 111 – 565 Mean: 429 (n=11) *Storage coefficient* Range: 4×10^{-12} – 0.024 Mean: 0.0039 (n=11)

Groundwater quality

2.4.9 The previous water quality studies for the A303 project area have shown that the groundwater quality is consistent with the BGS baseline data for Chalk groundwater. This is described in more details in the water quality section of the *Appendix 11.4: Groundwater Risk Assessment of the Environmental Statement (*Highways England, October 2018).

2.4.10 A Piper diagram (Figure 2.1) has been produced from the analytical results of groundwater samples collected from the 2017 ground investigation monitoring boreholes in April 2018 and shows that the groundwater quality signature in the area is a calcium bicarbonate (Ca-HCO_3) type. The diagram shows there is little variation in the groundwater chemistry across the study area. The pH recorded in 2018 ranged between 7.15 and 8.08 pH units, temperature ranged between 9.3 and 15.1°C, and electrical conductivity ranged between 460µS/cm and 619µS/cm. The location of the 2017 monitoring boreholes is presented on Drawing 4.

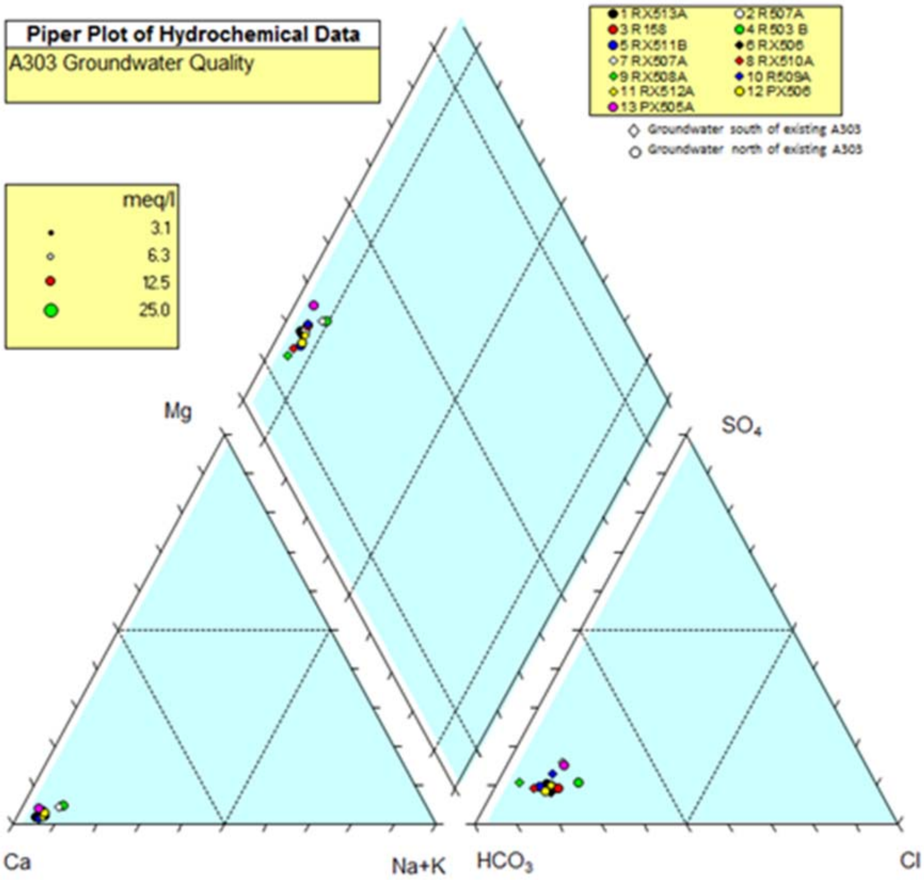


Figure 2.1 Groundwater Piper Diagram April 2018

3 Borehole construction

3.1.1 Structural Soils Ltd was appointed in 2018 for the drilling, installation and development (by airlift method) of the three pumping wells and associated monitoring boreholes.

3.1.2 Pumping wells W623, W601 and W617 were drilled using a rotary technique and installed with 250 mm nominal diameter (ND) PVC casing in an open hole (no gravel pack). Table 3-1 below summarises their construction and installation details, schematic drawings are also presented in Appendix B. The abstraction well locations are shown in Drawing 4.

3.1.3 All observation boreholes were drilled at a diameter of 146mm and installed with 50mm ND PVC casing and a pea size gravel pack. Borehole construction details are summarised in Table 3-2 below.

3.1.4 Robertson Geologging ran geophysical tools down the pumping wells prior to installation of the casing and recorded caliper, natural gamma, temperature, conductivity, fluid velocity as well as an optical image of the borehole walls. The composite logs are presented in Appendix C.

Table 3-1 Pumping Well Construction Details

Well ID	Easting	Northing	Ground Level (mAOD)	Top Hat Level (mAOD)	Start Date	Completion Date	Drilled diameter	Drilled depth (mbgl)	Plain Casing Depth (mbgl)	Slotted Casing Depth (mbgl)	Sump Depth (mbgl)
W623	413433	141268	111.68	112.56	13/04/2018	25/05/2018	13" 3/4	70	0-40	40-67	67-70
W601	412304	141872	93.10	93.81	03/05/2018	04/06/2018	13" 3/4	60	0-15	15-57.5	57.5-60
W617	412751	141969	79.60	80.50	19/04/2018	11/07/2018	0-21 mbgl: 16" 21-36 mbgl: 14" 36-48 mbgl: 13 ¼ "	W617	412751	141969	79.60

Table 3-2 Observation Boreholes Construction Details

Cluster	BH No	Easting	Northing	Distance from Pumping Well (m)	Ground Level (mAOD)	Top Hat Level (mAOD)	Start Date	Completion Date	Drilled diameter	Method	Drilled depth (mbgl)	Plain Casing Depth (mbgl)	Slotted Casing Depth (mbgl)	Sump Depth (mbgl)
W623	RX624	413356	141334	102	108.15	108.55	13/04/2018	25/04/2018	146 mm	ROH	70	0-38	38-65	65-68
	RX625	413429	141274	8	111.65	112.05	11/04/2018	17/05/2018		ROH	70	0-40	40-67	67-70
	RX626	413448	141255	19	111.61	112.07	16/04/2018	19/04/2018		ROH	70	0-40	40-65	65-68
	RX627	413449	141282	21	112.00	112.35	16/04/2018	17/05/2018		ROH	70	0-40	40-65	65-68
	RX628	413469	141302	50	112.58	112.94	11/04/2018	16/04/2018		ROH	70	0-40	40-67	67-70
W601	R602	412295	141858	17	92.69	93.01	03/05/2018	17/05/2018		ROH/RC	35	0-18	18-33	33-34

Cluster	BH No	Easting	Northing	Distance from Pumping Well (m)	Ground Level (mAOD)	Top Hat Level (mAOD)	Start Date	Completion Date	Drilled diameter	Method	Drilled depth (mbgl)	Plain Casing Depth (mbgl)	Slotted Casing Depth (mbgl)	Sump Depth (mbgl)
	R606	412220	141912	93	94.91	95.33	16/05/2018	23/05/2018		RC	60	0-20	20-56	56-59
	R607	412276	141893	34	93.99	94.38	16/05/2018	24/05/2018		RC	60	0-20	20-56	56-59
	R608	412277	141926	60	94.65	94.98	10/05/2018	23/05/2018		RC	60	0-20	20-56	56-59
	RX609	412288	141884	20	93.64	93.92	08/05/2018	17/05/2018		ROH	60	0-20	20-56	56-59
	R610	412334	141913	51	93.84	94.14	21/05/2018	23/05/2018		RC	53	0-19	19-49	49-52
	R612	412396	141886	93	93.08	93.43	25/05/2018	01/06/2018		RC	55	0-18	18-51	51-54
W617	R618	412771	141969	20	79.51	79.89	03/05/2018	16/05/2018		RC	48	0-8	8-44	44-47
	R619	412786	141969	35	79.58	80.14	19/04/2018	01/05/2018		RC	48	0-8	8-44	44-47
	R620	412752	141959	10	79.56	80.06	25/04/2018	04/05/2018		RC	48	0-8	8-44	44-47
	RX621	412751	141919	50	79.87	80.42	24/04/2018	02/05/2018		ROH	48	0-8	8-44	44-47
	RX622	412750	141870	99	80.58	81.08	01/05/2018	03/05/2018		ROH	48	0-8	8-44	44-47

RC: Rotary Core; ROH: Rotary Open Hole

4 Pumping Test Programme

4.1 Scope

4.1.1 The pumping test programme consisted of

- A seven day monitoring period preceding the pumping test (observation and production boreholes)
- An equipment test to estimate the maximum pumping rate achievable by each abstraction borehole and to select the appropriately sized pump
- A five stage step-test, each step lasting 100 mins
- A seven days constant rate test
- Monitoring of groundwater levels and discharge in the production borehole
- Monitoring of groundwater levels in local observation boreholes
- Visual monitoring of West Amesbury Spring flow
- Water quality testing, sampling and laboratory analysis

4.2 Monitoring Programme

4.2.1 A Section 32 Consent SWWGIC097 was issued by the Environment Agency for the drilling and test pumping of the three abstraction boreholes. The Consent permitted two phases of testing with each location being tested during both phases. Phase One was planned to coincide with seasonal high groundwater levels in early 2018. A maximum pumping rate of 90 m^3/hour was permitted at each location for the constant rate test for up to seven days. A maximum rate of 180 m^3/hour was permitted at each location for the equipment tests and step-tests with maximum durations of 240 minutes and 500 minutes respectively.

4.2.2 The Consent specified that monitoring of the water levels had to be undertaken in all boreholes listed in Table 3-1 and Table 3-2. Thereafter the water level had to be measured at a minimum frequency as stated in the British Standards ISO 14686:2003 from the commencement and completion of each pumping session until water levels have recovered to within 5% of their original level. This was achieved using data loggers set at 1 minute intervals. In addition manual monitoring was carried out in order to ensure that the instrumentation had not drifted out of calibration, so that data integrity was not compromised.

4.2.3 The discharge location was set up downgradient in Stonehenge Bottom dry valley, about 700m south of W601 and 650 m west of W623 as shown on Drawing 5.

4.2.4 The discharge rate was recorded at the same frequency as the water level measurement throughout the tests, manually and using telemetry.

4.2.5 Visual monitoring of the discharge at West Amesbury Spring was also required for 7 days before the pumping commenced and at least twice daily during the pumping test at Coneybury Hill and for 7 days following the cessation of the constant rate test. Photographic records were kept.

4.2.6 Water quality field parameters (pH, temperature, electrical conductivity and total dissolved solids) were monitored during the pumping well development and recorded at regular intervals throughout the pumping test. Water samples were collected during well development, at the start and the end of the constant rate test and sent to an accredited laboratory for analysis of major and minor ions, PAH, TPH and pesticides.

4.3 Equipment

4.3.1 An Exa FX110/7 45kW electrical submersible pump was used in borehole W623 for both the step-test and the constant rate test. The pump intake was set at 65 mbgl in W623.

4.3.2 In borehole W601, the Exa pump was used for the step-test first, then due to electrical malfunctioning of the pump, it was swapped for a Caprari E895-6/5A coupled with a MAC635/2A-8 for the constant rate test. The pump intake was set at 52mbgl.

4.3.3 In borehole W617, the equipment test with the Caprari pump indicated high drawdowns. Subsequently a pump of smaller capacity was installed to accommodate the lower pumping rates. The pump intake was set at 42.7 mbgl.

4.3.4 All pumps were powered using a duty and standby 150kVA generator with automatic changeover panel.

4.3.5 Flow rate was monitored using a series of two Siemens Sitrans Mag 6000 electromagnetic flow meters each with telemetry permitting remote monitoring of flow rate. A v-notch tank was installed before the boost pumps at the discharge location as a back up to measure the flow should the flow meters fail at any time.

4.3.6 At the discharge point, a series of 5.5 to 11kw electrical submersible drainage pumps were utilised as a boost system to push the discharge water out in the discharge field via a set of small discharge pipes.

4.3.7 Electronic Solinst data loggers were used at each borehole to record water levels at 1 minute intervals for the duration of the pumping test period. Direct read cables were installed on each data logger enabling the use of a Bluetooth transmitter to download the data through the test without the need for removing the data logger.

4.3.8 Manual readings were also recorded following the British Standard ISO 14686:2003, using manual dip tapes. Due the land access agreements in place, manual measurements were only taken during 8am-6pm Monday to Friday and at reduced intervals during the weekends.

4.3.9 Field water quality measurements were taken using a Hannah Pocket meter HI-98129.

5 Schedule

5.1.1 The pumping tests were undertaken from June to August 2018. Table 5-1 summarises the programme dates for each cluster. The pumping rates applied for each of the tests are summarised in Table 5-2.

Table 5-1 Pumping Tests Programme

Activity	W623	W601	W617
Pre-Test Monitoring	29/05/2018 to 6/06/2018	14/06/2018 to 25/06/2018	13/07/2018 to 23/07/2018
Equipment Test	06/06/2018	27/06/2018 and 9/07/2018 (2nd pump)	24/07/2018 and 25/072018 (2nd pump)
Step-Test	07/06/2018 9.30am	3/07/2018 9am	26/07/2018 9.20am
Constant Rate Test	12/06/2018 1pm to 19/06/2018 1pm	10/07/2018 10am to 17/07/2018 11am	27/07/2018 10am to 3/08/2018 10am
Recovery	19/06/2018 1pm to 22/06/2018	17/07/2018 11am to 23/07/2018	3/08/2017 10am to 6/08/2018

Table 5-2 Pumping Tests Rates

		W623	W601	W617
Step-Test (100 mins steps)	Step 1	10 l/s	15 l/s	2 l/s
	Step 2	15 l/s	19.5 l/s	3 l/s
	Step 3	20 l/s	23 l/s	5 l/s
	Step 4	25 l/s	26.5 l/s	6 l/s
	Step 5	30 l/s	30 l/s	7 l/s
Constant Rate Test		25 l/s	25 l/s	5.8 l/s
Constant Rate Test Duration		10,080 mins	10,140 mins	10,080 mins

6 Pumping Test Results, Analysis and Interpretation

6.1 W623 – Coneybury Hill

6.1.1 The pumping test at Coneybury Hill was carried out to determine the characteristics of the aquifer on the interfluve between the Stonehenge Bottom dry valley and the valley of the River Avon.

Pre-test monitoring

6.1.2 Data loggers were installed in the production well and the six observation boreholes and recorded water levels for nine days before the pump installation, from 29th May to 6th June 2018. The data is presented in Figure 6.1 below and show a natural decline of the groundwater levels during the pre-test period between 0.19m and 0.33m. Water levels are summarised in Table 6-1.

Table 6-1 W623 cluster - Pre-test water levels

Borehole ID	Water levels on 29th May (mAOD)	Water levels on 6th June (mAOD)	Decline (m)
W623	65.79	65.53	0.26
RX624	66.40*	66.07	0.33
RX625	66.10	65.86	0.24
RX626	65.92	65.70	0.22
RX627	66.30	66.11	0.19
RX628	66.58	66.31	0.28

* Level from the 30/05/2018 as data logger was only installed on 30/05/2018 in that borehole.

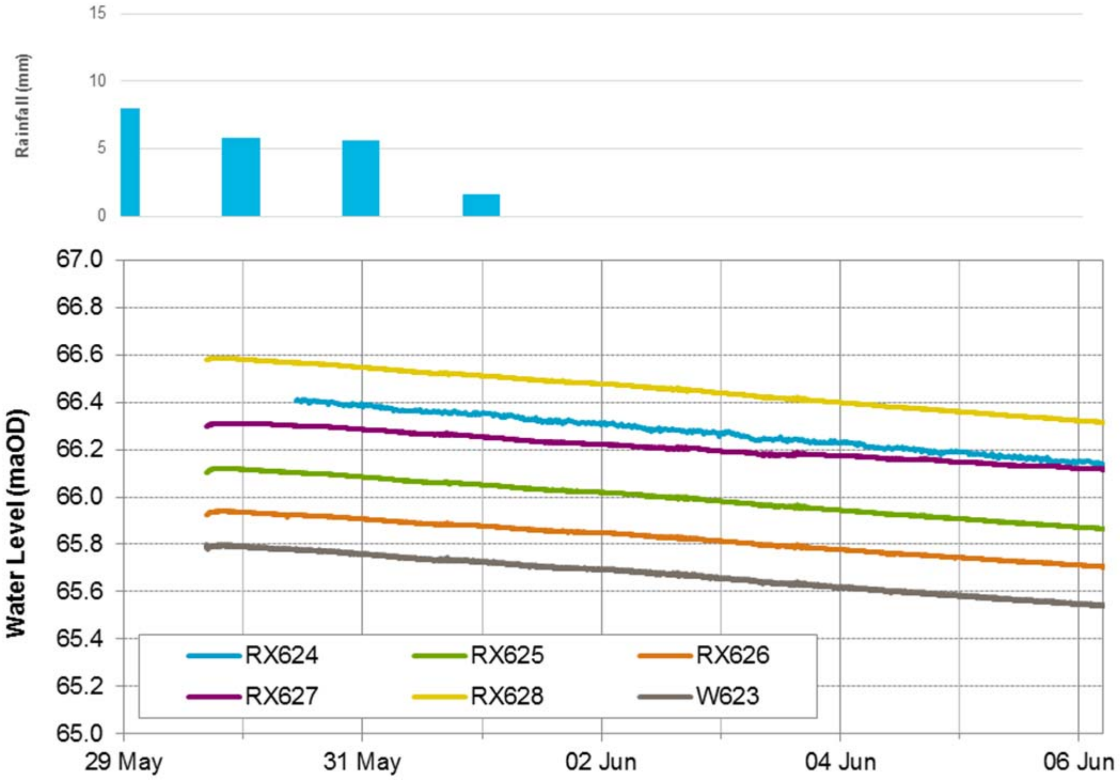


Figure 6.1 W623 Cluster Pre-test Water levels and Rainfall

Step-Test Results

6.1.3 The test data and graphical presentation are provided in Appendix D. A summary of the results of the step-test is presented below in Table 6-2. The reference point was set at 0.38 m above ground level (magl) on W623 for this test.

Table 6-2 W623 Step-Test Summary

W623		Discharge Rate (l/s)	Water level at the end (mbrp)	Cumulative Drawdown (m)
Rest Water Level			46.33	
Step-Test (100 mins steps)	Step 1	10 l/s	47.330	1.00
	Step 2	15 l/s	48.115	1.785
	Step 3	20 l/s	49.095	2.765
	Step 4	25 l/s	50.295	3.965
	Step 5	30 l/s	51.57	5.24

mbrp: metres below reference point

6.1.4 Jacob (1947) described the drawdown in a pumped well as $s_w = BQ + CQ^2$ where:

B = Linear aquifer and well loss coefficient
C = Turbulent well loss coefficient
s_w = Drawdown in the well (m)
Q = Discharge rate (m^3/d)

6.1.5 The step-test was analysed using the Hantush-Bierschenk method to determine the B and C parameters (aquifer loss and apparent well loss coefficients respectively) and gave the following result:

$s_w = 7.89E\text{-}04 \times Q + 4.23E\text{-}07 \times Q^2$ for t =100 mins

The well efficiency can also be estimated as E_w = (BQ/(BQ + CQ2) x 100

6.1.6 The method also gives an indication of the most suitable pumping test rate for the constant rate test to limit the possibility of turbulent flow conditions. Figure 6.2 below presents the analysis charts used for W623. The straight line on the s/Q = f(Q) indicates that the well could be pumped at approximately 25l/s, the maximum rate authorised by the Environment Agency consent. Table 6-3 summarises the analysis results for the step-test.

Table 6-3 W623 Step-Test Analysis

Step (100 mins each)	Average Discharge (l/s)	Discharge (m3/d)	Incremental Drawdown (m)	Cumulative Corrected Drawdown (m)	Predicted Drawdown (m)	s/Q	Apparent Efficiency (Ew)
1	10.0	866	1.00	1.00	1.00	1.16E-03	68.3
2	15.1	1301	0.73	1.73	1.74	1.33E-03	58.9
3	20.1	1732	0.92	2.65	2.64	1.53E-03	51.8
4	25.1	2170	1.06	3.71	3.71	1.71E-03	46.2
5	30.3	2619	1.25	4.96	4.97	1.89E-03	41.6

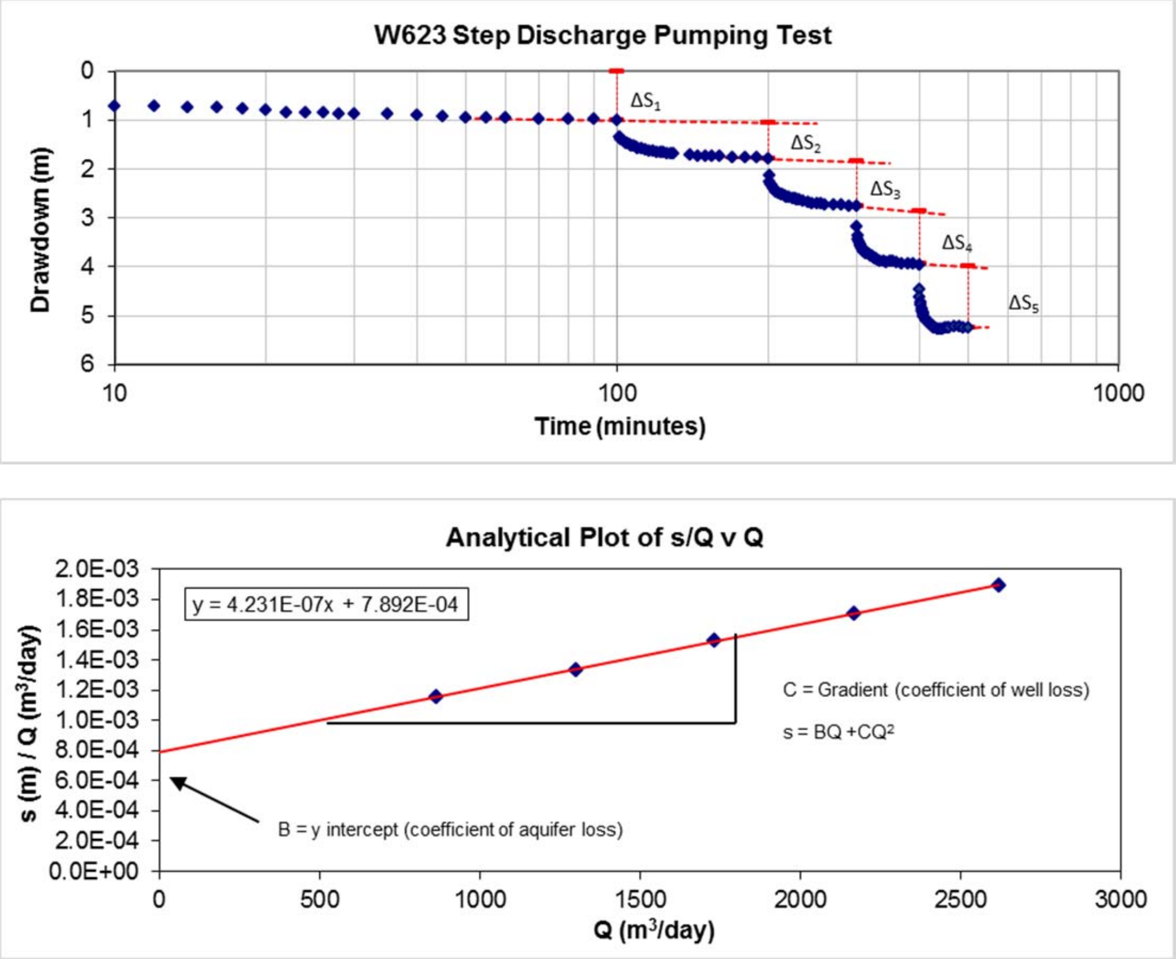


Figure 6.2 W623 Step Test Analysis charts

Constant Rate Test Results

6.1.7 W623 was pumped for 7 days (10,080 minutes) at an average flow rate of 24.8 l/s (2143 m^3/day) from 12th to 19th June 2018.

6.1.8 Figure 6.3 shows the water levels in the cluster boreholes from before and during the test and during recovery. The water levels were influenced by the natural seasonal recession as seen during the pre-test monitoring and also visible on the recovery levels from the 20th June to 26th June. Consequently the drawdown was corrected by removing the natural recession factor before analysing the data. The natural recession factor was calculated using levels between the 12th June 2018 10:00 and the 21st June 2018 13:00. Figure 6.4 presents the corrected drawdown and the original drawdown on a semi log chart.

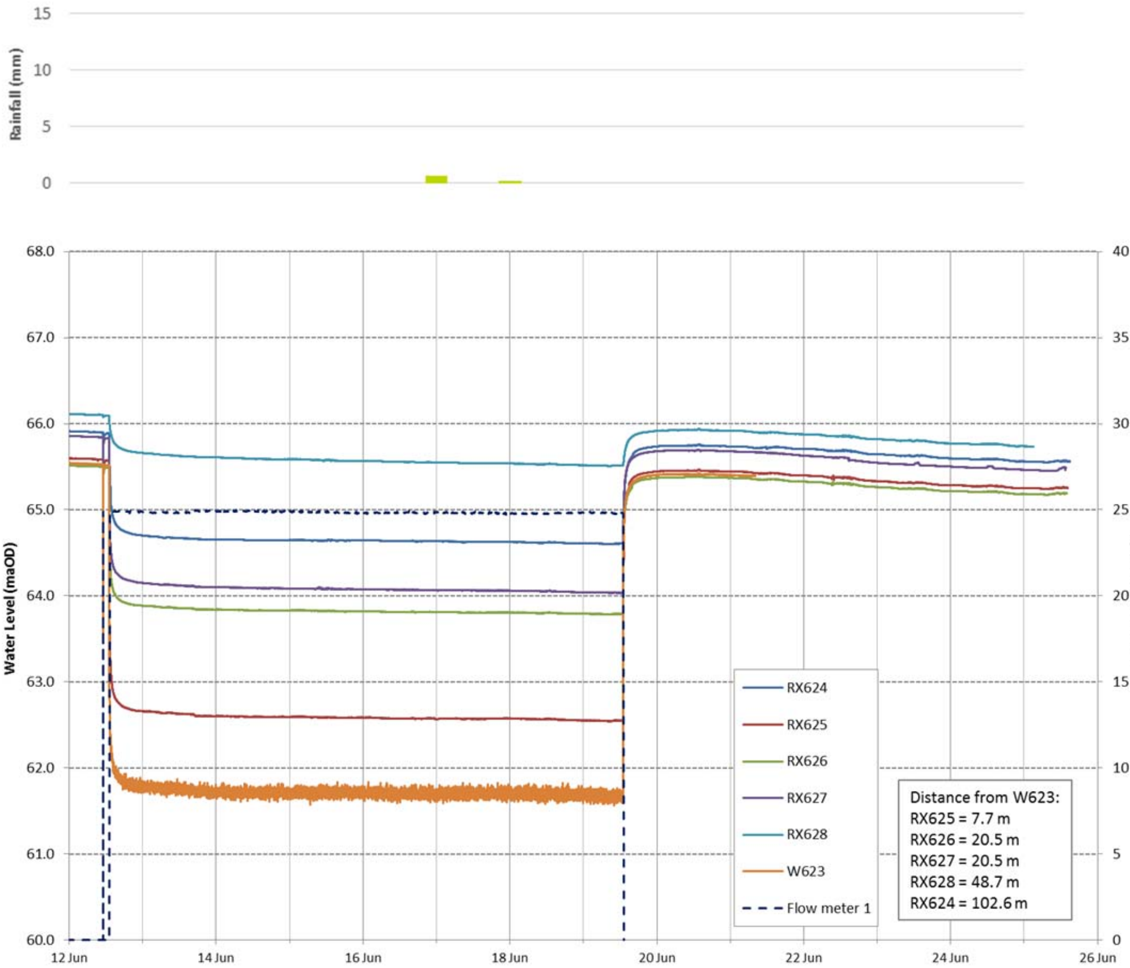


Figure 6.3 W623 Constant Rate Test Water Levels

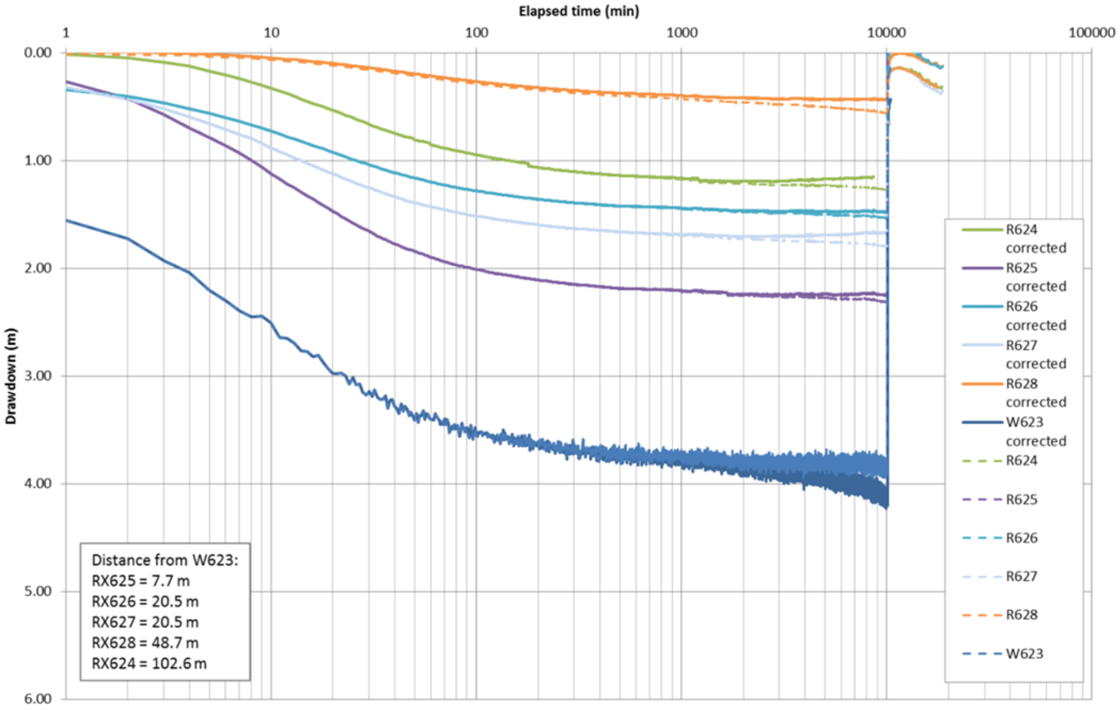


Figure 6.4 W623 Constant Rate Test Drawdown on semi log

6.1.9 The time-drawdown and recovery data from the observation boreholes was analysed to estimate the local hydraulic parameters of the Chalk aquifer. The data was also analysed using distance-drawdown plots at different times during the constant rate test. Using the Cooper-Jacob method, the transmissivity and storage coefficient could be estimated using the following formulas:

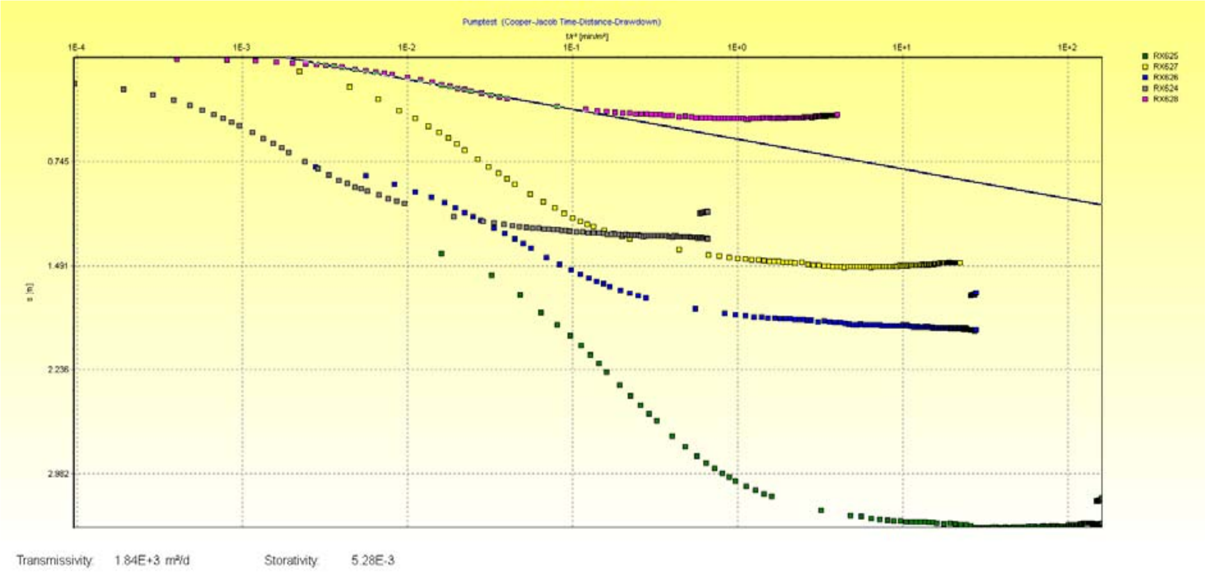
$$T = \frac{2.303\ Q}{4\pi\Delta s} \qquad S = \frac{2.25\,T\,t}{r_0^2}$$

where
T = Transmissivity (m^2/d)
Q = Discharge rate (m^3/d)
Δs = Drawdown per log cycle of distance (m)
S = Storage coefficient (dimensionless)
T = time (day)
r_0 = distance at which the straight line intercept the zero drawdown axis (m)

6.1.10 Analysis was undertaken using the AquiferTest software which allows multiple solutions and plots to be explored iteratively to find the best overall fit with the observed data.

6.1.11 Cooper-Jacob time-distance-drawdown plots for the W623 cluster are shown in Figure 6.5 with straight line fits for the observation boreholes recording the highest and lowest values for transmissivity. The straight line fit is not valid for early data (a characteristic of the Cooper-Jacob method) and it is clear from these graphs that there is a significant flattening off of drawdown for later data. In itself, the shape of curve could be explained by delayed yield, the presence of a recharge boundary (or other recharge) or the heterogeneities in the aquifer which result in the cone of depression intercepting a zone of higher transmissivity at greater radial distances (and thus later times). However, comparison of the individual drawdown curves suggests that aquifer heterogeneity is the most likely explanation as the furthest observation borehole to the northeast (RX628) implies a much higher transmissivity (~1,800 m^2/day) than the others. The locations of the observation boreholes with respect to the pumping well are shown in Figure 6.6.

6.1.12 Since the groundwater response in RX628 is significantly different from the other boreholes, it should not be used for the Cooper-Jacob distance-drawdown analysis as the shape of the cone of depression in this direction is not defined by a single value of transmissivity. Likewise, the curve for the closest borehole, RX625, implies a lower transmissivity (~350 m^2/day) which may not be representative if, for example, there is a direct connection to the pumping well through a fissure. Although the best fit straight line for the distance-drawdown analyses would appear to include RX628 and RX625, and exclude RX624, this line gives an improbably low value of transmissivity which is not consistent with the time drawdown analyses of the individual observation wells. Using the three remaining observation boreholes which are more consistent in their response gives a value of transmissivity which is more consistent with the time-drawdown analyses. Nevertheless, these observations are useful because they highlight the aquifer heterogeneity.



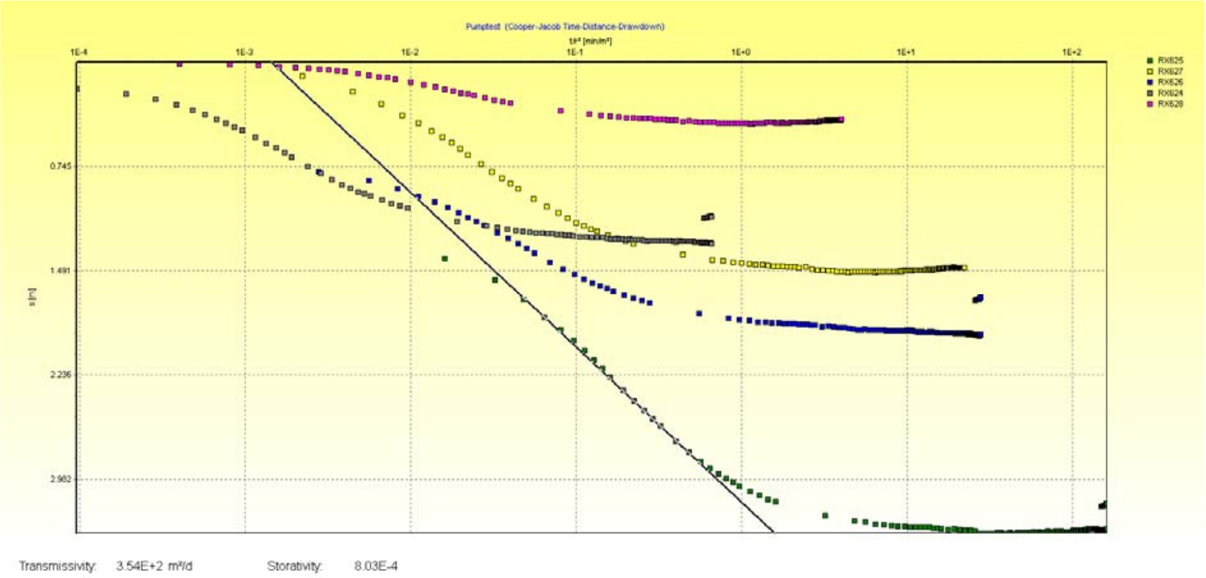


Figure 6.5 Cooper-Jacob Time-Distance-Drawdown Plot for W623 Constant Rate Test

6.1.13 The distance drawdown analysis based on the remaining three observation boreholes is shown in Figure 6.5 for 180, 720, 1440 and 4320 minutes. The values of transmissivity derived from these analyses are somewhat higher than the range of transmissivity derived from the time drawdown analyses, with the exception of RX628, possibly indicating the presence of a fissure zone nearby, and the apparent increase in transmissivity for the later times is consistent with the cone of depression spreading into a zone of higher permeability. It should be noted that it is not possible from the pumping test analysis alone to determine whether these higher transmissivities result from a lateral variation in hydraulic conductivity or a vertical variation. The observation borehole showing the highest transmissivity also has the highest ground elevation and the highest rest water level which could imply that, at this particular moment during the recession, the saturated portion of the aquifer was greater to the north east with more flow taking place in the higher permeability layers.

6.1.14 The aquifer parameters derived from each observation borehole are summarised in Table 6-4.

Table 6-4 Aquifer Parameters Derived from Pumping Test of W623

	Mean Transmissivity (m^2/day)	Storage coefficient
RX624	608	0.0002
RX625	388	0.0012
RX626	615	0.0008
RX627	544	0.0029
RX628	1,617	0.0074
Distance drawdown	928	0.0004

6.1.15 The complete analyses are given in Appendix F. The frequency distribution of interpreted transmissivities is shown in Figure 6.8. The average transmissivity for the Coneybury Hill test (of all individual estimates) is approximately 800 m^2/day.

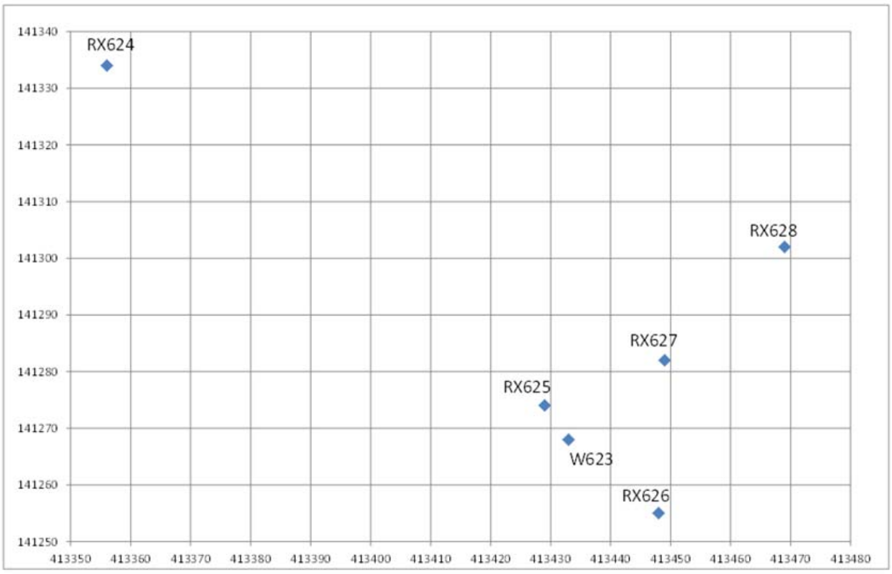
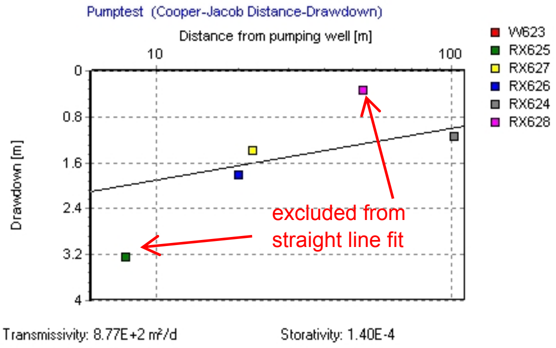


Figure 6.6 Observation Boreholes in the W623 Cluster

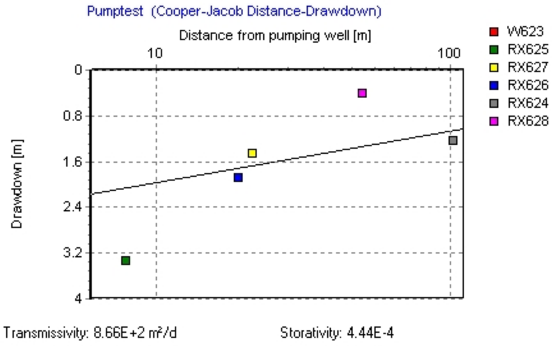
W623 Pumping Test – Coneybury Hill

Cooper-Jacob distance drawdown analysis
t= 180, 720, 1440 and 4320 minutes
Average transmissivity: 928 m^2/day
Average storage coefficient: 0.0004

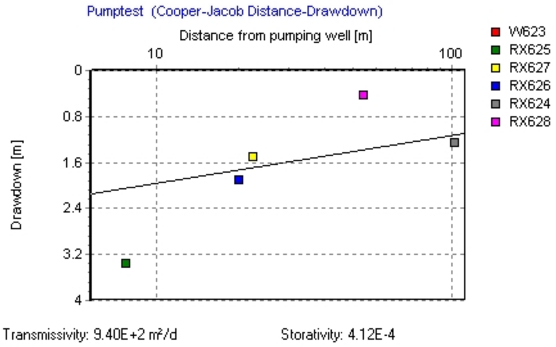
t=180



t=720



t=1440



t=4320

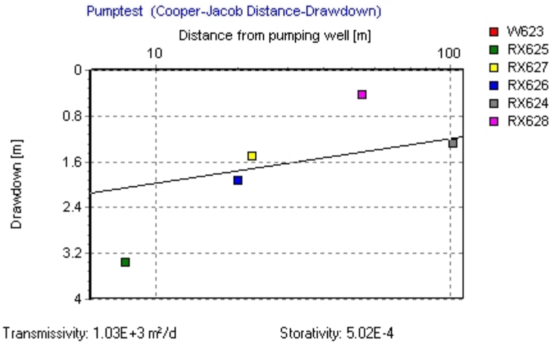


Figure 6.7 Distance drawdown analysis for W623

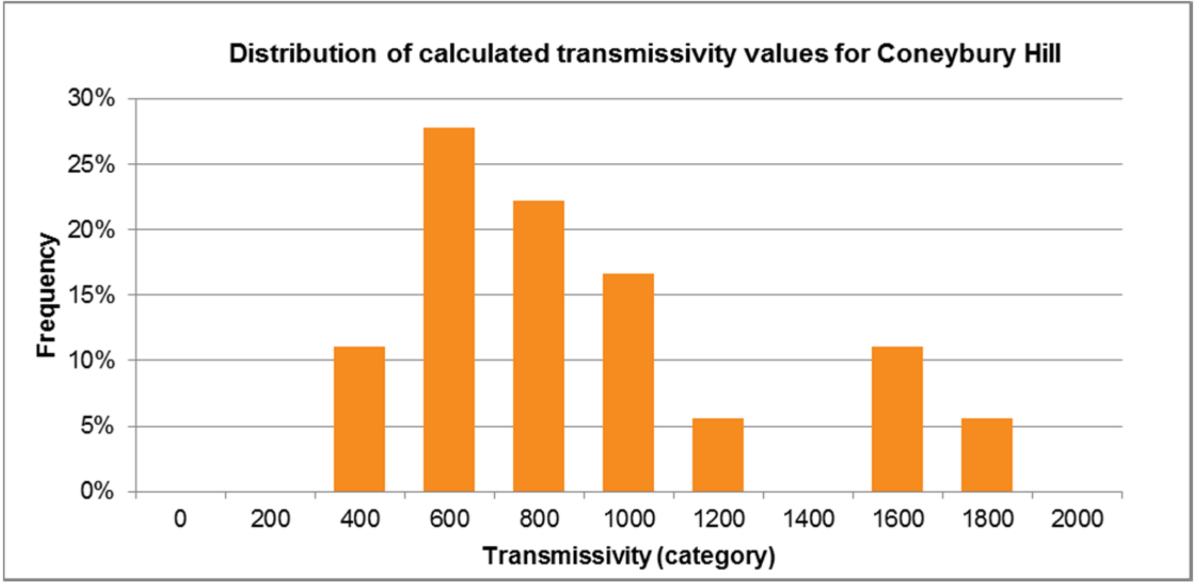


Figure 6.8 Frequency Distribution for Transmissivity Values Calculated from the W623 Pumping Test

6.2 W601 Stonehenge Down

6.2.1 This pumping test was carried out in a similar location to W137 which was tested in 2002 and 2004. It is located on the interfluve to the east of Stonehenge Bottom and in the previous tests, showed lower values of transmissivity than the dry valley. It also showed a significant change from summer to winter. This test was undertaken during the groundwater recession but when groundwater levels were closer to the minimum than the maximum.

Pre-test monitoring

6.2.2 Data loggers were installed in the production well (W601) and in the seven observation boreholes and recorded water levels for at least seven days before the pump installation on the 26th June. The data is presented in Figure 6.9 and show a natural decline of the groundwater levels during that period between 0.41 m and 0.43 m between the 19th and the 25th June 2018. Water levels are summarised in Table 6-5.

6.2.3 It should be noted that the 20th June marks an inflection point between two natural recession rates for the groundwater levels in this cluster. The daily noise observed on the water levels collected by the data logger is due to the fact that the barometer used to correct the data was originally located at the surface and was directly exposed to sunlight at regular times of the day. The temperature of the logger would rise above 40 degrees Celcius and affect the barometer reading. This was corrected on the 26th June in the test by placing the barometer a few meters below ground level in a borehole.

Table 6-5 W601 cluster - Pre-test water levels

Borehole ID	Water levels on 19th June (mAOD)	Water levels on 25th June (mAOD)	Decline (m)
W601	69.20	68.76	0.41
R602	69.32	68.91	0.42
R606	69.40	68.98	0.42
R607	69.34	68.92	0.43
R608	69.35	68.92	0.43
R609	69.34	68.91	0.42
R610	69.30	68.88	0.43
R612	69.19	68.76	0.41

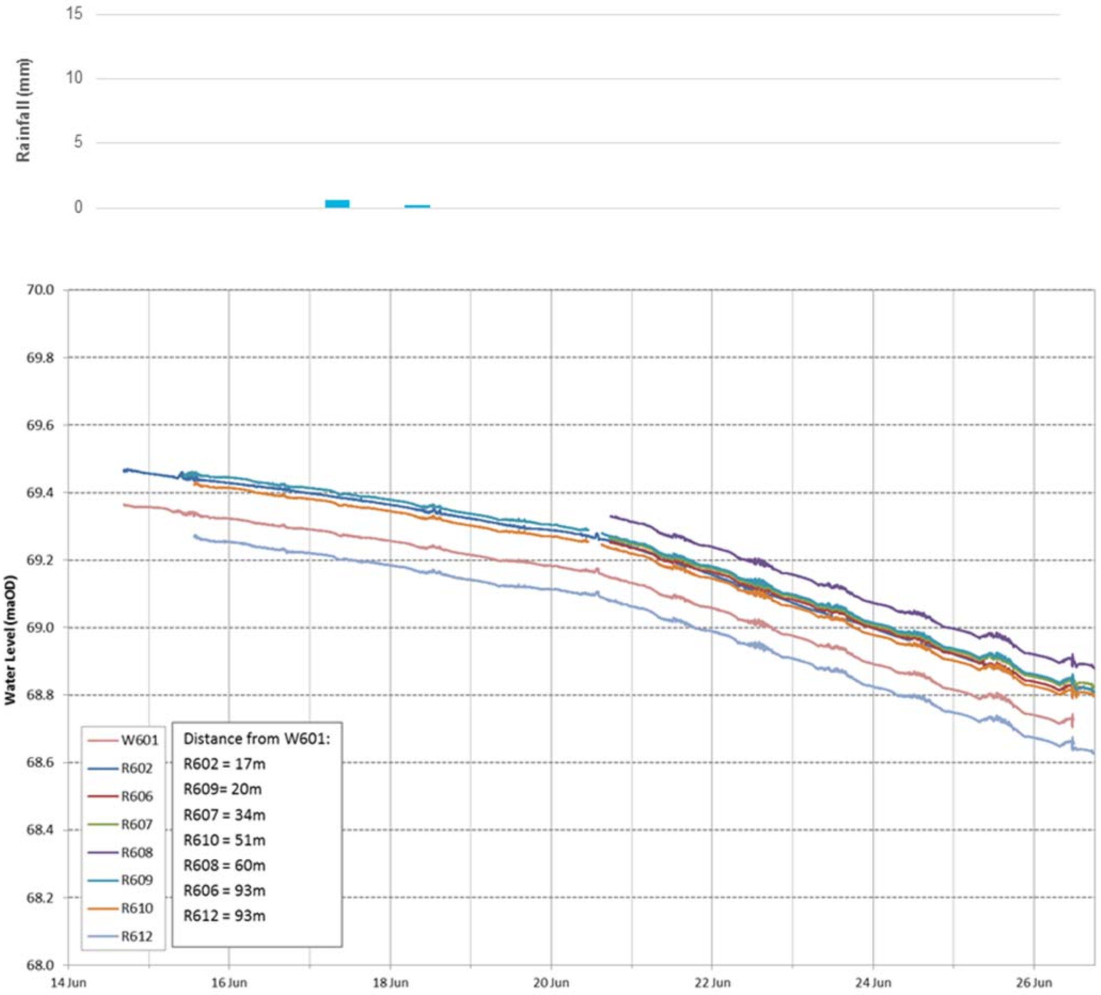


Figure 6.9 W601 Cluster Pre-test Water Levels

Step-Test Results

6.2.4 The test data and graphical presentation are provided in Appendix D. A summary of the results of the step-test is presented in Table 6-6. The reference point was set at 0.37 magl on W601 for this test.

Table 6-6 W601 Step-Test Summary

W601		Discharge Rate (l/s)	Water level at the end (mbrp)	Cumulative Drawdown (m)
Rest Water Level			25.23	
Step-Test (100 mins steps)	Step 1	15	47.330	1.27
	Step 2	19.5	48.115	2.06
	Step 3	23	49.095	3.10
	Step 4	26.5	50.295	4.45
	Step 5	30	51.57	6.92

mbrp: metres below reference point

6.2.5 The step-test was analysed using the Hantush-Bierschenk method to determine the aquifer and well-loss coefficients. The data did not permit the estimation of the coefficients as the interpolated y-intercept was negative as shown on Figure 6.10.

6.2.6 However the analysis still gave an indication of the most suitable pumping rate for the constant rate test to limit the turbulent flow conditions. This indicated that the well could be pumped at approximately 25 l/s, the maximum rate authorised by the Environment Agency consent. Table 6-7 summarises the analysis results.

Table 6-7 W601 Step-Test Analysis

Step (100 mins each)	Average Discharge (l/s)	Discharge (m3/d)	Incremental Drawdown (m)	Cumulative Corrected Drawdown (m)	Predicted Drawdown (m)	s/Q	Apparent Efficiency (Ew)
1	14.7	1268	1.27	1.27	1.20	1.00E-03	N/A
2	19.2	1661	0.67	1.94	2.07	1.17E-03	N/A
3	22.8	1970	0.91	2.85	2.91	1.45E-03	N/A
4	26.1	2256	1.09	3.94	3.82	1.75E-03	N/A
5	29.5	2552	2.12	6.06	4.90	2.37E-03	N/A

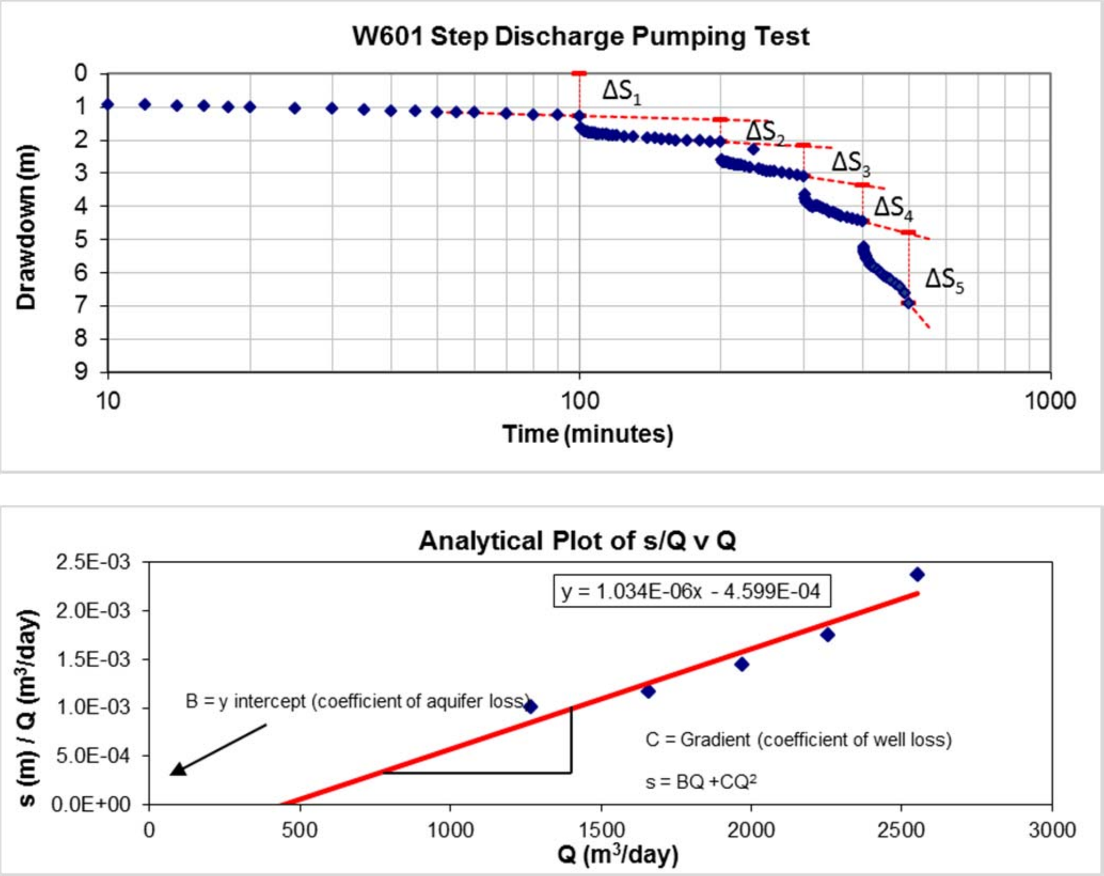


Figure 6.10 W601 Analysis charts

Constant Rate Test Results

6.2.7 Borehole W601 was pumped for seven days and one hour (10,140 minutes) at an average flow rate of 23.3 l/s (2,013 m^3/day) from 10th to 17th July 2018. The time drawdown data from the observation boreholes was analysed to estimate the local hydraulic parameters of the Chalk aquifer.

6.2.8 Figure 6.11 shows the water levels in the cluster boreholes from before and during the test and during recovery. Note that some data is missing on the 16th and 17th July as the site was vandalised overnight and data loggers went missing in R602 and R609. Data loggers were replaced on the 17th July before the pump was turned off. The rate of drawdown increased in W601 when water levels reached c. 62 mAOD (c. 6 m drawdown), which correlates to the depth of a large void/fracture seen on the optical televiewer log and the caliper log. The water level in the pumping borehole continued to drop in phases, possibly as different parts of the fissure system were drained.

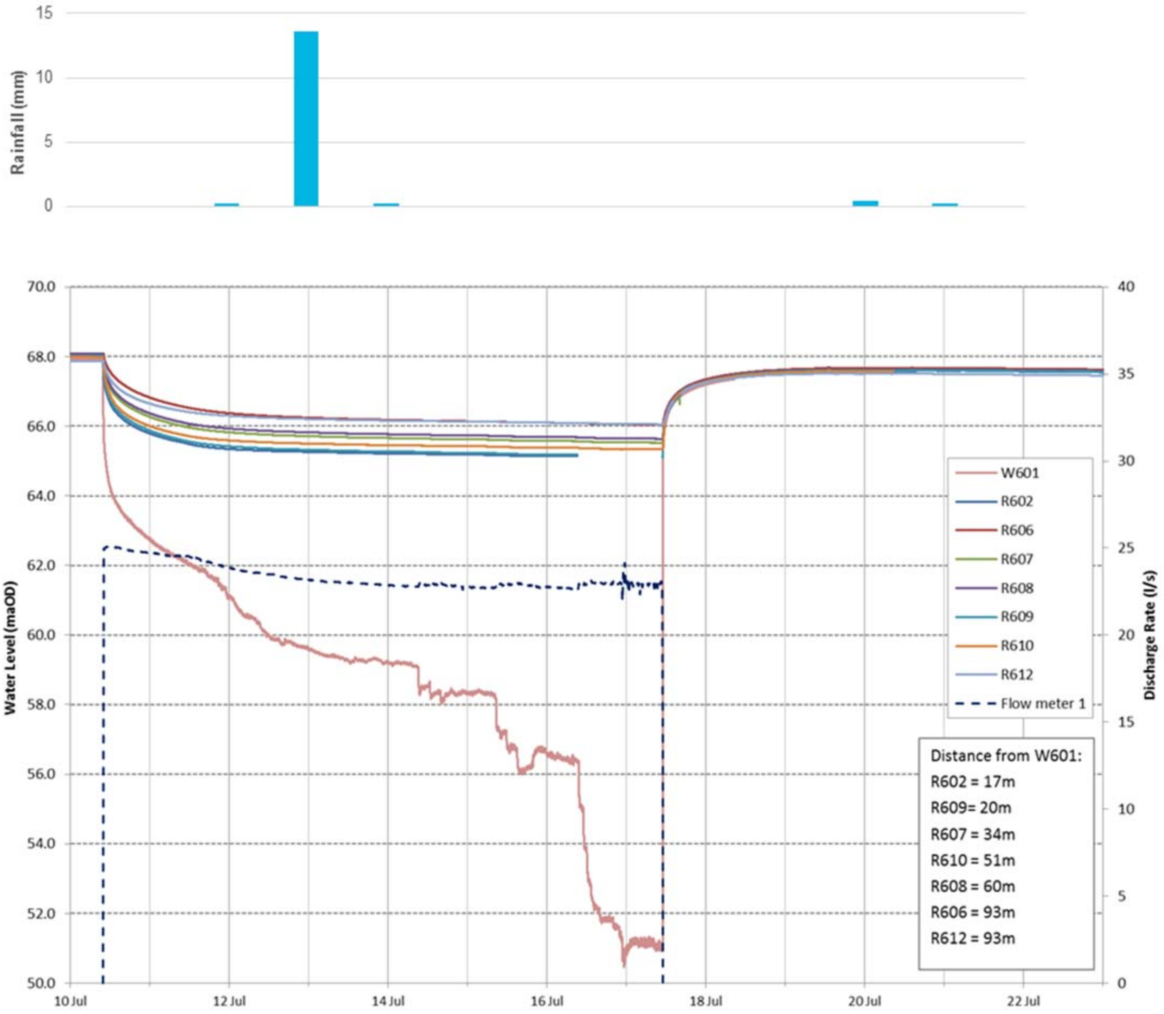


Figure 6.11 W601 Constant Rate Test Water Levels

6.2.9 The water levels were influenced by the natural seasonal recession as seen during the pre-test monitoring and also visible on the recovery levels from the 18th July to 23rd July 2018. Consequently the drawdown was corrected by removing the natural recession before analysing the data. The natural recession was initially calculated using levels between the 10th July and the 20th July as a straight line. While the correction was partially successful, the recovery was followed by a subsequent decline in levels and cast doubt on the validity of the drawdown and recovery analysis. A further correction was then applied using a polynomial curve based on rest water levels between 20th June and 20th July. This correction is shown in Figure 6.12 for R602. Whilst this improved the correction, it was found that it made little difference to the calculated transmissivity values from either curve fitting (Theis) or straight line analysis (Cooper-Jacob).

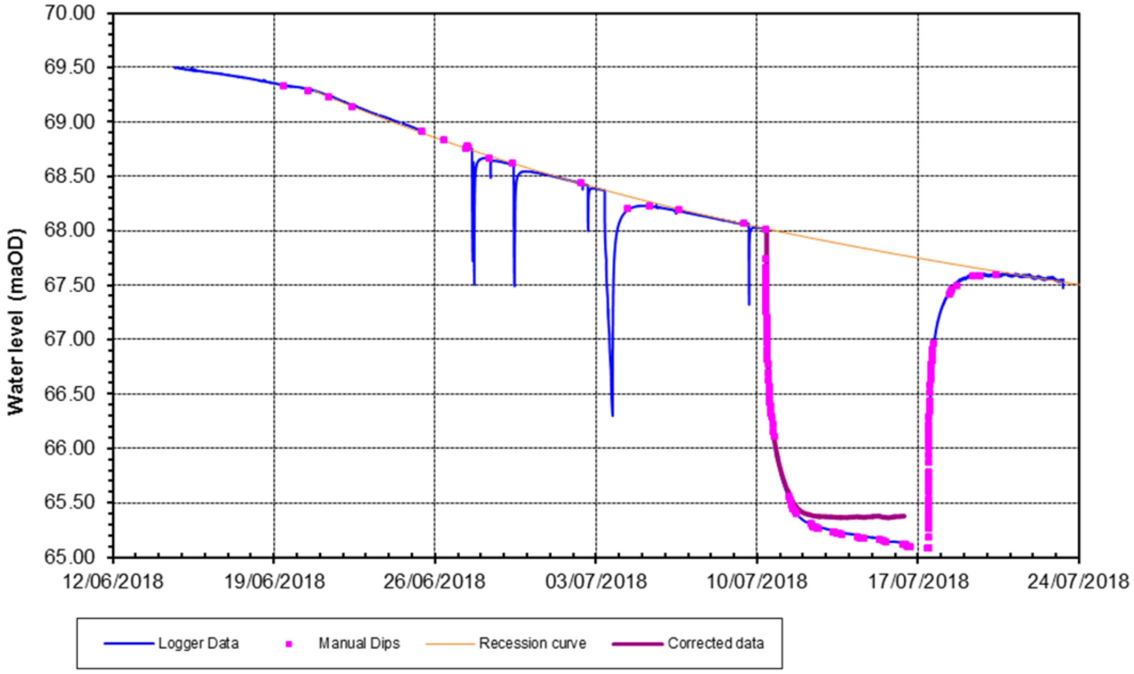


Figure 6.12 Recession curve defined using polynomial expression for R602

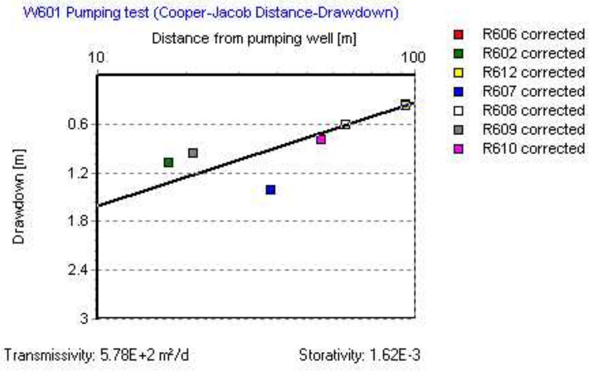
6.2.10 The corrected drawdowns and recovery data were analysed using AquiferTest software considering a range of solutions. Unlike the W623 pumping test, all the observation boreholes in the W601 cluster were used in the Cooper Jacob distance–drawdown analysis and showed a better fit to a straight line (Figure 6.13). The transmissivity ranged from 404 m^2/day to 617 m^2/day with an average of 547 m^2/day. The storage coefficient ranged from 6.6×10^{-4} to 9.86×10^{-3} with an average of 2.5×10^{-3}.

6.2.11 In addition to the seven observation boreholes in the W601 cluster, it was noted that the effect of the pumping test was detected in two of the catchment observation boreholes which were recording 15-minute groundwater level data at the time, RX509 and PX506 (Figure 6.14), located 1200m north west and 450m south west respectively from W601. The drawdown arising from the pumping tests was clearly much less in these boreholes than in the boreholes within the cluster due to the distance but nonetheless provided additional data for analysis. The correction for the recession curve was much more critical in the case of these boreholes since the fall in water levels due to the recession was greater than the drawdown for pumping during the period of the test. After applying a correction based on a polynomial fit (using all pre-test and post-test data), the shape of the drawdown and recovery curves was clearly adequate for analysis, albeit somewhat noisy. The estimated drawdown at RX509 and PX506 was 0.21m and 0.52 m respectively at the end of the constant rate test.

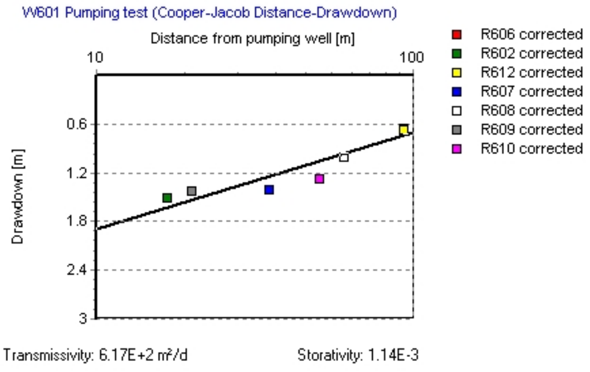
6.2.12 Adding these boreholes into the distance drawdown analysis did not significantly change the calculated transmissivity value (3% change in the average values) but they do suggest that the storage coefficient is around 30% higher than the values calculated from the cluster boreholes located in close proximity to the pumping borehole.

Cooper-Jacob distance drawdown analysis
t= 60, 180, 720, 1440, 4320 and 10000 minutes
Average transmissivity: 547 m^2/day
Average storage coefficient: 0.0025

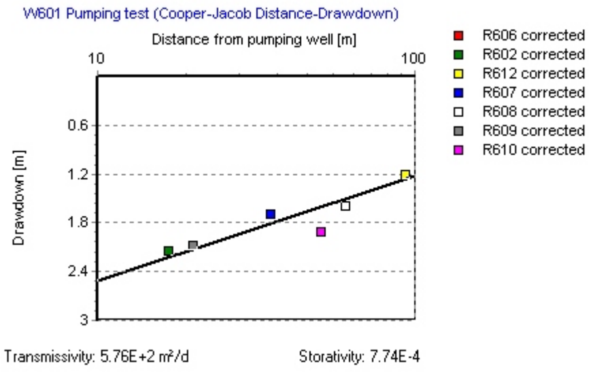
t=60



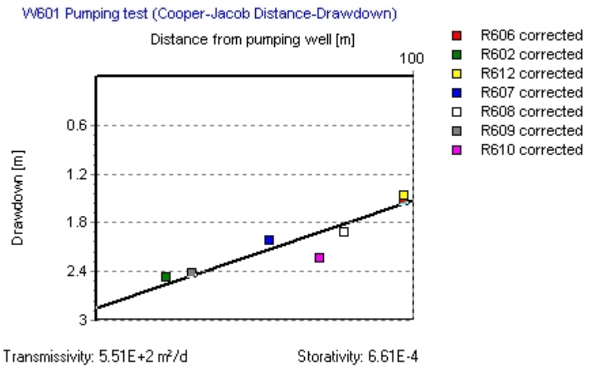
t=180



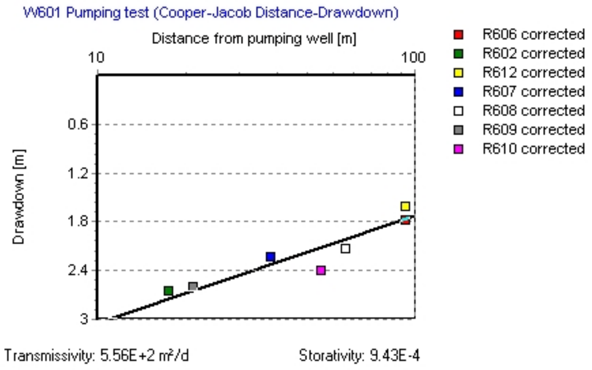
t=720



t=1440



t=4320



t=10000

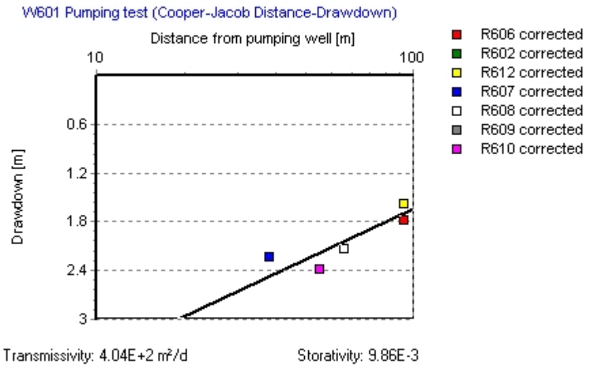


Figure 6.13 Cooper-Jacob distance drawdown analyses for W601 cluster plus PX506 and RX509

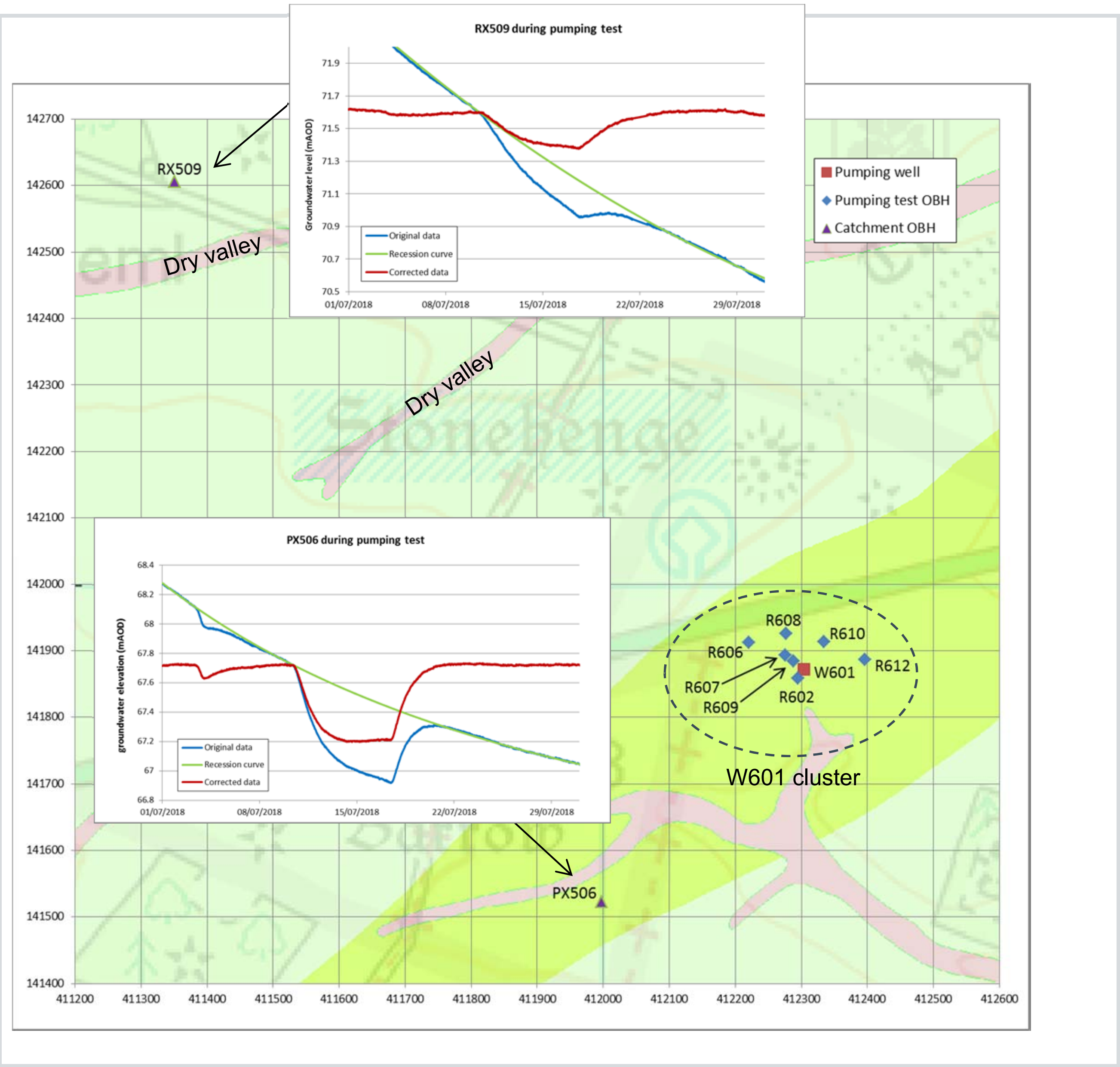


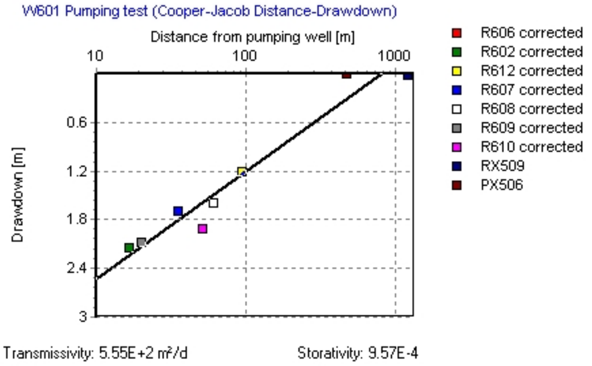
Figure 6.14 Catchment boreholes RX509 and PX506 and their relationship to the W601 cluster

6.2.13 The aquifer parameters derived from time-drawdown analysis of each observation borehole are summarised in Table 6-8. The complete analyses are given in Appendix F. The frequency distribution of interpreted transmissivities is shown in Figure 6.16.The average of all values for Stonehenge Down is approximately 435 m^2/day and there was consistency between the estimates derived from different observation boreholes and different analytical methods. The only exception to this was the time-drawdown analysis of the distant well RX509 which gave values of up to 1,490 m^2/day with an average of 1,085 m^2/day. Whilst the drawdown in this well was only 21 cm and the logger data showed some noise, this value could be a reflection of the fact that RX509 is situated on the opposite side of a dry valley from the pumping well with a zone of higher transmissivity between the pumped well and the observation borehole (Figure 6.14).

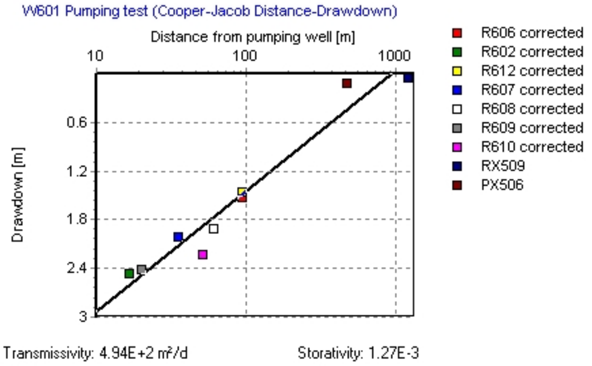
6.2.14 Not only are the values of transmissivity consistent between observation boreholes, but they are also consistent with the result of the previous pumping test in 2004 on borehole W137, when groundwater levels were low (Figure 6.17).

Cooper-Jacob distance drawdown analysis (with additional catchment boreholes)
t= 720, 1440, 4320 and 10000 minutes
Average transmissivity: 507 m^2/day
Average storage coefficient: 0.0023

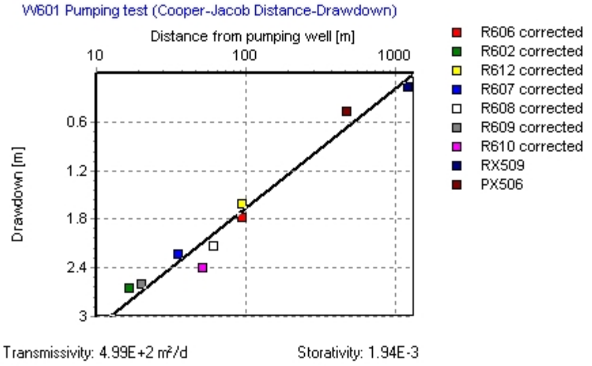
t=720



t=1440



t=4320



t=10000

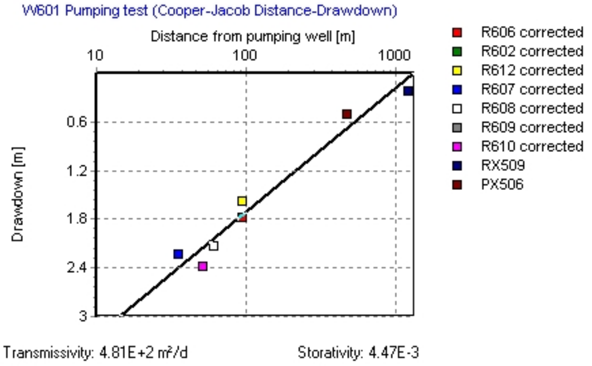


Figure 6.15 Cooper-Jacob distance drawdown analyses for W601 cluster, including catchment boreholes at 450 m and 1,200 m from the pumping well.

Table 6-8 Aquifer Parameters Derived from Pumping Test of W601

	Mean Transmissivity (m^2/day)	Storage coefficient
R602	404	0.0057
R606	420	0.0021
R607	403	0.0057
R608	411	0.0022
R609	386	0.0072
R610	366	0.0021
R612	434	0.0023
PX506	448	0.0047
RX509	1,085	0.0021
Distance drawdown	531	0.0024

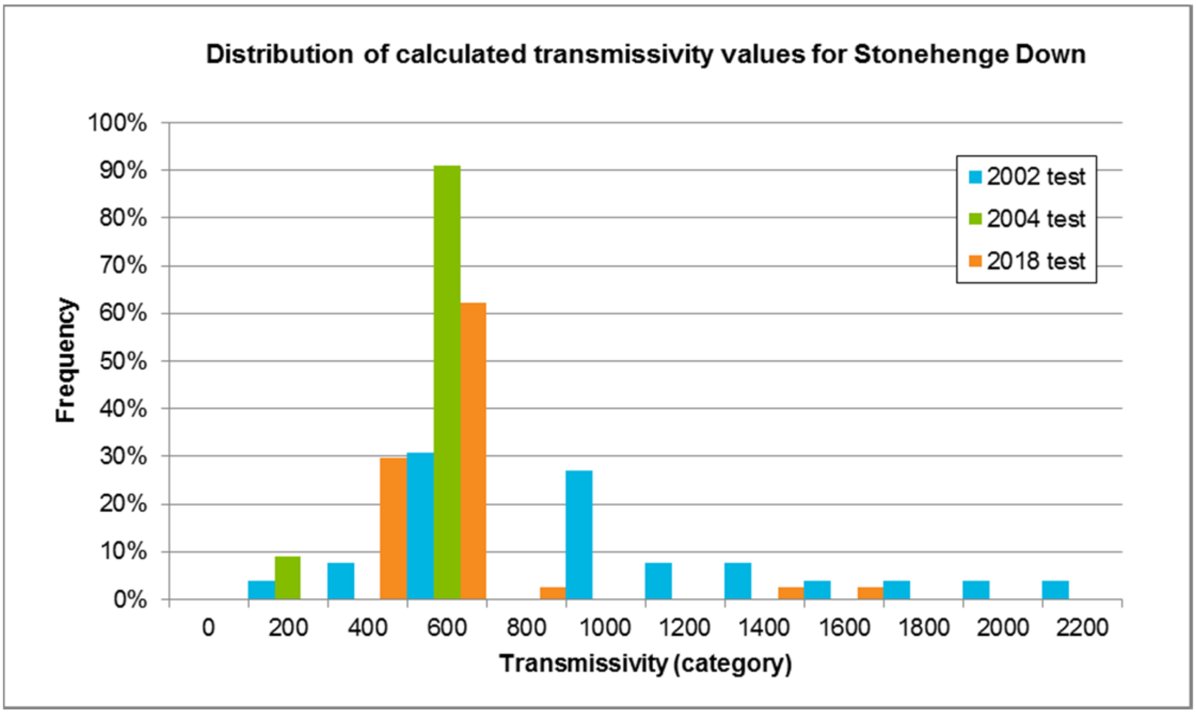


Figure 6.16 Frequency Distribution for all Transmissivity Values Calculated from W601 Pumping Test Compared with Values from W137 tests.

6.3 W617 – Stonehenge Bottom

6.3.1 This pumping test was carried out Stonehenge Bottom, approximately 100 m to the west of W148 which was tested in 2002 and 2004. In the previous tests, this area showed higher values of transmissivity than the interfluve, as well as a significant change from summer to winter. This test was undertaken when groundwater levels were close to the minimum

Pre-test monitoring

6.3.2 Data loggers were installed in the production well and in the five observation boreholes and recorded water levels for 11 days, between the 13th and 23rd July 2018, before the pump installation on the 24th July. The data is presented in Figure 6.17 and show a natural decline of the groundwater levels during that period between 0.11m and 0.15m between the 14th and the 23th July 2018. Water levels are summarised in Table 6-9.

6.3.3 The lower water levels seen on the 13th July and the 23rd July are due to the airlift activities that took place on borehole W617. Due to the influence of the airlift on water levels, Table 6-9 only presents data between the 14th 8:00 and 23rd July 8:00, excluding the effects of the airlifting. The rise in the water levels observed from the 17th July until the 19th July is a likely delayed response to the high rainfall event of the 13th July 2018.

Table 6-9 W617 cluster - Pre-test water levels

Borehole ID	Water levels on 14th July (mAOD)	Water levels on 23rd July (mAOD)	Decline(m)
W617	67.23	67.08	0.14
R618	67.28	67.13	0.15
R619	67.22	67.08	0.14
R620	67.22	67.08	0.14
RX621	67.17	67.04	0.12
RX622	67.02	66.90	0.11

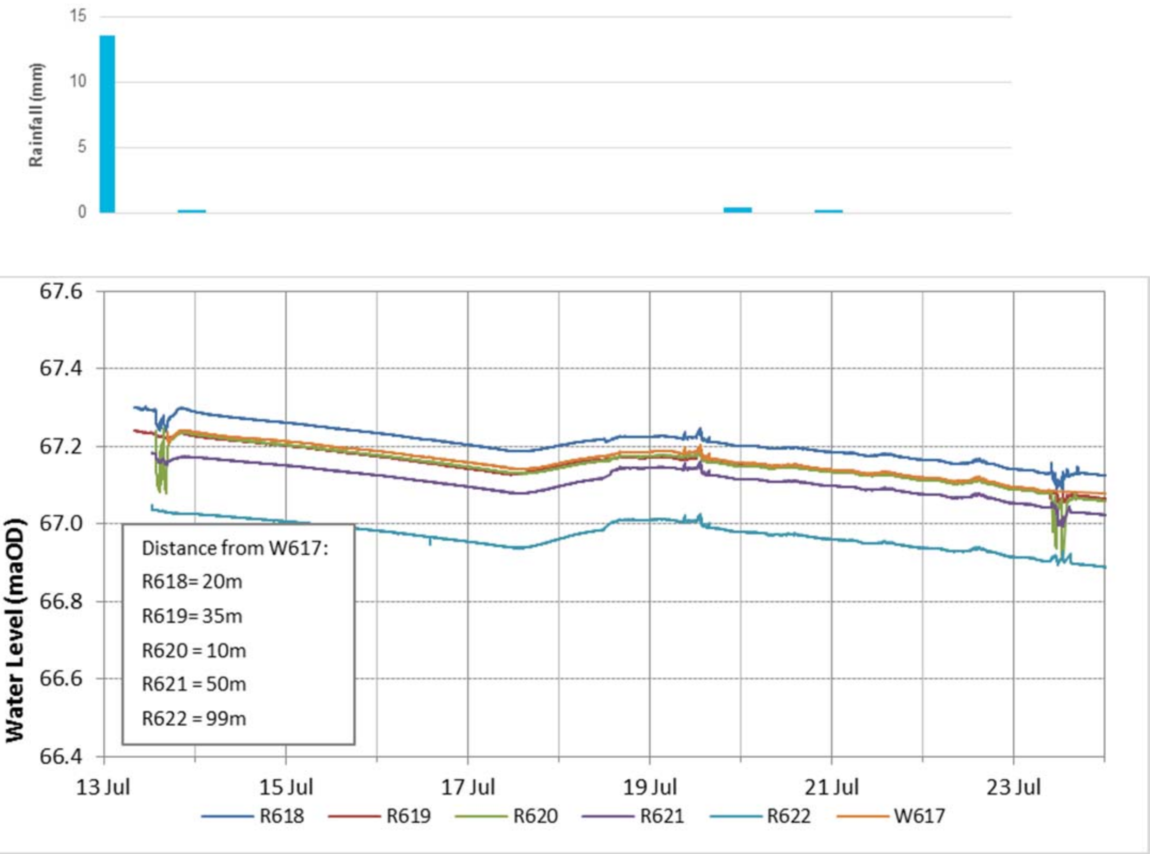


Figure 6.17 W617 Cluster Pre-test Water levels

Step-Test Results

6.3.4 The test data and graphical presentation are provided in Appendix D. A summary of the results of the step-test are presented in Table 6-10. The reference point was set at 0.48 magl on W617 for this test. Compared with boreholes W601 and W623, the proven borehole yield was much lower.

Table 6-10 W617 Step-Test Summary

W617		Discharge Rate (l/s)	Water level at the end (mbrp)	Cumulative Drawdown (m)
Rest Water Level			13.25	
Step-Test (100 mins steps)	Step 1	2	14.35	1.1
	Step 2	3	15.26	2.01
	Step 3	5	17.92	4.67
	Step 4	6	21.09	7.84
	Step 5	7	30.50	17.25

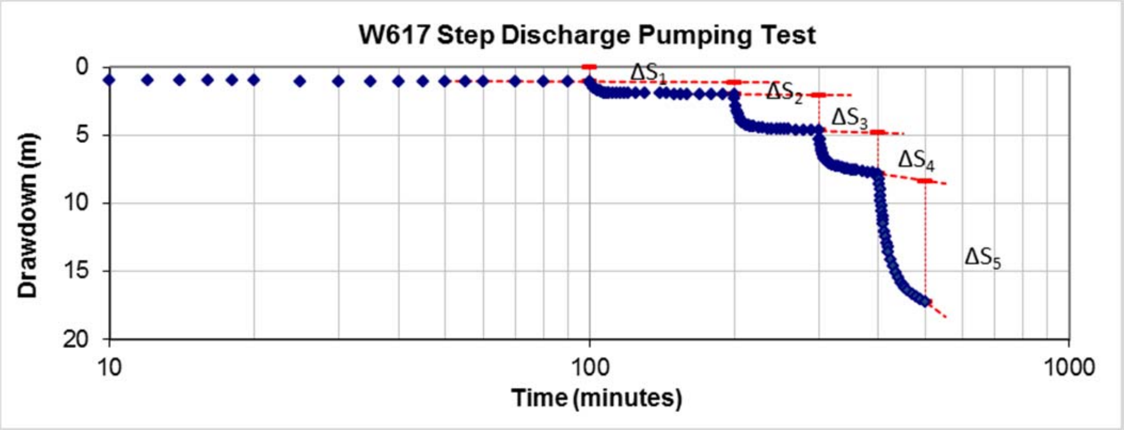
mbrp: metres below reference point

6.3.5 The step test was analysed using the Hantush-Bierschenk method to determine the B and C parameters (aquifer loss and apparent well loss coefficients respectively). Due to the disproportionate amount of drawdown that occurred during Step 5, it was discarded/ The analysis gave the following result:

$_{sw}$ = 1.71E-03 x Q + 2.32E0-5 x Q^2 for t =100 mins and Q < 6L/s

The well efficiency was estimated as $E_w = (BQ/(BQ + CQ^2) \times 100$

6.3.6 The method also gives an indication of the most suitable pumping test rate for the constant rate test to limit the turbulent flow conditions. Figure 6.18 presents the analysis charts used for W617. The straight line on the s/Q = f(Q) indicates that the well could be pumped at a maximum sustainable rate of approximately 5.8l/s for the constant rate test. Table 6-11 summarises the analysis results for the step-test.



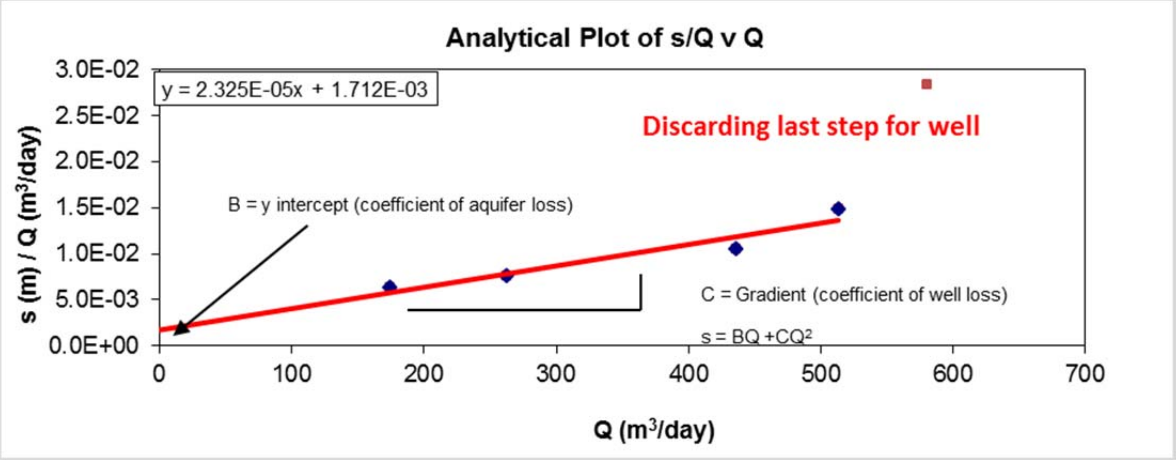


Figure 6.18 W617 Analysis charts

Table 6-11 W617 Step Test Analysis

Step (100 mins each)	Average Discharge (l/s)	Discharge (m3/d)	Incremental Drawdown (m)	Cumulative Corrected Drawdown (m)	Predicted Drawdown (m)	s/Q	Apparent Efficiency (Ew)
1	2.0	175	1.10	1.10	1.01	6.30E-03	29.6
2	3.0	263	0.88	1.98	2.05	7.53E-03	21.9
3	5.1	436	2.60	4.57	5.17	1.05E-02	14.4
4	5.9	513	3.01	7.58	7.00	1.48E-02	12.6
5	6.7	580	8.89	16.47	8.82	2.84E-02	11.3

Constant Rate Test Results

6.3.7 Abstraction borehole W617 was pumped for seven days (10,080 minutes) at an average flow rate of 5.8 l/s (501m^3/day) from 27th July to 3rd August 2018. The time-drawdown data and recovery data from the observation boreholes were analysed to estimate the local hydraulic parameters of the Chalk aquifer.

6.3.8 Figure 6.19 shows the water levels in the cluster boreholes from before pumping, during the test and during recovery. The water levels were influenced by the natural seasonal recession as seen during the pre-test monitoring and also visible on the recovery levels from the 3rd to 6th August. Consequently the drawdowns were corrected by removing the natural recession factor before analysing the data. The natural recession factor was calculated using levels between the 27th July 10:00 and the 5th August 00:00. Figure 6.20 presents the corrected drawdown and the original drawdown in the observation boreholes on a semi log chart. The correction required due to the natural recession during the period of the pumping test resulted in a reduction in drawdown of up to 0.21 m.

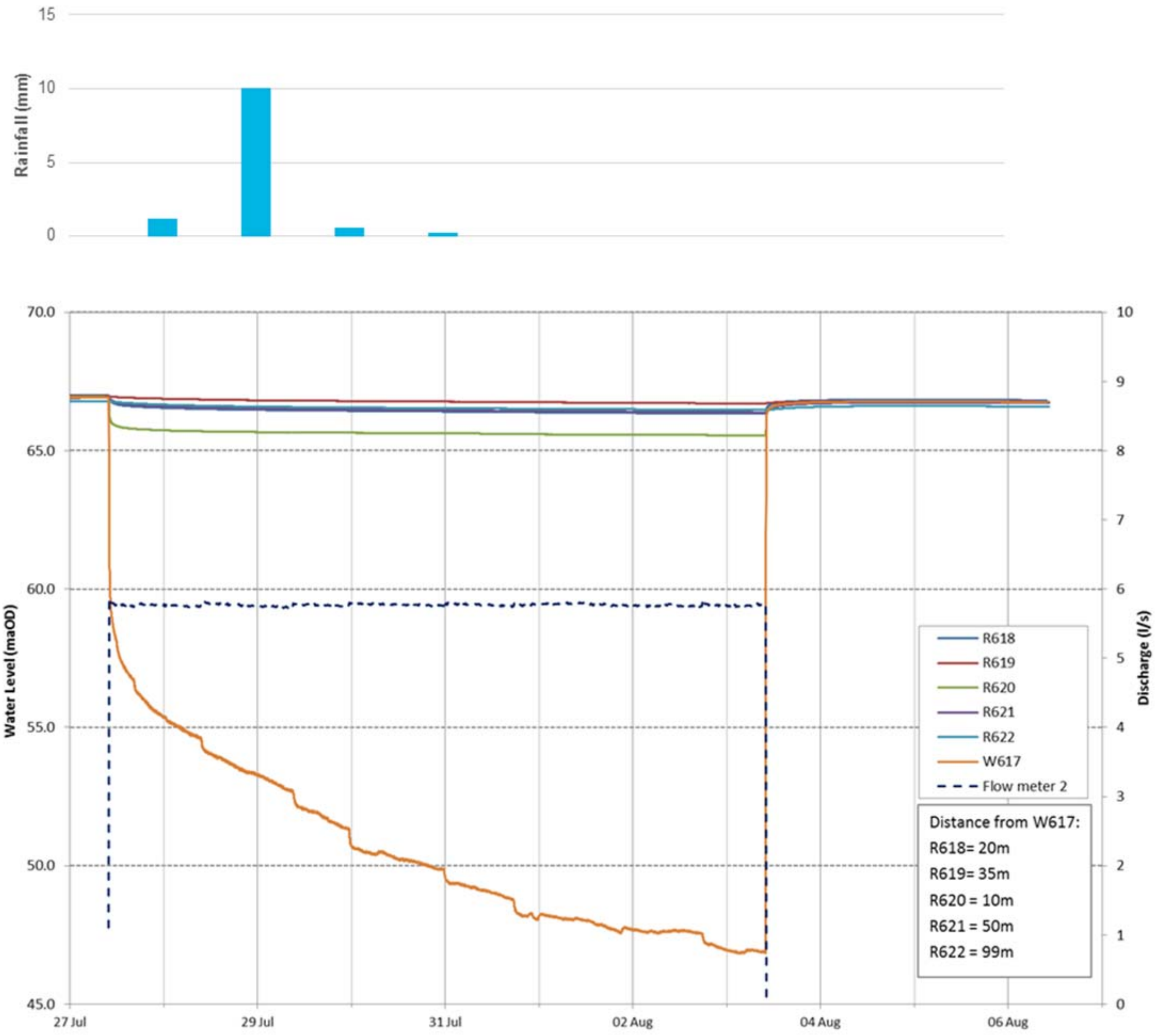


Figure 6.19 W617 Constant Rate Test Water Levels

6.3.9 It is clear from the drawdown curve in the pumping well that this is a very low yielding borehole. Levels had not stabilised by the end of the seven day constant rate test and the pumping rate was less than 25% of the rate contemplated in the design. The very high drawdown in the pumping well with relatively low drawdown in the observation boreholes is indicative of high well losses or of significant heterogeneity in the aquifer.

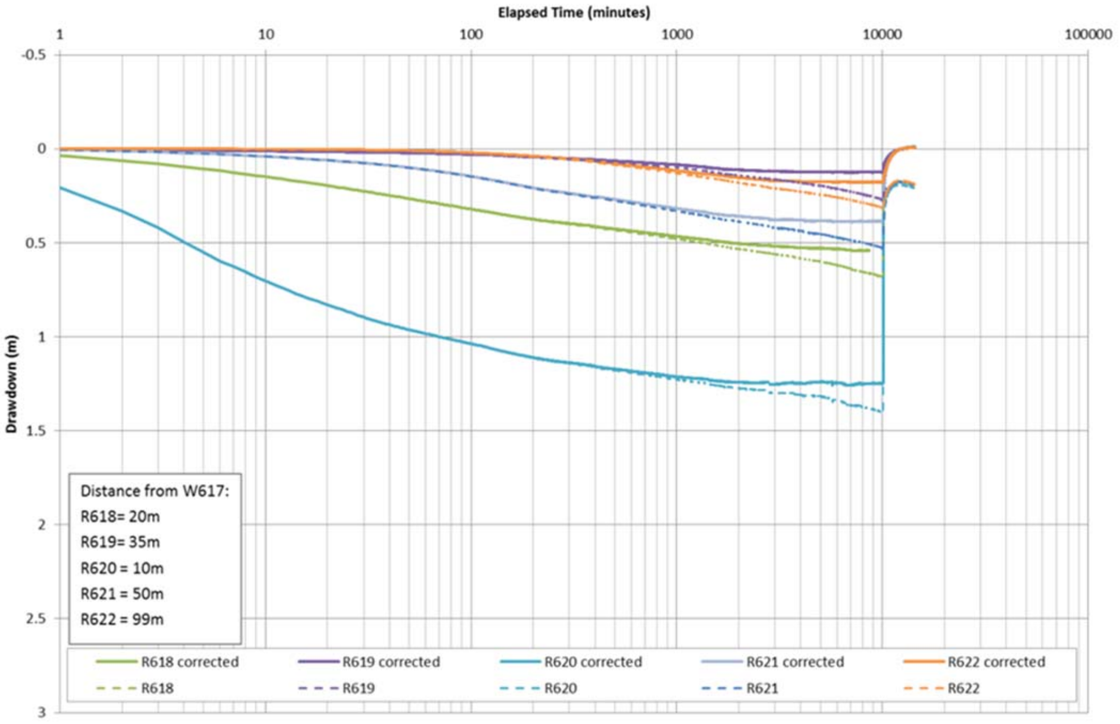


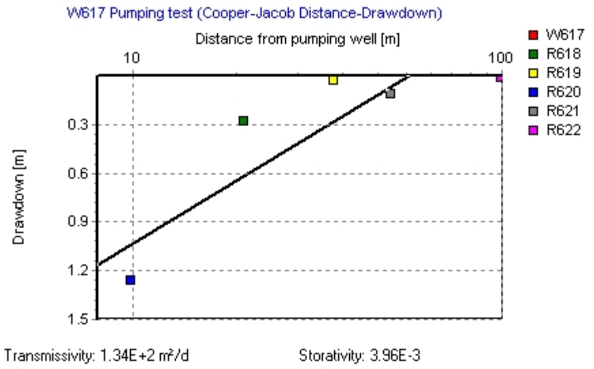
Figure 6.20 W617 Constant Rate Test Drawdown on semi log – Observation boreholes

6.3.10 In the first instance, distance-drawdown plots using data from all observation boreholes were analysed (Figure 6.21). The five data points showed a large scatter with a poor fit to the regression line which also gave a very low value of transmissivity compared with time-drawdown analyses. This was repeated for all times which were analysed. It is apparent that no single line can be fitted to all the data for this analysis.

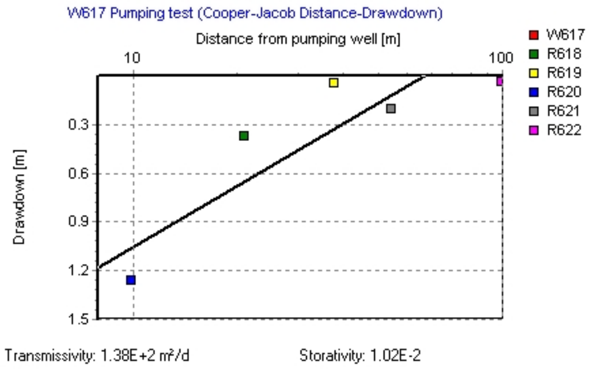
6.3.11 The Cooper-Jacob time-distance-drawdown plot shown in Figure 6.22 shows a wide range of drawdown responses implying significantly different values of transmissivity between each observation borehole. The W617 cluster was installed to provide north-south and east-west profiles (Figure 6.23) but it does not appear that the differences in implied transmissivity can be explained purely by anisotropy. Borehole R620 is located very close to the pumping well and showed a rapid drawdown. Whilst the amount of drawdown could be explained by a low transmissivity, boreholes further away from the pumping well along the same line do not support this. It is likely that this borehole response is due to a direct connection (fissure) between the pumping well and the observation borehole.

Cooper-Jacob distance drawdown (analysis using all available data)
t= 60, 180, 720, 1440, 4320 and 10000 minutes
Average transmissivity: 146 m^2/day
Average storage coefficient: 0.0996

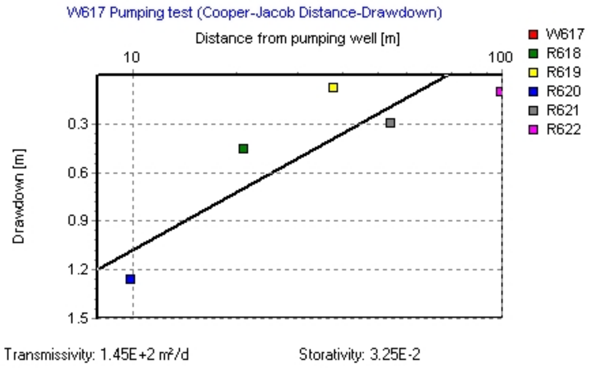
t=60



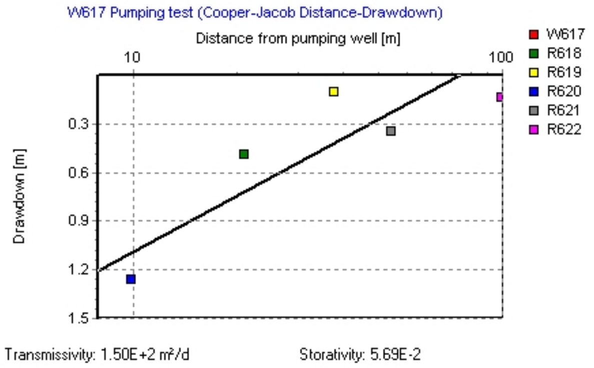
t=180



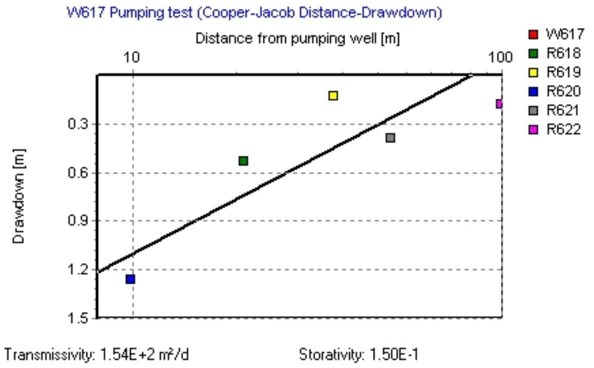
t=720



t=144-



t=4320



t=10000

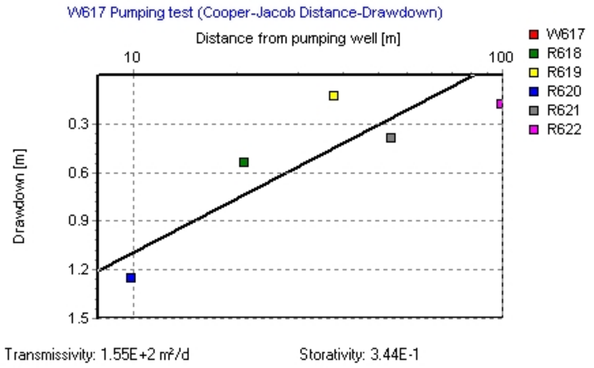


Figure 6.21 Cooper-Jacob distance drawdown analyses for W617 cluster, including all boreholes

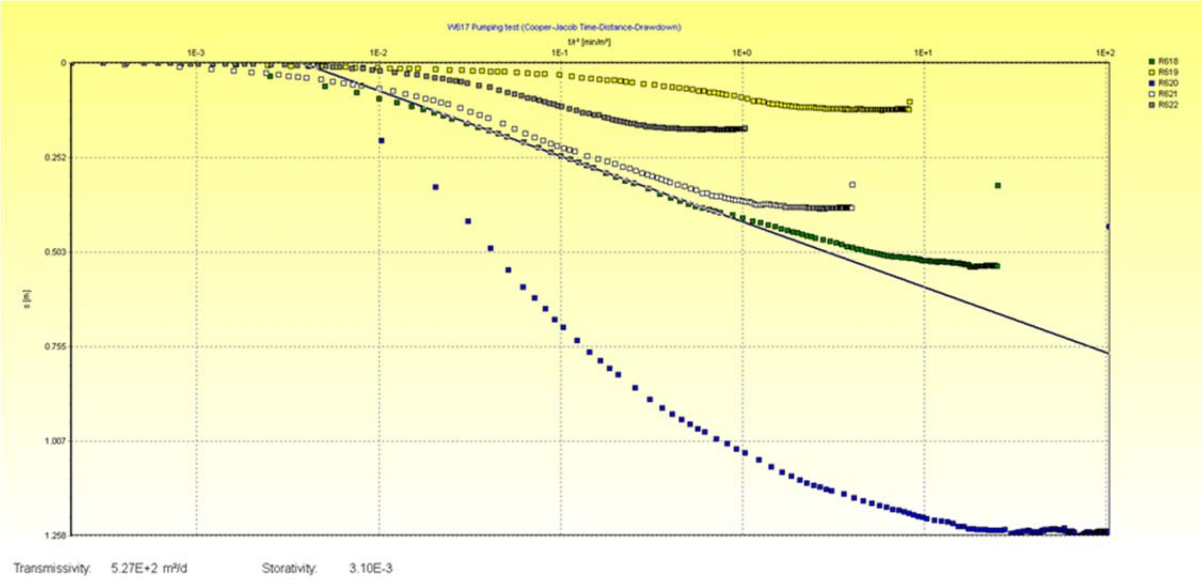


Figure 6.22 Cooper-Jacob Time-Distance-Drawdown Plot for W617 Constant Rate Test

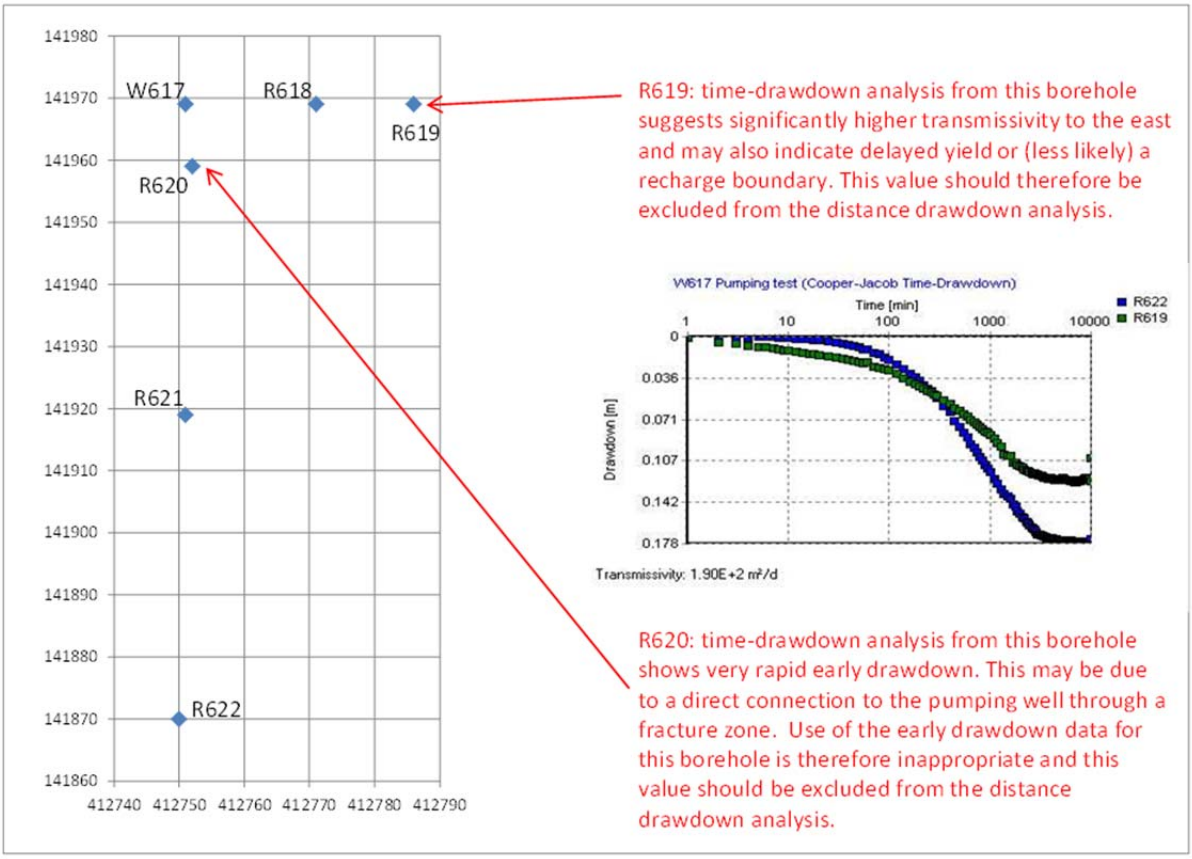
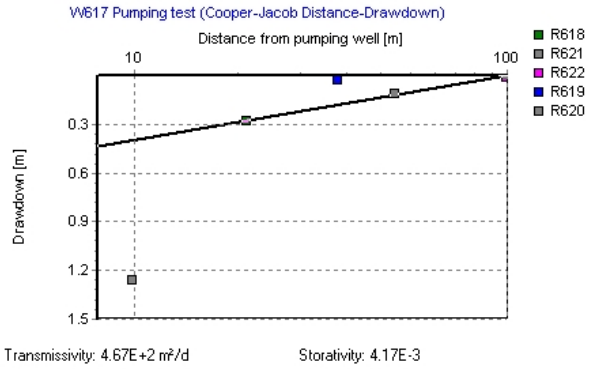


Figure 6.23 Locations of observation boreholes in the W617 cluster with plots of R619 and R622

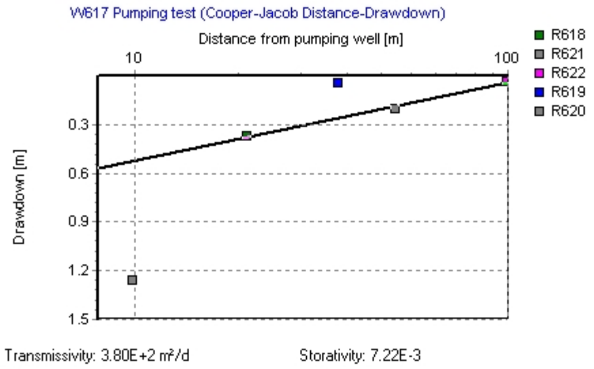
6.3.12 Borehole R619 showed a very different response, suggesting a much higher transmissivity towards the east. In Figure 6.23 it can be seen that the drawdown in R619 was initially greater than in R622, much further away. However, after approximately 3 hours of pumping, the drawdown in R622 exceeded that of R619. The drawdown in R619 flattened off after approximately one day, which could be explained by a recharge boundary towards the east, delayed yield, or a zone of higher transmissivity. Given the context of the dry valley, a zone of higher transmissivity is most likely.

Cooper-Jacob distance drawdown (removing R619 and R620)
t= 60, 180, 720, 1440, 4320 and 10000 minutes
Average transmissivity: 380 m^2/day
Average storage coefficient 0.0162 (eliminating early and late data - assumptions do not apply)

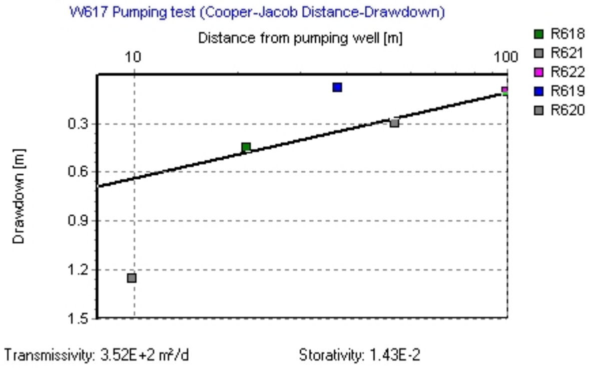
t=60



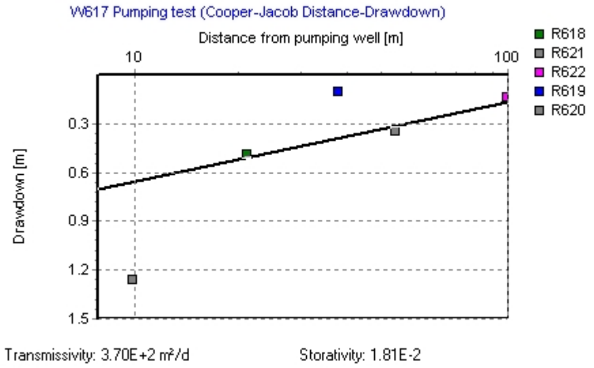
t=180



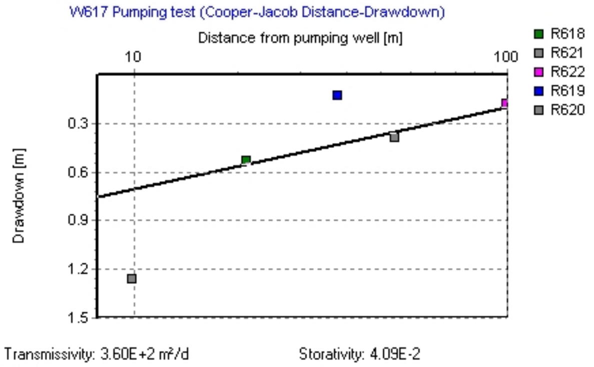
t=720



t=1440



t=4320



t=10000

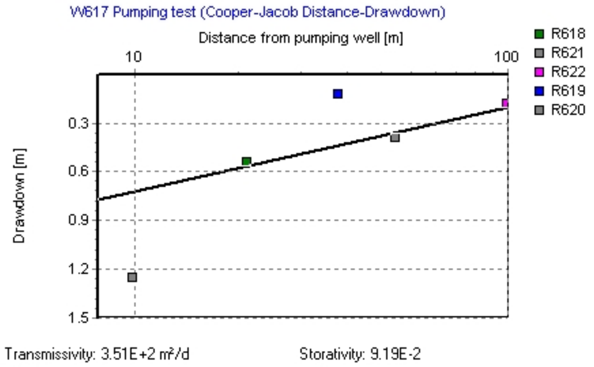


Figure 6.24 Cooper-Jacob distance drawdown analyses for W617 cluster, excluding R619 and R620

6.3.13 In the light of these observations, the distance-drawdown plot was recalculated, excluding data from R619 and R620 (Figure 6.24). This gave a better fit with the three remaining boreholes, although the implied transmissivity was still somewhat lower (380 m^2/day) than the values given by the time-drawdown analyses.

6.3.14 The aquifer parameters derived from each observation borehole are summarised in Table 6-12. The complete analyses are given in Appendix F. The frequency distribution of interpreted transmissivity values is shown in Figure 6.25 compared with previous tests undertaken in Stonehenge Bottom at W148 (located to the east of W617). The average of all values for the 2018 test in Stonehenge Bottom is approximately 660 m^2/day.

Table 6-12 Aquifer Parameters Derived from Pumping Test of W617

	Mean Transmissivity (m^2/day)	Storage coefficient
R618	624	0.0024
R619	1,253	0.0875
R620	293	0.0018
R621	543	0.0037
R622	778	0.0192
Distance-drawdown	380	0.0162

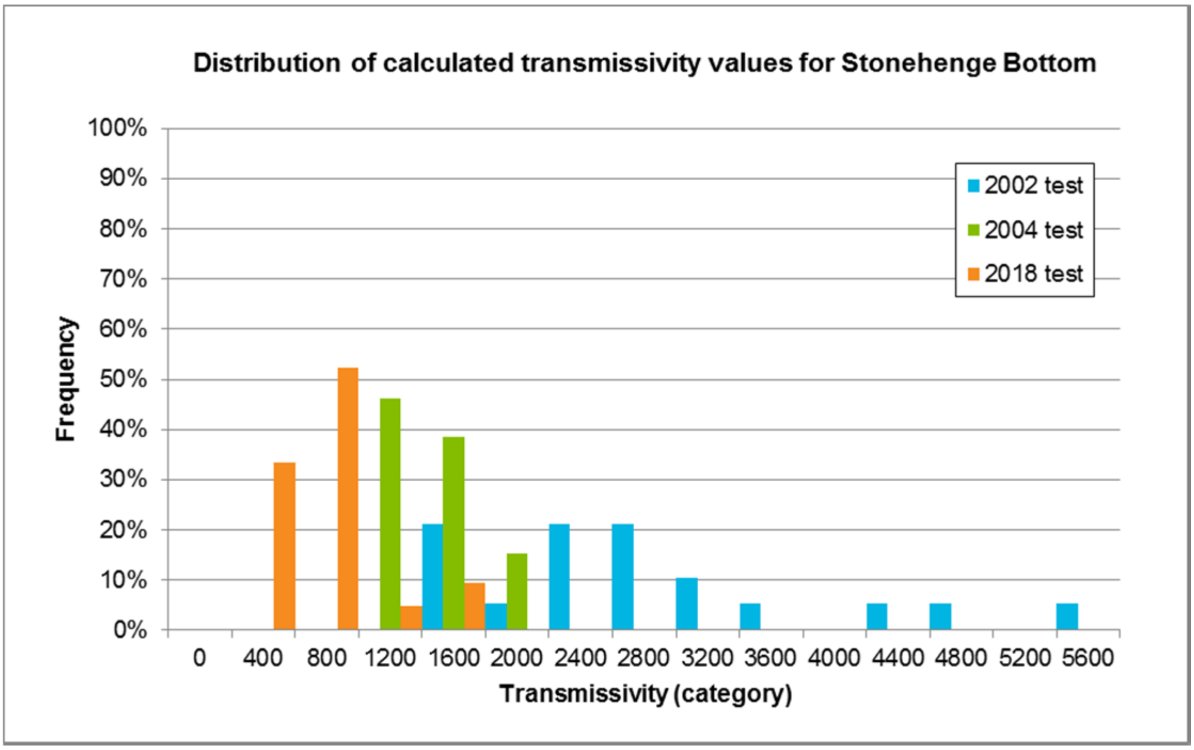


Figure 6.25 Frequency Distribution for all Transmissivity Values Calculated from W148 and W617 Pumping Tests

7 Groundwater Quality

7.1.1 Water samples were collected from the three pumping boreholes during the borehole development stage (or at the start of the Step-Test) and at the start and the end of the Constant Rate Test. A summary of the main determinands is presented in Table 7-1. PAH, TPH and Pesticides were below detection limit in all samples. The results of the full list of determinands tested is presented in Appendix G.

Table 7-1 Pumping Test Water Quality Summary

Sample ID			W623-Step test	W623-CRT1	W623-CRT2	W601-Dev.	W601-CRT1	W601-CRT2	W617-Dev.	W617-CRT1	W617-CRT2
Sample date	Units	LOD	07/06/18	12/06/18	19/06/18	13/06/18	10/07/18	17/07/18	12/07/18	27/07/18	04/08/18
Lab Physico-chemical and Ions											
Dissolved Oxygen	mg/l	<1	9	9	9	9	9	10	9	9	9
Dissolved Organic Carbon	mg/l	<2	<2	<2	<2	<2	3	2	<2	<2	<2
Electrical Conductivity @25C	uS/cm	<2	470	506	493	451	477	535	593	570	557
pH	pH units	<0.01	6.74	6.93	7.2	6.76	6.66	7.6	7.56	7.26	6.89
Total Dissolved Solids	mg/l	<35	400	408	415	349	386	486	359	368	340
Turbidity	NTU	<0.1	691	47.2	2.9	55.5	11.8	1.9	152	5.4	1
Sulphate as SO4	mg/l	<0.5	18.7	18.2	18.5	15	14.1	15.2	18.9	17.7	17.4
Chloride	mg/l	<0.3	16.1	16.8	16.4	20.1	19.4	18.6	27.7	24.3	21.6
Nitrate as NO3	mg/l	<0.2	34.5	28.2	33.4	8.5	31.8	36.8	31.7	30.2	30.9
Dissolved Alkalinity as CaCO3	mg/l	<1	240	240	232	212	218		232	238	242
Total Alkalinity as CaCO3	mg/l	<1	855	255	221	200	210	230	298	251	238
Bicarbonate Alkalinity as CaCO3 (water soluble)	mg/l	<1	855	255	221	200	210	230	298	251	238

Sample ID			W623-Step test	W623-CRT1	W623-CRT2	W601-Dev.	W601-CRT1	W601-CRT2	W617-Dev.	W617-CRT1	W617-CRT2
Sample date	Units	LOD	07/06/18	12/06/18	19/06/18	13/06/18	10/07/18	17/07/18	12/07/18	27/07/18	04/08/18
Metals											
Dissolved Arsenic	ug/l	<2.5	4	2.6	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Dissolved Beryllium	ug/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dissolved Boron	ug/l	<12	17	15	14	<12	<12	<12	15	15	27
Dissolved Calcium	mg/l	<0.2	96.3	95	101.4	90.3	97.8	97.1	108.1	97.3	102.2
Dissolved Iron	ug/l	<20	<20	22	<20	<20	<20	<20	<20	<20	<20
Dissolved Magnesium	mg/l	<0.1	1.5	1.5	1.4	1.2	1.1	1.1	1.4	1.3	1.3
Dissolved Manganese	ug/l	<2	<2	<2	<2	<2	<2	<2	12	<2	<2
Dissolved Phosphorus	ug/l	<5	7	6	5	6	<5	70	<5	9	9
Dissolved Potassium	mg/l	<0.1	0.5	0.5	0.5	0.3	0.3	0.4	0.8	0.8	0.9
Dissolved Sodium	mg/l	<0.1	8.1	7.6	7.4	8.5	7.9	7.6	16.9	13.2	12.7
Dissolved Zinc	ug/l	<3	40	38	72	5	43	56	7	105	110
Total Iron	ug/l	<20	1720	216	<20	62	25	<20	265	<20	<20
Total Phosphorus	ug/l	<5	459	75	23	183	67	93	71	29	34
Total Zinc	ug/l	<3	65	43	52	8	27	53	18	68	101

7.1.2 Water samples collected during borehole development or the early stage of the step-test showed high turbidity. As the test progressed, the well further developed and turbidity decreased. Total concentrations became closer to the dissolved concentrations, as would be expected when the concentration of suspended solids decreases.

7.1.3 The concentration of dissolved substances generally decreased with pumping. The exception being dissolved zinc which increased with pumping time and a higher phosphorus concentration at the end of the test at BH601.

7.1.4 The major ions analysed from the samples from the three abstraction boreholes were plotted in a Piper diagram against samples collected within the catchment in April 2018. As expected the water samples from the pumping test present a similar calcium bicarbonate (Ca-HCO_3) signature to those collected in the catchment.

7.1.5 Water quality monitoring is continuing.

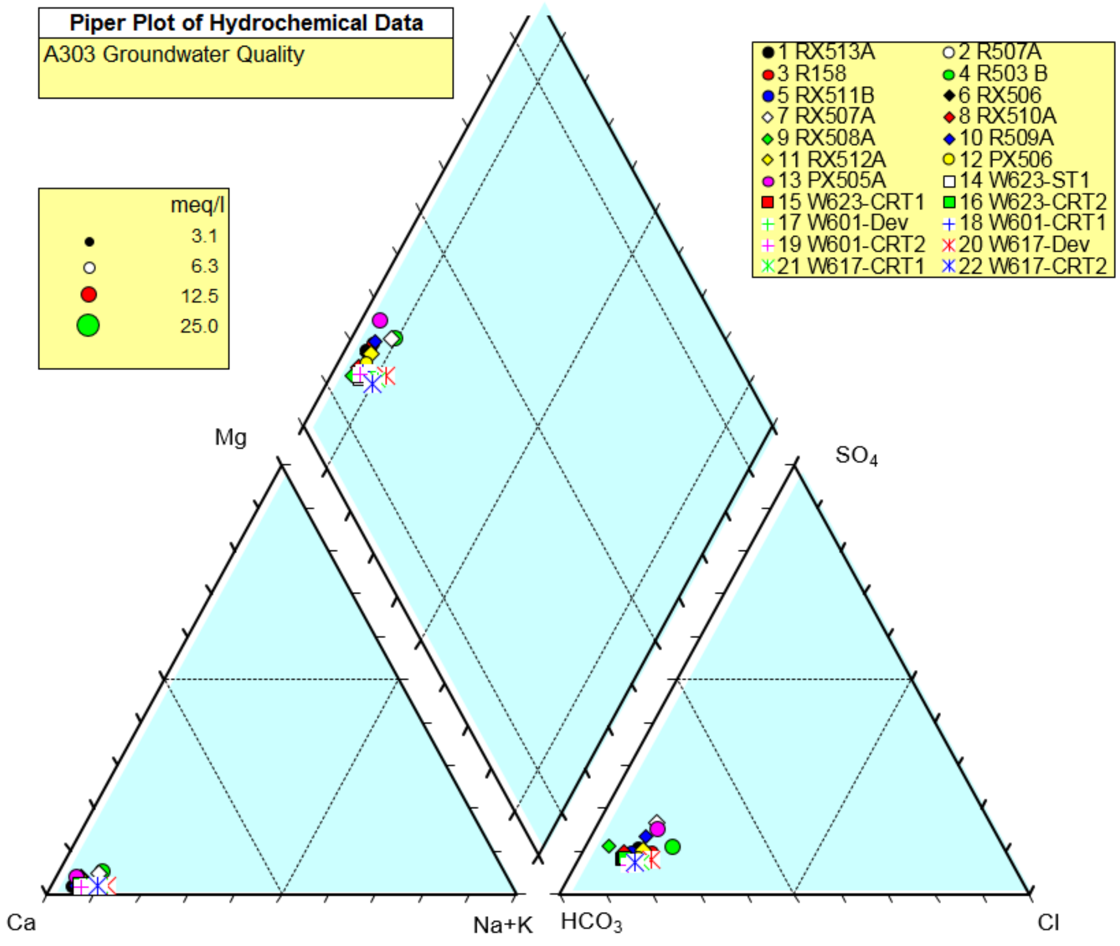


Figure 7-7.1 Major ions analysed from the samples from the three abstraction boreholes with samples collected within the catchment in April 2018

8 West Amesbury Spring

8.1.1 Visual monitoring of West Amesbury Spring (Drawing 4) was undertaken at least daily during all pump test activities. Thirty second videos were recorded from the same observation point. No change in flow was observed during the whole duration of the pump tests.

9 Summary

9.1.1 Water level monitoring indicated that a natural recession of groundwater levels occurred throughout the period of the pumping tests in 2018.

9.1.2 The constant rate test on borehole W623 was undertaken at 24.8 l/s with a maximum drawdown of 3.8 m in W623. There appears to be a higher transmissivity area to the north east of the pumped well.

9.1.3 The constant rate test on borehole W601 was undertaken at 23.3 l/s with a maximum drawdown of 17.5 m in W601. The drawdown rates in the pumping borehole seemed to be influenced by the presence of a fracture/void at 62 mAOD and there is strong evidence of variable hydraulic conductivity with depth.

9.1.4 The constant rate test on borehole W617 was undertaken at a much lower abstraction rate than the two other tests at 5.8 l/s with a maximum drawdown of 20.1 m in W617. This borehole appears not to intercept a high transmissivity zone in the valley floor but there appears to be a higher transmissivity zone to the east where previous testing of W148 in 2002 and 2004 gave high values of transmissivity.

9.1.5 A summary of the hydraulic properties of the Chalk aquifer derived from the analysis of the three pumping tests is provided in Table 9-1.

Table 9-1. Summary of pumping test results - average (and range of transmissivity)

Pumping Borehole	Transmissivity	Storage coefficient
W623 Coneybury Hill	800 m^2/d (319 - 1,750 m^2/d)	1.5 x 10^{-3}
W601 Stonehenge Down	435 m^2/d (348 - 617 m^2/d)	3.2 x 10^{-3}
W617 Stonehenge Bottom	660 m^2/d (134 - 2,320 m^2/d)	1.7 x 10^{-2}

9.1.6 The groundwater samples collected from the pumping tests present a similar calcium bicarbonate (Ca-HCO3) signature to samples collected in the catchment. Water quality parameters remained generally stable throughout the tests except for turbidity which decreased with pumping, dissolved zinc which increased with pumping time and a higher phosphorus concentration at the end of the test at BH601.

9.1.7 Whilst water level and water quality monitoring is ongoing in the catchment to inform the development of the detailed design for the Scheme, the results of the testing in this report does not change the conclusions of the GRA or the ES.

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