HATFIELD ROAD QUARRY

Pumping Test Assessment Report

DRAFT

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SLR

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1.0 Introduction

SLR Consulting Ltd (SLR) was retained by Robert Brett & Sons Limited (Brett) to design, supervise and report on aquifer tests completed at the Hatfield Road Quarry (the "site"). The tests were required to inform future development planning and satisfy details required by the Environment Agency in support of an application for a Water Resources Abstraction Licence. Works were conducted in general accordance with the work plan submitted to Brett on March 15th, 2018 included in **Appendix 01**. The basic tasks included:

- Drilling of a shallow borehole (PW1) to 8.5m below ground level (bgl) and install a well screen and riser pipe in the upper mineral aquifer (UMA);
- Drilling of a deeper borehole (PW2) through the UMA and clay interburden (Anglian Till) to 19m bgl and install a well screen and riser in the lower mineral aquifer (LMA). A piezometer was also place in the annulus of the borehole across the UMA for water level monitoring;
- Development of both wells;
- Undertaking a series of pumping tests in each aquifer to assess well and aquifer performance.

WJ Groundwater Ltd (WJ) was awarded the contract to construct the wells and complete the aquifer tests in April 2018. WJ subcontracted the drilling and installation of the wells to BH Drilling Services (BH).

The boreholes were advanced and completed under the direction of SLR between 22nd and 25th of May 2018. The testing programme, including mobilisation and deployment of infrastructure (piping etc.), aquifer testing, and demobilisation was completed between May 26th and June 20th, 2018. A photolog documenting works is available in **Appendix 02**.

1.1 Location

PW1 and PW2 were installed adjacent to existing monitoring wells (BH107U, BH107D, BH107C) located near the centre of the proposed mineral site, as shown on DWG 1 included in the work plan (Appendix 01). The as-built well layout is shown Drawing 1**.**

1.2 Consent

Consent to Investigate a Groundwater Source (TP 18/005 & TP 18/006) was issued to Brett Group Limited by the Environment Agency on 10th May 2018 and are included in **Appendix 03.**

2.0 Methodology

2.1 Drilling

Drilling and installation was supervised by an SLR geologist who recorded a continuous, descriptive geological and hydrogeological log of all aquifer and aquitard materials in general accordance with BS 5930 a2 2010.

The boreholes were constructed using a Dando 3000 cable percussion rig operated by BH Drilling Services. This technique advances steel casing as the borehole proceeds to prevent collapse. Soils are removed using a “clay cutter” for cohesive soils and a bailer for gravels and other non-cohesive materials.

PW1 was advanced through the overburden and UMA using a nominal 10’’ diameter steel casing and terminated 1m into the underlying interburden unit, a total depth of 8.5m bgl.

PW2 was advanced using a nominal 12’’ casing which was terminated 1m into the top of the interburden unit. A 1m thick bentonite seal was placed in the interburden and nominal 10’’ casing was then advanced through the 12” casing and through the LMA and 1.5m into the underlying chalk, a total depth of 19m bgl.

This aquifer protection methodology minimises the potential for hydraulic connection between the UMA and the LMA.

2.2 Well Installation

Upon completion of the boreholes the wells were constructed using Boode Select PVCTM well screen and casing with the following specifications:

- PW1 comprised of a 165 mm OD PVC plain pipe connected to a 165 mm OD vertically slotted screen (slot size 1mm) from 7.0m to 2m bgl;
- PW2 comprised of a 200 mm OD PVC plain pipe connected to a 200mm OD vertically slotted screen (slot size 2mm) from 17.3m to 10.3m bgl;
- PW2-A comprised a 19mm diameter slotted pipe installed from 7m to 2m bgl. PW2-A was installed to allow for another measuring point in the UMA.
- Each abstraction was constructed with a length of capped plain pipe below the well screen to act as sump in which pumps could be installed to increase available drawdown.

The sumps were backfilled with bentonite after which a clean graded silica sand pack was placed around each well screen to approximately 0.3 metres above the screened interval. A 1-2mm pack was placed around the screen in PW1 and a 2-3 mm sand pack around PW2. Slot size and sand pack grade were selected based on the grade of aquifer materials identified in each unit. Bentonite seals were then installed above each sand pack to surface.

In PW1 the bentonite seal extended to within 0.5m of grade after which it was backfilled with cuttings.

In PW2 the bentonite seal extended to the top of the interburden unit with a sand pack installed adjacent to PW1-A between 7m and 2.0m of ground surface. A surface bentonite seal was then installed to within 0.5m of grade.

The casing of each well was extended above ground approximately 0.5m with an appropriately sized steel security casing with padlock. The security casings were installed after the pumping tests were completed.

The borehole logs are included in **Appendix 04** and the borehole and monitoring well locations are illustrated on **Drawing 1**.

2.3 Well Development

PW1 and PW2 were 'developed' after installation to maximize well efficiency by removing fines introduced to the well after installation and remove/stabilise fines adjacent to the well bore. Development was conducted utilizing a dual pipe eductor system in which a column of air is injected into an air pipe within a 4'' diameter eductor pipe. This air then displaces water in the hollow centre of pipe thereby creating a vacuum for additional well water to enter the base of exterior eductor pipe. Continued introduction of air continues the process of displacement at the surface.

Development in each well continued for at least 3 hours and included several interruptions when the system was turned off to effectively "surge" the well and formation. The wells were considered developed when discharge water settled in an Imhoff Cone indicated the presence of < 15ppm of entrained fines. Drawdown within the well during development was also measured to gain initial estimates of potential yields.

2.4 Pumping Infrastructure

Pumped water was discharged into a historical 'lagoon-like' feature (approximately 50m x 20m x 4m deep) situated approximately 600m to the northeast of the pumping wells. This legacy lagoon feature originates from early investigations conducted by others around 2000-2001 and is presently heavily vegetated with trees and shrubs. Water was delivered to the lagoon during the testing through 100mm diameter Bauer® pipe deployed in 6m lengths and connected via closure ring couplings, with each coupling also secured with a zip fastener. The pipe was buried at two vehicle crossing points.

The discharge pipe was modified south of the lagoon to provide a discharge diversion for flow to the culverted River Nast in the event the lagoon reached capacity **(Drawing 1).**

Each abstraction well was equipped with a designated Grundfos® downhole pump capable of delivering yields up to 10 L/s. Flow rates were controlled via a geared gate valve and flow rates were measured in real-time via a Siemens® electromagnetic flow meter installed immediately up-flow of the controlling gate valve. The flow meter was wired into WJ's on site data logger unit. Backflow after well shutdown was prevented by inline ball valves.

The site data logging unit was remotely connected via a telecom link to WJ's office so that data could be uploaded in real time.

2.5 Equipment Test

After development, equipment tests were conducted to ensure all apparatus (pumps, flow meters, Data logger etc) was functioning correctly. The equipment tests involved pumping each well to a maximum predicted sustainable flow rate attained from development. The tests were conducted at 3L/s in PW1 and 8 L/s in PW2 for a short time period.

2.6 Water Level Monitoring

The following wells were monitored for the durations of field works:

- PW1 (UMA)
- PW2 (LMA)
- PW2A (UMA)
- BH101-U, BH101-L, BH101-C (UMA, LMA, Chalk)
- BH102-U, BH102-L, BH102-C (UMA, LMA, Chalk)
- BH107-U, BH107-L, BH107-C (UMA, LMA, Chalk)
- GMW112 (UMA)
- GMW113 (UMA)
- GMW114 (UMA)
- BHF (UMA)
- BHU (UMA)
- BHG (LMA)
- Discharge Lagoon and adjacent BHA (UMA)

Water levels in the PW1, PW2, BH107-U, BH107-L and BH107-C were recorded by Geosense ® VWP, vibrating wire loggers which were also wired directly into the on-site data logging unit.

Recording intervals varied depending on the interval of the well test. During the first 5 minutes of a test water levels were recorded every 30 seconds. During advanced periods of the tests, water levels were recorded every 5 minutes.

Additional monitoring wells were equipped with a Solinst Levelogger® which recorded water levels which were later compensated for barometric changes with an onsite Barologger®. Each of the wells was also manually dipped at least twice daily to confirm logger accuracy and calibration points.

2.7 Bromate/Bromide Sampling

Water samples were obtained from the PW1 and PW2 well heads twice daily during the constant rate tests. Samples were submitted to Affinity Water (Affinity) for bromate and bromide on a 24-hour turnaround basis.

2.8 Step-Drawdown Tests

Step-drawdown tests were conducted in each well prior to the constant rate tests to investigate well performance (Efficiency and Specific Capacity) under variable discharge conditions. The results were also used to finalise the rate used during the constant discharge tests.

During the step-drawdown tests, the discharge rate was incrementally increased from an initial low rate through a sequence of 4 pumping intervals (steps) of progressively higher constant rates (0.25_{max}, 0.5_{max}, 0.75_{max}, Q_{max}). Each step lasted 100 minutes after which the pump was stopped and well recovery monitored.

A second step-drawdown test was undertaken in PW2 after the constant rate test was concluded. This was due to sand ingress into PW2 at the highest flow rate which interfered with accurate water level measurement, plus an electronics malfunction with the central data logging unit resulted in some data loss. It was therefore determined by SLR and WJ that the test should be repeated. The flow rates are shown in Table 2-1 below.

Table 2-1
Step- Drawdown Test Flow Rates (Litres/Second)

	PW1 (UMA)	PW2 (LMA)	PW2 (Test 2) (LMA)
Step 1	0.6	2.2	2
Step 2	1.2	4.4	4
Step 3	1.8	6.6	6
Step 4	2.4	8.8	8

2.9 Constant Rate Tests

Constant rate tests were conducted in each well on the day following their respective step tests. During each test the aquifer was pumped for a 72-hour period at a constant rate determined to be sustainable for the duration of the test. The target rate for PW1 was set at 1.6 L/s and PW2 at 6.0 L/s. Upon completion of the pumping period the pumps were stopped, and the recovery phase monitored.

All water pumped from the wells was discharged into the infiltration lagoon except for water pumped during the second PW2 step test which was discharged into the River Nast culvert.

Appendix 05 contains hydrographs for the PW1 and PW2 pumping tests illustrating the complete testing period (step test and constant rate tests), including the pumping rates on the second graph axis.

3.0 Geology and Groundwater Occurrence

3.1 Geology

Both aquifers at the investigation location were similar in character to those observed elsewhere across the site. The geological sequence encountered in PW1 and PW2 is set out in Table 3-1.

Table 3-1
Geological Sequence

Depth (m bgl)	Lithology	Thickness (m)	Base Elevation (m AOD)
0 - 0.3	**Top Soil** - Brown silty SAND with frequent organics, loose, dry.	0.3	77.0
0.3 - 1.2	**Made Ground & Overburden**: Brown clayey SILT with some sand and gravel. Gravel consists of chalk and asphalt, dense, moist.	0.9	76.1
1.2 - 6.9	**Upper Mineral Horizon**: sandy GRAVEL from 1.2 to 3.0m changing to a 0.5m thick clay SILT bed from 3.0-3.5mbg. Fine to medium SAND from 3.5 to 6.9 m. Saturated at 2.8m.	5.7	70.4
6.9 - 9.0	**Interburden**- grey CLAY and SILT with some gravel, very stiff, moist.	2.1	68.3
9.0 - 18.05	**Lower Mineral Horizon**- sandy GRAVEL, with rare cobbles. Brown sandy gravel with clay from 9.0-9.8m. Silty SAND with clay layer from 11.9-12.3m. Medium to coarse sand layer from 13.9-14.5m.	9.05	59.25
18.05	**CHALK**- Recovered as grade Dc chalk cobbles.	Unproven	Unproven

3.2 Groundwater Occurrence

A groundwater strike was recorded in the UMH at a depth of 2.4m. This represents the piezometric surface of the UMA. Saturated conditions continued to the base of the UMH at the interface with the interburden (6.9m bgl) being the UMA perching layer. The saturated thickness of the UMA was therefore 4.5m.

The UMA is an unconfined aquifer (atmospheric pressure exists at the water table surface) that is perched upon a regional aquitard consisting of stiff clay and silt (the interburden) also referred in literature as the Anglian Till. The surface of the interburden dips to the north-east and along with locations of aquifer recharge and discharge the dipping surface of the interburden influences the aquifers lateral flow direction.

In June 2018 the water level in the UMA was at a depth of 2.48m bgl but has previously been recorded at 1.058m bgl in BH107U (March 2014), meaning the saturated thickness of the aquifer can vary quite significantly between 4.5m (currently) and approximately 6m (March 2014).

A groundwater strike was also recorded in the LMH at a depth of 9.9m, which is 0.9m below the base of the interburden. This water strike represents the unconfined piezometric surface of the LMA. Saturated conditions continued to the base of the LMH and into the chalk bedrock underlying the LMH. The saturated thickness of the LMA was therefore 8.15m but is far greater if the underlying chalk aquifer is included.

In June 2018 the water level in BH107L was at a depth of 9.9m bgl but has previously been recorded at 8.14m bgl (May 2014), meaning the saturated thickness of the aquifer can increase but also that the aquifer is then confined by the interburden at this site location. This feature of seasonal change in groundwater levels will be exploited by Brett in the future to avoid groundwater pumping.

4.0 Pumping Test Analysis

4.1 Step- Drawdown Tests and Well Performance

Step-Drawdown Tests were conducted prior to the constant rate test in both PW1 and PW2 to assess well performance (efficiency) and potential yield.

Well inefficiencies are a result of head losses arising because of turbulent flow close to and across the well screen that result in drawdown in the well which is unrepresentative of the head in the aquifer. Head loss reduces the amount of drawdown available and therefore yields but also increased drawdown requires larger pumping lifts which results in additional energy costs.

Under low flow conditions flows to the well are generally laminar (Darcy flow) and well losses are minimal, with inefficiencies increasing with pumping rate. Wells which perform over 80% are generally considered very efficient.

4.1.1 PW1 – Upper Mineral Aquifer

PW1 was determined to be very efficient (>90%) during the first three steps with a significant drop-off observed when pumped at 2.4 L/s. During the first three steps the Specific Capacity (Sc) was between 0.78 L/s/m and 0.85 L/s/m whereas the 4th step resulted in a reduction to 0.6 L/s/m. This is because the drawdown in the 4th step resulted in less than 1m of saturated screen which was unable to efficiently transmit the volume of water being pumped. During higher aquifer periods with more available drawdown it is likely that PW1 will deliver 2.4 L/s very efficiently. Step test results are shown in Table 4-1 and in **Appendix 06 (Figure 1)**.

Table 4-1
PW1 - Step Test Results and Analysis

PW1	Flow Rate (L/s)	Observed Total Drawdown (m)	Calculated Drawdown at 100% Efficiency (m)	Actual Efficiency %	Specific Capacity (Sc) (L/s/m)
Step 1	0.6	0.7	0.7	100.0	0.83
Step 2	1.2	1.4	1.4	100.0	0.85
Step 3	1.8	2.3	2.2	94.4	0.78
Step 4	2.4	4.0	2.9	72.2	0.60

4.1.2 PW2 – Lower Mineral Aquifer

Considerably more drawdown was available in PW2 than in PW1 so the inefficiencies which affected PW1 at higher rates were not observed. The well was found to be very efficient (>85%) at all pumped rates and the well delivered between 2.16 L/s/m and 2.53 L/s/m. Given the drawdown available the well would likely remain very efficient at 10 L/s. Step test results are shown in

Table 4-2 and Appendix 06 (Figure 2).

Table 4-2
PW2 Step Test Results and Analysis

PW2	Flow Rate (L/s)	Observed Total Drawdown (m)	Calculated Drawdown at 100% Efficiency (m)	Actual Efficiency %	Specific Capacity (Sc) (L/s/m)
Step 1	2.0	0.8	0.8	100.0	2.53

PW2	Flow Rate (L/s)	Observed Total Drawdown (m)	Calculated Drawdown at 100% Efficiency (m)	Actual Efficiency %	Specific Capacity (Sc) (L/s/m)
Step 2	4.0	1.7	1.6	92.5	2.34
Step 3	6.0	2.7	2.4	89.0	2.25
Step 4	8.0	3.7	3.2	85.4	2.16

4.2 Aquifer Properties

Estimations of the aquifer's hydraulic properties (Transmissivity (T), Storativity (S) and Hydraulic Conductivity (K)) have been calculated using a variety of analytical solutions that typically comprise matching time-drawdown measurements with curves created by an in analytical model. The hydraulic parameters (T, S) controlling the matching curves are varied within the model (AQTESOLV®) to result in a best fit with the field data. The model curves also differ for a variety of hydrogeological conditions (unconfined, confined, leaky, partial penetration and more).

It is worth noting that both aquifers contain interbeds of clays and silts (some around 0.5m thick) which serve to semi-confine each unit, and which we believe could be influencing the analysis of the tests.

4.2.1 Upper Mineral Aquifer (UMA)

The response of the UMA to pumping in PW1 was monitored at three locations: PW1, PW2-A and BH107-U. PW2A and BH 107 are located 5m and 15m away from PW1 respectively (DWG 1). Pumping at a constant rate of 1.6 L/s induced a total drawdown of 2.51m over 72 hours after which near equilibrium conditions were attained. Drawdowns of 1.25m and 0.91m were recorded in PW2-A and 107-L respectively (see hydrograph in **Appendix 05**).

Some limited drawdown was also observed in the more distant monitoring wells BHF, BHH, BH101, GMW112 and GMW113 located between 225m and 330m from PW1. The observed maximum drawdowns in all monitored wells in the UMA are shown in Table 4-3.

Table 4-3
Observed Drawdowns during PW1 Constant Discharge Rate Test

Wall/ Piezometer	Distance from PW1 (m)	Water level 09:00 05/06/18 (mAOD)	Water level 09:00 08/06/18 (mAOD)	Drawdown (m)
PW1	0	74.28	71.77	2.52
PW2A	5.1	74.29	73.04	1.25
BH107S	15	74.45	73.52	0.93
BHFU	225	73.45	73.26	0.19
BHHU	254	73.67	73.44	0.22
BH101U	288	74.93	74.72	0.20
GMW113	317	74.76	74.67	0.10
GMW112	329	74.26	74.17	0.09

Transmissivity (T) and Storativity (S)

Step Test

Transmissivity has been calculated using the Theis solution for the step test data (drawdown and recovery) recorded from PW1 and from BH107S. Both time-drawdown cures are plotted on a log-log graph (**Appendix 06, Figure 3**) with model curves matched to the field data. The upper curve is PW1 and the lower is BH107S.

A very good curve match to the recorded drawdown data can be seen (the blue lines) which equates to:

Transmissivity (T) = 78m^2/d

Storativity (S) = 0.002

Hydraulic Conductivity (k) = 18.8m/d[1]

Appendix 06, Figure 4 represents the drawdown and recovery during the constant discharge test for PW1, PW2-a and BH107S calculated using the Neuman (1973) unconfined aquifer equation. A good curve match has been produced with the following results:

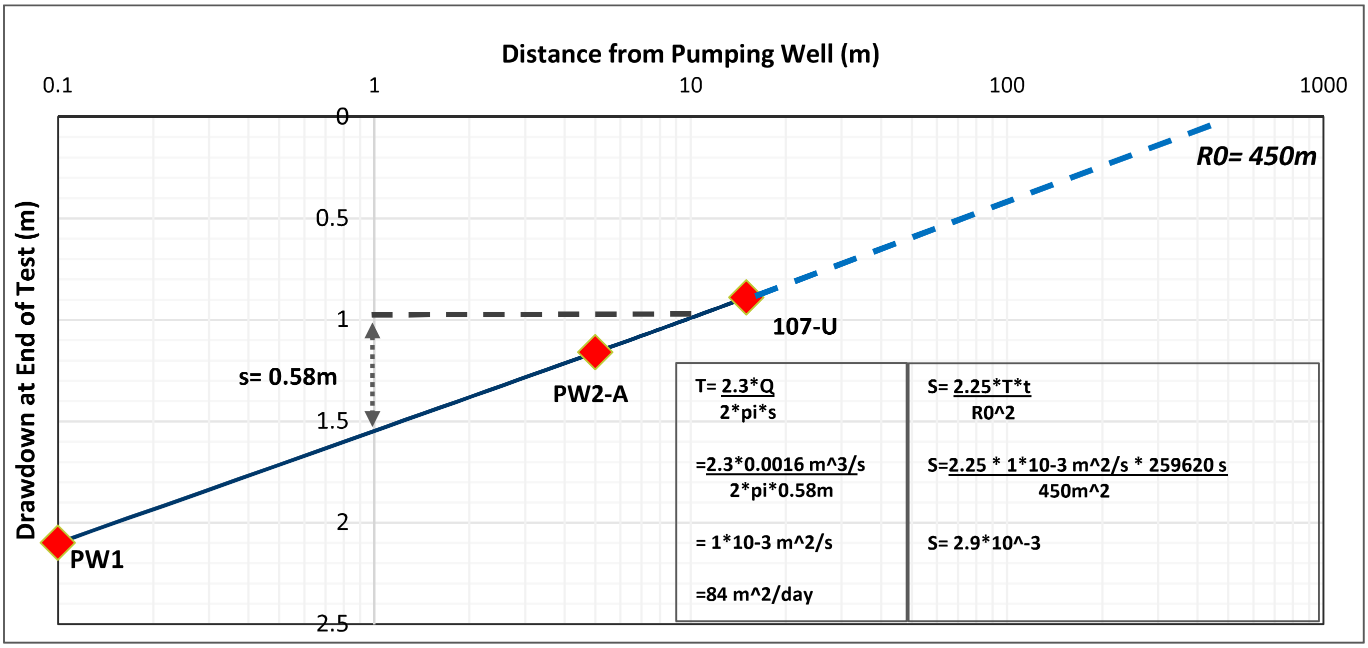
Transmissivity (T) = 79m^2/d

Storativity (S) = 0.002

Hydraulic Conductivity (k) = 19.0m/d

The results were also analysed graphically using the Cooper-Jacob Distance-Drawdown method illustrated on Figure 4-1. The calculated T and S agreed with the AQTESOLV solutions at 84m^2/day and 2.9x10^{-3} m^3/ m^2/ m, respectively. These numbers are typical of fine to medium sands.

Figure 4-1
Cooper-Jacob Distance-Drawdown plot for Constant Rate Test in PW1



Using a variety of unconfined and confined solutions a Storage coefficient (S) of between 2x10^{-3} m^3/ m^2/ m and 2.9x10^{-3} m^3/ m^2/ m was attained. In an unconfined aquifer (like the UMA) it would be expected that the storage

[1] K = T/b (where b = saturated thickness of the aquifer, which is 4.15m)

value would be considerably higher and approximate the aquifer's Specific Yield (Sy) and effective porosity (generally between 0.1 and 0.3).

The calculated low S value is possibly because of the semi confining influence of the fine-grained beds within the unit which are inducing an elastic storage release response over at least some of the drawdown interval.

Radius of Influence (R_0)

R_0 is a measurement of the theoretical radius of influence induced by the pumping test. An R_0 value of 450m was obtained using the Cooper-Jacob method (Figure 4-1), but there is a lack of data points between 10m and 200m which reduces the confidence in this R_0 value.

Limited drawdown was observed in BHFU, BHU and BH101 (225m, 254m and 288m distant) at 0.19m, 0.22m and 0.20m respectively, which may represent a mixture of induced drawdown and the regional fall of UMA water levels. Based on a measured fall of 0.09m in GMW112 located 329m SE (down gradient) of PW2 we might expect at least 50% of the water level change in BHF and BHU to be due to regional falls in the aquifer. This means that although the calculated R_0 value is 450m this represents the absolute upper distance that any drawdown effect should be anticipated and is likely to be much less, closer to 300m – 350m.

4.2.2 Lower Mineral Aquifer (LMA)

Aquifer response to pumping adjacent to PW2 was measured at two locations within the LMA (PW2 and 107-L) and at one location within the underlying chalk (107-C). Both 107-L and 107-C are situated 10.3 m from PW2 and installed as a nested pair of wells within the same borehole.

Pumping at a constant rate of 6.0 L/s induced a total drawdown of 3.1m over 72 hours in PW2. Over the same period 1.02m of drawdown was observed in 107-L and 0.42m in 107-C, with limited drawdown (0.15m) in BHG located 215m from PW2.

Some water level drop was observed in BH101 in both the LMA and the chalk but given there was no difference between the two monitored intervals it is possible this reflects a background fall in aquifer water levels, i.e., not related to the pumping test. In addition, very little recovery was observed after the test concluded. The maximum drawdown results for the PW2 constant rate test are presented in Table 4-4.

Table 4-4
Observed Drawdowns in during Constant Rate Test (PW2)

Wall/ Piezometer	Distance from PW1 (m)	Water level 09:00 05/06/18 (mAOD)	Water level 09:00 08/06/18 (AmOD)	Drawdown (m)
PW2	0	66.89	63.84	3.05
BH107L	10.3	67.28	66.31	0.97
BH107C (Chalk)	10.3	67.32	66.90	0.42
BHGL	215	66.97	66.81	0.15
BH101L	293	66.66	66.60	0.07*
BH101C (Chalk)	293	66.71	66.64	0.07*

*Interpreted to be background fluctuation.

Conceptual Model

The LMA differs to the UMA in that the aquifer comprises approximately 9m of saturated sand and gravel above approximately 100m of fully saturated Chalk. Although a slight vertical gradient is frequently recorded between water levels in the two geological intervals they fundamentally have a common piezometric surface implying they hydraulically behave as a single aquifer.

Although the geological unit is estimated at 100m thickness, based on conversations with Affinity Water, it is more likely that the 'contributing portion' of the chalk aquifer is less than the measured thickness of the chalk with most of the flow being contributed from the upper 50m-60m of the unit. We have therefore also analysed the data assuming a reduced aquifer thickness.

Partial Penetration

The pumping test was carried out in a well screened across the sand and gravel so from a hydraulic standpoint the well is partially penetrating the combined sand and gravel and chalk aquifer unit.

The pumping test induced a drawdown in the underlying chalk monitoring well (0.42m in BH107C), implying that upward vertical flow from the chalk into the overlying sand and gravel was occurring. This supports the concept that pumping test data may fit partially penetrating solutions better than confined or unconfined solutions.

Transmissivity (T) and Storativity (S)

Step Test

The confined aquifer Theis solution has been applied to the step test data as illustrated in **Appendix 06, Figure 5.** The drawdown curve match is good and derived:

T = 264m^2/day, k=33m/d (assumed that b = 8m, i.e., non-partial penetrating)

Constant Rate Test

The confined aquifer Theis solution has also been applied to the constant rate time-drawdown data using different approaches:

1. A defined aquifer thickness of 8m (fully penetrating solution),
2. Varying the total saturated thickness between 50m and 100m utilising a partially penetrating solution,
3. Cooper Jacob Distance-Drawdown,
4. Empirical analysis - Driscoll

1) Fully Penetrating Solution (Theis)

Figure 7 included in **Appendix 06** plots water level drawdown vs time at a log-log scale for the pumping well and the observation well (107-L).

The analytical solution assumes a fully penetrating well and a saturated thickness of 8m. BH107-C cannot be used in this analysis since it is screened in the underlying chalk and therefore the scenario assumptions are broken.

The blue lines represent the analytical match that are created by varying T and S in the model. An ideal solution would result in both analytical curves matching the actual drawdowns simultaneously but, in this case, the combined curve match is poor. The best fit results in:

T = 226m^2/d, k = 28m/d

S = 1x10^{-4}

2) Partially Penetrating Solution (Theis and Neuman)

Since the functional thickness of the chalk contributing to the test is unknown the aquifer thickness was varied between 50m and 100m using a partially penetrating solution. BH107-C is included in these solutions.

The 100m saturated thickness, partial penetration solution (**Appendix 06, Figure 8**) provides a more convincing curve match across all 3 wells, and results in:

T =1,545m^2/d, k = 15.45 m/d (assumes 100m aquifer thickness)

S = 1.1x10^{-2}

Assuming an aquifer thickness of 50m the predicted Transmissivity necessarily drops and a reasonable fit (**Appendix 06, Figure 9**) results in:

T=729 m2/d, k=14.6 m/d

S = 5.7x10^{-3}

The data was also analysed using the unconfined aquifer Neuman solution (**Appendix 06, Figure 10**) using the partial penetration assumptions. The following hydraulic parameters were derived:

T =777 m^2/d, k = 13.0m/d (assumes 60m aquifer thickness)

S = 8.3x10^{-3}

3) Cooper Jacob Distance-Drawdown Technique

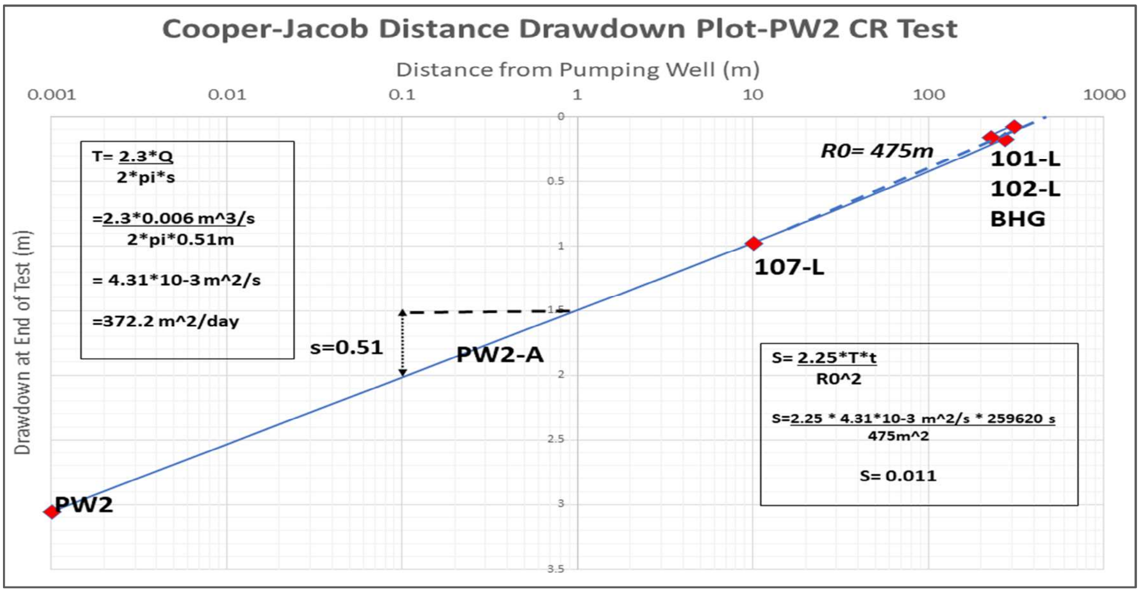
The data was also analysed graphically using the Cooper-Jacob Distance-Drawdown method illustrated on Figure 4-2. The analysis is strictly more applicable for fully penetrating test, so it is not surprising that the value for T is like that derived using the non-partial penetrating solution presented in analysis technique 1 in this report section and for the step test analysis.

The calculated T and S values were:

T = 372m^2/day, k = 47m/d

S = 2.9x10^{-3}

Figure 4-2
Cooper-Jacob Distance-Drawdown plot for Constant Rate Test in PW2



4) Empirical Analysis

There are many specific capacity approximations for estimating transmissivity, perhaps the most widely used being Driscoll (1986) which uses the observed drawdown in the pumped well after a day of pumping modified by a coefficient (confined aquifer):

T = 1.385(Q/sw) *where Q= 6L/s = 518.4m^3/day, and Sw=2.8m*

= 256m^2/d

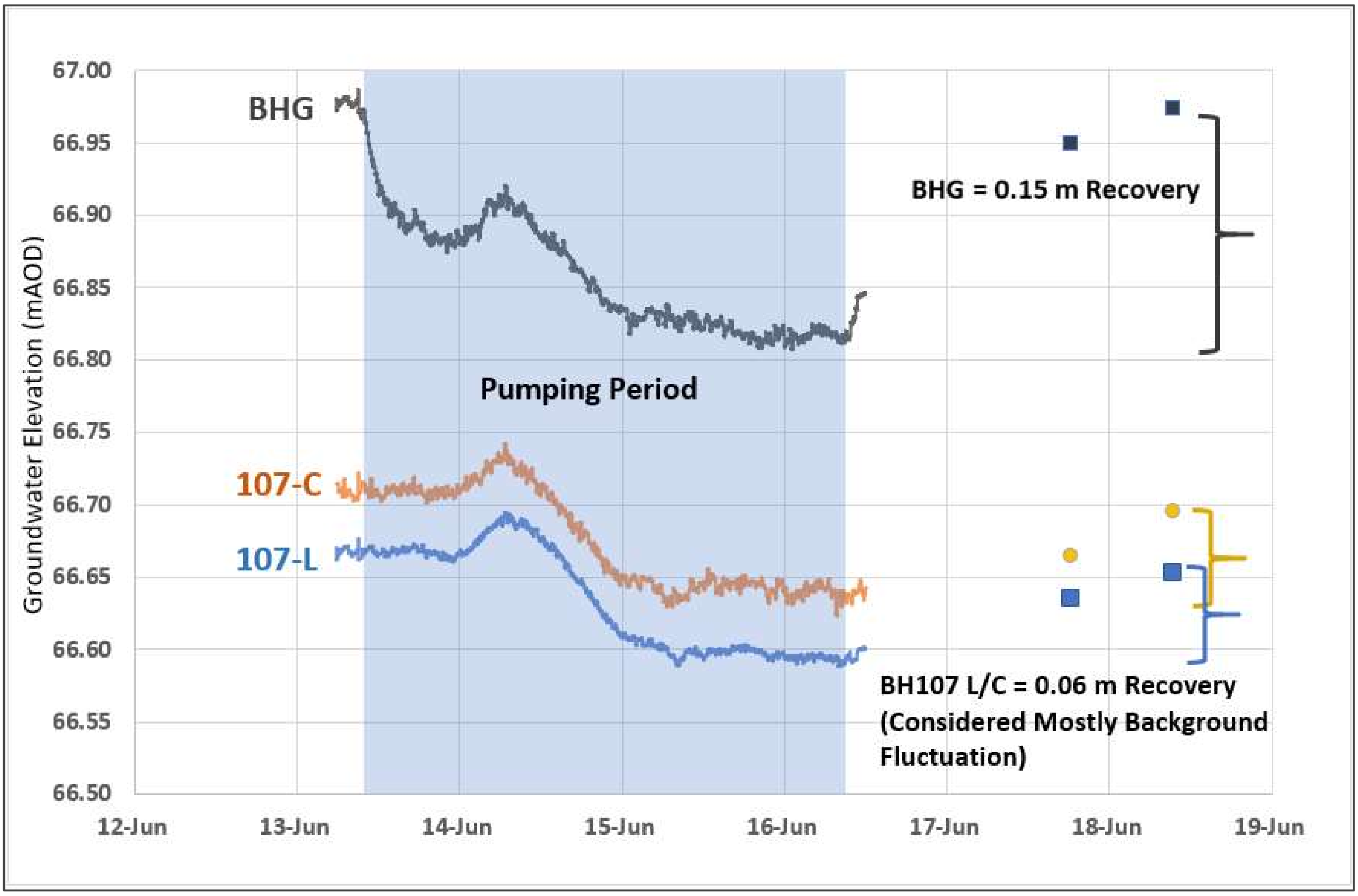
Boundary Affects

Approximately 18 hours into the test a slight increase in the rate of water level drawdown was observed in PW2, 107-L and 107-C (Appendix 06, Figure 6), which is indicative of the drawdown reaching a low flow boundary. The nature of this boundary is unknown although it could relate to an unconfined/confined aquifer boundary some distance from the pumping well

Radius of Influence (R_0)

A radius of influence (R_0) of 475m was estimated using the Cooper-Jacob distance-drawdown method (Figure 4-2). An important well in determining R_0 in this case is BHG located 215m from PW2 where 0.15m of drawdown was recorded, but also BH101L&C at 293m with a drawdown c.0.06m. The result in BHG is considered real whereas drawdown in BH101L&C is likely to be a response water levels falling regionally. This is best shown by the recovery of water levels in BHG and the lack of recovery in BH101L&C (Figure 4-3). On this basis, an R_0 between 250m and 350m is reasonable.

Figure 4-3
BHG, B101 L&C Pumping Test Hydrographs



4.2.3 Conclusions

Upper Mineral Aquifer

Analysis of the UMA pumping test data from the step test and the constant rate test provides a narrow range of T values ($78m^2/d$ to $84m^2/d$) equating to a K of approximately 20m/d. This value is realistic for a medium to coarse sand and a high degree of confidence can be given to this value for groundwater calculations.

The storage values calculated for the UMA ($2x10^{-3}$ to $3x10^{-3}$) are lower than expected for an unconfined aquifer and we have explained how this could be related to significant clay bands within the saturated aquifer unit which may be confining the aquifer close to the pumping well and would result in a lower storage value.

Lower Mineral Aquifer

Before discussing findings from the pumping test, it is worth revisiting the conceptual hydrogeological model for the site. If we consider the geology, we have relatively thin (8m) permeable granular sand and gravel overlying a comparatively thick (100m) dual porosity chalk with variable hydraulic properties that changes with depth.

Although we know there is a weathered low permeability chalk horizon at the interface with the granular horizon, water levels in the chalk and the LMA indicate we have a single water body that is saturated across both geological units. We have pumped the granular horizon at the top of the combined aquifer system.

We have analysed the pumping test data using 2 conceptual assumptions; a fully penetrating scenario assuming the LMA acts independently of the chalk, and a partially penetrating scenario whereby the aquifer is assumed to have a far greater thickness incorporating the chalk. We have also taken into consideration that only the upper 50m-60m of the chalk may be contributing to groundwater flow.

It is now clear that the fully penetrating analysis with the LMA acting as a single aquifer is an inadequate conceptual model of the system. This is based upon:

- a poor curve match to PW2 and BH107L (Figure 7, Appendix 06);
- an improved curve match with the partially penetrating aquifer solutions;
- Nearly 50% of the drawdown observed in the LMA (BH107L) was also observed in the underlying chalk (BH107C) indicating that the chalk is hydraulically connected to the overlying LMA.

Consequently, the system is best conceptualised as a single aquifer and any future pumping analysis should be considered within a partially penetrating conceptual model.

In an aquifer pumped by a partially penetrating well, vertical flow components are introduced which introduces the importance of an aquifer's vertical hydraulic conductivity (Kv). In general, Kv is typically significantly less than its horizontal hydraulic conductivity (Kh) and becomes dominant closer to a well. Consequently, drawdown in a well is greater than those observed in fully penetrating conditions which can result in underestimations of T if the system is treated as being pumped by a fully penetrating well. This underestimation is clear in the fully penetrating analysis reported in Section 4.2.2.

It remains unknown how thick the chalk aquifer is below the site or more importantly what thickness is contributing to flow in the overlying sand and gravels. However, reasonable type curve matches were attained by assuming that the contributing aquifer is in the range of 50m to 60m which is consistent with the thickness stated by Affinity.

The T values obtained using the partially penetrating solutions were significantly higher and represent a composite T for the modelled system. An average of the 3 partially penetrating solutions (100m, 60m & 50m thickness) results in a T of approximately $1,000m^2/d$ although we believe the reduced aquifer thickness model is a better representation so a conservative T of approximately $800m^2/day$ should be adopted for future operational planning purposes.

5.0 Lagoon Performance

All water pumped during the Step-Drawdown and Constant Rate tests were discharged into the infiltration lagoon except for the repeated Step-Drawdown test in PW2. Water levels in the lagoon and the underlying aquifer (BHA) were recorded with data loggers.

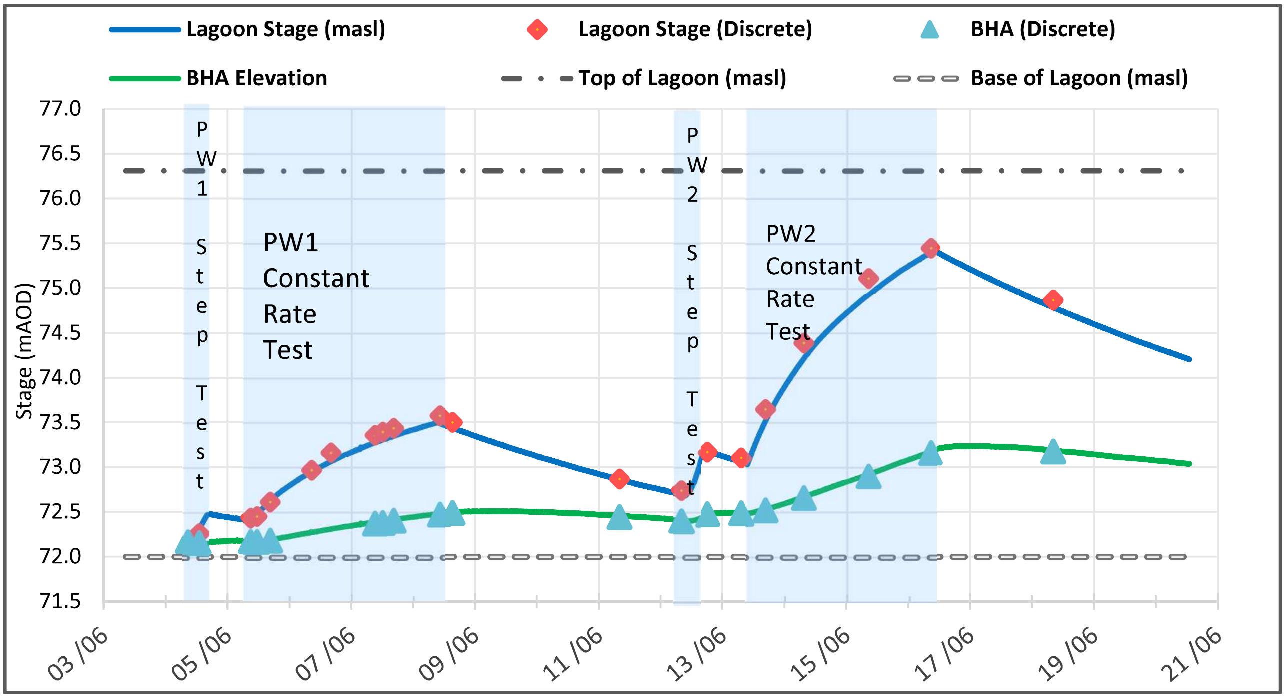
The storage capacity of the lagoon during the programme was approximately 1500m^3 which was slightly below its maximum capacity because of the presence of water at its base (the local UMA water table).

In total 2,200m^3 of water was discharged over four major intervals which allowed for intervening recovery periods. At its peak the lagoon was at approximately 65% capacity and contained 930m^3 of discharged water.

5.1 Infiltration Rates

Figure 5-1 illustrates the water level change in the lagoon throughout the entire testing period comprising two Step-Drawdown and Constant Rate tests. Infiltrations rates were calculated from the four recovery periods which followed the end of each of the Step-Drawdown and Constant Rate tests.

Figure 5-1
Lagoon Stage during Pumping Programme



Infiltration rate was observed to increase with the stage in the lagoon (Table 5-1). This is mostly a result of increased applied head driving water into the unsaturated surrounding formation. Consequently, calculated infiltration rates ranged between 1.27x10^{-6} m/s and 3.38 x10^{-6} m/s. It should be considered that the lagoon was heavily vegetated during the programme which likely reduced the infiltration capacity in comparison to an open formation.

Figure 5-2 Lagoon Performance during Pumping Programme

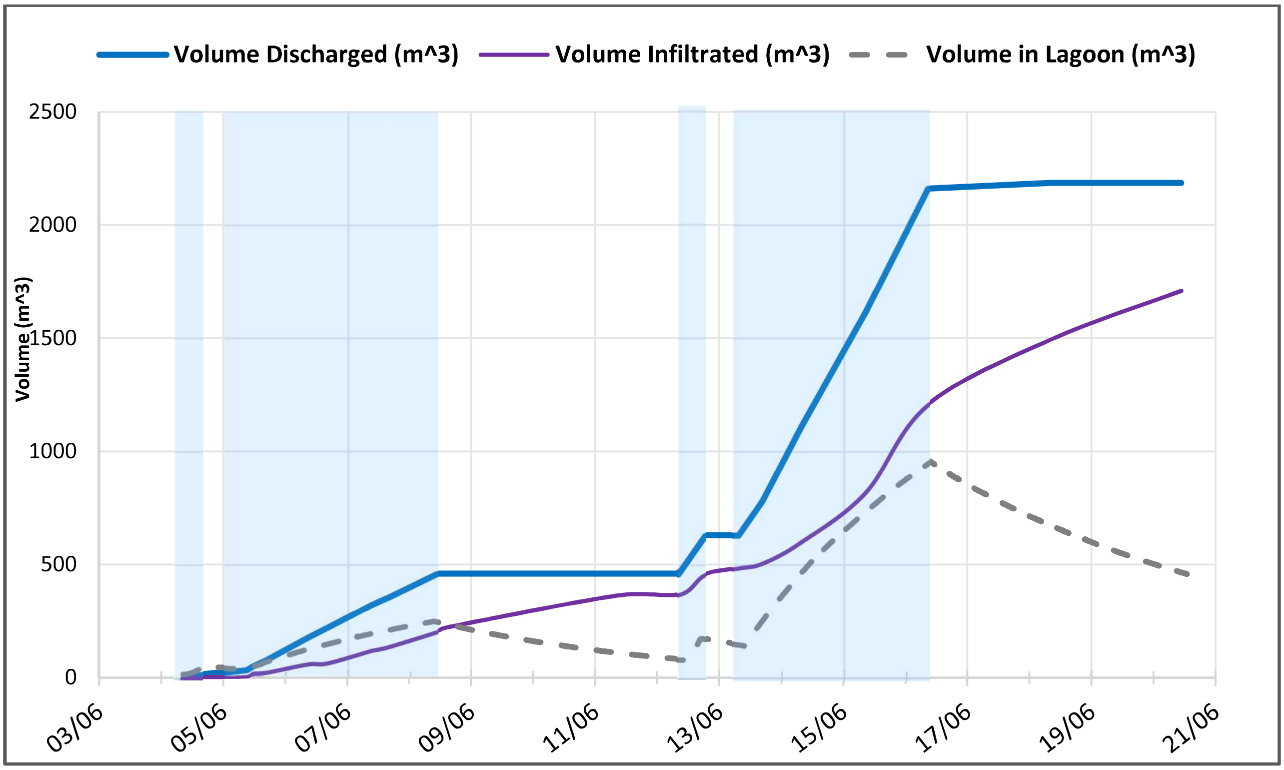


Table 5-1
Lagoon Infiltration Rates

Recovery Period	1	2	3	4
Infiltration rate (m^3/m^2 /s)	1.27x10-6	2.42x10-6	2.52x10-6	3.38x10-6
Recovery Interval (mAOD)	72.46-74.36	73.4-72.75	73.18-73.03	75.45-74.22
Volume Lost (m^3/day)	15	42	36	120

As discussed water generated during the second Step-Drawdown test was discharged into the River Nast culvert. The culvert is constructed of a buried 500mm concrete pipe and runs roughly south across the site and discharges to the drainage ditch which runs along the north side of Hatfield Road. Approximately 360m^3 was discharged directly into the open culvert over an approximately 6.5-hour period.

Initially the culvert appeared to convey the discharged water however within 4 hours it had backed up to the top elevation of the pipe and was back welling into the up-gradient ditch. A manhole 300m downgradient of the ditch was also investigated and no running water was observed. By the following morning the pipe was again dry. Based on these observations it is likely the pipe is blocked at some point before the manhole and the discharged water was lost to the surrounding formation. Brett plans to replace the drain as part of its water management strategy.

5.2 Bromate Results

Seven samples were taken from each well during their respective Constant Rate Test and submitted to Affinity Water laboratories for analysis of Bromate and Bromide. Bromate was not detected at concentrations above method detection limits in any of the samples.

Bromide concentrations were lower in the UMA than the LMA which is consistent with historical findings in groundwater concentrations elsewhere on site. Results are available in Table 5-2 and Table 5-3. Certificates of analysis are included in **Appendix 07**.

Table 5-2
Bromate and Bromide Results PW1

Well	DWS	(mg/L)	05/06/2018		06/06/2018		07/06/2018		08/06/2018
PW1	-	**Bromide**	0.093	0.088	0.088	0.091	0.092	0.092	0.092
	0.01	**Bromate**	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005

Table 5-3
Bromate and Bromide Results PW2

Well	DWS	(mg/L)	13/06/2018		14/06/2018		15/06/2018		16/06/2018
PW2	-	**Bromide**	0.191	0.206	0.204	0.183	0.205	0.117	0.106
	0.01	**Bromate**	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005

6.0 Conclusions

6.1 Upper Mineral Aquifer

The Transmissivity (T) of the aquifer at the time of the test is between $78m^2/d$ and $84m^2/d$.

Transmissivity (T) = Hydraulic Conductivity (k) x Saturated Thickness (b), so the k of the aquifer based on a b of 4.15m is approximately 20m/d although there will be significant difference across the site due to localised changes in the UMH geology.

Storativity (S) is uncharacteristically low, between 2×10^{-3} and 3×10^{-3} which could be related to low permeability horizons acting as semi-confining layers in the UMH. In an unconfined aquifer we would expect S to be like the effective porosity (0.1 to 0.3)

The theoretical Radius of Influence (R_0) has been estimated at 450m based on the distance-drawdown plot but as there is no data between 10m and 200m and only minor drawdown recorded in the background monitoring wells 200m to 300m from the pumping well, this it is considered . The calculated R_0 value is a function of the analysis and we expect that 450m would be the upper limit of any area of influence with the real number likely to be closer to 300m - 350m.

The specific capacity (Sc) of PW1 is calculated to be approximately 0.8 L/s/m of drawdown (for an efficiently operating well based on a maximum drawdown no greater than 60% of the available drawdown). This rate may increase if the water table rises and the thickness of saturated gravel increases. Therefore, if we assume an average saturated thickness of 4.5m (Phase F) then the yield would be 2.16 L/s (4.5 x 0.6 x 0.8). Clearly, if the aquifer thickness increases then the Sc will also increase and well yield increases.

Seven water samples were collected from PW1 during the constant rate pumping test. Bromate was not detected above the method detection limit in any of the samples.

6.2 Lower Mineral Aquifer

For the purposes of future planning, analysis of the pumping test data has indicated that the chalk and the LMH should be considered a single aquifer. This is not a new or unexpected finding, and nor does it have a significant impact on previous work given the assumptions that were made at that time. It does, however, confirm the situation.

Affinity Water plc has indicated that the 'contributing portion' of the chalk aquifer is less than the measured thickness of the chalk with most of the flow being contributed from the upper 50m-60m of the unit.

SLR has analysed the pumping test data under variable aquifer thickness assumptions (100m to 50m) and a better type curve fit is achieved with an aquifer thickness within the range stated by Affinity, which results in a T of approximately $800m^2/d$, which should be considered appropriate for future operational planning purposes. The BGS website[2] indicates the T of the chalk in the Chilterns region ranges from 276 (25^{th} percentile) to 2,100 (75th percentile), with a median of $860m^2/d$.

Transmissivity (T) = Hydraulic Conductivity (k) x Saturated Thickness (b), so the k of the aquifer based on assigned b values of 50 - 60m is approximately 15m/d although there will be significant difference across the site due to local changes in the chalk and LMH geology.

As with the UMA, the Storativity (S) is low ($1 \times 10^{-2} – 8 \times 10^{-3}$) for an unconfined aquifer but a comparison with BGS data provides a useful benchmark and indicates the site compares to the upper percentile value for the Chilterns – [8×10^{-4} (25^{th}percentile) to 2.8×10^{-2} (75^{th} percentile), with a median of 2.9×10^{-3}].

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[2] http://www.bgs.ac.uk/research/groundwater/waterResources/thames/chalk.html

The theoretical Radius of Influence (R_0) has been estimated at 475m based on the distance-drawdown plot. However, there was no convincing drawdown response in wells close to this radius (BH101, BH102) so this distance should be considered the upper theoretical limit of an area of influence. A value ranging between 250m and 350m is considered a reasonable estimate.

The specific capacity of PW2 is calculated to be approximately 2.3 L/s/m of drawdown (for an efficiently operating well based on a maximum drawdown no greater than 60% of the available drawdown). This rate may increase if the water table rises and the thickness of saturated gravel increases. Therefore, if we assume an average saturated thickness of 9m (Phase F) then the yield would be 12.4 L/s (9 x 0.6 x 2.3). Clearly, if the aquifer thickness increases then the Sc will also increase and well yield increases.

Seven water samples were collected from PW2 during the constant rate pumping test. Bromate was not detected above the method detection limit in any of the samples.

6.3 Infiltration Lagoon/ Nast Culvert Performance

Approximately 2,200m^3 of water was discharged into the lagoon during the pumping test programme. The lagoon had a total capacity of approximately 1,500 m^3 and was 65% full as a maximum. Water readily infiltrated from the lagoon and levels dropped between 0.1 and 0.3 m/day.

Infiltration volumes increased when the pond was at higher stages because of higher driving heads. Discharge rates varied over the four recovery stages between 15m^3/day and 127m^3/day. At the time of the programme the lagoon has developed a soil horizon and was heavily vegetated which is likely to have compromised the lagoon's infiltration potential.

Water discharged during the 2nd step test in PW2 was discharged into the Nast at the opening of the culvert. Water was observed to back-up in the culvert to the point of discharge and we can conclude that the Nast culvert is damaged and that it is unable to discharge water introduced into the drain at a rate greater than 1,500 m^3/day.

Brett plans to replace the Nast drain as part of its surface water management strategy at the site so capacity issues will be addressed at that time.

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EUROPEAN OFFICES

United Kingdom

AYLESBURY
T: +44 (0)1844 337380

BELFAST
T: +44 (0)28 9073 2493

BRADFORD-ON-AVON
T: +44 (0)1225 309400

BRISTOL
T: +44 (0)117 906 4280

CAMBRIDGE
T: + 44 (0)1223 813805

CARDIFF
T: +44 (0)29 2049 1010

CHELMSFORD
T: +44 (0)1245 392170

EDINBURGH
T: +44 (0)131 335 6830

EXETER
T: + 44 (0)1392 490152

GLASGOW
T: +44 (0)141 353 5037

GUILDFORD
T: +44 (0)1483 889800

LEEDS
T: +44 (0)113 258 0650

LONDON
T: +44 (0)203 805 6418

MAIDSTONE
T: +44 (0)1622 609242

MANCHESTER
T: +44 (0)161 872 7564

NEWCASTLE UPON TYNE
T: +44 (0)191 261 1966

NOTTINGHAM
T: +44 (0)115 964 7280

SHEFFIELD
T: +44 (0)114 245 5153

SHREWSBURY
T: +44 (0)1743 23 9250

STAFFORD
T: +44 (0)1785 241755

STIRLING
T: +44 (0)1786 239900

WORCESTER
T: +44 (0)1905 751310

Ireland

DUBLIN
T: + 353 (0)1 296 4667

France

GRENOBLE
T: +33 (0)6 23 37 14 14