Aldbrough 4z Borehole Support

Hydrogeological Impact Assessment

SSE Hornsea Ltd

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1. Introduction

1.1. Project context

SSE Hornsea Ltd (herein referred to as SSE) is seeking to secure a licensed groundwater abstraction borehole in the Chalk aquifer at its gas storage facility, SSE Aldbrough Installation, Garton, East Yorkshire, HU11 4QB.

The site is a gas storage facility, used for the storage of compressed natural gas within nine underground salt caverns approximately 2 km underground. There is no existing water supply borehole at the site. Securing of a groundwater abstraction licence would allow SSE to meet operational requirements for water supply, namely for the rewatering of gas storage caverns during cavern decommissioning.

1.2. Recent work

Atkins carried out a desk study to assess the feasibility of securing a groundwater supply in 2017 (Atkins, 2017a). Following this work Atkins applied for a Water Resources Act 1991 Section 32 consent for construction and test pumping of a borehole at SSE Aldbrough. As part of this application Atkins carried out a survey of water features within a 2 km radius of the proposed abstraction (Atkins, 2017b).

Between July and September 2019 SSE constructed a borehole into the Chalk aquifer at the Aldbrough site and carried out a pumping test in accordance with the Section 32 consent (ref: NE0260033011).

1.3. Report structure

This hydrogeological impact assessment (HIA) summarises the findings of this test pumping and assesses the potential impacts of the proposed abstraction at the Aldbrough site to support a licence application.

2. Borehole construction and test pumping

2.1. Programme of works

SSE commissioned specialist drilling contractor G. Stow Plc (Stows) to drill and test pump the abstraction borehole. Stows were on site at SSE Aldbrough between 10 June 2019 and 20 September 2019. The programme of works undertaken by Stows is summarised in Table 2-1 (G Stow Plc, 2019).

Table 2-1 – Summary programme of works

Dates	Works
10 June – 11 July 2019	Mobilisation Auger drilling to 27.50 m bgl Rotary drilling to 100.45 m bgl Installation and grouting of casing Baseline monitoring of observation boreholes begins
12 July – 23 July 2019	Borehole development using airlift
24 July – 30 July 2019	Geophysical logging Further borehole development by acidisation
31 July – 5 August 2019	Borehole development using airlift Logger installed in pumped well for baseline monitoring
2 September – 4 September 2019	Pump installation, equipment testing and clearance pumping
5 September – 8 September 2019	Step testing and recovery monitoring
9 September – 16 September 2019	Constant rate testing at 144 m^3/hr for 7 days
16 September – 20 September 2019	Recovery monitoring and demobilisation

2.2. Borehole construction

SSE commissioned Stows to drill the borehole into the Chalk to a depth of 100 m during July and August 2019.

The geology encountered is summarised in Table 2-2 and borehole construction details are summarised in Table 2-3 (G Stow Plc, 2019) and shown in the as-built drawing included here below as Figure 2-1.

Table 2-2 – Geology encountered during drilling

Depth to base of unit (m bgl)	Base of unit (m AOD)	Geology encountered
41	-28.07	Diamicton (slightly gravelly clay, sandy gravelly clay from 28 m)
65	-52.07	Fractured chalk
>100	-87.07	Competent chalk

Table 2-3 - Abstraction borehole construction details

Grid reference	TA 26198 37079
Ground level elevation (m AOD)	12.93
Flange plate level elevation (m AOD)	13.57

Depth* (m bgl)	Elevation (m AOD)	Drilled diameter (mm)	Casing diameter (OD)
4.00	8.93	1270	914 mm and 660 mm
19.85	-6.92	1028	914 mm and 660 mm
27.00	-14.07	863	660 mm
46.00	-33.07	762	660 mm
65.00	-52.07	610	None (open hole)
100.00	-87.07	457	None (open hole)

*Depths are based on as-built drawing provided by Stows (Figure 2-1).

2.3. Acidisation

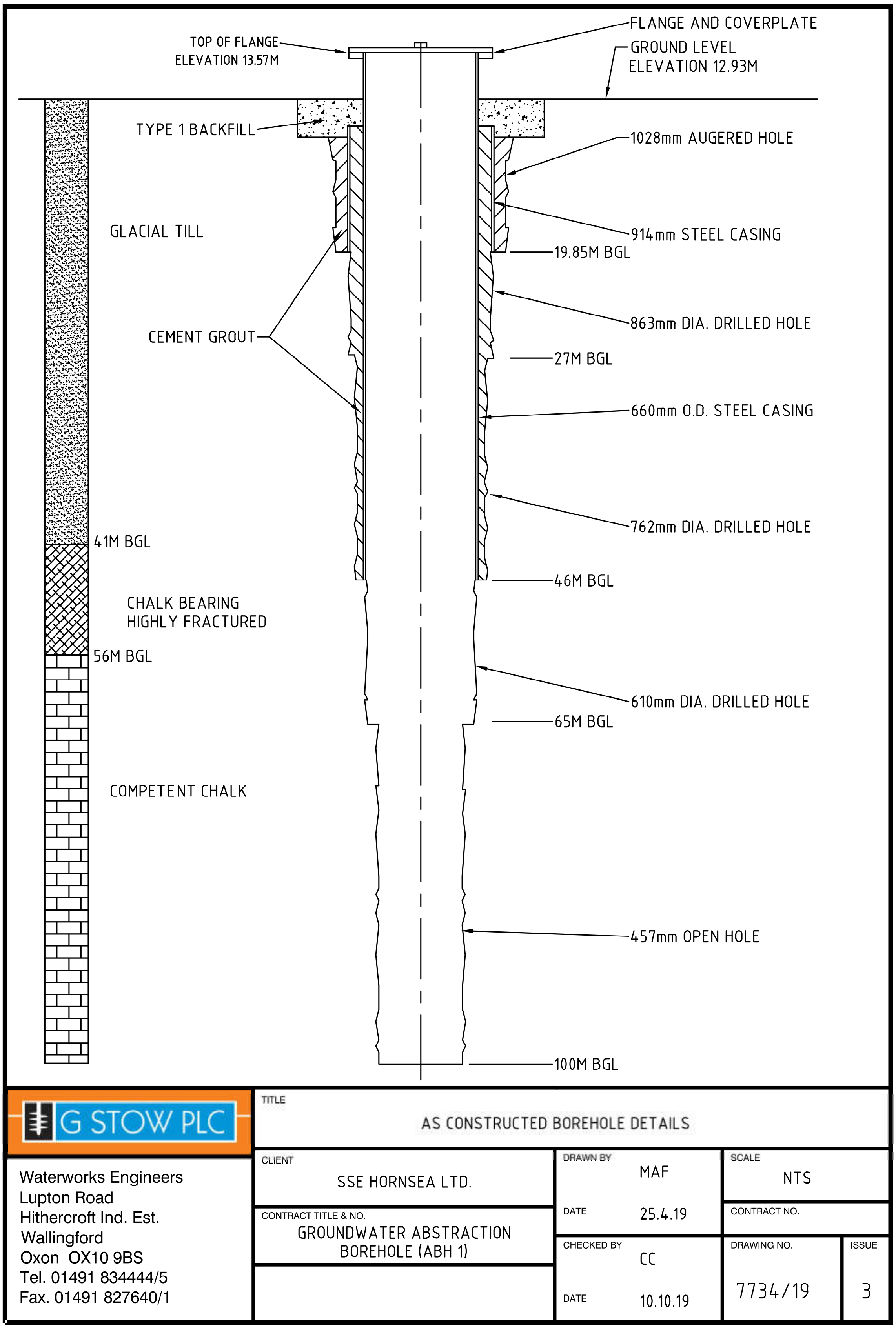
Once the completion depth of 100 m was reached, Stows developed the borehole for three days using airlift. The results of the airlift indicated that the yield of the borehole may not be sufficient to supply the desired abstraction rates. In order to maximise yield, SSE instructed Stows to carry out acidisation on the borehole.

Prior to acidisation, Stows arranged for a calliper log of the borehole to be undertaken to identify areas of fracturing that should be targeted with the acid injection. Based on this survey, Stows, Atkins and SSE decided on an injection depth of 48 m bgl to target fractured chalk identified between 46 m bgl and 56 m bgl.

4000 litres of food grade hydrochloric acid at 32% concentration was injected into the borehole, venting when the pressure in the borehole reached 20 psi. The acid was re-circulated within the borehole until the pH was neutralised. The water was then discharged to a dry lagoon on adjacent SSE land and allowed to infiltrate and evaporate. Any remaining solids were removed for off-site disposal at a licensed facility.

Following the acidisation the borehole was developed using airlift during day shifts for three more days, and by clearance pumping using an electro-submersible pump for two days at 50 l/s and 40 l/s respectively.

Figure 2-1 - Borehole as-built drawing (from G. Stow Plc (2019))



2.4. Test pumping

2.4.1. Pumping rates and drawdown

Stows carried out a step test and subsequent 7-day constant rate pumping test in September 2019. The testing schedule, flow rates and observed drawdown in the abstraction borehole during these tests are summarised in Table 2-4.

Rest water level at the borehole was 0.57 m above Ordnance Datum (AOD) prior to the start of the step test, and 0.75 m AOD prior to the start of the constant rate test.

Table 2-4 - Abstraction rates and drawdown during step and constant rate test

Date	Activity	Duration	Target flow rate (l/s)	Target flow rate (m^3/hr)	End drawdown (m)
05/09/19	Step test – step 1	100 mins	30	108	15.52
	Step test – step 2	100 mins	35	126	19.34
	Step test – step 3	100 mins	40	144	23.34
	Step test – step 4	100 mins	45	162	27.56
	Step test – step 5	100 mins	50	180	32.07
	Step test recovery	100 mins	-	-	1.46
09/09/19 – 16/09/19	Constant rate test	7 days	40	144	26.88
1609/19 – 20/09/19	Constant rate test recovery	5 days	-	-	1.04

Throughout the testing flows were monitored by two in-line electromagnetic flow meters. These were manually read throughout all phases of the testing, at the same time as manual dips for water levels were collected.

2.4.2. Groundwater level monitoring

Groundwater levels in the abstraction borehole were monitored using a pressure transducer datalogger installed prior to the testing. These data were supplemented by manual dips throughout the tests, and for five days recovery following the end of the constant rate test. The datalogger was installed in the abstraction borehole on 09 August 2019, several weeks before testing commenced, in order to provide baseline groundwater level data, and Atkins removed the datalogger on 09 October 2019.

Atkins' installed dataloggers recording water level, electrical conductivity (EC) and temperature at two observation boreholes - a disused borehole at Ringborough Farm West (TA 27256 37250) and a private farm supply borehole at Springfield Farm (TA 25402 36769). These locations are shown on Figure 2-2. A third private water supply borehole at Hilltop Farm could not be used as an observation borehole due to its sealed headworks. Dataloggers were installed at Springfield and Ringborough Farms on 19 June 2019 and removed from Springfield Farm on 18 September 2019 and from Ringborough Farm on 09 October 2019.

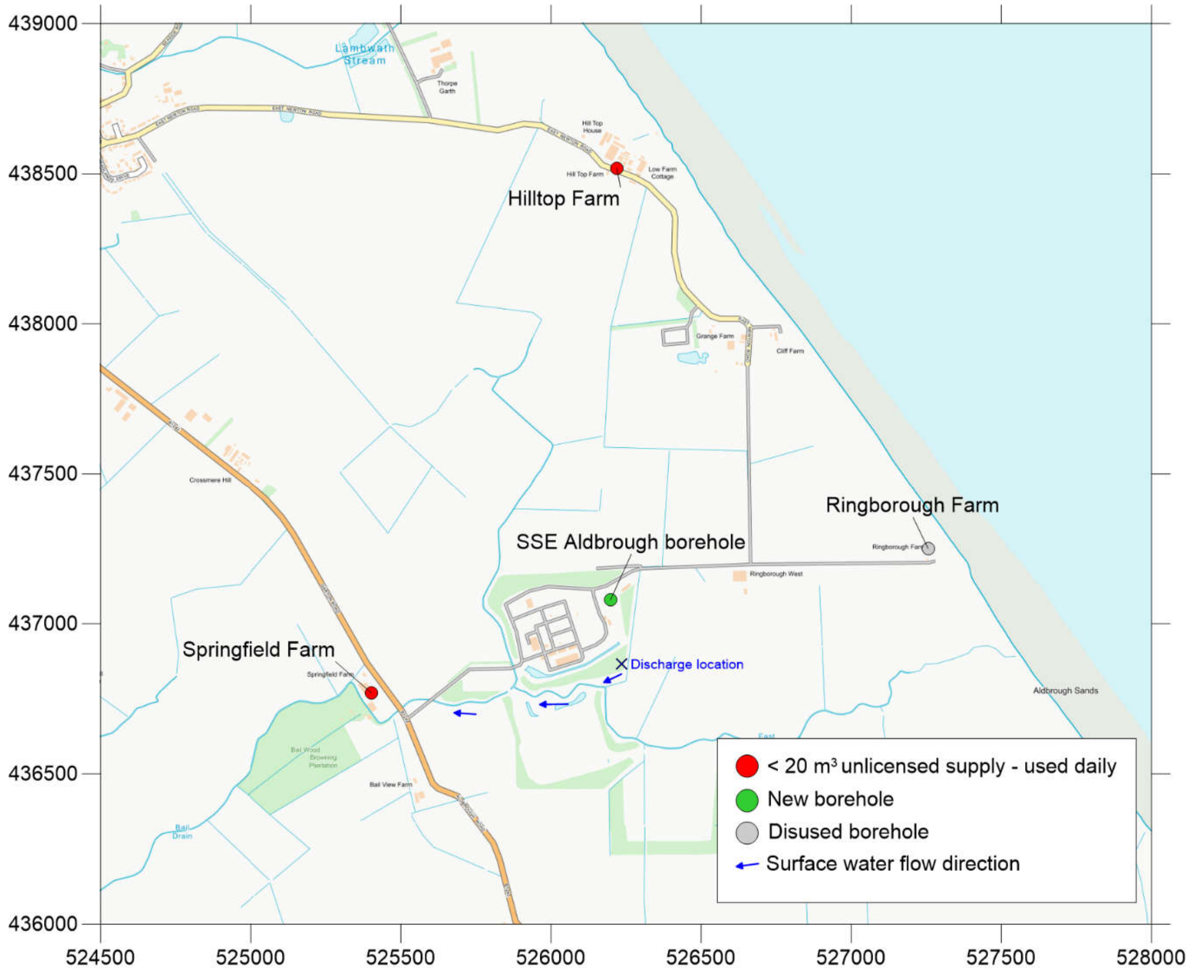
2.4.3. Discharge arrangements

During the borehole development airlifting water was discharged to on-site tanks. This water was then tankered to an existing balancing lagoon at Aldbrough Phase 2, land owned by SSE which is adjacent to the SSE Aldbrough site.

Once the water being abstracted from the borehole was visibly clear and within acceptable limits for pH and EC it was pumped from the on-site tanks along a temporary discharge pipeline to a farm drainage ditch which flows into East Newton Drain, as shown on Figure 2-2. During the constant rate test the on-site tanks were removed and water was pumped directly to the discharge pipeline. SSE carried out daily checks at the discharge location during the test pumping to check that the water being discharged was visibly clear and that the receiving drain was not likely to flood.

Photographs of the discharge arrangements are included in Appendix A.

Figure 2-2 - Locations of abstraction and nearby private boreholes



2.4.4. Water quality monitoring

During the testing water samples were collected from the abstraction borehole as follows:

- During Step 3 of the step test
- After 1 hour of the constant rate test.
- 30 mins before the end of the constant rate test.

The results of the laboratory analysis are included in Appendix B.1.

The abstracted water was also monitored for pH, EC, turbidity and temperature throughout the step and constant rates tests. The results of the field water quality measurements are summarised in Appendix B.2.

Four water samples were collected from the private agricultural borehole at Springfield Farm prior to testing commencing to provide a baseline water quality dataset. A sample was collected after the testing was complete to assess for any water quality impacts. One sample was collected at Hilltop Farm before and after the pumping test. Water quality results from Springfield and Hilltop Farms are presented in Appendix B.3 and B.4.

EC was also measured by dataloggers installed in both the observation boreholes. As both observation boreholes contain pumps and associated pipework it was not possible to install the dataloggers within the open section of the borehole, and they were installed in the cased section, so may not be fully representative of water in the aquifer. However, samples collected from the sampling tap at Springfield Farm were tested for EC and showed similar concentrations to those recorded by the logger, validating the logger data. EC recorded in the observation boreholes is shown in Figure 3-17 and discussed in section 3.4.

3. Pumping test analysis

3.1. Baseline water levels

Baseline water levels in the abstraction borehole were recorded from 09 August 2019 and in the observation boreholes from 19 June 2019, until equipment testing on 03 September 2019. Water levels for all three boreholes during this period are shown in Figure 3-1. Water level observations are summarised below:

- Levels at the abstraction borehole (ALD1) ranged between 0.85 m AOD and 1.05 m AOD and showed a tidal oscillation of around 0.10 m.
- Levels at Springfield Farm varied between 0.68 m AOD and 1.10 m AOD. This location shows a small tidal oscillation (<0.10 m) and changes in water level assumed to be due to pumping of this borehole. The owner of the borehole was not able to provide a record of when pumping was occurring at this source.
- Levels at Ringborough borehole varied between 0.20 m AOD and 1.50 m AOD. The main influence on water level at this location was tidal.

3.2. Step test

3.2.1. Theory

Well hydraulics theory is based on the assumption that laminar flow conditions exist in the aquifer during pumping. If the flow is laminar, drawdown in the borehole is directly proportional to the pumping rate. Upon entrance to a borehole the flow frequently becomes turbulent and under turbulent flow conditions this linear relationship no longer holds true. The specific capacity of the borehole, i.e. the ratio of discharge to steady drawdown, starts to decline as the turbulent flow losses become a greater proportion of the total head losses.

The purpose of a step-drawdown pumping test ('step test') is to define those elements of head loss attributable to laminar flow and those attributable to turbulent flow. This allows a prediction of total drawdown in the borehole for a particular discharge and pumping duration.

3.2.2. Analysis

Measured flows and maximum recorded drawdown during each step are summarised in Table 2-4. The test was planned to pump the borehole up to a maximum rate of 50 l/s (180 m^3/hr, which is 25% above the desired licensed rate from the borehole of 40 l/s (144 m^3/hr).

Water levels and flows at the abstraction borehole during the step test are shown in Figure 3-2. Water levels stabilised towards the end of each step and were approaching steady state.

Atkins has analysed the step test using the Eden-Hazel (1973) method as presented below. The Eden-Hazel method is based on the Jacob approximation for Theis (1935) and generates coefficients for linear and non-linear well losses which can be used to estimate transmissivity. The method is applicable for confined aquifers where the saturated thickness remains the same throughout the test.

In step 1 of the Eden-Hazel method (Figure 3-3) the change in drawdown at each step is plotted against a function of the increased discharge for that step and previous steps. Best-fit lines are matched to the late stage data from each step. The intercept of these lines is a function of discharge at each step and the turbulent well losses at that discharge. In step 2, these intercepts are plotted against discharge to give an indication of specific capacity, this linear regression is used to derive the coefficients of linear and non-linear losses, which can then be used to estimate transmissivity (Figure 3-4).

The estimated transmissivity can then be used to predict the drawdown response during the step test and compare this to the observed data. The predicted drawdown is shown in Figure 3-5. There is an excellent match between the predicted and observed drawdown.

Figure 3-1 - Baseline water levels at new Aldbrough borehole and observation boreholes

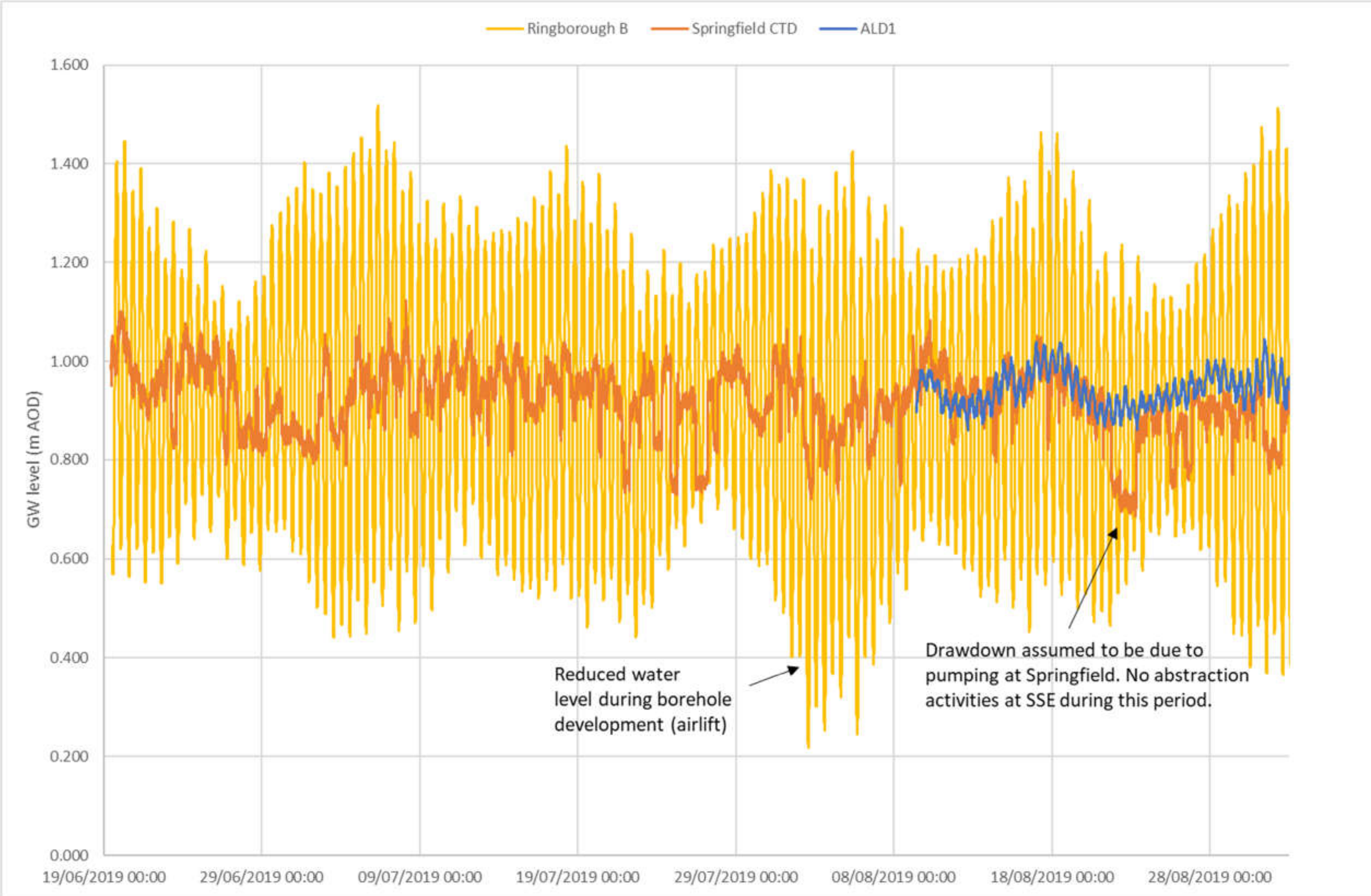


Figure 3-2 - Water levels and recorded flow during step test at new Aldbrough borehole (Ald1) (05/09/2019)

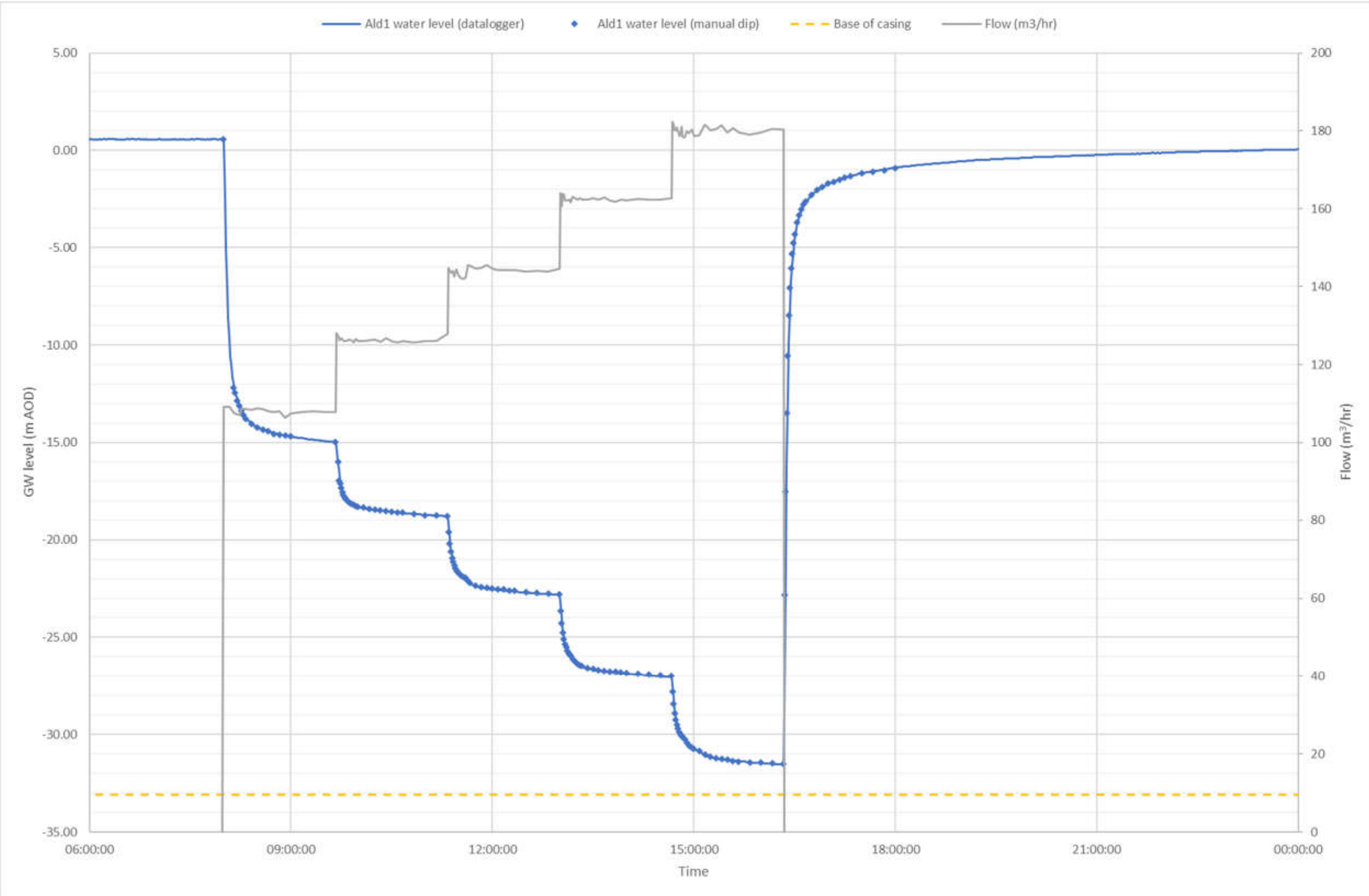


Figure 3-3 - Eden- Hazel (1973) analysis - Step 1

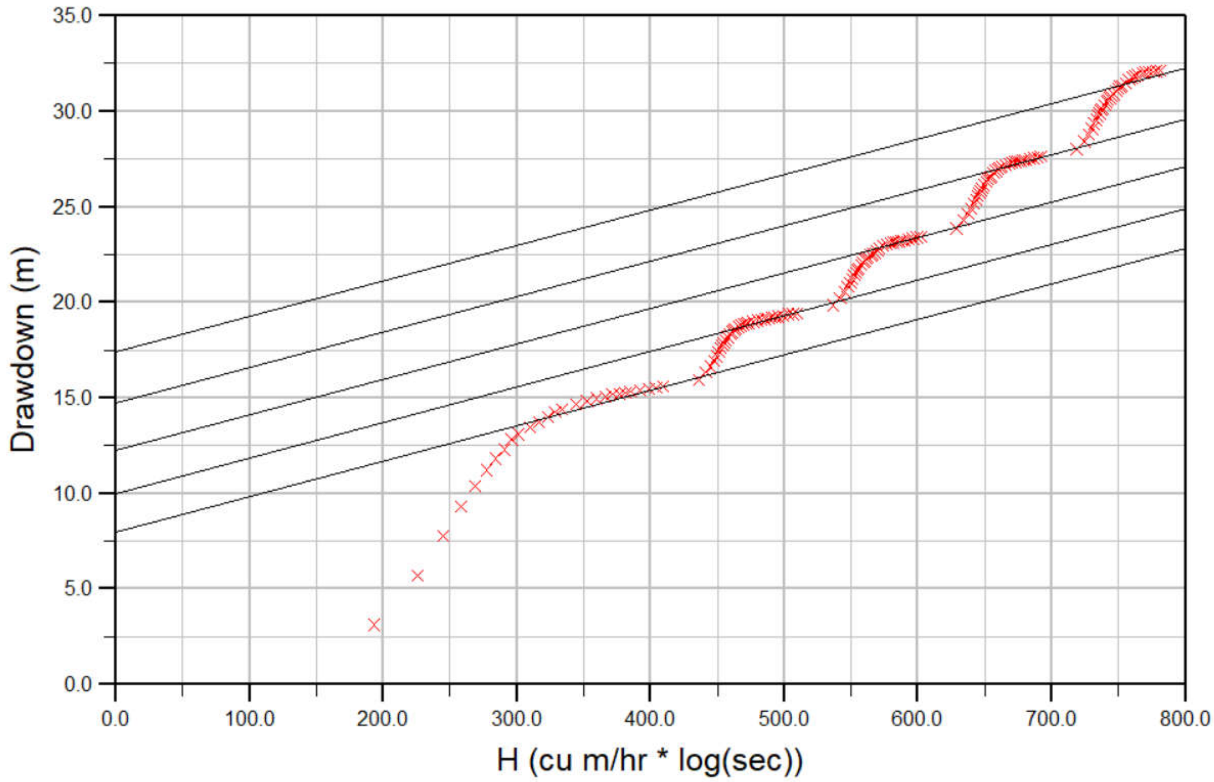


Figure 3-4 - Eden-Hazel (1973) analysis - Step 2

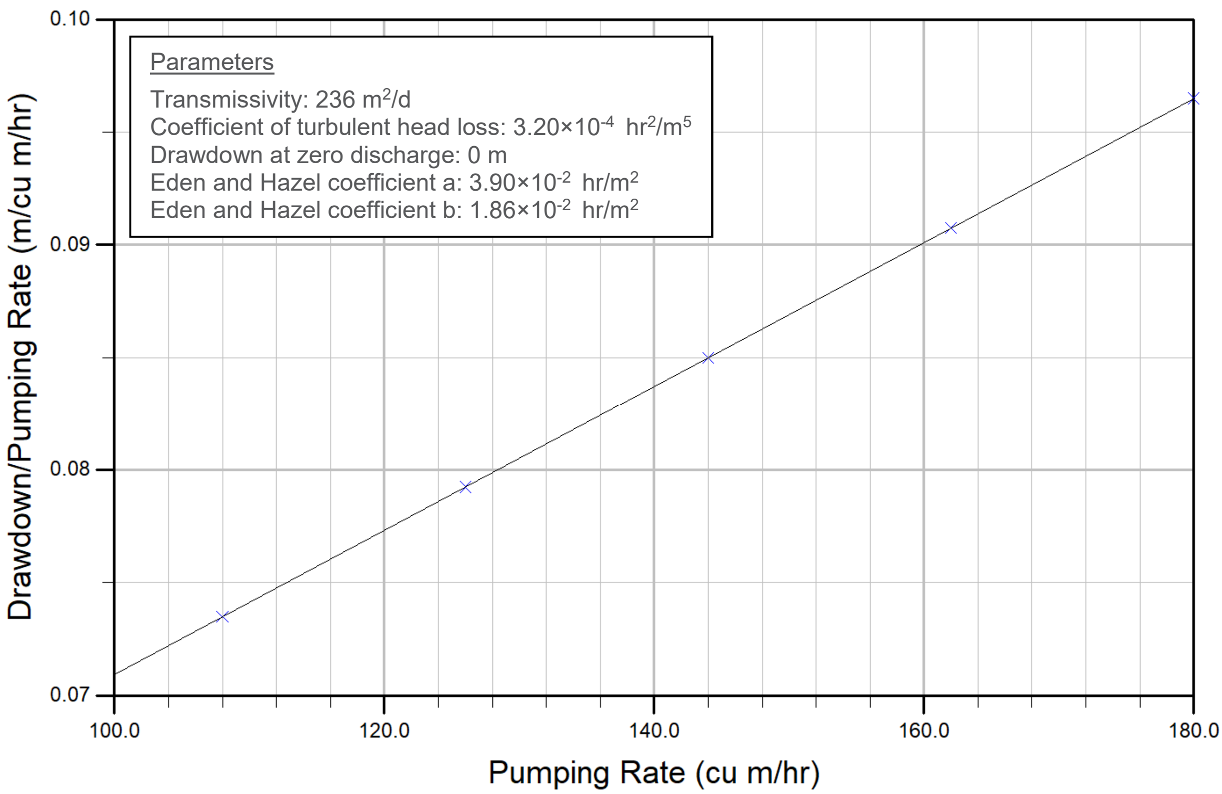
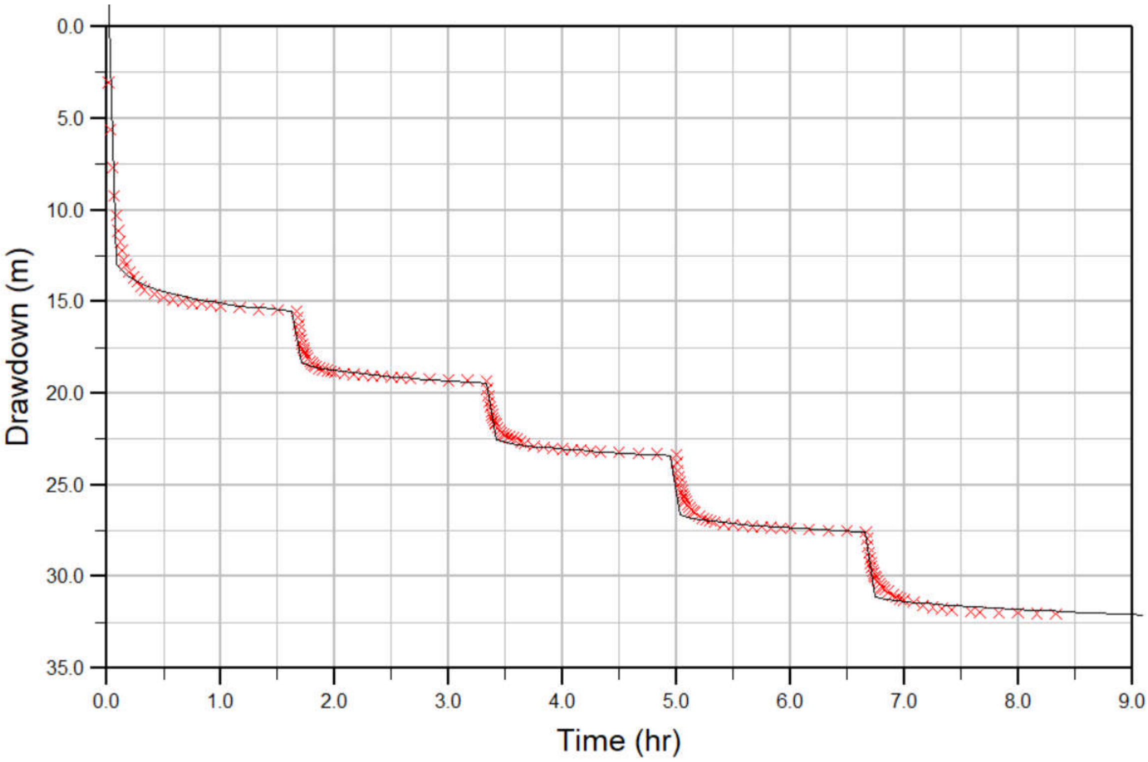


Figure 3-5 - Predicted well response to step test



The outputs from the Eden- Hazel (1973) analysis can be used to predict the drawdown in the borehole for pumping rates and pumping durations other than those followed during the step test. The predicted yield against drawdown relationship for a pumping period for 100 minutes is shown in Figure 3-6 and for 7 days pumping is shown in Figure 3-7.

The observations from the constant rate test can be used as a check of the validity of the step test derived predictive model by comparing the observed drawdown at the end of the constant rate test with the predicted drawdown after 7 days. During the constant rate test the borehole was pumped at 144 m^3/hr; the predicted drawdown at this pumping rate after 7 days is 28 m. This is a slight overestimate compared to the observed maximum drawdown of 26.88 m (Table 2-4), but nonetheless a relatively accurate predictor.

During the planned operation of the borehole it is likely to be pumped at periods of several weeks at a time, up to a maximum of 100 days. The predicted yield against drawdown for a pumping period of 100 days is shown in Figure 3-8. The likely maximum operational pumping rate is 125 m^3/hr. At this flow rate, Figure 3-8 predicts approximately 26 m of drawdown for 100 days' pumping. Given that this method overestimated drawdown over a 7-day period compared to what was observed during the constant rate test, the 26 m estimate of drawdown will be an upper estimate.

Rest water levels in the borehole are generally between 0.85 m AOD and 1.05 m AOD. A drawdown of 26 m would take water levels to approximately -25 m AOD. The casing in the borehole extends to -33.07 m AOD (Table 2-3), so water levels are not expected to drop below the base of the casing.

Figure 3-6 - Theoretical drawdown against pumping rate for 100 minutes of pumping

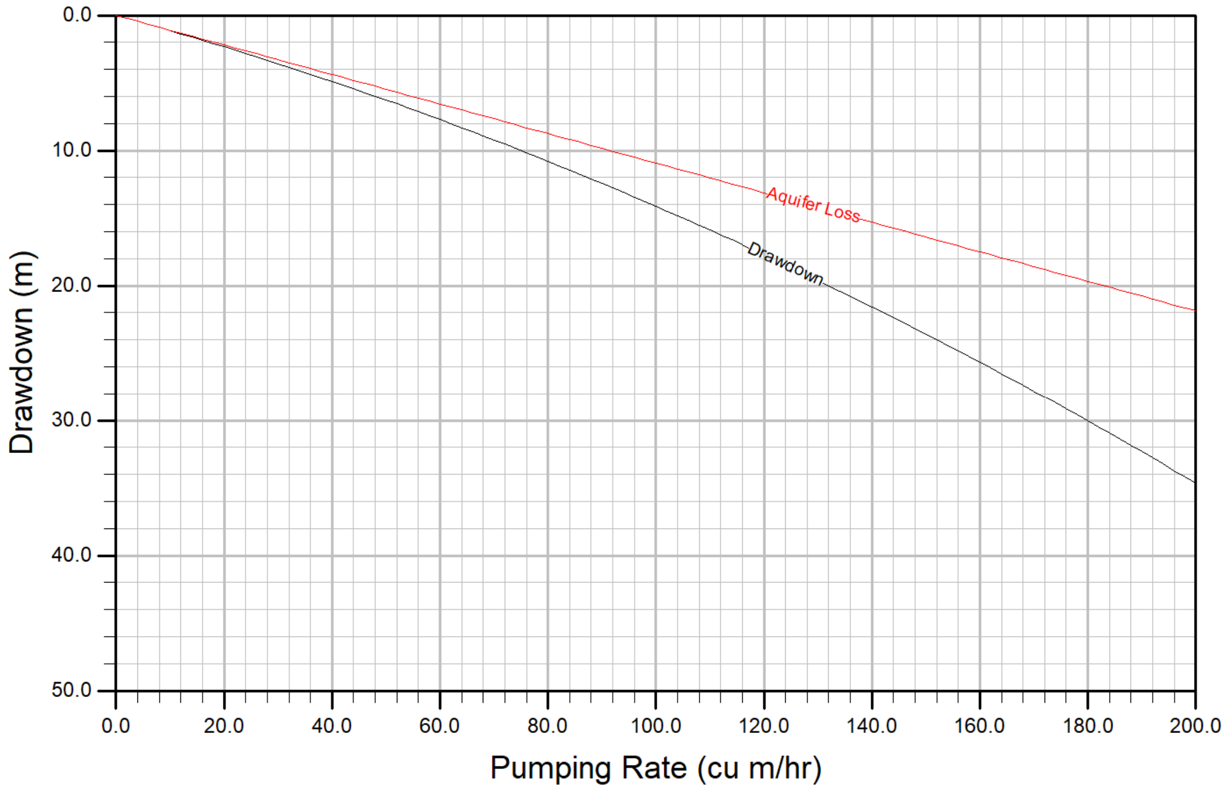


Figure 3-7 - Theoretical drawdown against pumping rate for 7 days of pumping

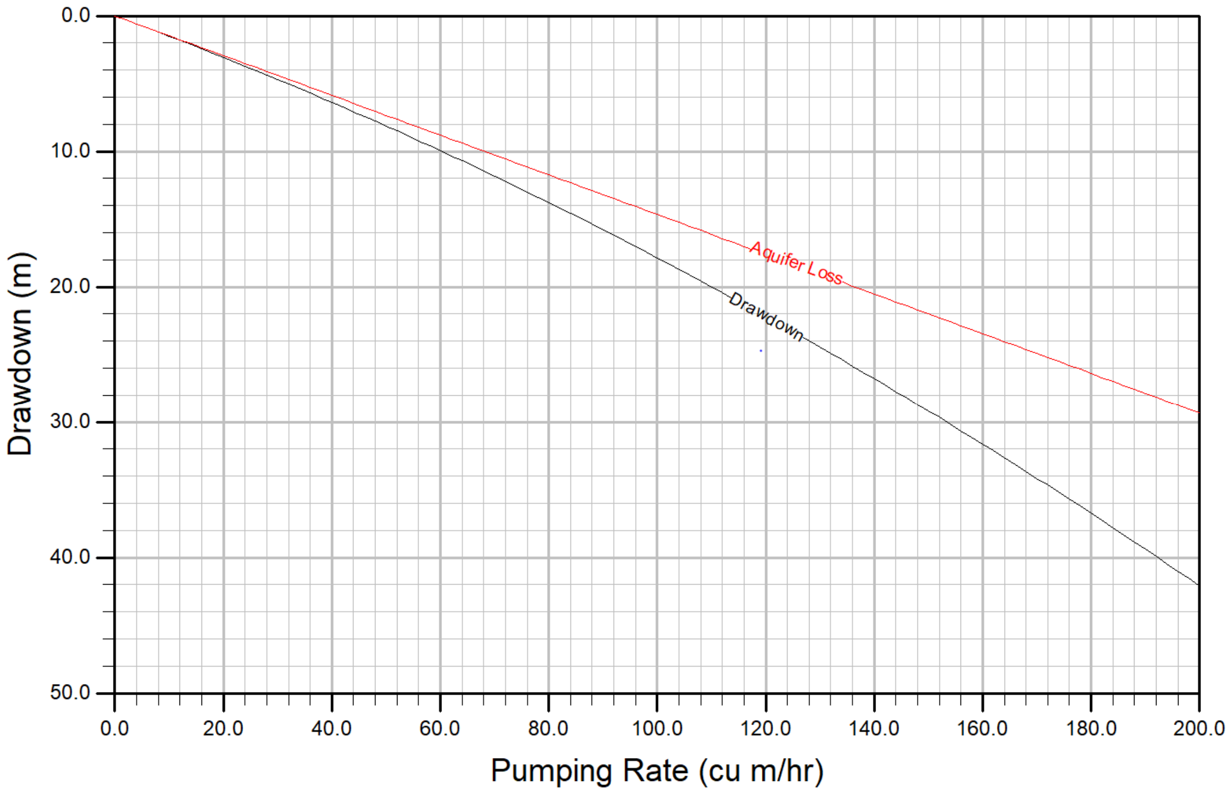
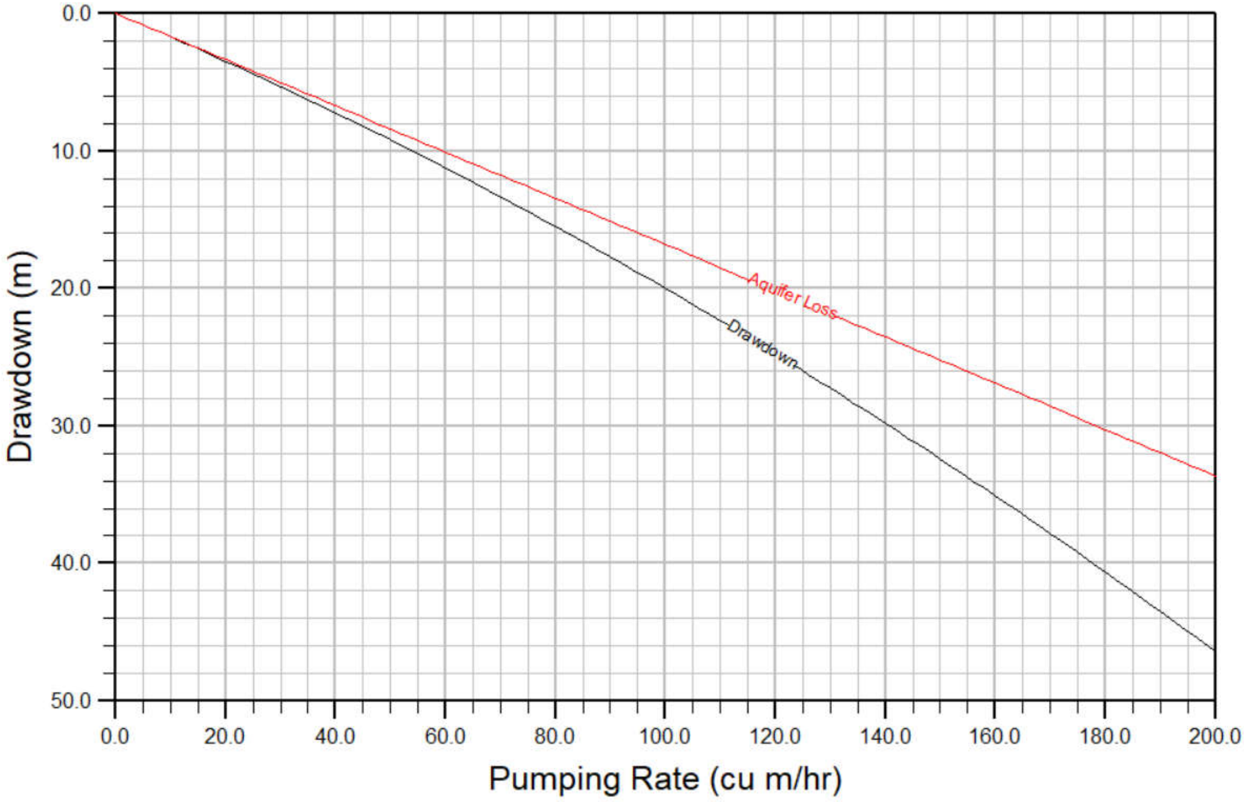


Figure 3-8 - Theoretical drawdown against pumping rate for 100 days of pumping



3.3. Constant rate test

3.3.1. Observed drawdown

Observed drawdown during the constant rate test at the pumping well is shown on Figure 3-9. Observed drawdown at Ringborough Farm is shown on Figure 3-10, and at Springfield Farm is shown on Figure 3-11. At both observation boreholes two loggers were installed in each well as a contingency measure, hence there are two water level lines on each chart. Maximum drawdown at each location is summarised in Table 3-1.

Drawdown at Springfield Farm has not been corrected for any pumping activities at this borehole, as no information about pumping times and durations was available.

Figure 3-11 shows three sudden drops in water level and associated recovery on 10 September and 17 September – Atkins assumes this is due to pumping activities within this borehole. It does not seem to impact the longer-term drawdown as a result of the constant rate test.

At Ringborough Farm the maximum drawdown has been estimated by removing the tidal effect on groundwater level using a rolling average (see section 3.3.3.2).

Table 3-1 shows that drawdown was actually greater at Ringborough Farm than Springfield Farm, despite being more than 200 m further away from the pumping well. This suggests that transmissivity is greater inland of the abstraction borehole than towards the coast.

Table 3-1 - Observed maximum drawdown during constant rate test

Borehole ID	Distance from pumped well (m)	Max. observed drawdown (m)
Aldbrough pumping well	0	26.88
Springfield Farm	855	1.52
Ringborough Farm	1070	2.12

Figure 3-9 - Water levels at Aldbrough abstraction borehole during constant rate pumping test

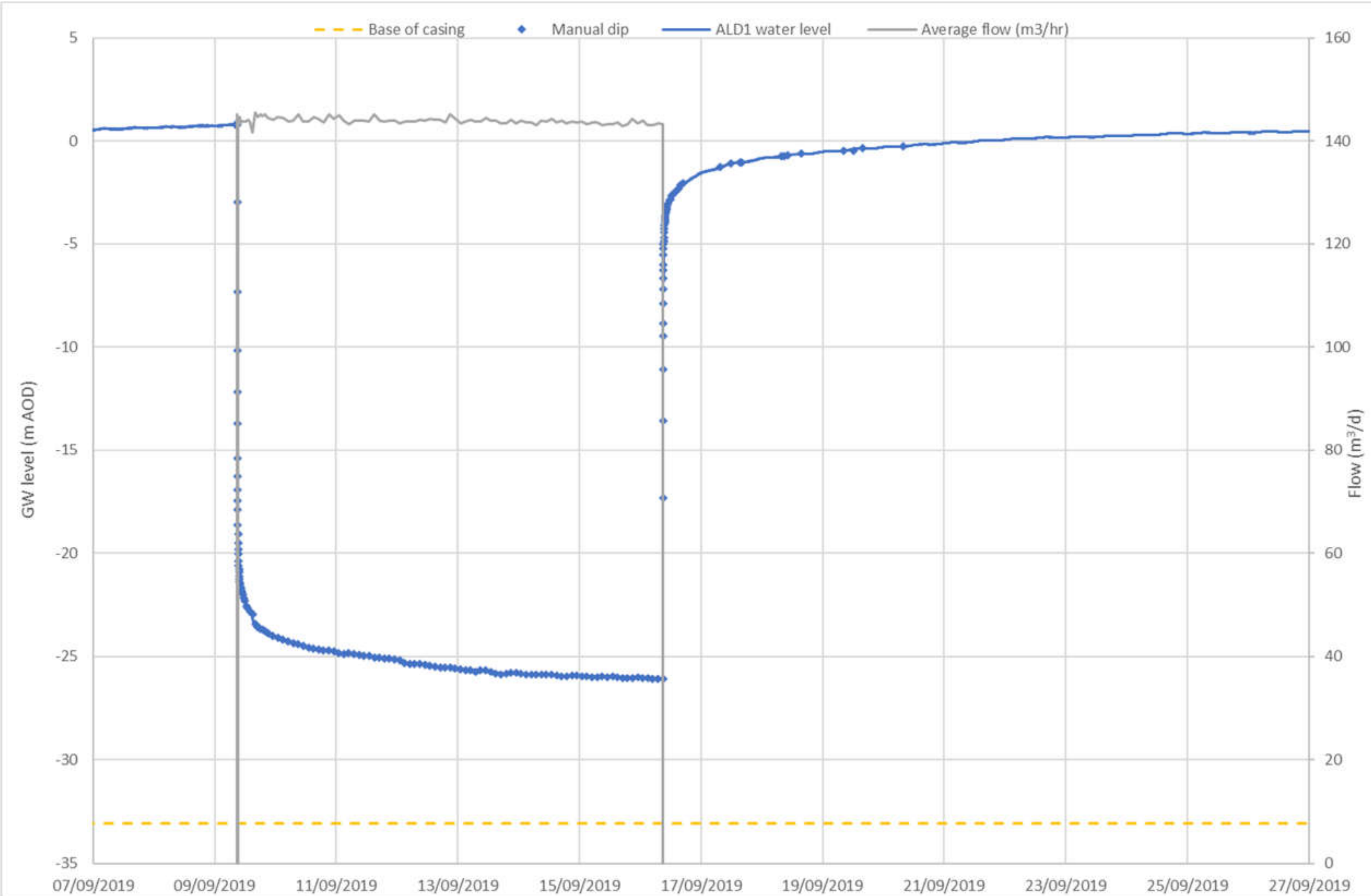


Figure 3-10 - Water levels at Ringborough Farm borehole during constant rate pumping test

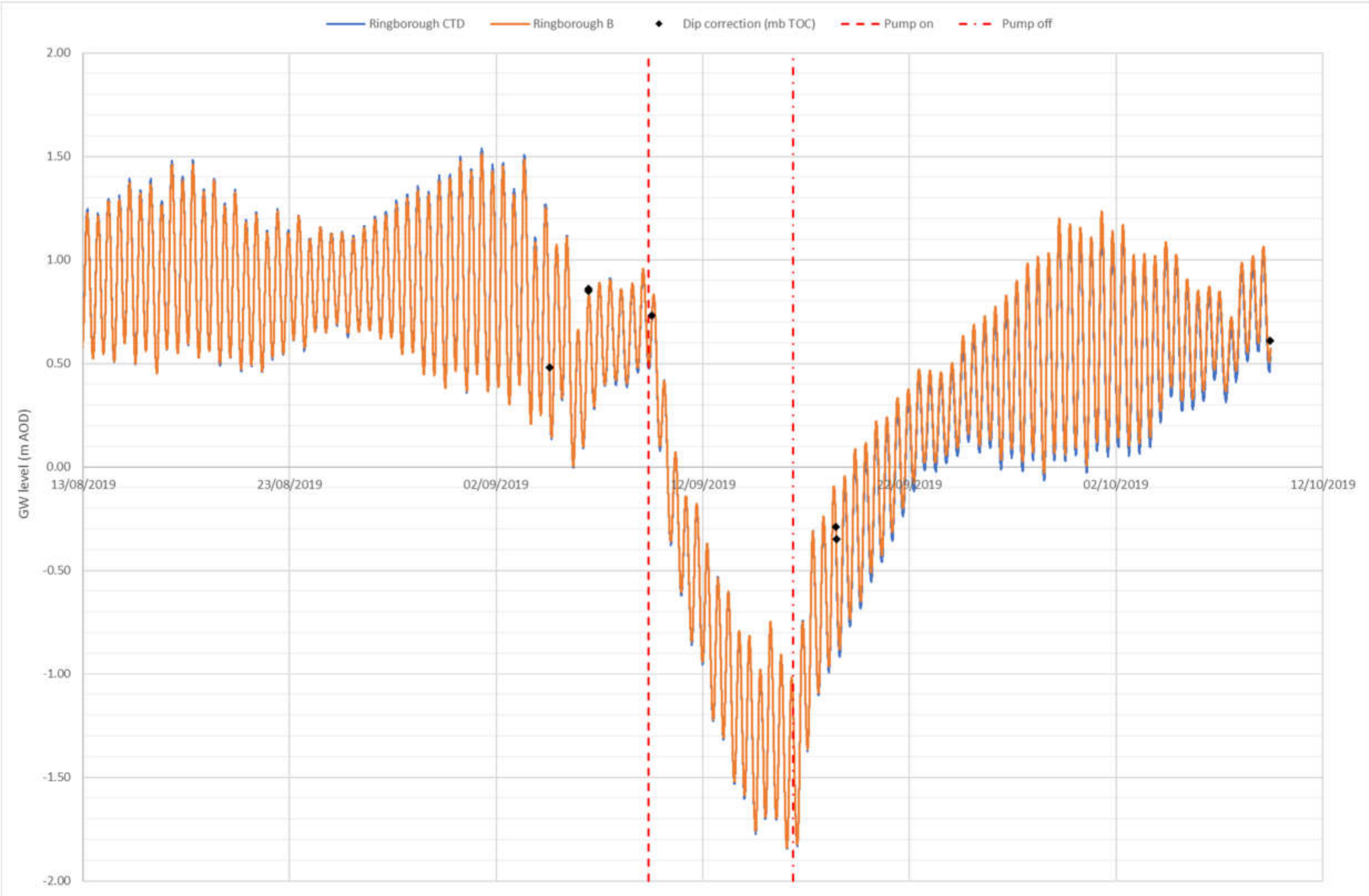
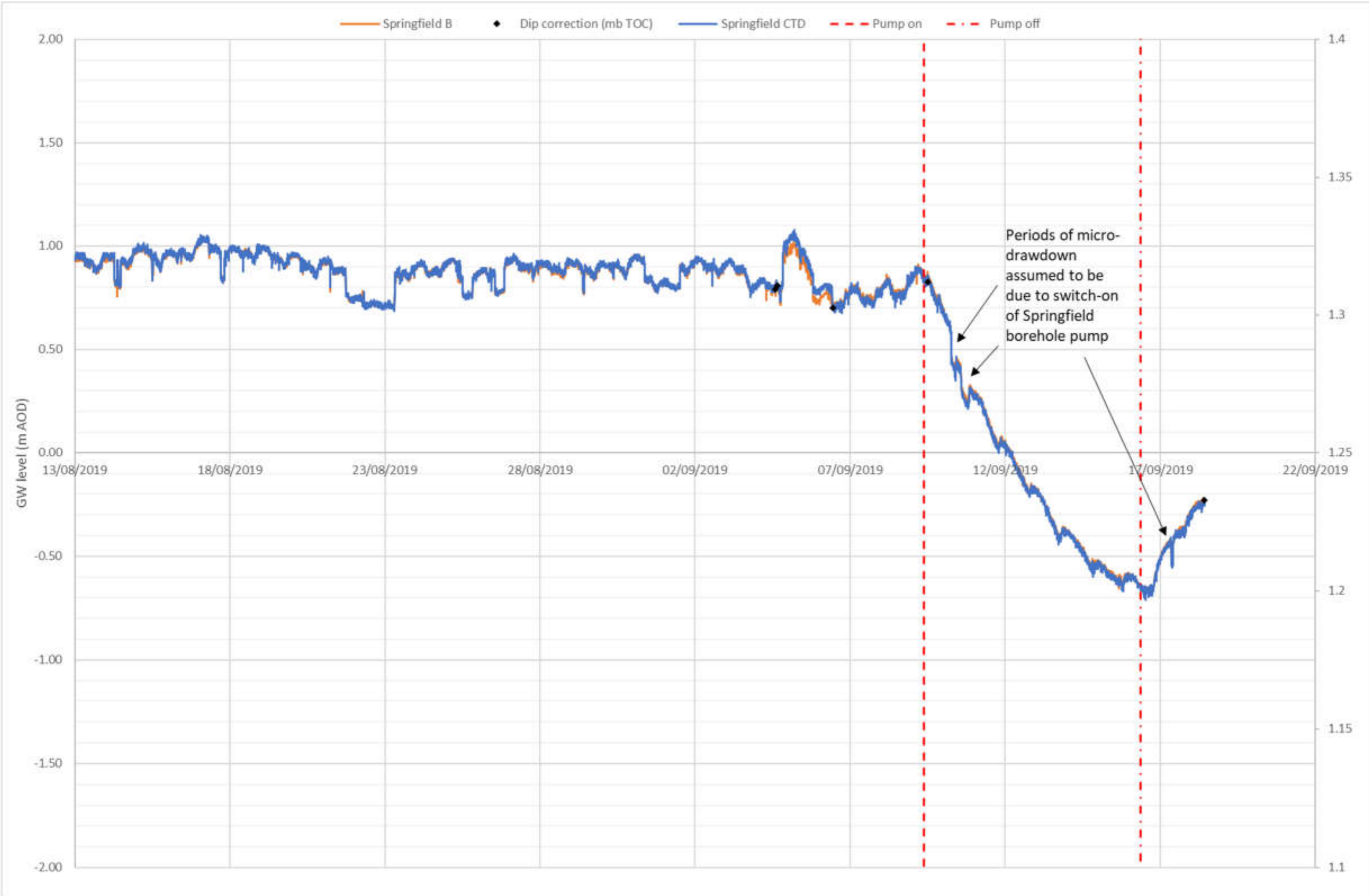


Figure 3-11 - Water levels at Springfield Farm during constant rate pumping test



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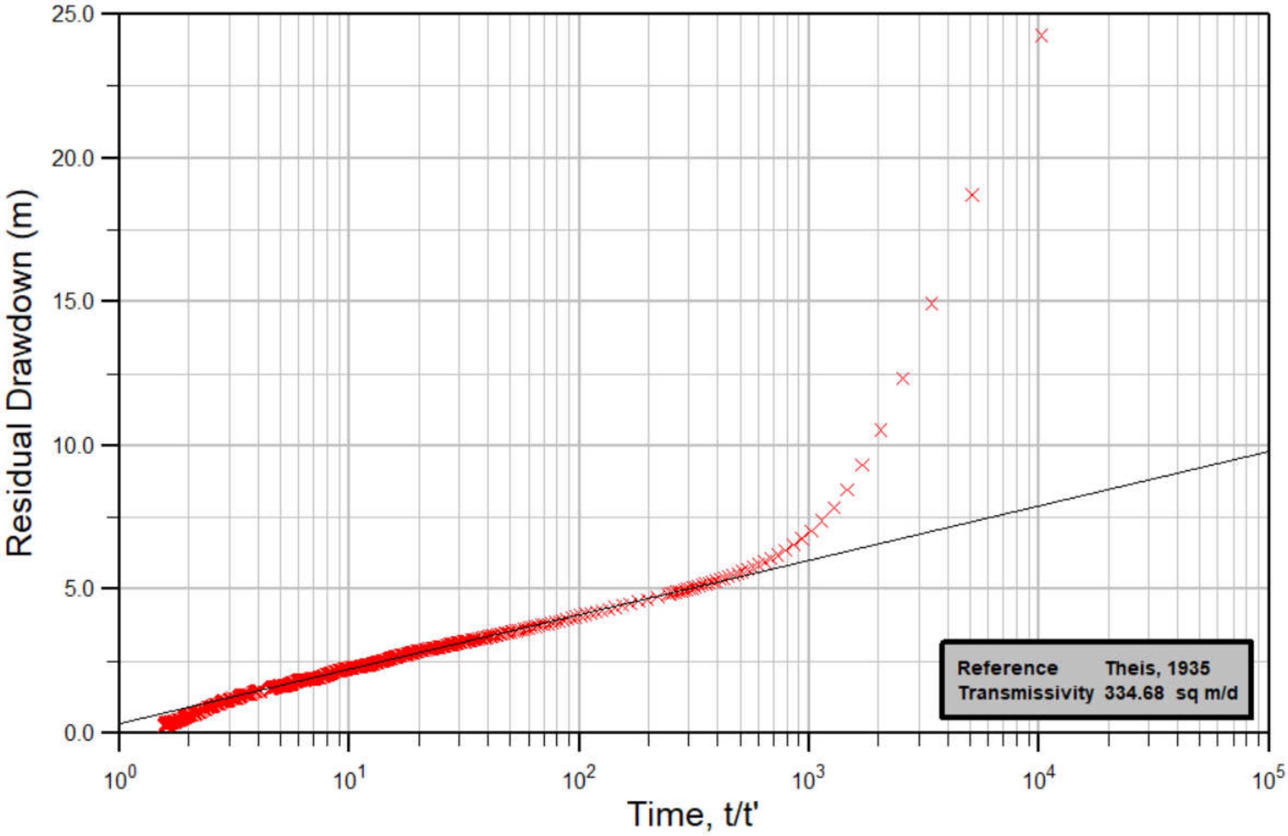
3.3.2. Pumped borehole

3.3.2.1. Theis (1935) recovery analysis

Transmissivity can be estimated from the pumped well using the Theis recovery method. In this method measured drawdown at the pumped source is plotted against time since the start of pumping (t) over time since the end of pumping (t'). The gradient of the line is a function of transmissivity. Theis (1935) recovery analysis using the abstraction borehole data is shown in Figure 3-12, and gives an estimated transmissivity of 335 m^2/d. Estimates of storage cannot be obtained from recovery data or from pumped well data in general.

In this method the early recovery data generally does not fit the straight-line: on Figure 3-12, the first 15 minutes of recovery does not follow a straight line. This is because the initial recovery within the borehole is recovery of drawdown attributed to well losses and storage in the well, rather than true representation of aquifer recovery.

Figure 3-12 - Theis (1935) recovery analysis of the pumped well



3.3.3. Observation boreholes

Theis (1935) analysis can be used to analyse the drawdown data from observation boreholes to give estimates of transmissivity and storativity. The Theis analysis is appropriate for confined aquifers, as in this case.

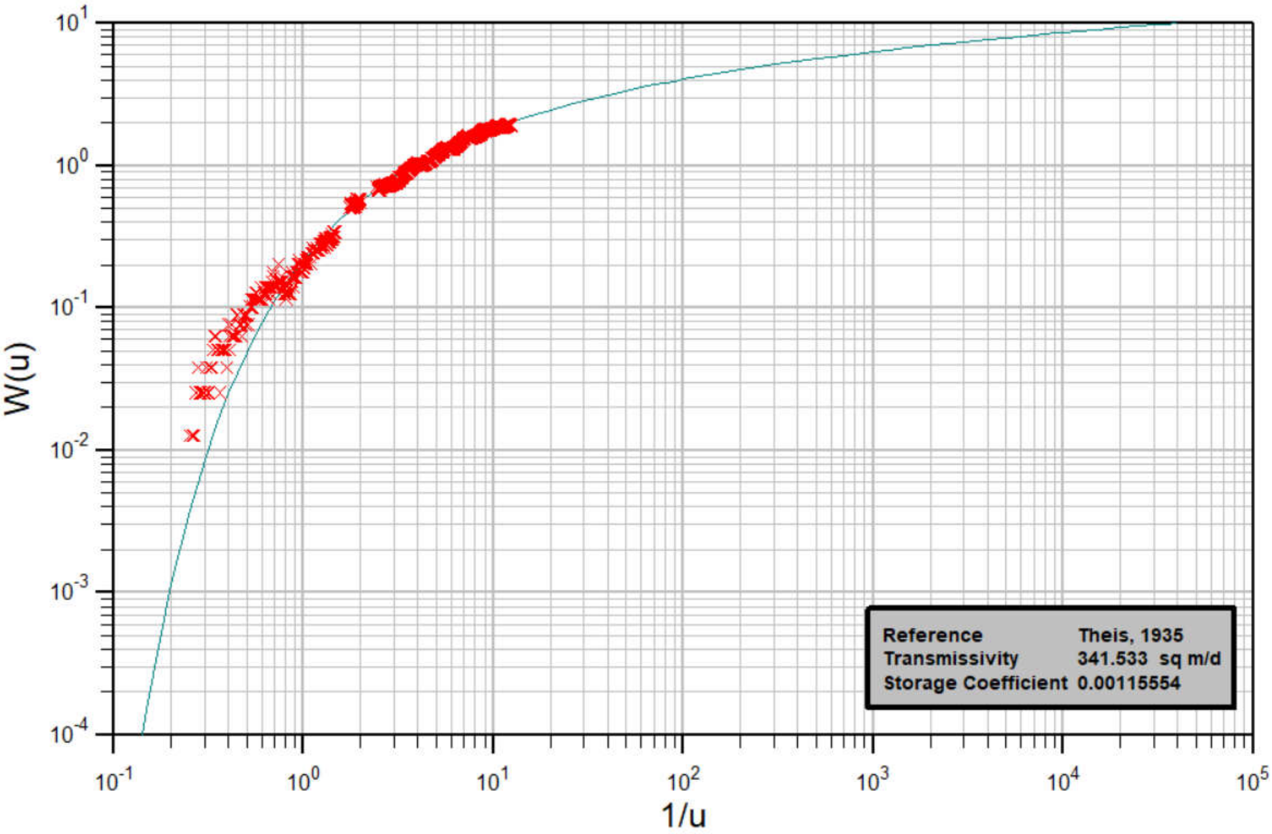
3.3.3.1. Springfield Farm

Figure 3-13 shows the Theis analysis of the data collected at Springfield Farm. Data from the assumed pumped periods have been removed from the analysis and show as gaps in the dataset.

The early time data, corresponding to the first 10 hrs from pump switch on, falls above the Theis type-curve, showing more drawdown than would be predicted by the type-curve. Some of this is likely to be a result of the impact of the tidal oscillation in groundwater levels being more apparent in the early time of the chart's x-axis log scale.

Baseline data show there is several hours' delay (between 3 and 6 hrs) between Hornsea high tide and peak groundwater level at Springfield Farm. On the day of the start of the constant rate test, the first low tide was at 08:34[1]. The pumping test started at 09:00 but the response to pumping at Springfield Farm is delayed because of the distance from the pumped well – the first drawdown was noted at the Springfield Farm borehole at 12:40 (this represents the earliest data points in Figure 3-13). At this time groundwater levels may still be responding to the morning low tide, which may result in more drawdown than expected. At later times, and greater drawdowns, the influence of the tidal oscillation (<0.1 m) becomes less significant and measured drawdown plots along the Theis type-curve.

Figure 3-13 - Theis (1935) analysis of water level data from Springfield Farm



3.3.3.2. Ringborough Farm

Under non-pumping conditions groundwater level at Ringborough Farm is dominated by a tidal oscillation of >1.0 m (Figure 3-1). In order to analyse the drawdown impacts at this location Atkins removed this tidal influence by averaging water levels over a 700-minute period. Raw and averaged groundwater level data are shown on Figure 3-14 – several averaging intervals were tested, but 700 minutes is the shortest interval which gives a smooth curve and approximates to one full tidal cycle.

This averaged groundwater level was used to calculate drawdown at this location, and these drawdown data were used to carry out a Theis (1935) analysis for this monitoring well, shown in Figure 3-15. The early time data (the first 4 hours) plot above the type-curve (i.e. greater drawdown than would be expected). This is likely to be in part due to the averaging to remove the tidal effect. Due to the distance from the pumped well, there will be a delay before drawdown impacts affect the groundwater level at Ringborough Farm – if there was no tidal impact Atkins would not expect to see drawdown at this location within the first few hours. By averaging the water level over 700 minutes, the drawdown observed after this delay affects the calculated drawdown immediately after pumping begins, effectively bringing the onset of drawdown forward. By late times, effects of averaging become

[1] https://tides4fishing.com/uk/england/hornsea

less significant and the data fits the Theis curve closely. For these reasons the early time data has not been used for curve matching in the Theis (1935) analysis.

For comparison, a Theis (1935) analysis without removing the tidal effects from the data is shown in Figure 3-16. The rest water level for drawdown was taken as the groundwater level at the mid-point of the tidal cycle before the testing commenced. This results in negative drawdown during the period of rising tide at the start of the test, and exaggerated drawdown during the falling tide. The effect is much more obvious at early times and small drawdowns, primarily because of the log-log nature of the Theis plot.

Figure 3-14 - Averaged groundwater level at Ringborough Farm

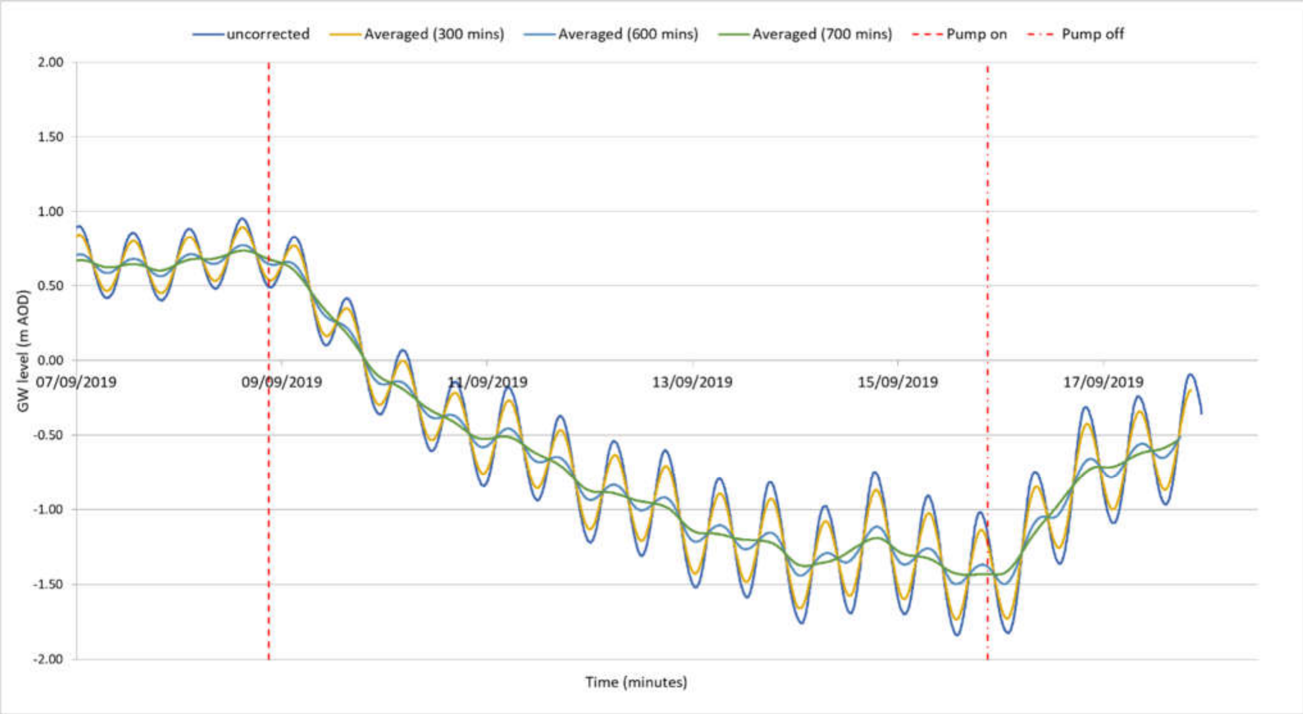


Figure 3-15 - Theis (1935) analysis of water level data from Ringborough Farm (tidal effect removed)

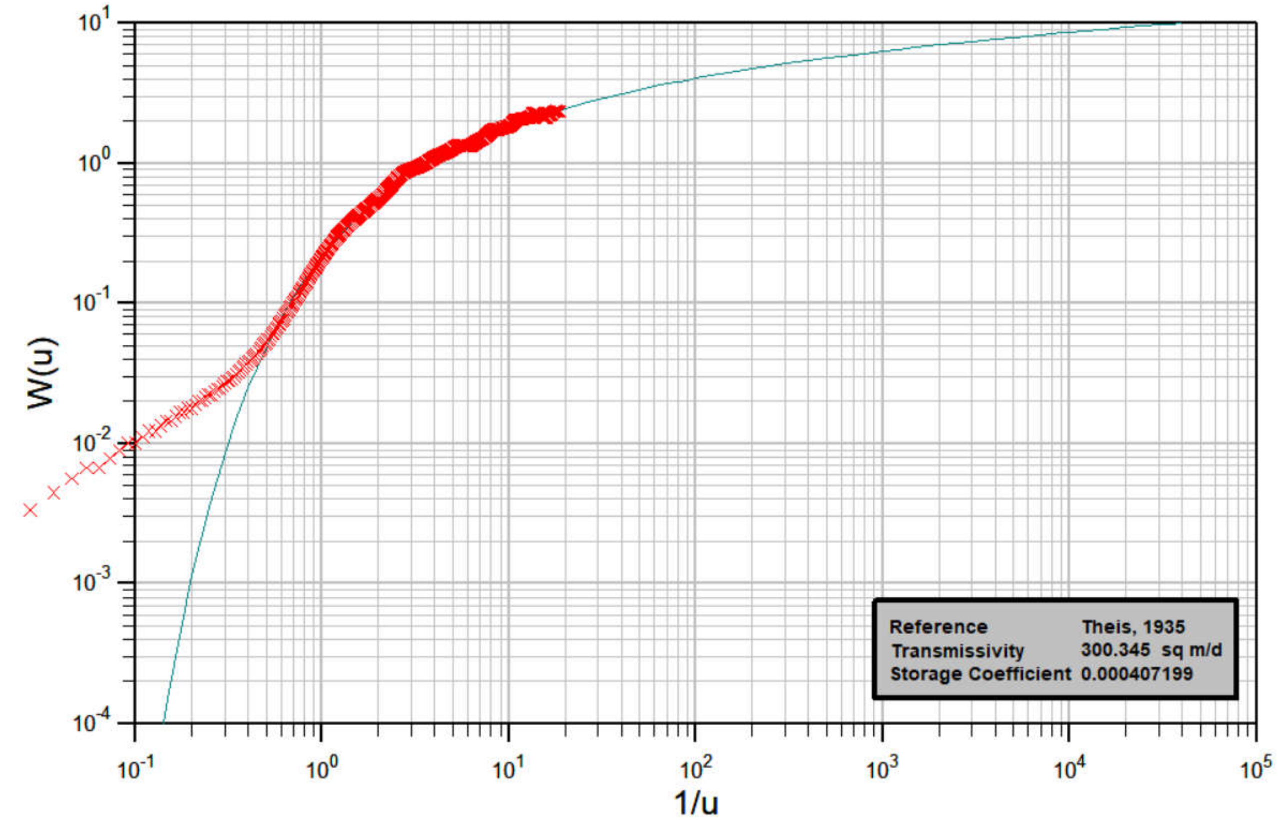
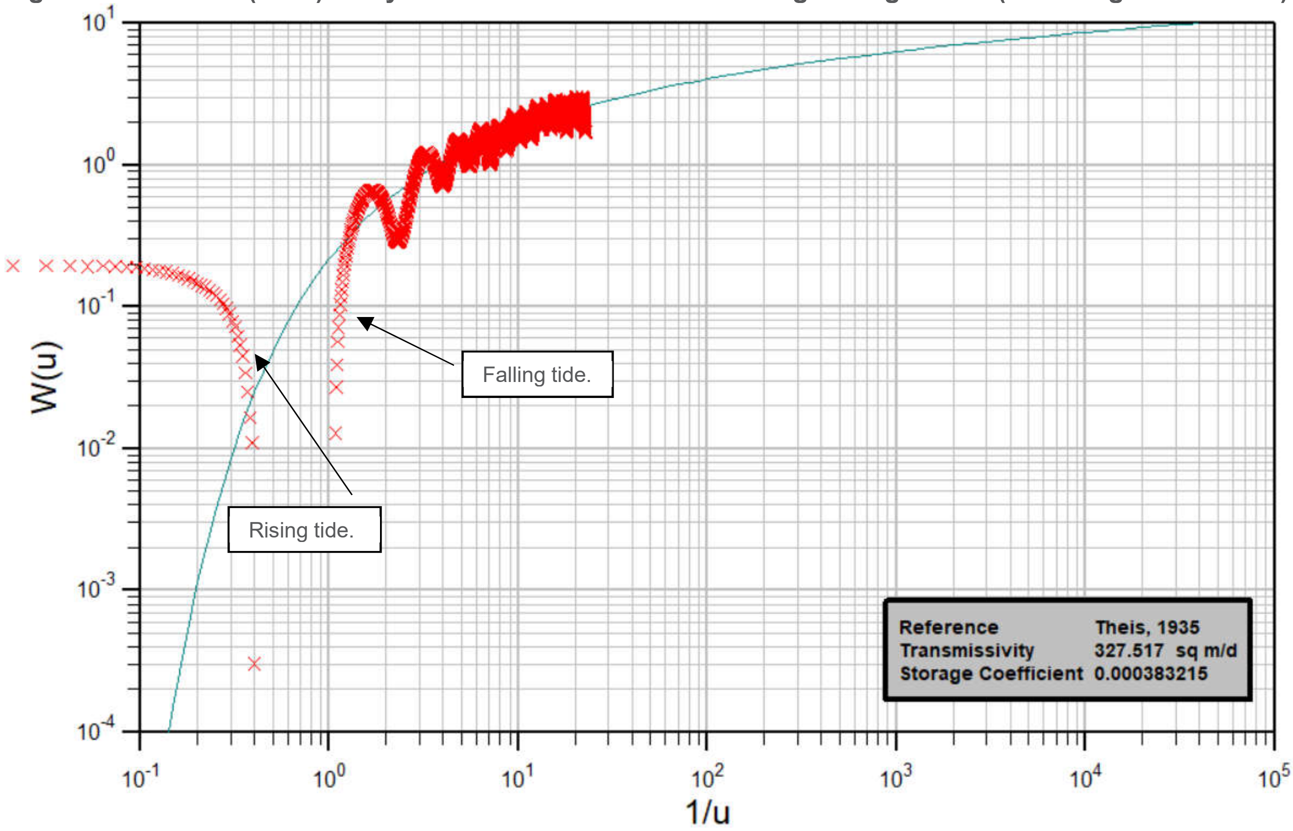


Figure 3-16 - Theis (1935) analysis of water level data from Ringborough Farm (including tidal effects)



3.3.4. Summary of estimated parameters

Table 3-2 summarises the calculated hydraulic parameters based on the various analytical methods discussed above. Estimated transmissivity and storativity values are consistent between the different methods. Literature values of transmissivity in the Yorkshire Chalk have an interquartile range of 500 m^2/d to 5968 m^2/d (Allen, et al., 1997). The transmissivities derived from the SSE Aldbrough pumping test are below the lower end of this range. However, Allen et al. 1997, state that transmissivity in the confined Chalk of the Holderness peninsula, immediately south of Aldbrough, is generally much lower, less than 50 m^2/d.

Transmissivity is lower at Ringborough Farm than at Springfield Farm. This was expected as greater drawdown was observed at Ringborough than at Springfield during the constant rate test (Table 3-1).

Literature values for storage coefficients given by Allen et al. (1997) range from 1.5×10^{-4} to 1.0×10^{-1}, with an interquartile range of 1.5×10^{-3} to 1.8×10^{-2}. The storativity values from the Aldbrough pumping test are at the lower end of this range.

Table 3-2 - Summary of derived hydraulic parameters

Test	Analytical method	Transmissivity	Storativity (-)
Constant rate test	Theis (1935) recovery	335 m^2/d	-
	Theis (1935) - Springfield Farm	342 m^2/d	1.16×10^{-3}
	Theis (1935) - Ringborough Farm	300 m^2/d	4.07×10^{-4}
Step test	Eden and Hazel (1976)	236 m^2/d	-
	Geometric mean*	274 m^2/d	6.87×10^{-4}

3.3.5. Predicted drawdown

Drawdown at observation boreholes can be predicted after a specified number of days pumping using the Theis (1935) equation:

$$s = \frac{Q}{4\pi T}W(u) = \frac{Q}{4\pi T}\left(-0.5772 - \ln(u) + u - \frac{u^2}{2\times 2!} + \frac{u^3}{3\times 3!} - \cdots\right)$$

W(u) is the Theis well function where:

$$u = \frac{r^2 S}{4Tt}$$

Where: s = drawdown (m),
Q = flow (m^3/d),
T = transmissivity (m^2/d),
r = radial distance from observation well to pumping well (m)
S = storage coefficient (-)
t = pumped duration (d)

Table 3-3 shows calculated drawdown at each of the observation wells based on the derived values for transmissivity and storativity summarised in Table 3-2. These have been calculated for pumping durations of 7 days at a pumping rate of 144 m^3/hr for comparison with observed data during the constant rate test, and for durations of 30 and 100 days at a pumping rate of 125 m^3/hr, which is most representative of maximum flow rates and periods during borehole operation.

Where the analytical method from Table 3-2 does not derive a storage coefficient, the geometric mean of the derived storage coefficients from the observation boreholes of 6.87×10^{-4} has been used. Calculated drawdown is also shown for Hilltop Farm, a private abstraction borehole 1470 m from the abstraction (see section 4.5).

Potential impacts of predicted drawdown at the receptors are discussed in Steps 4-7 of the HIA in section 4.5.

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Table 3-3 - Predicted drawdown at observation wells

Analytical method	Drawdown (m)							
	7 days pumping at 144 m³/hr		30 days pumping at 125 m³/hr			100 days pumping at 125 m³/hr		
	Spring-field Farm	Ring-borough Farm	Spring-field Farm	Ring-borough Farm	Hilltop Farm	Spring-field Farm	Ring-borough Farm	Hilltop Farm
Observed	1.52	2.12	-	-	-	-	-	-
Theis (1935) recovery	1.97	1.63	2.72	2.41	1.97	3.57	3.25	2.81
Theis (1935) - Springfield Farm	**1.55**	1.23	**2.32**	2.01	1.59	**3.15**	2.84	2.40
Theis (1935) Ringborough Farm	2.57	**2.17**	3.36	**3.01**	2.51	4.32	**3.96**	3.46
Eden and Hazel (1976)	2.42	1.94	3.51	3.07	2.45	4.72	4.27	3.63
Geometric mean	2.11	1.73	2.95	2.60	2.11	3.90	3.55	3.04
Maximum calculated	2.57	2.17	3.51	3.07	2.51	4.72	4.27	3.63
Minimum calculated	1.55	1.23	2.32	2.01	1.59	3.15	2.84	2.40

Values shown in **bold underlined text** are most appropriate for that location, as they are based on derived parameters using observed drawdown from that location during the constant rate test.

3.4. Water quality

3.4.1. Electrical conductivity

EC was monitored at the Aldbrough abstraction borehole and at the observation boreholes throughout the test due to the proximity of the abstraction to the coast. Figure 3-17 shows the results of this monitoring. At the abstraction borehole the EC of the abstracted water was measured at the borehole using an in-line probe, as well as in samples sent for laboratory testing during the step test and constant rate tests. All water quality data are included in Appendix B.

In the observation boreholes the EC was measured by EC dataloggers installed in the boreholes. As both observation boreholes contain pumps and rising mains it was not possible to install the dataloggers within the open section of the borehole, and they were installed in the cased section, so may not be fully representative of water in the aquifer. At Springfield Farm, samples were also collected from the sampling tap prior to and after the test that were tested for EC. Figure 3-17 shows that these had ECs similar to those recorded by the logger, validating the logger data for this location. At Ringborough Farm, Atkins would have expected higher ECs to be recorded as the location is immediately next to the coast. It was not possible to collect validation samples from the open section of this borehole to validate the logger data.

At the abstraction borehole EC was measured by the in-line probe between 3500 and 4100 μS/cm, which showed a slight increase during the constant rate test (Figure 3-17). However, the laboratory samples taken at the start and end of test show no change in EC, which suggests that this increasing trend is likely to have been due to drift in the calibration of the probe, rather than a true change in EC.

EC was lower at both the observation boreholes than at the pumped well: 1100 μS/cm in samples collected from the borehole tap, and between 1100 and 1250 μS/cm recorded by the logger. At Ringborough Farm, EC was consistently 1250 μS/cm. Although, as discussed above, this may not be representative of EC in the aquifer at this location. Water tested from the private water supply borehole at Hilltop Farm, also very close to the coast, had ECs of 2200 μS/cm. None of the observation boreholes showed any change in EC as a result of the pumping test – the samples collected from the borehole tap at Springfield Farm and Hilltop Farm showed the same EC in baseline samples and in the sample collected after the pumping test.

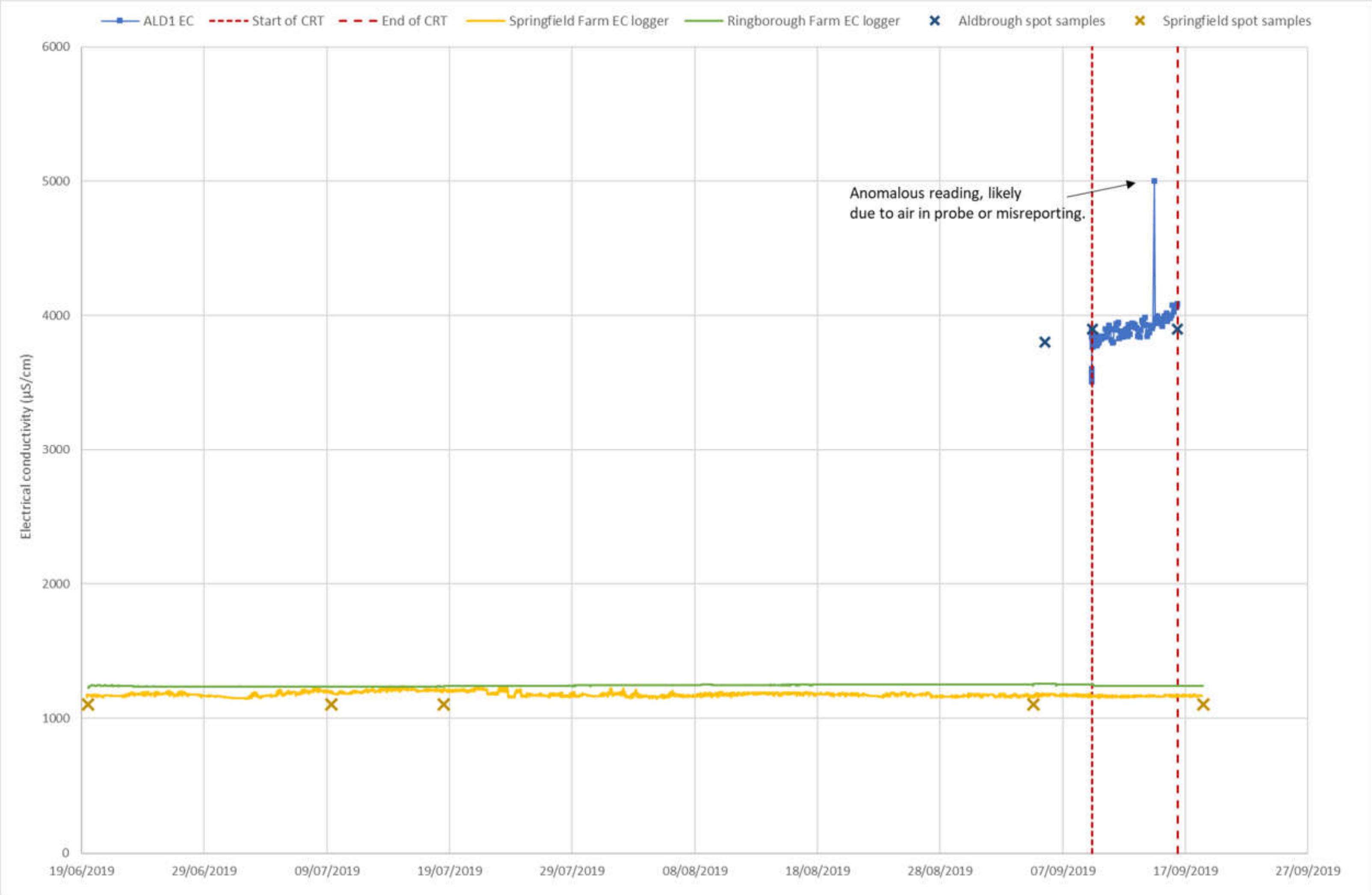
3.4.2. Overall water quality

The water abstracted from the borehole will be used for industrial purposes, primarily for the rewatering of underground gas caverns. As part of this process the water will likely be filtered and heated before use.

At SSE Atwick, SSE has already carried out similar rewatering operations using Chalk groundwater. There, SSE encountered iron-manganese fouling in its existing boreholes and clogging of filters as a result of iron-manganese oxide build-up. This problem is likely to be encountered at Aldbrough. Chalk groundwater in this area typically has elevated iron and manganese concentrations and when groundwater is abstracted it undergoes some degree of de-carbonation and aeration which results in precipitation of iron-manganese oxides. After the constant rate test an ochre residue was left on the grass adjacent to the discharge point used during the pumping test (see Appendix A photo 07), which Atkins attribute to iron-manganese precipitate. During the constant rate test dissolved iron concentrations measured in the collected samples were relatively low (<0.1 mg/l, Table B-1), but it is likely this doesn't reflect total iron, including precipitates. Total iron was tested in the samples collected at Springfield Farm and Hilltop Farm and exceeded 2 mg/l in all samples (Table B-4 and Table B-5). At these concentrations, formation of iron oxide precipitate would be expected upon abstraction.

Precipitation of iron and manganese may be accelerated if the top of the Chalk aquifer were dewatered around the borehole during pumping, due to oxygenation of the aquifer. The Eden- Hazel (1973) analysis indicates that the water level in the borehole would likely remain above the base of the casing throughout a 100-day pumped period, preventing dewatering of the Chalk, and therefore helping to reduce the amount of iron-manganese precipitation.

Figure 3-17 - Electrical conductivity measured at the pumped source and observation boreholes



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4. Hydrogeological Impact Assessment

4.1. Introduction

This HIA follows the Environment Agency methodology as laid out in the guidance document Hydrogeological Impact Appraisal for Groundwater Abstractions Science Report SC040020/SR2 (Environment Agency, 2007). For some of the steps the information has already been collated in the desk study and water features survey reports. In this case these reports will be referenced within this document and only any relevant additional information will be summarised here. This approach has been agreed with Ruth Buckley, Environment Agency Technical Officer for Groundwater and Contaminated Land.

4.2. Step 1 – Establish the regional water resource status

The Abstraction Licensing Strategy for Hull and East Riding summarises the resource availability within the catchment based on the Environment Agency's monitoring data and modelling. The area around the Aldbrough site is classified as "water available" under all flow conditions, even during dry flow conditions (Environment Agency, 2013). Further details of the regional water resource status are provided in the desk study for this project (Atkins, 2017a).

4.3. Step 2 – Develop a conceptual site model (CSM) for the abstraction and the surrounding area.

4.3.1. Preliminary CSM

A detailed preliminary CSM for the site and surrounding area was presented in Section 5 of the Atkins' 2017 desk study (Atkins, 2017a).

4.3.2. Updated CSM

During the Water Features' Survey for this project (Atkins, 2017b) Atkins identified two additional receptors within 2 km of the borehole location, at Springfield Farm and Hilltop Farm. These are both unlicensed private water supply boreholes used for agricultural purposes, shown as locations 1 and 3 on Figure 4-2. Springfield Farm was used as an observation borehole during the pumping test.

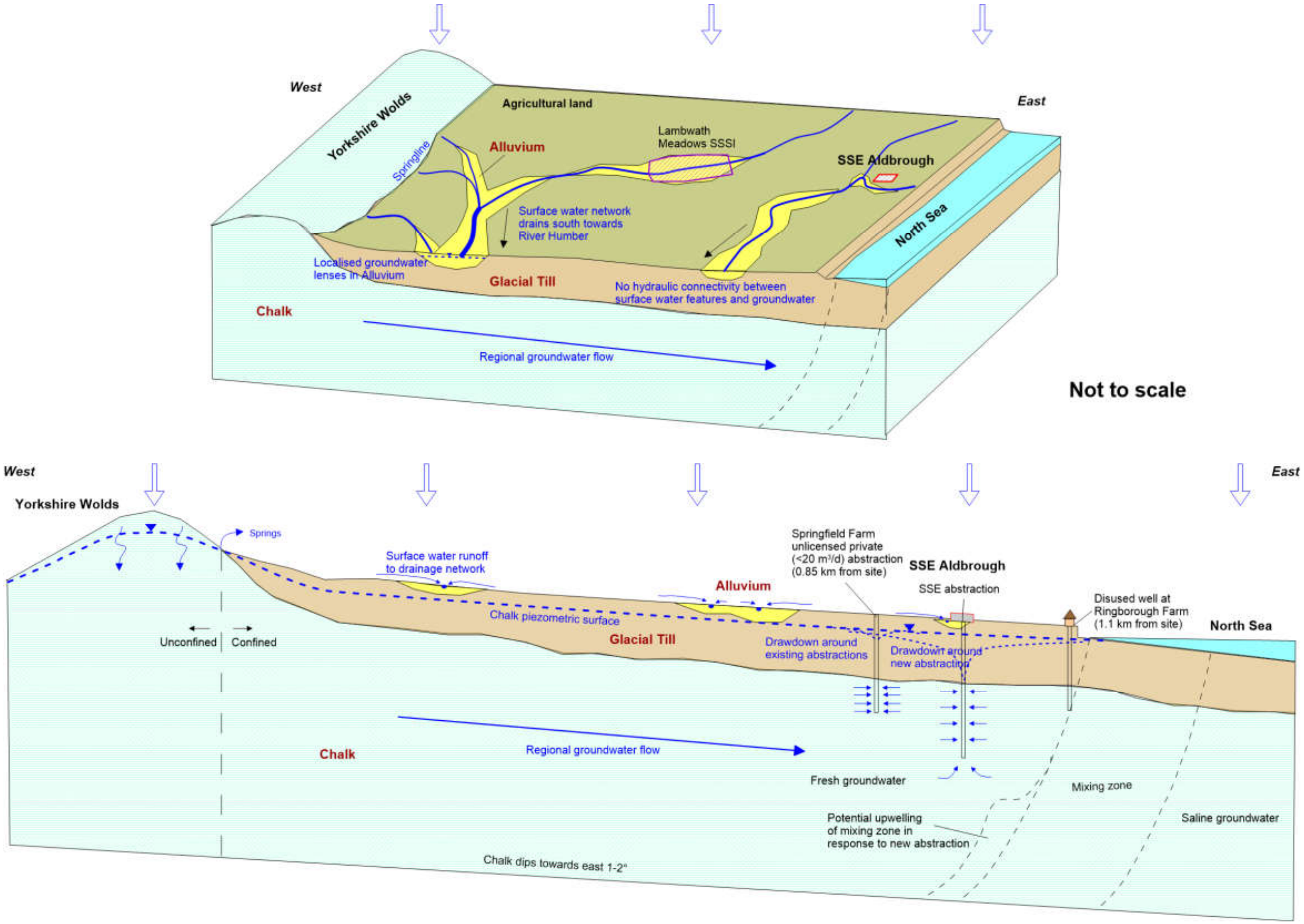
Figure 4-1 shows the updated conceptual site model for the site and surrounding area. This CSM figure has been updated since the Atkins Desk Study (Atkins, 2017a) was prepared to include the additional receptors. As well as the risk of drawdown derogation to private agricultural supply boreholes, the other key potential impact from this abstraction is in the inducing of saline intrusion into the aquifer from the adjacent North Sea or from the saline groundwater wedge at depth that occurs at the coast.

Baseline monitoring during this project shows that water levels at the abstraction borehole and nearby observation boreholes are tidally influenced. The tidal oscillation in groundwater at Ringborough Farm, immediately adjacent to the coast, is approximately 1.2 m, decreasing to <0.1 m at Springfield Farm, approximately 2 km inland. At the abstraction borehole water level varies by around 0.1 m in response to the tide.

Assuming groundwater flow direction is perpendicular to the coast, and therefore parallel to the spread of abstraction and observation boreholes, which run in a line east-west, Atkins has used the baseline monitoring data to calculate the average hydraulic gradient to be approximately 4×10^{-5} towards the coast.

The derived hydraulic parameters from the pumping test works for the Chalk in for the area around SSE Aldbrough are summarised in Table 3-2.

Figure 4-1 - Updated conceptual site model drawing



4.3.3. Planned abstraction

The proposed abstraction would be for maximum hourly abstraction volumes of 144 m^3/hr, daily volumes of 3456 m^3/d and annual volumes of 500,000 m^3/yr. These values represent absolute maxima, including 15% contingency for the licence application. During periods of operation the borehole would likely be pumped at flow rates up to a maximum of 125 m^3/hr.

Water would be abstracted during periods where there was a site requirement, primarily for the rewatering of one of the gas caverns. During this period the abstraction may be continuous, but the volume of water required would be finite. It is likely that each pumping cycle would be ongoing for periods of between 30 and 100 days, depending on the size of the cavern being filled. Following each pumping cycle the abstraction would cease.

SSE also intend to have the groundwater supply as a contingency for fire-fighting purposes in the event of emergency. This will be included on the licence application by allowing for an additional 3 days' continuous pumping at maximum daily flow rates.

4.4. Steps 3 – 6: Potential flow impacts

As summarised in the Atkins desk study (Atkins, 2017a), the Chalk aquifer at the site is overlain by of 41 m of diamicton. Recharge to the Chalk occurs approximately 25 km west in the Yorkshire Wolds where the Chalk is unconfined. In this area the overall flow direction is towards the coast, and with no abstractions, groundwater would just discharge to the North Sea east of the site.

Due to the thickness of the overburden and distance from the recharge zone Atkins does not consider there to be any connectivity between surface water features and groundwater in this area. Therefore, flow impacts on surface water features have not been considered here. This approach was agreed with the Environment Agency during the GIC application process, and as such surface water features were not included in the Water Features Survey.

It is possible that the abstraction could cause a reduction in groundwater discharge to the North Sea, and hence migration or upwelling of saline water inland into the Chalk aquifer. This potential impact is discussed in Step 12 (section 4.6).

4.5. Steps 7 – 11: Potential drawdown impacts

Step 7 – define the search area for drawdown impacts

Atkins carried out a Water Features Survey during the Section 32 consent application. This survey considered receptors within a 2 km radius of the site. However, for completeness several receptors outside of this area were also included.

The water features identified during this survey are shown in Figure 4-2.

Step 8 – identify features within the search area which could potentially be impacted by drawdown

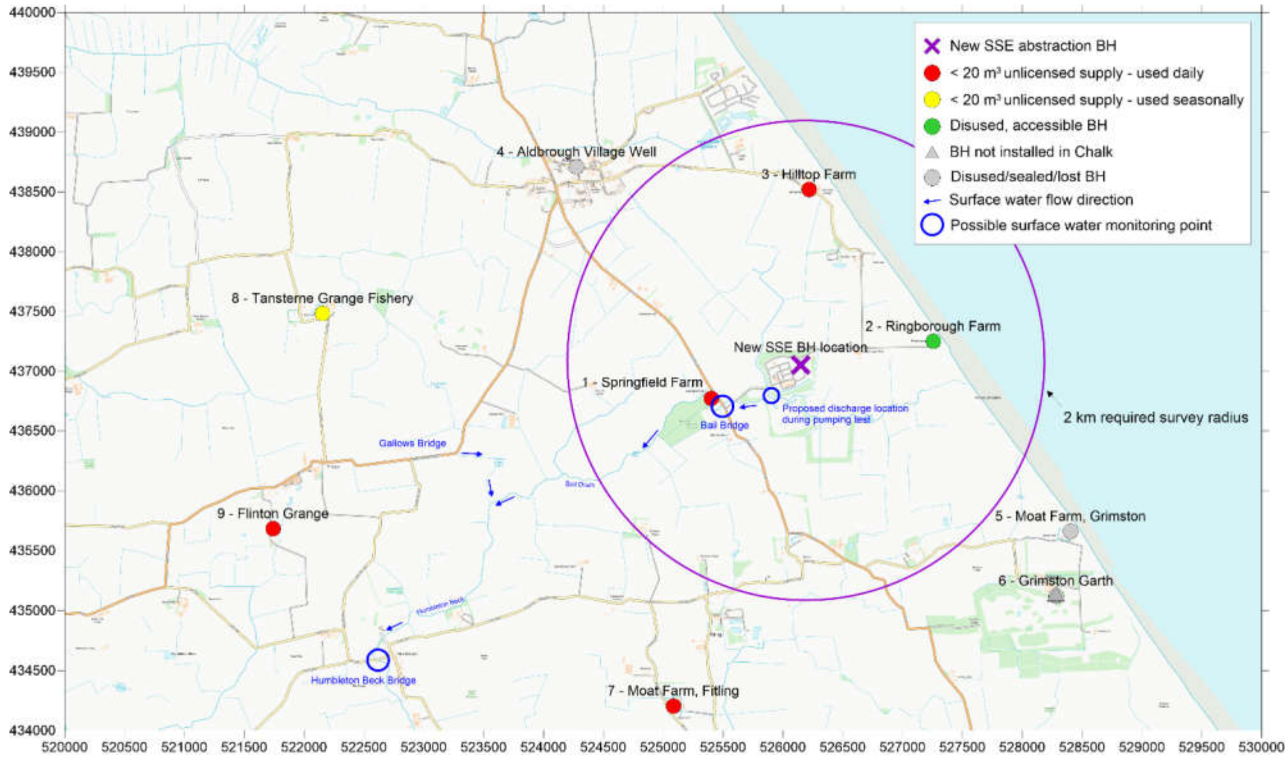
During the water features survey (Atkins, 2017b) Atkins identified two private abstractions, at Springfield Farm and Hilltop Farm, that could both be affected by drawdown. Both boreholes are owned by the same farmer who uses them to supply two pig farms. Details of the boreholes are summarised in Table 4-1.

Table 4-1 - Private water supply boreholes within 2 km of SSE Aldbrough

<table>
<tr><th>Borehole</th><th>Distance from proposed abstraction</th><th>Depth</th><th>Pump depth</th><th>Approximate rest water level</th><th>Usage</th></tr>
<tr><td>Springfield Farm</td><td>855 m</td><td>65 m bgl</td><td>≈ 40 m bgl</td><td>9.3 – 9.8 m bgl</td><td rowspan="2">Private, unlicensed supplies for pig farms.
Daily use, year-round, operating at <<20 m³/d.</td></tr>
<tr><td>Hilltop Farm</td><td>1470 m</td><td>65 m bgl</td><td>Unknown</td><td>21 m bgl*</td></tr>
</table>

*water level not measured by Atkins but reported by borehole owner (Atkins, 2017b)

Figure 4-2 - Existing groundwater features surrounding SSE Aldbrough



Contains OS data © Crown copyright and database right (2019)

Step 9 – for these features, predict the likely drawdown impacts

Springfield Farm was monitored during the constant rate test and showed 1.52 m drawdown at the end of 7-days' pumping. No monitoring was carried out at Hilltop Farm, although water level monitoring was carried out at nearby Ringborough Farm, where 2.12 m of drawdown was observed (section 3.3.1).

Atkins has calculated the range of predicted drawdown values for the Springfield Farm and Hilltop Farm boreholes using the derived hydraulic parameters calculated from analysis of the pumping test carried out at Aldbrough (section 3.3.5, Table 3-3). Predicted drawdown has been calculated for 30-day and 100-day periods of pumping at 125 m^3/hr, which is representative of the most likely maximum sustained flow rates.

The range of calculated drawdown values for each receptor are:

- Springfield Farm:
  - Predicted drawdown after 30 days pumping = 2.32 – 3.51 m, geometric mean of 2.95 m.
  - Predicted drawdown after 100 days pumping = 3.15 – 4.72 m, geometric mean of 3.90 m.
- Hilltop Farm:
  - Predicted drawdown after 30 days pumping = 1.59 – 2.51 m, geometric mean of 2.11 m.
  - Predicted drawdown after 100 days pumping = 2.40 – 3.63 m, geometric mean of 3.04 m.

For Springfield Farm drawdown can be predicted with some accuracy as this location was monitored during the constant rate test. The derived transmissivity and storage coefficient from analysis of observed drawdown at Springfield predict drawdown over 30 days at 125 m^3/hr of 2.32 m, and over 100 days at 125 m^3/hr of 3.15 m. These values are at the low end of the stated range. For Hilltop Farm, no monitoring was carried out, so the geometric mean is the best available estimate of likely drawdown.

Step 10 – allow for the effects of any measures being taken to mitigate drawdown impacts

The proposed abstraction will not operate year-round. It is likely to be operational for periods of 30-100 days and then out of use. This means that any drawdown impacts will be temporary. Monitoring at both observation boreholes during the pumping test showed that water levels recovered rapidly after the pumping test ceased.

Step 11 – assess significance of net drawdown impacts

At Springfield Farm the borehole pump is installed at approximately 40 m bgl, which is approximately 30 m below rest water level. For a period of 100 days' pumping, the anticipated drawdown of approximately 3.2 m is therefore unlikely to cause derogation of the existing water supply.

At Hilltop Farm, the depth of the pump intake is unknown, but the borehole is 65 m deep and rest water level reported as approximately 20 m bgl. The borehole and pump were installed by the same contractor as at Springfield Farm so Atkins would assume that the pump setup is similar, and a reduction in water level of 2.4 – 3.6 m for a period of 100 days' pumping is therefore unlikely to cause derogation of the existing water supply.

However, it is possible that, depending on the capabilities of the pumps installed in these boreholes, that reduced head during periods of abstraction may mean that the pump cannot maintain the required lift to pump at the normal rate, or may have to pump for longer periods to keep header tanks topped-up.

4.6. Step 12 – assess water quality impacts

4.6.1. Saline intrusion

The SSE Aldbrough abstraction borehole is approximately 1100 m inland from the coast. One of the key potential impacts from this abstraction was the drawing of saline water into the Chalk, and the potential for subsequent water quality impacts on the nearby private supply boreholes.

Water quality, including EC, was monitored at the abstraction borehole and at both observation boreholes as described in section 2.4.4. The results of EC monitoring at all boreholes is shown in Figure 3-17, and full results of all water quality monitoring is included in Appendix B.

EC was higher at the abstraction borehole than at either Springfield or Ringborough Farm. At Springfield Farm this would be expected as the borehole is both shallower and further inland than the Aldbrough borehole. The Ringborough borehole is also shallower than the Aldbrough borehole (approximately 61 m) (Atkins, 2017b), but it is much closer to the coast, so the EC of <1500 µS/cm recorded here is lower than expected. As discussed in section 3.4, Atkins suspect that the EC recorded by the logger at Ringborough Farm may not be representative of EC within the Chalk at this location.

At the abstraction borehole, in-line measurements of EC using a hand-held probe showed a gradual increase during the 7-day constant rate test. However, this was not corroborated by the laboratory sample analysis which showed no change in EC between samples taken from the abstracted water at the start and end of the test. Atkins therefore attribute the increase recorded in the in-line monitoring to drift in calibration.

At Springfield Farm, the EC logger data showed no change in EC during the test. Laboratory samples from both Springfield and Hilltop Farms showed no change in EC or chloride concentrations in post-testing sampling compared to baseline samples.

There is no evidence that saline intrusion affected water quality at the abstraction or at the observation boreholes during the pumping test. However, there is a theoretical risk that drawdown at the abstraction well could induce upwelling of saline water at depth during longer periods of abstraction. SSE proposes carrying out monitoring at the abstraction well during periods of pumping to mitigate this risk (see section 4.8).

Any periods of abstraction from the Aldbrough borehole will be temporary (likely limited to 100 days at a time). Under baseline conditions, groundwater flow is towards the coast at SSE Aldbrough; as such Atkins would anticipate that once the abstraction at Aldbrough was switched off, that any increase in salinity in the Chalk aquifer at the site would decrease over time. Atkins have observed this effect at other sites in East Yorkshire where temporary abstraction has taken place in chalk close to the coast.

4.6.2. Other water quality impacts

Four baseline samples were collected at Springfield Farm prior to the constant rate test, and one sample was collected two days after the test ended. One sample was collected at Hilltop Farm before and after the testing. No significant changes in water quality were observed in the post-testing samples compared to baseline sampling.

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4.7. Step 13 – if necessary, redesign mitigation measures to minimise flow and drawdown impacts

Step 11 highlights that drawdown impacts at Springfield Farm and Hilltop Farm are unlikely to cause a derogation of the water supplies at these boreholes due to the depth of the wells and pumps. However, as the specifications of the pumps in these wells are not known, it is possible that the reduction in piezometric heads at these locations could affect the water supply. SSE therefore proposes that SSE would notify the farmer prior to periods of abstraction from the Aldbrough borehole, and where necessary, either provide an interim water source (e.g. pay for additional mains water use) or supply an upgraded pump for the affected well.

4.8. Step 14 – develop a monitoring strategy

Step 14 is to develop a monitoring strategy for the abstraction. Atkins would propose that salinity is monitored at the abstraction well during periods of abstraction, e.g. by the collection of weekly samples for field testing for chloride concentrations. In the event that increasing chloride concentrations are identified in the abstraction borehole, water sampling could then be undertaken from Springfield Farm and Hilltop Farm to monitor any impacts on the quality of these private groundwater sources, and mitigation measures instigated if required e.g. provision of a bowser of water to the farmer or paying for additional mains water use.

5. Summary and conclusions

SSE has installed a 100 m deep borehole into the confined Chalk aquifer at Aldbrough, East Yorkshire. SSE commissioned Stows to carry out a step-test and 7-day constant rate test at the borehole. Atkins has used the results of this pumping test to derive transmissivity values of 236 m^2/d – 342 m^2/d and storage coefficients of 1.16×10^{-3} – 4.07×10^{-4} for the Chalk aquifer at Aldbrough. These sit at the lower range for literature values within the Chalk in the Yorkshire region, but higher than average values for elsewhere on the Holderness peninsula.

The borehole is intended to be used to supply the SSE Aldbrough site with a water supply for industrial use, principally for the rewatering of existing underground salt caverns. SSE intends to apply for a licence to abstract 3456 m^3/d at maximum flows of 144 m^3/hr. During operation the borehole would likely be pumped up to a maximum flow rate of 125 m^3/hr – the instantaneous rates applied for include 15% contingency. The borehole would be pumped for periods of 30-100 days, depending on the volume of the cavern being rewatered, and then be switched off.

Atkins has calculated the likely drawdown impacts at the principal receptors, two private agricultural water supply boreholes within 2 km of the abstraction. Atkins anticipates the closest borehole at Springfield Farm would experience worst case < 4.7 m drawdown during a pumped duration of 100 days at 125 m^3/hr. Due to the depth of these boreholes and the low abstraction rates they operate under, Atkins considers that the planned abstraction poses a low risk of derogation to these supplies, although depending on the capabilities of the installed pumps it is possible that water supply at these locations could be affected by reduction in piezometric head. This risk would be mitigated by informing the farmer prior to any pumping activities, and if difficulties are encountered, providing an interim water source and offering to upgrade the pumps installed at the farm boreholes. It is important to note that any drawdown impacts would be temporary as the Aldbrough borehole will not be in use year-round.

The other principal concern from this abstraction was the potential intrusion of saline water into the aquifer or upwelling from depth. Water quality was monitored at the pumped source and two observation boreholes during the pumping test and no water quality impacts were observed. There is a theoretical risk that saline intrusion or upwelling could occur during longer periods of pumping, although no evidence of this was observed during the testing. To mitigate this risk, particularly to nearby private abstraction boreholes, SSE proposes monitoring chloride concentrations at the abstraction borehole during periods of abstraction using a hand-held probe. In the event that increasing chloride concentrations are identified in the abstraction borehole, water sampling could then be undertaken from the nearby private water supply borehole to monitor any impacts on the quality of these private groundwater sources, and mitigation measures implemented if necessary (e.g. providing an interim water supply such as paying for additional mains water use).

Any impacts are likely to be temporary as baseline groundwater flow in this area is towards the coast, as such Atkins would anticipate that once the abstraction at Aldbrough was switched off, any increase in salinity in the Chalk aquifer at the site would decrease over time. Atkins has observed this effect at other sites in East Yorkshire where temporary abstraction has taken place in the Chalk close to the coast.

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6. References

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Appendices

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Appendix A. Photographs

Photo 01: Abstraction borehole showing rising main and in-line flowmeters

Photo 02: Discharge pipeline along compound boundary

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Photo 03: Discharge pipeline along compound boundary

Photo 04: Discharge point

Photo 05: Straw bales dissipating water below discharge point

Photo 06: Receiving water course for discharge

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Photo 07: Orange staining in discharge area after pumping test is complete

Appendix B. Water quality analysis

B.1. Abstraction borehole – sample results

Table B-1 – Aldbrough abstraction borehole water quality analysis

Analytical Parameter (Water Analysis)	Units	LOD	Step Test (step 3: 40 l/s)	Constant rate test (start & end)	
			05/09/2019 12:30	09/09/2019 10:00	16/09/2019 08:30
pH	pH Units	N/A	7.2	7.2	7.4
Electrical Conductivity at 20 °C	µS/cm	10	3800	3900	3900
Total Cyanide	µg/l	10	< 10	< 10	< 10
Sulphate as SO_4	mg/l	0.045	640	575	703
Chloride	mg/l	0.15	820	830	840
Total Phosphate as PO_4	µg/l	62	86	80	86
Ammonium as NH_4	µg/l	15	1300	1200	1400
Dissolved Organic Carbon (DOC)	mg/l	0.1	2.61	1.86	1.85
Total Organic Carbon (TOC)	mg/l	0.1	2.45	3.00	2.37
Nitrate as N	mg/l	0.01	0.51	0.43	0.48
Nitrate as NO_3	mg/l	0.05	2.24	1.92	2.13
Nitrite as N	µg/l	1	5.0	1.1	4.9
Nitrite as NO_2	µg/l	5	16	< 5.0	16
Alkalinity	mgCaCO3/l	3	480	210	52
Alkalinity	mgCaCO3/l	3	500	170	53
Total Suspended Solids	mg/l	2	25	< 2.0	5.0
Bromine	mg/l	0.05	0.27	0.31	< 0.05
Bicarbonate	mgHCO3/l	10	< 10	< 10	< 10
Lithium (dissolved)	µg/l	1	22	22	19
Aluminium (dissolved)	µg/l	1	4.5	3.2	< 1.0
Arsenic (dissolved)	µg/l	0.15	1.02	0.70	0.54
Barium (dissolved)	µg/l	0.06	11	12	10
Boron (dissolved)	µg/l	10	500	510	520
Cadmium (dissolved)	µg/l	0.02	< 0.02	< 0.02	< 0.02
Calcium (dissolved)	mg/l	0.012	150	190	140
Chromium (dissolved)	µg/l	0.2	< 0.2	0.3	< 0.2
Copper (dissolved)	µg/l	0.5	8.1	6.4	2.4
Iron (dissolved)	mg/l	0.004	1.0	0.088	0.022
Lead (dissolved)	µg/l	0.2	0.2	< 0.2	< 0.2
Magnesium (dissolved)	mg/l	0.005	82	95	86

Manganese (dissolved)	µg/l	0.05	20	32	16
Mercury (dissolved)	µg/l	0.05	< 0.05	< 0.05	< 0.05
Molybdenum (dissolved)	µg/l	0.05	1.4	1.1	1.2
Nickel (dissolved)	µg/l	0.5	0.7	1.4	1.1
Potassium (dissolved)	mg/l	0.025	32	32	30
Selenium (dissolved)	µg/l	0.6	10	16	16
Sodium (dissolved)	mg/l	0.01	550	550	570
Strontium (dissolved)	µg/l	1	6900	8300	10000
Tin (dissolved)	µg/l	0.2	< 0.20	< 0.20	< 0.20
Zinc (dissolved)	µg/l	0.5	44	62	51

B.2. Abstraction borehole – field parameters

Table B-2 – Step test water quality parameters

Step (flow)	EC (uS/cm)		pH		Turbidity (ntu)		Temp. (°C)**	
	min	max	min	max	min	max	min	max
Step 1 (108 m^{3}hr)	431.6*	4108	6.46	7.07	0.40	5.27	9.7	12.7
Step 2 (126 m^{3}hr)	3748	4198	6.83	6.98	0.59	2.87	12.7	14.2
Step 3 (144 m^{3}hr)	3920	4525	6.79	6.9	0.70	5.71	13.7	14.9
Step 4 (162 m^{3}hr)	3982	6421*	6.77	6.95	2.14	13.2	13.9	14.7
Step 5 (180 m^{3}hr)	3744	3938	6.93	6.96	6.53	41.4	13.1	14.7

*anomalous data due to air in flow-through cell

** temperature readings are affected by air temperature at surface, in-hole dataloggers record consistent temperature at 11°C.

Table B-3 – Summary of constant rate test water quality parameters

Date and time	EC (uS/cm)	pH	Turbidity (ntu)	Temp. (°C)**	Dissolved oxygen (%)
09/09/2019 09:05	3889	7.04	10.60	12.4	40.40
09/09/2019 10:00	3806	7.01	1.13	12.2	9.20
09/09/2019 11:00	3808	7.04	1.35	12.6	2.90
09/09/2019 12:00	3803	7.05	1.42	12.7	1.50
09/09/2019 13:00	3822	7.06	1.14	12.8	0.80
09/09/2019 14:00	3815	7.07	0.92	13.2	0.30
09/09/2019 15:00	3804	7.07	1.12	12.5	0.20
09/09/2019 16:00	3806	7.08	1.05	12.1	0.50
09/09/2019 17:00	3857	7.08	1.09	11.9	0.30
09/09/2019 18:00	3808	7.09	0.78	11.9	0.30
09/09/2019 19:00	3777	7.09	0.76	11.7	0.50

Date and time	EC (uS/cm)	pH	Turbidity (ntu)	Temp. (°C)**	Dissolved oxygen (%)
09/09/2019 20:00	3784	7.09	0.80	11.6	0.50
09/09/2019 21:00	3821	7.09	0.90	11.5	0.50
09/09/2019 23:00	3795	7.10	0.76	11.4	0.30
10/09/2019 01:00	3822	7.10	0.78	11.4	0.30
10/09/2019 03:00	3823	7.10	0.60	11.4	0.40
10/09/2019 05:00	3844	7.11	0.53	11.4	0.40
10/09/2019 07:00	3832	7.11	0.55	11.1	0.50
10/09/2019 09:00	3847	7.11	0.55	12.1	0.20
10/09/2019 11:00	3898	7.11	0.50	13.0	0.30
10/09/2019 13:00	3840	7.11	0.50	12.5	0.20
10/09/2019 15:00	3838	7.11	1.94	12.3	0.10
10/09/2019 17:00	3876	7.11	0.50	13.3	0.20
10/09/2019 19:00	3923	7.11	0.51	12.1	0.00
10/09/2019 21:00	3895	7.12	0.58	11.3	0.10
10/09/2019 23:00	3816	7.12	0.50	11.5	0.00
11/09/2019 01:00	3794	7.12	0.35	11.5	0.20
11/09/2019 03:00	3802	7.12	0.32	11.1	0.10
11/09/2019 05:00	3897	7.12	0.34	11.2	0.30
11/09/2019 07:00	3891	7.13	1.45	11.6	0.2
11/09/2019 09:00	3935	7.12	0.33	11.7	0.2
11/09/2019 11:00	3942	7.12	0.89	14.6	0.4
11/09/2019 13:00	3947	7.11	0.70	15.8	0
11/09/2019 15:00	3827	7.11	0.22	15.4	0.2
11/09/2019 17:00	3881	7.11	0.30	15	
11/09/2019 19:00	3862	7.12	0.27	12.4	0.2
11/09/2019 21:00	3839	7.13	0.34	11.5	0.1
11/09/2019 23:00	3859	7.13	0.26	11.7	0.4
12/09/2019 01:00	3877	7.13	0.25	11.4	0.3
12/09/2019 03:00	3894	7.13	0.27	11.6	0.3
12/09/2019 05:00	3897	7.13	0.28	11.6	0.4
12/09/2019 07:00	3847	7.13	0.32	11.6	0.1
12/09/2019 09:00	3931	7.1	0.31	13.1	23.5*
12/09/2019 11:00	3858	7.1	0.26	13.5	1.9
12/09/2019 13:00	3916	7.12	0.32	14.6	0.3
12/09/2019 15:00	3942	7.1	0.26	15.8	0.4
12/09/2019 17:00	3930	7.1	0.23	14.7	2.2
12/09/2019 19:00	3935	7.13	0.28	13.8	0.2
12/09/2019 21:00	3931	7.13	0.20	13.5	0.4

ATKINS BASELINE

Date and time	EC (uS/cm)	pH	Turbidity (ntu)	Temp. (°C)**	Dissolved oxygen (%)
12/09/2019 23:00	3908	7.13	0.19	11.9	0.2
13/09/2019 01:00	3905	7.14	0.23	11.7	0.3
13/09/2019 03:00	3844	7.14	0.17	10.7	0.1
13/09/2019 05:00	3858	7.15	0.55	10.1	0.4
13/09/2019 07:00	3837	7.15	0.26	9.9	0.3
13/09/2019 09:00	3887	7.15	0.20	11.8	0.2
13/09/2019 11:00	3960	7.14	0.18	13.7	0.1
13/09/2019 13:00	3945	7.13	0.18	13.8	0.3
13/09/2019 15:00	3925	7.13	0.19	13.4	0.1
13/09/2019 17:00	3985	7.13	0.17	13.2	0.1
13/09/2019 19:00	3932	7.14	0.24	11.3	0.2
13/09/2019 21:00	3843	7.14	0.26	10.6	0.2
13/09/2019 23:00	3878	7.15	0.19	10.4	0.2
14/09/2019 01:00	3869	7.15	0.23	10.3	0.3
14/09/2019 03:00	3927	7.15	0.24	10.3	0.3
14/09/2019 05:00	3906	7.15	0.19	10.2	0.3
14/09/2019 07:00	3902	7.15	0.18	10.1	0.4
14/09/2019 09:00	3927	7.15	0.19	11.8	0.3
14/09/2019 11:00	4999*	7.14	0.25	13.9	0.3
14/09/2019 13:00	3951	7.14	0.15	14.4	0.1
14/09/2019 15:00	3977	7.14	0.17	14.5	0.2
14/09/2019 17:00	3992	7.13	0.22	14.9	0.1
14/09/2019 19:00	3942	7.14	0.20	12.8	0.2
14/09/2019 21:00	3964	7.14	0.20	12.2	0.2
14/09/2019 23:00	3972	7.14	0.15	11.8	0.4
15/09/2019 01:00	3937	7.15	0.18	11.5	0.5
15/09/2019 03:00	3919	7.15	0.14	11.9	0.3
15/09/2019 05:00	3968	7.15	0.17	11.9	0.1
15/09/2019 07:00	3993	7.15	0.26	12.1	0.2
15/09/2019 09:00	3997	7.15	0.17	12.7	0.3
15/09/2019 11:00	4014	7.14	0.15	14.9	0.2
15/09/2019 13:00	3956	7.15	0.13	15.1	0.1
15/09/2019 15:00	4001	7.14	0.13	12.9	0.2
15/09/2019 17:00	3999	7.15	0.25	11.7	0.1
15/09/2019 19:00	3979	7.15	0.12	11.4	0.3
15/09/2019 21:00	4001	7.16	0.13	11.3	0.2
15/09/2019 23:00	4074	7.15	0.17	11.3	0.2
16/09/2019 01:00	4025	7.15	0.17	11.3	0.3

Date and time	EC (uS/cm)	pH	Turbidity (ntu)	Temp. (°C)**	Dissolved oxygen (%)
16/09/2019 03:00	4064	7.16	0.19	11.2	0.1
16/09/2019 05:00	4061	7.13	0.14	11	0.2
16/09/2019 07:00	4066	7.13	0.18	10.9	0.3
16/09/2019 09:00	4087	7.16	0.11	11.5	0.4

*anomalous reading likely due to air in probe or misreporting

** temperature readings affected by air temperature at surface, in-hole dataloggers record consistent temperature at 11°C.

B.3. Springfield Farm borehole – sample results

Table B-4 - Springfield Farm water quality analysis

Analytical Parameter (Water Analysis)	Units	LOD	Baseline samples				Post-testing sample
			19/06/19	09/07/19	18/07/19	04/09/19	18/09/19
pH	pH Units	N/A	7.4	7.4	7.4	7.4	7.5
Electrical Conductivity at 20 °C	µS/cm	10	1100	1100	1100	1100	1100
Sulphate as SO_4	mg/l	0.045	109	94	102	88	94.4
Chloride	mg/l	0.15	120	110	120	110	110
Fluoride	µg/l	50	800	480	660	790	1000
Ammonium as NH_4	µg/l	15	670	810	650	910	940
Nitrate as N	mg/l	0.01	0.28	0.10	0.16	0.30	0.24
Nitrate as NO_3	mg/l	0.05	1.23	0.43	0.70	1.33	1.07
Nitrite as N	µg/l	1	1.3	< 1.0	21	10	4.5
Nitrite as NO_2	µg/l	5	< 5.0	< 5.0	69	34	15
Alkalinity	mg $CaCO_3$/l	3	380	340	450	620	430
Total Dissolved Solids (Gravimetric)	mg/l	4	490	620	470	760	670
Hardness - Total	mg $CaCO_3$/l	1	351	398	382	311	339
Iron (total)	mg/l	0.004	2.3	2.0	2.2	2.2	2.3
Calcium (dissolved)	mg/l	0.012	77	99	86	71	77
Copper (dissolved)	µg/l	0.5	3.1	2.0	2.5	9.6	3.3

Iron (dissolved)	mg/l	0.004	1.20	0.026	0.008	1.60	0.006
Magnesium (dissolved)	mg/l	0.005	38	36	40	32	36
Manganese (dissolved)	µg/l	0.05	510	380	460	380	410
Potassium (dissolved)	mg/l	0.025	8.6	8.3	8.8	7.9	8.0
Sodium (dissolved)	mg/l	0.01	120	110	130	120	110

B.4. Hilltop Farm borehole – sample results

Table B-5 - Hilltop Farm water quality analysis

Analytical Parameter (Water Analysis)	Units	LOD	Pre-testing sample 19/06/19	Post-testing sample 18/09/19
pH	pH Units	N/A	7.5	7.6
Electrical Conductivity at 20 °C	µS/cm	10	2200	2200
Sulphate as SO_4	mg/l	0.045	387	388
Chloride	mg/l	0.15	390	370
Fluoride	µg/l	50	1400	2000
Ammonium as NH_4	µg/l	15	1200	1300
Nitrate as N	mg/l	0.01	0.31	0.26
Nitrate as NO_3	mg/l	0.05	1.39	1.17
Nitrite as N	µg/l	1	3.4	9.9
Nitrite as NO_2	µg/l	5	11	33
Alkalinity	mg $CaCO_3$/l	3	230	390
Total Dissolved Solids (Gravimetric)	mg/l	4	1500	1500
Hardness - Total	mg $CaCO_3$/l	1	520	511
Iron (total)	mg/l	0.004	2.3	2.6
Calcium (dissolved)	mg/l	0.012	120	120
Copper (dissolved)	µg/l	0.5	7	0.9
Iron (dissolved)	mg/l	0.004	1.5	< 0.004
Magnesium (dissolved)	mg/l	0.005	54	54
Manganese (dissolved)	µg/l	0.05	30	29
Potassium (dissolved)	mg/l	0.025	21	19
Sodium (dissolved)	mg/l	0.01	300	260

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