**Cambridge Waste Water Treatment Plant Relocation Project**
Anglian Water Services Limited

# Appendix 20.4: Dewatering Pump Test Technical Note

Application Document Reference: 5.4.20.4
PINS Project Reference: WW010003
APFP Regulation No. 5(2)a

**Revision No. 01**
April 2023

MOTT MACDONALD

# CWWTPR

Pumping test analysis and dewatering assessments

| | | | |
|---|---|---|---|
| **Project:** | Cambridge Waste Water Treatment Project Relocation (Anglian Water Services Ltd) | | |
| **Our reference:** | 100381548BH02-MMD-00-TN-P-01 | **Revision:** | Rev B |
| **Prepared by:** | Mott MacDonald Limited | **Date:** | 19 August 2022 |
| **Subject:** | Pumping test analysis and dewatering assessments | | |



# 1 Background

Cambridge Waste Water Treatment Project Relocation (CWWTPR) includes the construction of a tunnel and associated shafts for the transfer of waste water from the existing WWTP to the proposed WWTP. The shaft for the terminal pumping station (TPS) at the proposed WWTP will penetrate the Grey Chalk, a Principal aquifer, and therefore dewatering may be required during construction. A ground investigation was completed for the project which included four test boreholes located at the proposed TPS shaft site. A series of pumping tests were completed at these boreholes to assess dewatering requirements and potential temporary impacts on the Grey Chalk aquifer during shaft dewatering.

The aquifer properties derived from the test pumping data were also used to revise estimates of temporary dewatering requirements in trenches during installation of pipelines.

## 1.1 Scope and objectives

This report provides the interpretation of the results of test pumping undertaken following construction and development of four test boreholes at the proposed location of the Terminal Pumping Station (TPS) shaft. The pumping tests were required to:

- Assess aquifer properties;
- Estimate shaft dewatering abstraction rates; and
- Estimate the potential impact of dewatering on groundwater levels in the Grey Chalk.

Estimation of dewatering rates and potential impacts on groundwater levels are required as part of an environmental impact assessment to determine the potential impacts on the aquifer and, in particular, conservation sites and abstractions in the area which may be dependent on groundwater from the Grey Chalk. Although this report provides an indication of potential rates of dewatering during construction, the estimation of dewatering rates should not be considered as forming a dewatering design for construction of the shaft.

MOTT MACDONALD

This report includes:

- Details of the test pumping undertaken;
- Presentation and discussion of the data obtained during the test pumping including discharges and observed groundwater levels;
- Interpretation of the pumping tests and assessment of aquifer properties;
- Estimation of dewatering rates for the TPS shaft; and
- Potential impacts on groundwater levels as a result of dewatering.

Revision B of this report also includes a reassessment of potential dewatering rates in the event that groundwater is encountered in any trench sections when excavating in the Grey Chalk. The original assessment was included in the Hydrogeological Impact Assessment (Mott MacDonald, 2021).

Details of the test borehole construction and development can be found with the ground investigation Factual Report (Soil Engineering, 2021).

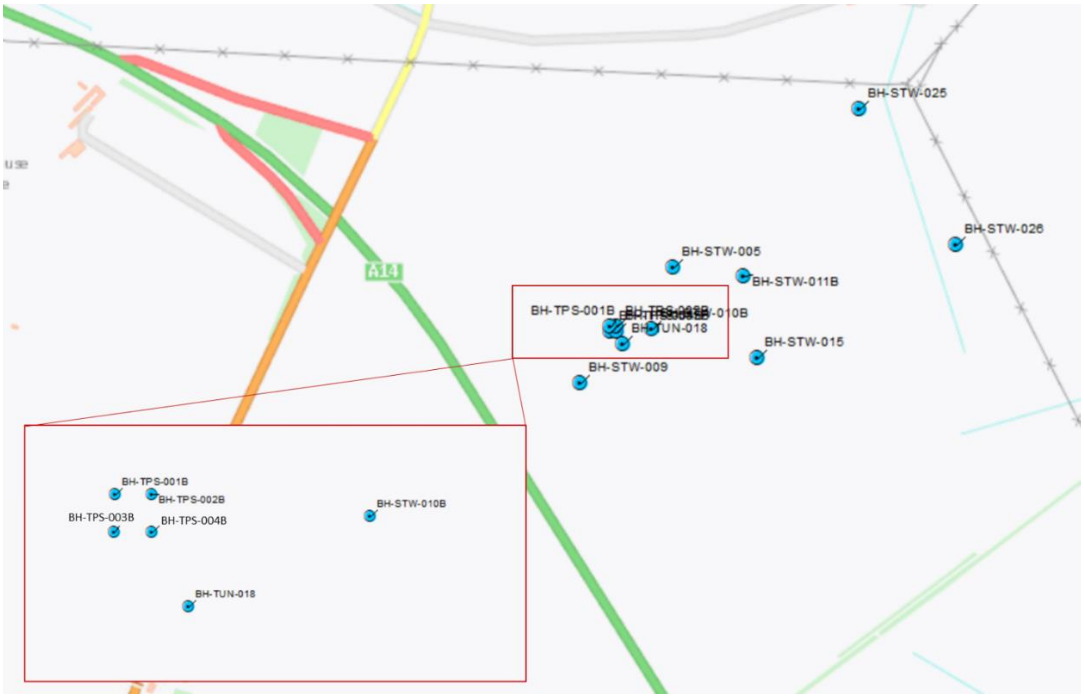
## 1.2 Site location

The proposed development includes several components including a wastewater transfer tunnel with associated shafts. Shafts will be located at the existing WWTP, the proposed WWTP and at intermediate locations along the alignment of the tunnel as required for tunnel construction.

Test boreholes were drilled at the proposed location for the Terminal Pumping Station (TPS) shaft, together with several observation boreholes. Four test boreholes (BH-TPS-001B to 004B) were constructed to account for the potential variability in aquifer properties in the lowermost section of the Grey Chalk which underlies the proposed WWTP. Groundwater flows in the Grey Chalk are likely to be dependent on fracture zones within more competent horizons. These fracture zones may vary considerably within a small area.

The location of the four test boreholes (BH-TPS-001B to 004B) and associated observation boreholes is provided in Figure 1.1.

**Figure 1.1: Borehole location map**




Source: Contains OS data © Crown copyright and database right (2022)

MOTT MACDONALD

## 1.3 Encountered Geology

Information on the anticipated geology and aquifer properties of the Grey Chalk underlying the proposed WWTP can be found within the Hydrogeological Impact Assessment (Mott MacDonald, 2021).

The geological sequence encountered during drilling of the test boreholes is detailed in Table 1-1 below. Water strikes were not recorded for any of the test boreholes.

**Table 1-1: Summary of geology in test boreholes**

| Strata | Depth to base (mbgl) [thickness (m)] | | | |
|---|---|---|---|---|
| | BH-TPS-001B | BH-TPS-002B | BH-TPS-003B | BH-TPS-004B |
| Topsoil | 0.30 [0.30] | 0.35 [0.35] | 0.35 [0.35] | 0.35 [0.35] |
| Superficial Deposits | 0.55 [0.25] | 0.55 [0.20] | 0.55 [0.20] | 0.55 [0.20] |
| West Me bury Marly Cha k Formation | 10.90 [10.35] | 11.00 [10.45] | 11.00 [10.45] | 11.00 [10.45] |
| Cambridge Greensand Member | 11.20 [0.30] | - | - | - |
| Gault Formation *(depth unproven)* | Drilled to 13.70 | Drilled to 13.30 | Drilled to 13.30 | Drilled to 13.30 |

Source: (Soil Engineering, 2021)

## 1.4 Borehole Construction

Key details of the construction of the test boreholes are summarised in Table 1-2. It should be noted that BH-TPS-001B collapsed to 8.70mbgl after removing the wireline casing and was subsequently redrilled.

**Table 1-2: Summary of borehole construction details**

| Item | BH-TPS-001B | BH-TPS-002B | BH-TPS-003B | BH-TPS-004B |
|---|---|---|---|---|
| Location (Easting, Northing) | 549426, 261029 | 549435, 261029 | 549425, 261019 | 549435, 261019 |
| Total Depth (mbgl) | 13.70 | 13.30 | 13.30 | 13.30 |
| Drilled diameter | 150mm:<br>0 - 1.60mbgl<br>146mm:<br>1.60 - 13.70mbgl<br>(Steel casing installed to 1.6mbgl and temporary steel casing installed to base during re-drill) | 150mm:<br>0 – 13.30mbgl<br>(Steel casing installed to 1.6mbgl, open hole to base) | 150mm:<br>0 – 13.30mbgl<br>(Steel casing installed to 1.6mbgl, open hole to base) | 150mm:<br>0 – 13.30mbgl<br>(Steel casing installed to 1.6mbgl, open hole to base) |
| Installation details (nominal 100mm diameter thermoplastic casing) | Plain:<br>0.00 – 4.00mbgl<br>Slotted:<br>4.00 – 12.00mbgl | Plain:<br>0.00 – 4.00mbgl<br>Slotted:<br>4.00 – 12.00mbgl | Plain:<br>0.00 – 3.85mbgl<br>Slotted:<br>3.85 – 11.85mbgl | Plain:<br>0.00 – 4.00mbgl<br>Slotted:<br>4.00 – 12.00mbgl |
| Formation support (mbgl) | Gravel: 0.00 – 13.70 | Gravel: 0.00 – 13.30 | Gravel: 0.00 – 13.30 | Gravel: 0.00 – 13.30 |

Source: (Soil Engineering, 2021)

MOTT MACDONALD

# 2 Test pumping

## 2.1 Data records

Full details of the test pumping data can be found within the Cambridge WwTW Pumping Test Report (Stuart Wells Limited, 2021).

## 2.2 Test pumping programme

A summary of the test pumping programme is included in Table 2-1.

**Table 2-1: Test pumping programme**

| Dates | Activity |
|---|---|
| 22 October 2021 | Step Test BH-TPS-004B |
| 26 October 2021 | Step Test BH-TPS-002B |
| 28 October 2021 | Step Test BH-TPS-003B |
| 1 November 2021 | Step Test BH-TPS-001B (one step only, see Section 2.4.2) |
| 2 November 2021 | Constant Rate Test BH-TPS-004B (0.36 l/s) |
| 4 November 2021 | Constant Rate Test BH-TPS-004B (reduced to 0.25 l/s) |
| 9 November 2021 | End of constant rate test |
| 9 – 11 November 2021 | Recovery monitoring |

Source: (Stuart Wells Limited, 2021)

## 2.3 Monitoring points

Details of the observation boreholes monitored during the test pumping are included in Table 2-2. These were monitored with data loggers and/or manual measurements. All the observation boreholes contained screened sections to monitor water levels in the whole of the saturated section of the Grey Chalk (comprising the West Melbury Marly Chalk Formation, and including the Cambridge Greensand Member), with the exception of BH-STW-10B. BH-STW-10B was screened over a depth of approximately 0.5m within the Cambridge Greensand Member at the base of Grey Chalk. The screen section was sealed off from the rest of the overlying Grey Chalk. However, groundwater within the Cambridge Greensand Member is expected to be closely hydraulically linked to the Grey Chalk bedrock aquifer.

**Table 2-2: Monitoring points**

| Observation borehole | Easting (m) | Northing (m) | Distance from BH-TPS-004B (m) | Borehole depth (m) | Monitoring type |
|---|---|---|---|---|---|
| BH-TPS-004B | 549435 | 261019 | n/a | 13.30 | Data logger + manual dips |
| BH-TPS-003B | 549425 | 261019 | 10 | 13.30 | Data logger + manual dips |
| BH-TPS-002B | 549435 | 261029 | 10 | 13.30 | Data logger + manual dips |
| BH-TPS-001B | 549426 | 261029 | 14 | 13.70 | Data logger + manual dips |
| BH-TUN-018 | 549445 | 260999 | 22 | 49.50 | Data logger + manual dips |
| BH-STW-010B | 549494 | 261023 | 59 | 30.00 | Data logger + manual dips |
| BH-STW-009 | 549374 | 260934 | 105 | 30.00 | Data logger + manual dips |
| BH-STW-015 | 549672 | 260975 | 241 | 30.20 | Data logger + manual dips |
| BH-STW-005 | 549531 | 261128 | 145 | 30.00 | Occasional manual dips |
| BH-STW-011B | 549650 | 261112 | 234 | 30.00 | Occasional manual dips |
| BH-STW-025 | 549844 | 261395 | 556 | 15.05 | Occasional manual dips |
| BH-STW-026 | 550007 | 261166 | 591 | 15.00 | Occasional manual dips |

## 2.4 Test Pumping Methods

### 2.4.1 Overview

Initial clearance discharge and flow calibration tests were carried out after completion of construction and development of boreholes BH-TPS-001B BH-TPS-002B, BH-TPS-003B and BH-TPS-004B. The calibration tests were used to make an initial assessment of the potential yield and performance characteristics of the boreholes for testing purposes. Step discharge tests were then undertaken to assess discharge/drawdown relationships for each borehole.

A seven day constant rate test was undertaken on the highest yielding borehole determined from the step discharge tests (BH-TPS-004B) to assess aquifer characteristics. Recovery was monitored following the constant rate test.

The pump used for testing was a 415v submersible borehole pump installed 11.6mbtoc (below top of casing) in all four test boreholes. Three inch (3”) diameter rising main was used to discharge abstracted groundwater to a small tank, to allow for visual inspection. Water was then conveyed from the tank to the discharge location via another three inch (3”) diameter pipe. Flow rates were monitored using two mechanical cumulative flowmeters mounted in series on the discharge pipeline. In addition to this, occasional manual checks of flow were also undertaken using a bucket (of known volume) at the end of the discharge line.

Groundwater levels were monitored in accordance with BS EN ISO 22282-4:2012 (British Standards Institute, 2012). The monitoring was undertaken using electronic data loggers and/or manual measurements (see Table 2-2). Atmospheric pressure was measured using a barometric logger. Manual water level readings were recorded using a manual dip tape.

During test pumping, a dip tube was installed to house the data logger and to record manual groundwater levels measurements in the test borehole.

### 2.4.2 Step discharge test

The purpose of the step discharge tests was to assess the variability in borehole yields and determine which of the boreholes had the highest yield. The constant rate test was then planned to be carried out using the highest yielding borehole. After each step test, groundwater levels were left to recover overnight prior to the next step test and the subsequent constant rate test.

The step tests comprised four steps each with a duration of 60 minutes, with the exception of BH-TPS-001B. Discharge was continuous from step to step, with the discharge increased and adjusted in the first few minutes at the start of each step.

The initial flow calibration test on BH-TPS-001B indicated that the maximum yield for testing purposes was very low (0.07l/s) and it would not be possible to conduct steps at lower rates. Therefore, a single step with a duration of 120 minutes was completed at the maximum sustainable rate for this period. Results from this short constant rate test could then be used for estimation of aquifer characteristics at the borehole location.

A summary of the step discharge tests can be seen in Table 2-3. The results of the step tests indicated that BH-TPS-004B was likely to be the highest yielding of the four boreholes and was therefore chosen as the abstraction borehole for the constant rate test.

MOTT MACDONALD

**Table 2-3: Summary of step discharge tests**

| Test borehole | Step | Nominal abstraction rate [l/s] | Drawdown at end of step (m) |
|---|---|---|---|
| BH-TPS-004B | 1 | 0.125 | 0.53 |
| | 2 | 0.250 | 1.32 |
| | 3 | 0.375 | 2.49 |
| | 4 | 0.500 | 5.16 |
| BH-TPS-003B | 1 | 0.125 | 0.63 |
| | 2 | 0.250 | 1.72 |
| | 3 | 0.375 | 3.40 |
| | 4 | 0.500 | 6.64 |
| BH-TPS-002B | 1 | 0.050 | 0.83 |
| | 2 | 0.100 | 1.68 |
| | 3 | 0.150 | 3.03 |
| | 4 | 0.200 | 5.98 |
| BH-TPS-001B | 1 | 0.066 | 2.49 |

### 2.4.3 Constant Rate Test

A constant rate test (CRT) was carried out over seven days between 2 and 9 November 2021 on BH-TPS-004B. The results of the step test were analysed to define a flow rate that could be sustainable for the duration of the CRT; a flow rate of 0.36l/s was selected. However, at this flow rate the borehole had dewatered to a level just above the pump approximately 36 hours after the start of the test. It was considered that continuing the test at a lower flow rate could, nonetheless, be beneficial. Therefore, the flow rate was reduced to 0.25l/s towards the end of the second day of testing. This discharge was then maintained for the remainder of the CRT.

The subsequent recovery was monitored for two days until 11 November 2021.

# 3 Pumping test interpretation

## 3.1 Step discharge test

The step test data was analysed for each borehole using the Hantush-Bierschenk method. The relationship between discharge ($Q$) and drawdown (s) for a step test is expressed as:

$$(1) \qquad s = BQ + CQ^2$$

in which $B$ is referred to as the aquifer constant and $C$ the well loss constant. Drawdown for each step of a step discharge test was plotted against elapsed time on a semi-log graph from the start of the step. The analysis uses estimates of the drawdown after 120 minutes of discharge in each step, extrapolated from the graph, to take into account the effect of the discharge in previous steps of the test. This is illustrated for BH-TPS-004B in Figure 5.1. Values of B and C are derived from the analysis.

The aquifer constant B can then be used to determine very approximately a value for aquifer transmissivity (T) using the following formula:

$$(2) \qquad T = 1.22 \times B$$

B needs to be in units of m/(m$^3$/d) in order to produce a very approximate value of transmissivity in m$^2$/d. The formula is an adaptation of the Logan approximation for estimation of transmissivity. In this adaption, well entry losses are effectively removed from the drawdown component. However, the Logan approximation itself is a highly simplified method and, therefore, any transmissivity values derived by this method may be subject to considerable error. The formula does, however, provide an initial assessment of transmissivity for comparison with values from other step tests.

Transmissivity (T) can also be calculated using the gradient of the first step on the semi-log plot (see Figure 5.1) by using Jacob's method of analysis, applying the following equation:

$$(3) \qquad T = \frac{2.3Q}{4\pi\Delta s}$$

Where Q is discharge and $\Delta s$ is the slope of the fitted line (change in drawdown per log cycle of time). Effectively the first step of the step discharge test is analysed as a short constant rate test.

## 3.2 Constant rate test

### 3.2.1 Test data

A constant rate test (CRT) was carried out in BH-TPS-004B, with subsequent period of recovery, to determine aquifer properties and the extent of drawdown in the Chalk. The following five methods were considered in assessing the aquifer properties from the CRT and recovery data.

- Theis curve fitting
- Jacob's method
- Theis recovery method
- Distance – drawdown analysis, based on Thiem's method
- Boulton's method for curve fitting, taking into account delayed yield in the aquifer, applied to both test data and recovery data

These methods, and their results, are discussed in the sections below.

Drawdown data are included in a set of figures, provided in Section 5, for the test borehole and six other boreholes in which data loggers were installed. The distances of the observation boreholes from the test borehole are included in the legend for the figures. Drawdown data for the observation boreholes is plotted against the left hand axis, with drawdown for the test borehole plotted at a different scale against the right hand axis. Observations from each of these figures is as follows.

- Figure 5.2 includes the drawdown data and also flow monitoring from the two flowmeters used during testing for the seven day period (10,080 minutes) of the test. The flow data is plotted against the left hand axis with the observation borehole drawdown data. The effect of the reduction in flow towards the end of the second day of the test (after 2,880 minutes) can be seen in the reduction in drawdown in the test borehole and the four closest observation boreholes. The drawdown in the test borehole also reduced by about a metre in the sixth day of the test. This was not a result of a change in discharge and did not affect the water levels in any of the observation boreholes. It may have been a result of further development of the borehole during the test.
- Figure 5.2 also includes a two day period following the test in which water levels recovered back towards the initial pre-test levels. For all boreholes the water levels were 0.07 to 0.10m below the pre-test levels at the end of this recovery period. The figure also includes manual dip data for two additional observation

boreholes, BH-STW-025 and BH-STW-026, located 556m and 591m from the test borehole. The locations are shown on Figure 1.1. At this distance, groundwater levels would not have been affected by the testing. Nonetheless, the manual dip data indicate that there was an overall decline in water levels during the test, although this decline then continued on into the recovery period. Hence, background groundwater levels in the aquifer appear to have been falling during the test. This overall decline in groundwater levels in the area is likely to account for the incomplete recovery in observation boreholes close to the test borehole.

- Figure 5.3 includes the drawdown data and also flow monitoring for the first day (1440 minutes) of the test in which flow was reasonable constant at about 0.36 l/s.
- Figure 5.4 presents the drawdown data, as in Figure 5.2, but with the elapsed time from the start of the test plotted on a logarithmic scale (i.e. the graph is in a semi-log format).
- Figure 5.5 presents the drawdown data, as in Figure 5.2, but with both the elapsed time from the start of the test and the drawdown plotted on logarithmic scales (in a log-log format).

Data in the formats presented in Figure 5.4 and Figure 5.5 are used in the methods of analysis discussed in the following sections.

### 3.2.2 Theis curve fitting

The Theis curve fitting method can be used to apply the Theis equation for non-steady state conditions in the aquifer around a pumping borehole to drawdown data for observation boreholes. The method involves plotting drawdown against the elapsed time for a constant rate test, with both time and drawdown plotted on log scales. A standard Theis type curve is overlaid and fitted as closely as possible to the log time - log drawdown data. The relative plotting positions of the data and the type curve can then be used to determine transmissivity (T) and storage coefficient (S) for the aquifer.

Theis curve fitting was carried out using a spreadsheet graph application in which the type curve was shifted into position close to the log time - log drawdown data. Transmissivity and storage coefficient were indicated automatically as the best fit was achieved. The data used was for the first part of the test in which the discharge was approximately 0.36 l/s.

It was possible to fit the standard Theis curve to some of the early drawdown data for all observation boreholes, ranging from a few minutes up to between about 15 and 250 minutes depending on location. This is illustrated for BH-STW-010B in Figure 5.6. However, in no cases was it possible to fit the Theis curve reasonably to the whole of the observation borehole drawdown data set. In all cases, the Theis curve indicated that, for later time, the drawdown in the boreholes was less than theoretically predicted using the Theis equation.

### 3.2.3 Jacob’s method and Theis recovery method

The test borehole and observation borehole data from the CRT and recovery data was also analysed using Jacob’s method and the Theis recovery method (not connected in approach to Theis curve fitting).

The Jacob method of analysis is based on the formula applied in Theis curve fitting but with additional assumptions which, in theory, restrict the use of the method. Drawdown for the constant discharge test in the test borehole and observation boreholes was plotted on a semi-log graph against the logarithm of elapsed time from the start of the test. For standard, uniform, confined aquifer conditions, the drawdown and recovery data would be expected to plot as a straight line on a semi-log graph.

The gradient or change in drawdown over a single log cycle of time, $\Delta s$, taken from a semi-log plot, can be used to determine the transmissivity of the aquifer at the test borehole and the observation borehole locations.

The following equation applies for the Jacob method:

$$T = \frac{2.3Q}{4\pi\Delta s}$$

in which:

- $T$ is the aquifer transmissivity (in $m^2$/d)
- $Q$ is the discharge (in $m^3$/d).

In practice, the gradients of the semi-log plots were found to vary significantly between early and late time data, as illustrated for BH-STW-010B in Figure 5.7. Transmissivity values were therefore calculated just from the early data, as for Theis curve fitting.

The same formula also applies for the Theis recovery method. However, in the Theis recovery method, the residual drawdown recorded in the test borehole and observation boreholes during the recovery are plotted against *t/t'* on the semi-log graph. *t/t'* is the ratio of the time since the start of the preceding test to the time since the start of recovery. $\Delta s$ is the change in residual drawdown over a single log cycle of *t/t'* and Q the discharge in the preceding constant discharge test.

The semi-log plots were in most cases found to form a smooth S-shaped curve. As a result, it was not possible to determine suitable $\Delta s$ values which were applicable over a range in t/t'. The method was not used in the analysis to derive transmissivity values.

Aquifer storage coefficient values (S) can also be calculated by the Jacob method, applying the following formula and using the drawdown data for observation boreholes:

$$S = \frac{2.25Tt_0}{r^2}$$

in which:

- $t_o$ is the time (in days) at which the straight line plotted through the drawdown data intercepts the time axis (at zero drawdown); and
- $r$ is the distance of the observation borehole from the test borehole.

As with transmissivity, storage coefficient values were calculated from the early drawdown data.

### 3.2.4 Distance-drawdown

Drawdown data from several observation boreholes can also be used to determine transmissivity by applying a procedure based on Thiem's method. The method assumes that the aquifer is confined, and also that groundwater flow to the test borehole is in steady state. However, Thiem's method is worth applying as part of the assessment when pumping has been carried out for a reasonable period of time, as was the case with the constant rate test on BH-TPS-004B. In the procedure, drawdown in each observation borehole after a fixed time is plotted against the distance of the respective boreholes from the test borehole, with the distances plotted on a log scale. The transmissivity (T) can then be determined from the following equation:

$$T = \frac{2.3Q}{2\pi\Delta s}$$

in which:

- $\Delta$s is the change in drawdown per log cycle of distance from the test borehole; and
- Q is the test discharge in $m^3$/d.

MOTT MACDONALD

The CRT data for the observation boreholes referred to in Figure 5.1 to Figure 5.5 was analysed using distance drawdown analysis. Distance drawdown analysis was undertaken using two sets of drawdown data:

- drawdown at the end of the first day of testing, using the discharge of 0.36l/s (31m$^3$/d) which was set at the start of the test; and
- drawdown after seven days, at the end of test, using the discharge of 0.25l/s (22m$^3$/d) which applied over the last five days of the CRT.

The graphs of linear drawdown against distance from the test borehole plotted on a log scale are shown in Figure 5.8 and Figure 5.9.

### 3.2.5 Boulton's method

The failure of Theis curve fitting led to consideration of other type curve fitting methods which allow for variations in drawdown responses during testing. Boulton's method is based on Theis curve fitting but takes into account the potential for delayed yield in the aquifer as drawdown occurs. Delayed yield may occur when the initial contribution to abstraction is obtained mainly from fractures, but a component of yield is also provided by delayed drainage from pore spaces within the bedrock. Abstraction produces a short-term response in reducing the groundwater pressure in the fractures. This reduction in pressure then leads to a slower release of groundwater from the overlying bedrock.

As with Theis curve fitting, the method involves plotting drawdown against the elapsed time for a constant rate test with both time and drawdown plotted on log scales. The Boulton type curve is overlaid and fitted as closely as possible to the log time - log drawdown data. The relative plotting positions of the data and the type curve can then be used to determine transmissivity (T) and storage coefficient (S) for the aquifer, as well as parameters which define the occurrence of the delayed yield.

Boulton type curve fitting was also carried out using a spreadsheet graph application in which the type curve was shifted into position close to the log time - log drawdown data. Transmissivity, storage coefficient and delayed yield parameters were indicated automatically as the best fit was achieved. As with Theis curve fitting, the data used was for the first part of the test in which the discharge was approximately 0.36l/s.

The Boulton type curve was adjusted each time and found to fit well with all sets of observation borehole drawdown data over much of the period of discharge at 0.36l/s. An example for observation borehole BH-TPS-001B is shown in Figure 5.10.

Boulton type curve fitting was also carried out using the recovery data for the two days following the termination of the CRT for each of the observation boreholes. In this case it is assumed that pumping had reached a steady state by the end of the seven day period of pumping. Recovery from the water level at the end of the CRT was plotted against time from the termination of pumping, with both time and recovery plotted on log scales. Although not a conventional application of Boulton's method, this use of the recovery data may also provide reasonably reliable transmissivity and storage coefficient values.

Figure 5.11 presents the recovery data, with both the elapsed time from the start of recovery and the recovery from the water level at the end of the CRT plotted on logarithmic scales (in a log-log format). The recovery curves are similar in overall shape to the drawdown curves shown in Figure 5.5.

The Boulton type curve was also found to fit reasonably well with all sets of observation borehole recovery data. However, for more distant boreholes, outside the shaft location, there was evidence that water levels first recovered and then started to fall again within the two day period, presumably due to the background seasonal variation in groundwater levels.

An example of the recovery analysis for observation borehole BH-TPS-001B is shown in Figure 5.11. The discharge applied in fitting the curve and calculating aquifer parameters was the average discharge over the last five days of the test (0.25l/s).

MOTT MACDONALD

## 3.3 Assessment of aquifer properties

### 3.3.1 Summary of results from analysis

Transmissivity values obtained from analyses for the step discharge tests, the constant rate test and the recovery following the constant rate test on BH-TPS-004B are summarised in Table 5.1. The results for the Theis curve fitting using early test data and the Theis recovery method are not included as the approach was replaced with Boulton's method as already discussed. A wide range of values of transmissivities has been obtained from the analysis, from 1m$^2$/d to 285m$^2$/d.

Some variability in transmissivity is to be expected taking into account:

- The potential variability in Chalk aquifer properties between borehole locations;
- The variety of method of analysis used; and
- The approximations made in the analyses.

However, the mean and median values, approximately 30 and 10 m$^2$/d respectively, are towards the lower end of the range. The highest value by a substantial margin (285 m$^2$/d), was derived by the Jacob method for borehole BH-STW-009B and is unlikely to be reliable as the straight line approximation only applied to a relatively short interval of drawdown data from 10 to 100 minutes. After 100 minutes the gradient of the drawdown curve steepens, which indicates a lower transmissivity. Two values of 34m$^2$/d were derived from data for the same borehole using Boulton's method.

Of all the methods of analysis, the Boulton's method fitting to observation borehole data is likely to provide values for transmissivity which are most representative of aquifer conditions. The values for Boulton's method range from 3 to 25m$^2$/d, with the two higher values of 34m$^2$/d derived for BH-STW-009B using both drawdown and recovery data. Figure 5.2 indicates that the recovery in BH-STW-009B was strongly affected by the background variations in groundwater levels in the area and therefore the analysis may not be reliable. The transmissivity values from the distance drawdown analysis (17 and 19m$^2$/d), which uses data from all observation boreholes, are towards the upper end of the range obtained from the other boreholes using Boulton's method.

The transmissivity value obtained by the Jacob method, applied to the first step of the step discharge test data for BH-TPS-001B and BH-TPS-002B, are lower than the transmissivity values obtained from observation boreholes during the CRT on TPS-004B. A possible explanation for this is that fracturing in more competent horizons in the Grey Chalk, in which groundwater is present, could be partially blocked by smearing or infill with marly chalk during drilling. Air-mist drilling was used to try and keep any fractures clean and open, as far as practicable. The boreholes were also airlifted after completion to try and remove residual drilling debris. However, with only minor fractures present in the Grey Chalk section this may not have been possible.

The lowest transmissivity (1m$^2$/d) was for BH-TPS-001B. In this case, the borehole had to be cased completely through the Chalk during drilling, due to instability in the formation. Installation and subsequent removal of the temporary casing may have affected any fractures that were present. Fractures in the Grey Chalk could also have been affected to some extent in all the boreholes. However, water pressures and levels in the boreholes, when used just for observation, should adjust to the minor changes in the surrounding aquifer during pumping from another borehole. In contrast, if fractures are partially blocked in the test borehole, then water levels will fall more rapidly under the immediate effect of pumping. The increased drawdown resulting from partially blocked fractures might lead to lower apparent transmissivity values in the analysis.

Boulton's method also provides aquifer storage coefficient and delayed yield aquifer parameter values which may be used, together with transmissivity, for estimating drawdown in the surrounding aquifer during dewatering at the TPS. All storage coefficient values are in the range 0.0002 to 0.0009 (2 x $10^{-4}$ to 9 x $10^{-4}$). These values are indicative of fracture flow in confined conditions. They contrast with the storage coefficients in the range 0.01 to 0.03 which are often considered applicable to unconfined chalk, assuming much of the groundwater flow occurs through pore spaces in the bedrock. The range of values from application of Boulton's method is also similar to values obtained from application of the Jacob method. The storage coefficients estimated using the various methods are provided in Table 5.1.

### 3.3.2 Modelling of constant rate test

A spreadsheet model of drawdown under pumping conditions was used as a further means to try and better define the potential range of aquifer properties in the Grey Chalk around the TPS shaft. The model uses the equations applied in Boulton's method, together with values for transmissivity, storage coefficient and the parameters defining delayed yield, to simulate the drawdown in the observation boreholes at specified times during the constant rate test at BH-TPS-004B. Transmissivity and storage coefficient values can then be varied in the model. The objective of the work was to determine the aquifer property values for which there was a best fit between the actual drawdown data in the observation boreholes and the model simulated data.

The sets of aquifer parameters derived by Boulton's method using the drawdown data for each observation borehole were used as inputs to the model to determine the resulting drawdown at all observation boreholes after one day and seven days testing. The model results were then compared with the actual drawdowns which occurred after one day and seven days. The following conclusions were drawn from this work.

- The best fit to the actual drawdown data after a day of pumping at 0.36 l/s was achieved using the aquifer parameters derived by applying Boulton's method to the actual drawdown data for BH-TPS-003B. This best fit is shown in Figure 5.13. A transmissivity value of 9 $m^2$/d and storage coefficient of 0.0003 were used to obtain this best fit. The aquifer parameters derived from the analysis of the recovery data for BH-STW-010B, including a transmissivity value of 15 $m^2$/d and storage coefficient of 0.0004, also produced a reasonable simulation of drawdown. However, the simulation was least accurate for the two observation boreholes closest, at a distance of 10m from, the test borehole.
- The best fit to the actual drawdown data after seven days of pumping, using a rate of 0.25 l/s was achieved using the aquifer parameters derived by applying Boulton's method to the actual drawdown data for BH-TPS-010B with slight variations to the transmissivity and storage coefficient. This best fit is shown in Figure 5.14. A transmissivity value of 12 $m^2$/d and storage coefficient of 0.0002 were used to obtain this best fit. Is it noted that using these parameters also produced a reasonable simulation of drawdown after a day of pumping.

The analysis for one day may be more reliable than for seven days as hydrographs for more distant boreholes indicate there were background, seasonal variations in groundwater levels occurring during the test. However, aquifer property values for both sets of modelling results are within a reasonably narrow range.

### 3.3.3 Aquifer property values for dewatering assessment

The transmissivity values obtained from the analysis described in the previous sections were used to provide a range of permeabilities for estimating the potential dewatering rates for the TPS shaft. The transmissivity values chosen, and resulting permeabilities, are shown in Table 5.2. A wide range of transmissivities was chosen just to gauge the impact that varying transmissivity would have on dewatering rates. The permeabilities were calculated by dividing the transmissivity values by the average saturated depth of Grey Chalk in the vicinity of the TPS shaft (6.81m) at the start of the CRT on BH-TPS-004B.

MOTT MACDONALD

# 4 Estimates for dewatering

## 4.1 TPS shaft dewatering – estimated discharge

High-level estimates of the potential dewatering rates during construction of the TPS shaft have been produced using the analysis of the test pumping data. As already indicated in Section 1.1, the purpose of these estimates is to inform the estimation of potential impacts on the aquifer and environmental receptors during dewatering activities. This estimation does not constitute a dewatering design and the dewatering rates provided in this report should not be used as design parameters.

The method used for calculating dewatering rates described in the Hydrogeological Impact Assessment (Mott MacDonald, 2021) was also applied in updating the calculations. Dewatering rates were calculated using analysis of full penetration by a single well for an unconfined aquifer in the Grey Chalk. In addition to the permeability and saturated depth of Grey Chalk indicated above, the calculations assumed a groundwater level at 4.24mbgl. This was the average depth to the rest groundwater level in the four boreholes within the TPS site at the start of the CRT.

In addition to this method, a second approach was used considering dewatering requirements in the event that the source of the groundwater encountered in dewatering was found to comprise a fracture system in a more competent horizon within the Grey Chalk. Examination of the geological logs for boreholes constructed at the proposed WWTP site in 2021 indicated that more competent chalk may extend over depth intervals up to several metres in many boreholes, although it is not possible to identify any particular depths of fracture systems which might have higher permeability. For the analysis, a theoretical one metre thick fracture zone was considered, located close to the base of the Grey Chalk. With a fracture zone of limited thickness at this greatest depth, the dewatering rates should be close to the theoretical maximum which could occur.

Dewatering rates were calculated for the range of permeabilities and transmissivities using both methods. The rates are plotted against a range of transmissivities for the Grey Chalk aquifer (on a logarithmic scale) in Figure 5.15, with transmissivity varying from 1 to 200 $m^2$/d. The dewatering rates are higher for the fracture condition as the transmissivity is applied just to the deep-seated, fracture horizon and not to the whole of the saturated Grey Chalk section.

The following points were considered when assessing the range of dewatering rates to be used for assessing impacts on groundwater levels in the area:

- Transmissivity values of 17 and 19 $m^2$/d were obtained from the distance-drawdown analysis for the CRT data. The method of analysis employs similar principles to the dewatering calculations, with neither method taking delayed yield into account. The transmissivity values are, however, based on data for several locations at various distances from the test borehole. They could therefore have reasonable validity for determining suitable dewatering rates.
- A range of values from 3 to 34m $^2$/d was obtained from analysis of test data using Boulton's method. A narrower range of values from 9 to 15 $m^2$/d appeared most applicable in modelling the distance-drawdown data points using Boulton's method, although this range of values was lower than the transmissivity values obtained from the distance-drawdown analysis.

From this assessment, a transmissivity value of 18 $m^2$/d was chosen for determining a 'best estimate' dewatering rate for the shaft based on the distance-drawdown analysis. This gives a dewatering rate of 3.0l/s, equivalent to 260 $m^3$/d, for the fracture condition. In addition, a range from 9 to 34 $m^2$/d was also considered, in order to provide lower and upper limits. The transmissivity range includes several of the transmissivity values from analysis using Boulton's method. Based on the results presented in Figure 5.15, the range of transmissivities gives a dewatering range of 1.7 to 5.2 l/s, equivalent to about 150 to 450 $m^3$/d.

If the groundwater level is closer to the ground surface at the time of shaft excavation than when the testing was undertaken, the dewatering rates could also be greater than estimated. With the groundwater level at ground surface, the highest theoretical level possible and highly unlikely ever to occur, the dewatering rates

MOTT MACDONALD

for the fracture condition increase by approximately 40%. In this scenario, dewatering rates would also rise for calculations assuming unconfined conditions in the Grey Chalk. However, it will not be possible to assess the actual variations in groundwater levels in the area of the proposed WWTP until longer term records of groundwater levels are available.

In contrast, if the fracture zone in the Grey Chalk is located above the base of the formation, then the calculated dewatering rates decrease for the fracture condition. For example, if the base of the fracture zone was 3m above the base of the formation, the estimated dewatering rates would be reduced by about 30%.

## 4.2 TPS shaft dewatering – drawdown impacts

Approximate assessments were made of the potential drawdown as a result of shaft dewatering, using the minimum, best estimate and maximum dewatering rates in combination with the transmissivities used in calculating each dewatering rate. The calculations assume the worst-case fracture condition, with highest associated dewatering rates, as described in the previous section. It was also assumed that the shaft section in the base of the Grey Chalk would be excavated and remain unlined over a period of seven days. In practice, if the shaft is constructed by underpinning, as discussed in the hydrogeological impact assessment, each section of the shaft is likely to be lined and grouted over a shorter period of a few days.

The assessments of drawdown were made using Boulton’s method, together with estimated ranges for aquifer parameters (transmissivity, storage coefficient and delayed yield parameters) derived from the analysis from test pumping, as follows.

- For the minimum dewatering rate (1.7 l/s equivalent to 146 $m^3$/d), calculated using a transmissivity of 9$m^2$/d, the additional aquifer parameters were taken from the analysis of the CRT data for BH-TPS-003B which included a transmissivity of 9.1 $m^2$/d.
- For the maximum dewatering rate (5.2 l/s equivalent to 450 $m^3$/d), calculated using a transmissivity of 34 $m^2$/d, the additional aquifer parameters were taken from the analysis of the CRT data for BH-STW-009 which included a transmissivity of 34.1 $m^2$/d.

None of the analyses for the CRT using Boulton’s method resulted in a transmissivity close to 18 $m^2$/d, as used for calculating the best estimate dewatering rate (3.0 l/s equivalent to 260 $m^3$/d). However, analysis of the CRT data for BH-TUN-018 included a transmissivity of 22.1 $m^2$/d. The assessment of drawdown for the best estimate dewatering rate was therefore undertaken using the transmissivity and additional aquifer parameters from the test analysis for BH-TUN-018. Using a transmissivity which is greater than the value used for calculating the dewatering best estimate should give rise to a calculation of greater drawdown over a larger area. However, it seemed preferable to maintain the same set of aquifer parameters as obtained from test pumping analysis (including transmissivity) for the assessment, whilst accepting that the extent of drawdown is likely to be an over-estimate.

Analysis using Boulton’s method is appropriate for assessing the impacts on the surrounding aquifer of abstraction/dewatering at a point source. The method is generally applied in assessing the impact of pumping from a relatively small diameter borehole and not a shaft with a diameter of the order of 30m. Nonetheless, as the distance to most of the locations at which impacts are considered are one to two orders of magnitude greater than the diameter of the shaft, use of the Boulton method should give a reasonable indication of the likelihood and order of magnitude of any impact.

The resulting drawdowns at the end of a seven day period were assessed for the minimum, best estimate and maximum dewatering rates at the following locations:

- Monitoring borehole BH-STW-009 at a radial distance of 105m from the centre of the TPS shaft.
- Monitoring boreholes BH-STW-025 and BH-STW-026, located towards the north-east and eastern boundary of the site, at a radial distance of about 560m and 590m from the TPS shaft. The boreholes are located between the TPS shaft and the Black Ditch watercourse and drainage network, and in the general

direction from the shaft towards nature conservation sites at Allicky Farm Pond County Wildlife Site (CWS) and Stow cum Quy Fen Site of Special Scientific Interest (Quy Fen SSSI).

- A private groundwater source located on the Grey Chalk in the vicinity of the proposed WWTP.
- Allicky Farm Pond CWS.
- Quy Fen SSSI.
- Wilbraham Fens SSSI.

Estimated drawdowns at the locations of the monitoring boreholes BH-STW-009, BH-STW-025 and BH-STW-026 were as follows:

- At a radial distance of 105m from the centre of the TPS shaft (at BH-STW-009), the calculated drawdown values for the minimum, best and maximum estimates of dewatering are 0.25, 0.46 and 3.1m respectively. However, the location is reasonably close to the TPS shaft. This is an additional factor likely to affect the reliability of the values obtained as an indicator of the drawdown.
- For the minimum estimate of dewatering, there would be no drawdown impact at BH-STW-025 and BH-STW-026.
- For the best estimate of dewatering, the calculated drawdown is 0.02 and 0.03m at BH-STW-026 and BH-STW-025.
- For the maximum estimate of dewatering, the calculated drawdown is 0.26 and 0.32m at BH-STW-026 and BH-STW-025.

The calculations provide an approximate indication of the range of drawdown at distances of between 100m and 600m from the TPS shaft, depending on the dewatering rates which may be required.

The following conclusions were also drawn from this assessment regarding impacts at the private groundwater source and the nature conservation sites:

- For the minimum estimate of dewatering, there would be no drawdown impact at the private groundwater source or at any of the conservation sites. The theoretical drawdown would be 0.001m (1mm) approximately 300m from the TPS shaft.
- For the best estimate of dewatering, the calculated drawdown in the Grey Chalk is less than 0.001m (<1mm) at the private groundwater source. There would be no drawdown at any of the conservation sites.
- For the maximum estimate of dewatering, the calculated drawdown in the Grey Chalk is 0.02m (20mm) at the location of the private groundwater source and less than 0.001m (<1mm) at Allicky Farm Pond CWS and Quy Fen and Wilbraham Fens SSSIs. The theoretical drawdown would be 0.001m (1mm) approximately 1,400m from the TPS shaft.

These assessments of drawdown provide a guide to impacts at distant locations. However, the drawdown assessment cannot take into account:

- The complexity of the minor fracture systems within the Grey Chalk which will affect the transmittal of drawdown impacts through the aquifer; or
- Potential connections between groundwater in the Grey Chalk and surface water features around the site of the proposed WWTP. If there are connections between groundwater and the local drainage system, the impacts of dewatering may not extend beyond these surface water drainage features.

## 4.3 Trench dewatering – estimated discharge

Trench dewatering rates during pipeline installation were estimated for indicative sections of both the treated effluent and Waterbeach transfer pipelines and presented in the Hydrogeological Impact Assessment (Mott MacDonald, 2021). The methodology for these calculations was set out in the Hydrogeological Impact Assessment. Results were included for dewatering in trenches in superficial deposits and the Grey Chalk.

The calculations provided an order of magnitude estimate and, hence, a very approximate indication of potential worst-case, temporary dewatering requirements.

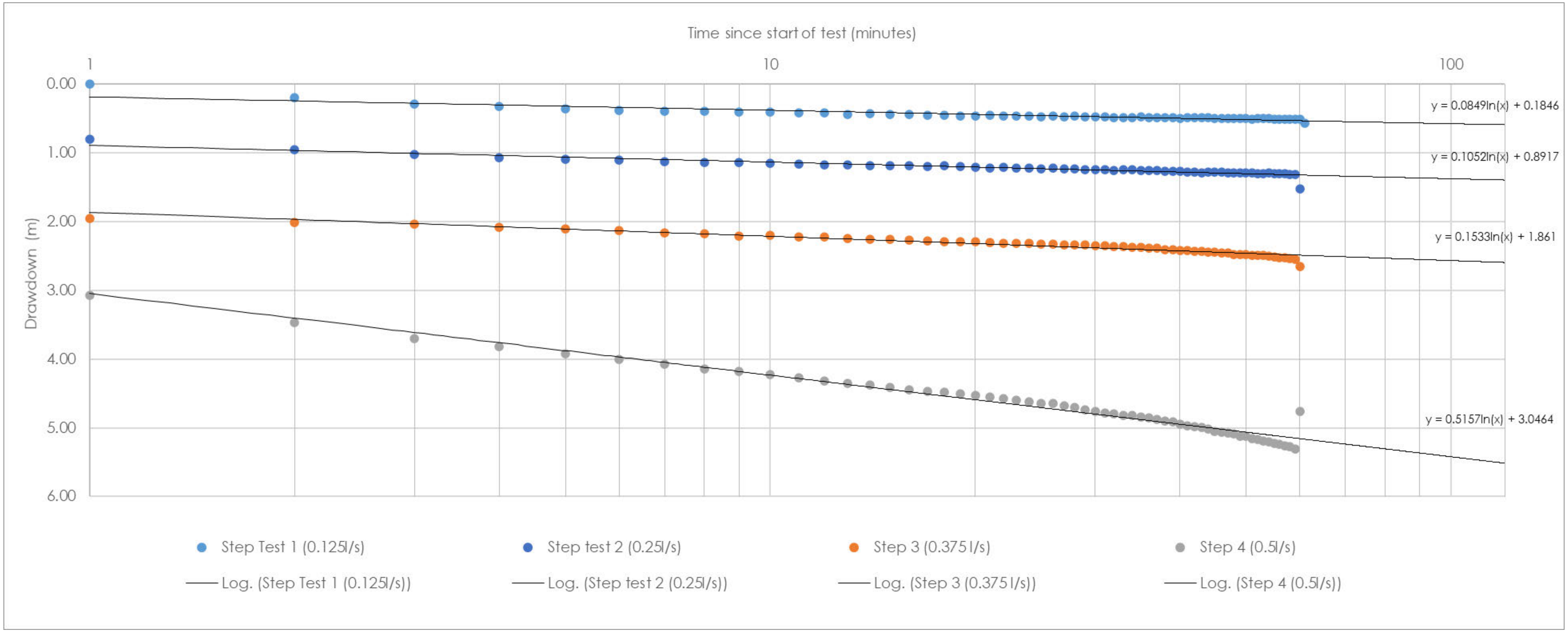
Calculations for the superficial deposits remain unchanged. However, the calculations for the Grey Chalk have been updated using permeability values obtained from analysis of the test pumping data. The results are included in Table 5.3.

The dewatering rates are higher than for the original results due to the higher permeability values for the Grey Chalk derived from test pumping data. The upper limit dewatering rates of 3.3 l/s for the Waterbeach transfer pipeline and 1.3 l/s for the treated effluent pipeline compare with 1.3 l/s and 0.5 l/s respectively for the original results.

# 5 Figures and tables

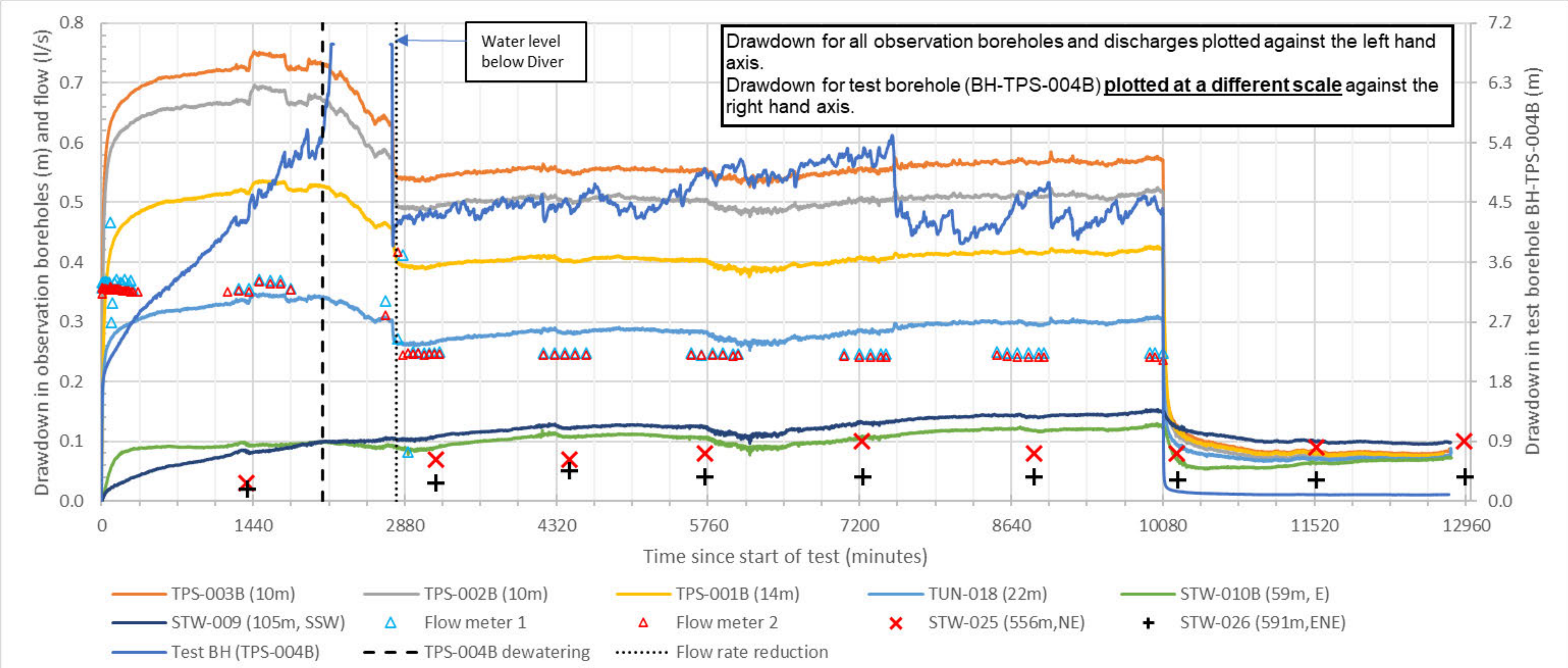
## 5.1 Figures

**Figure 5.1: Step discharge test plot BH-TPS-004B Drawdown vs. Time (elapsed)**



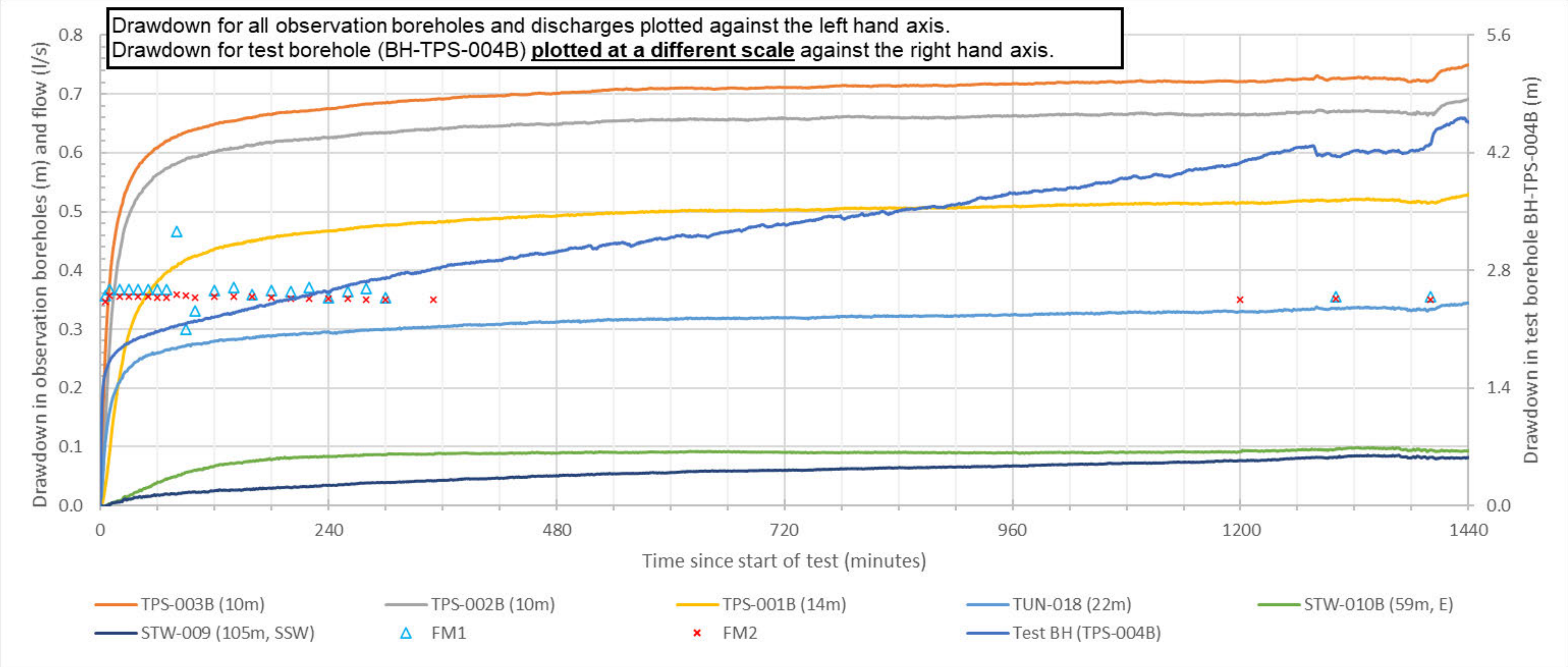
MOTT MACDONALD

**Figure 5.2: Drawdown during seven day CRT and recovery**



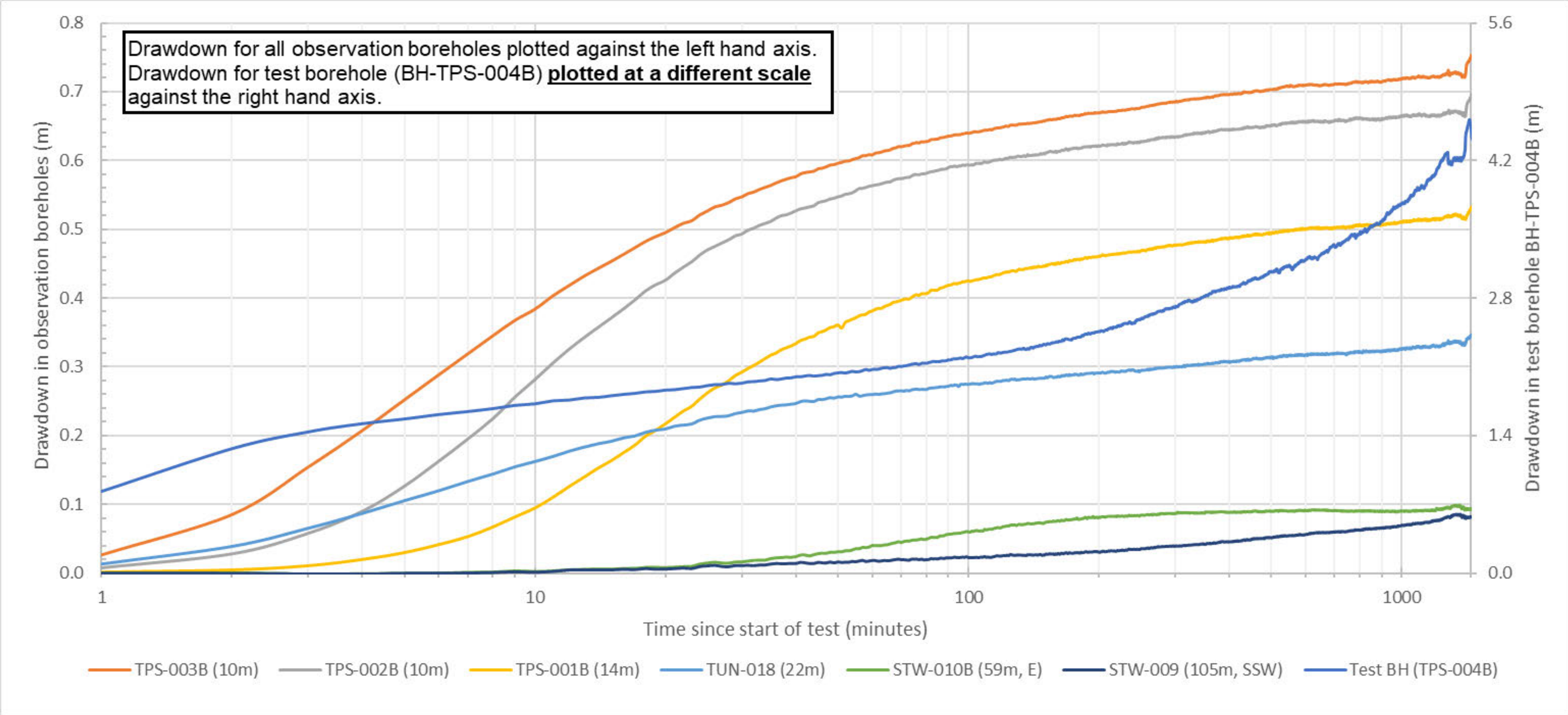
MOTT MACDONALD

**Figure 5.3: Drawdown during first day of CRT – linear scale**



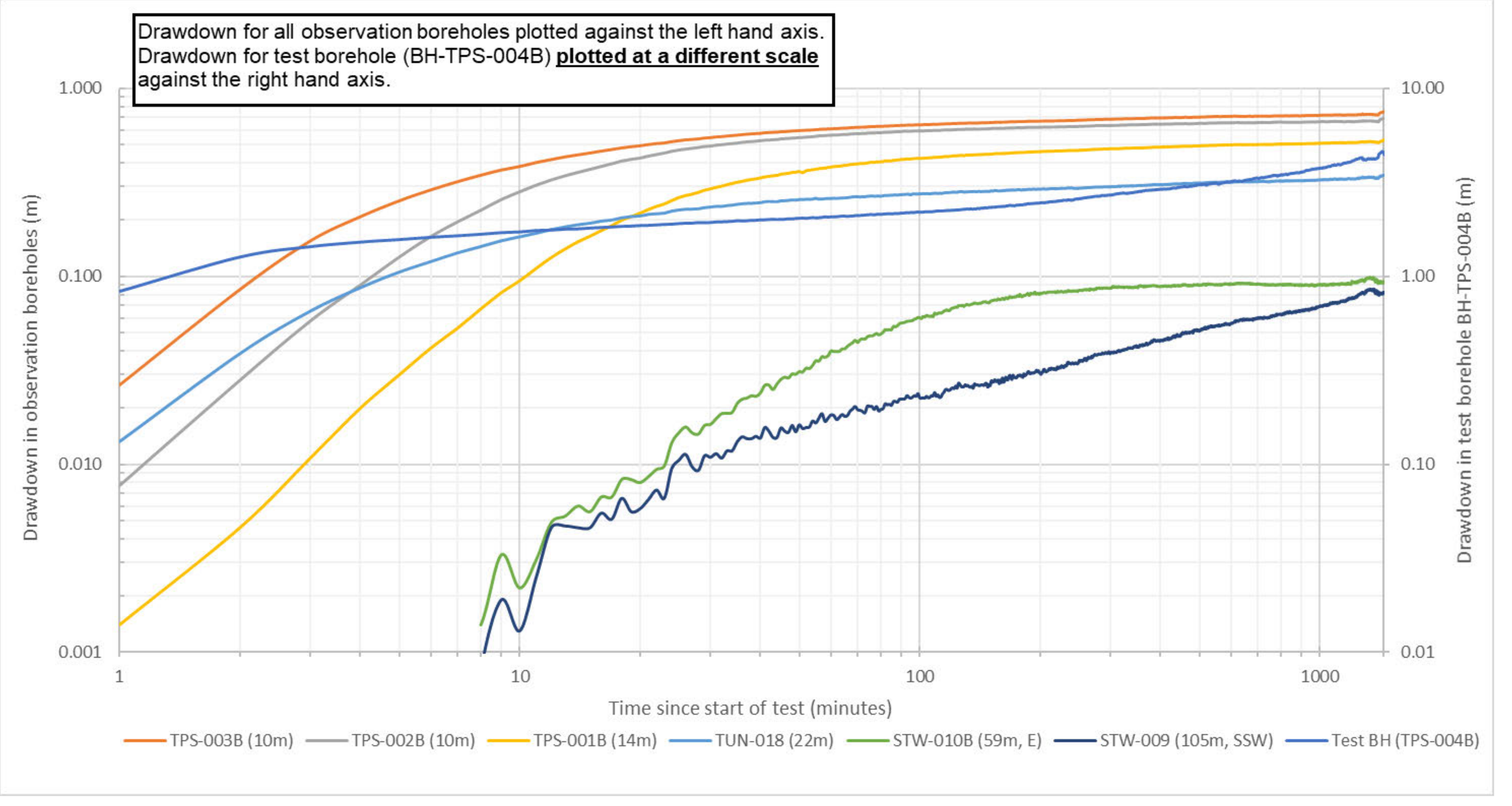
MOTT MACDONALD

**Figure 5.4: Drawdown during first day of CRT – semi-logarithmic scale**



MOTT MACDONALD

**Figure 5.5: Drawdown during first day of CRT – logarithmic scales**



MOTT MACDONALD

**Figure 5.6: Theis curve fitting example plot (BH-TPS-010B)**

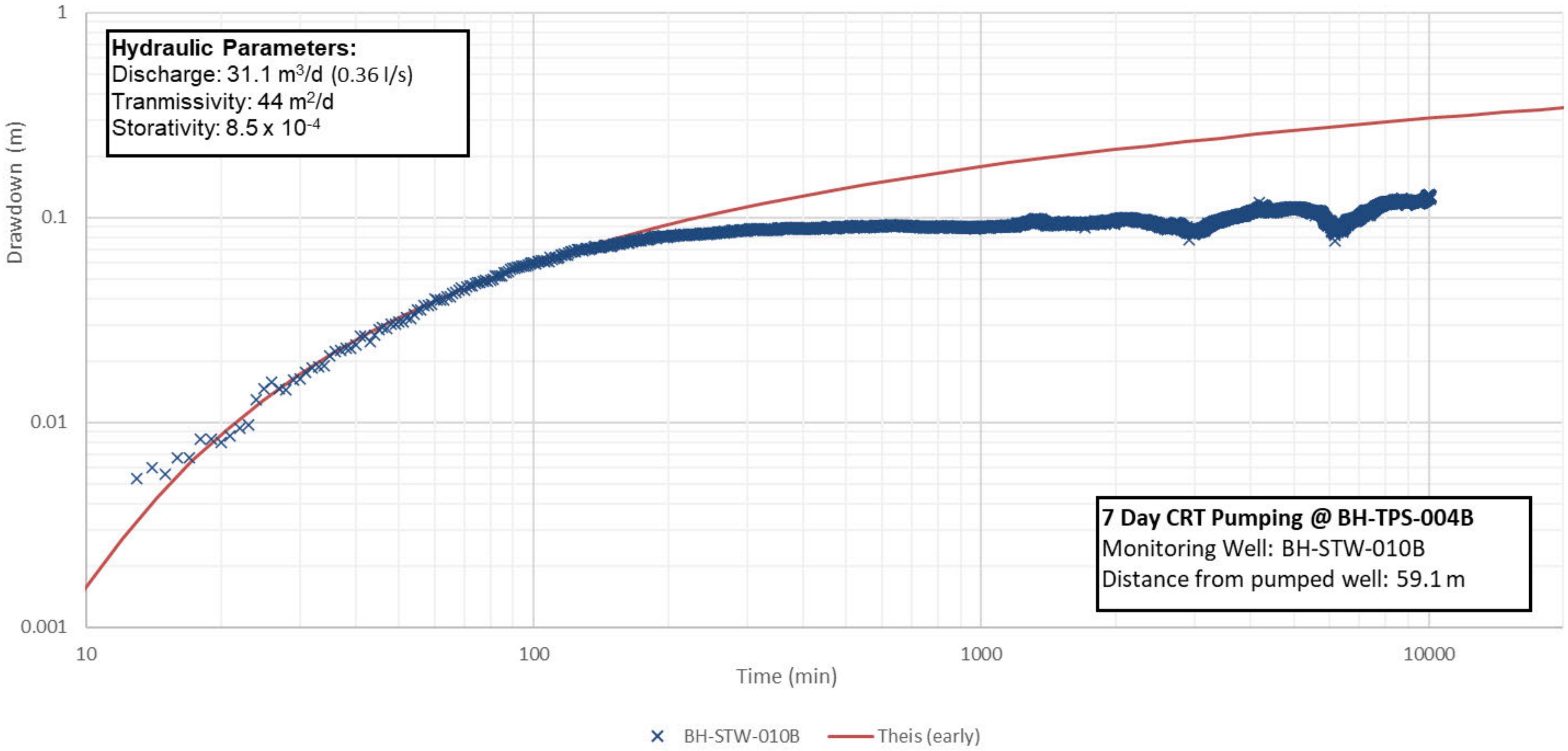
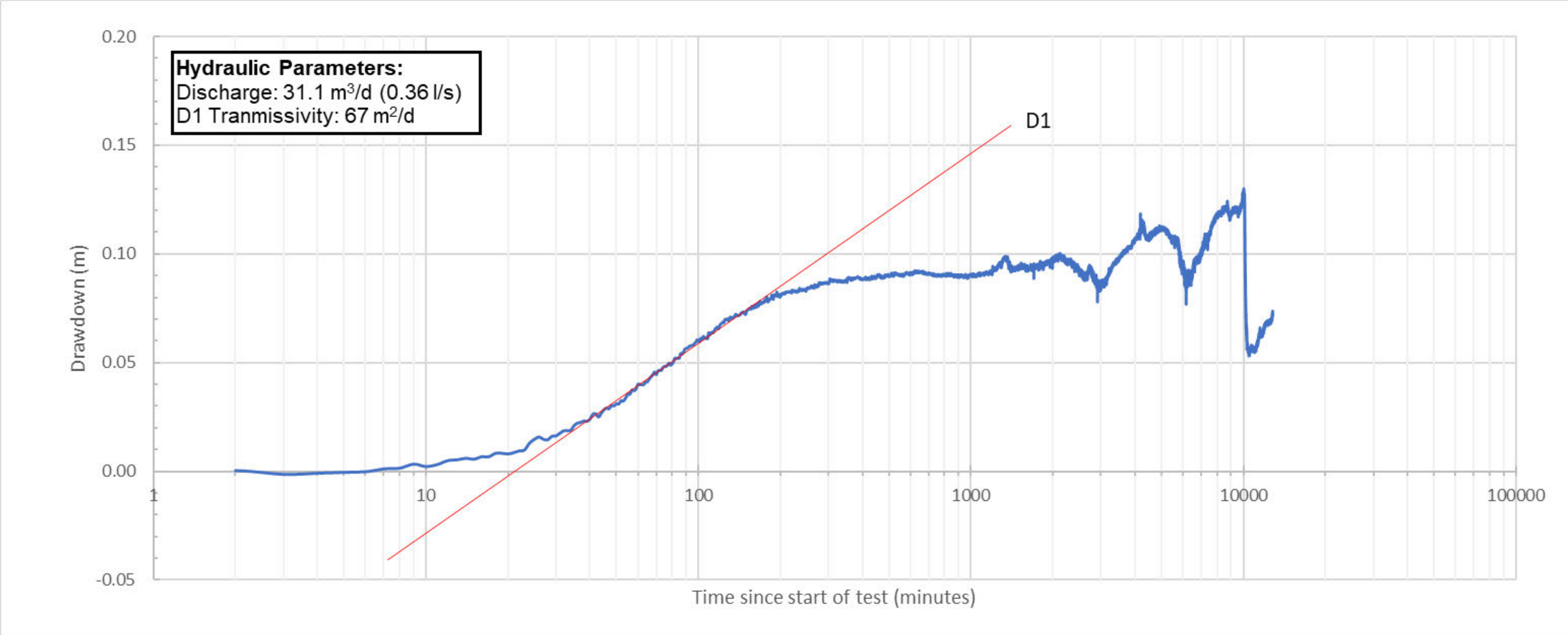


**Figure 5.7: Jacob's method example plot (BH-TPS-010B)**



MOTT MACDONALD

**Figure 5.8: Distance drawdown plot (one day)**

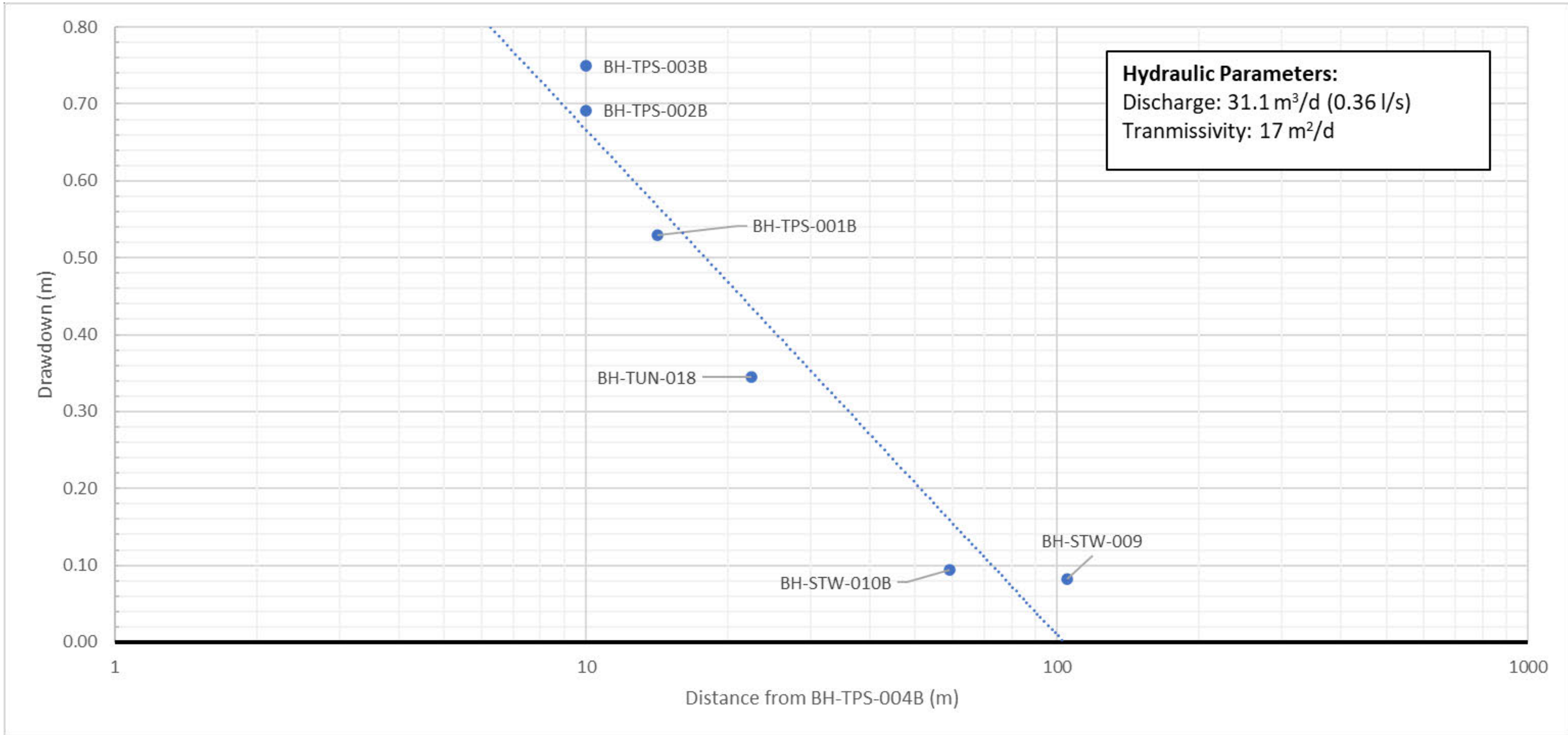
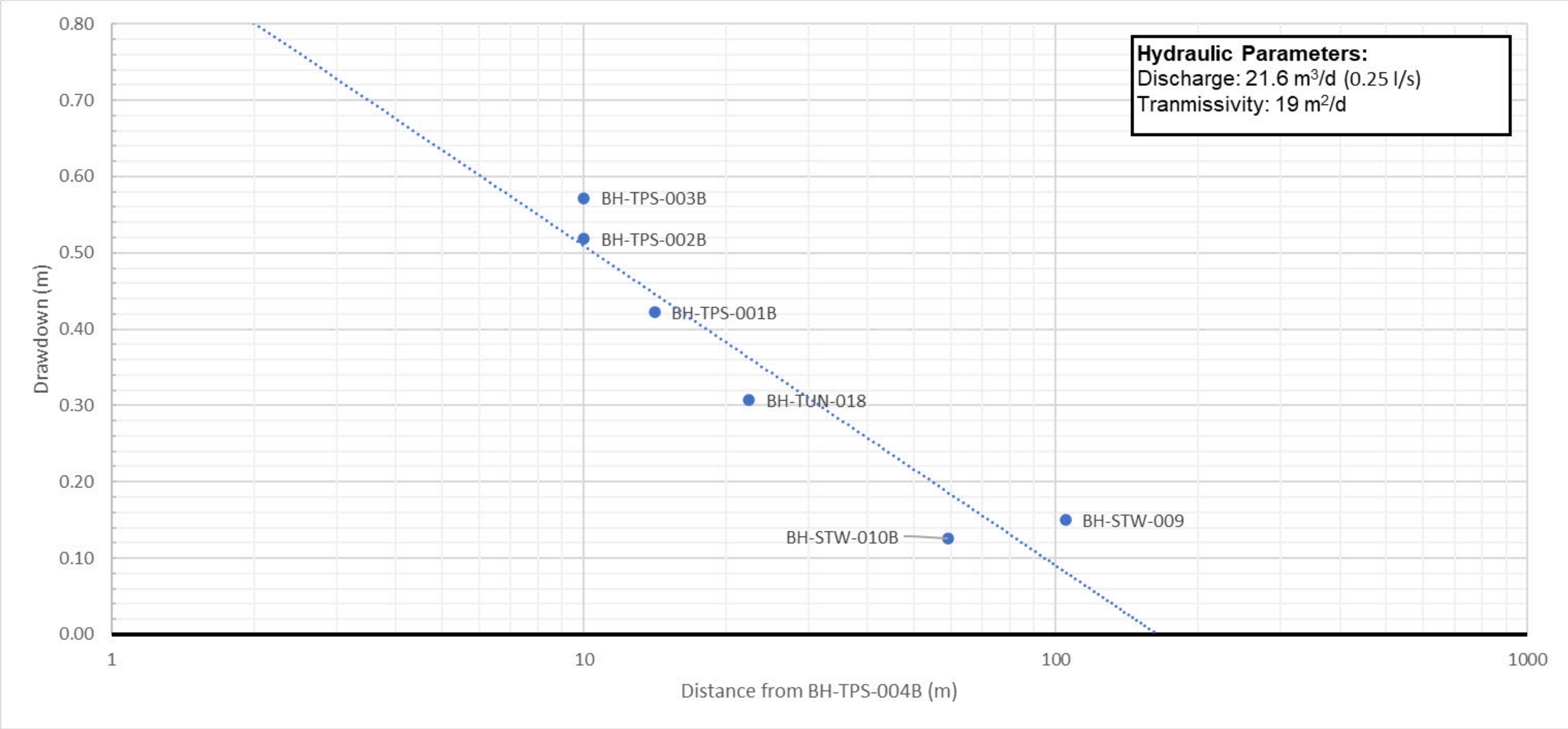
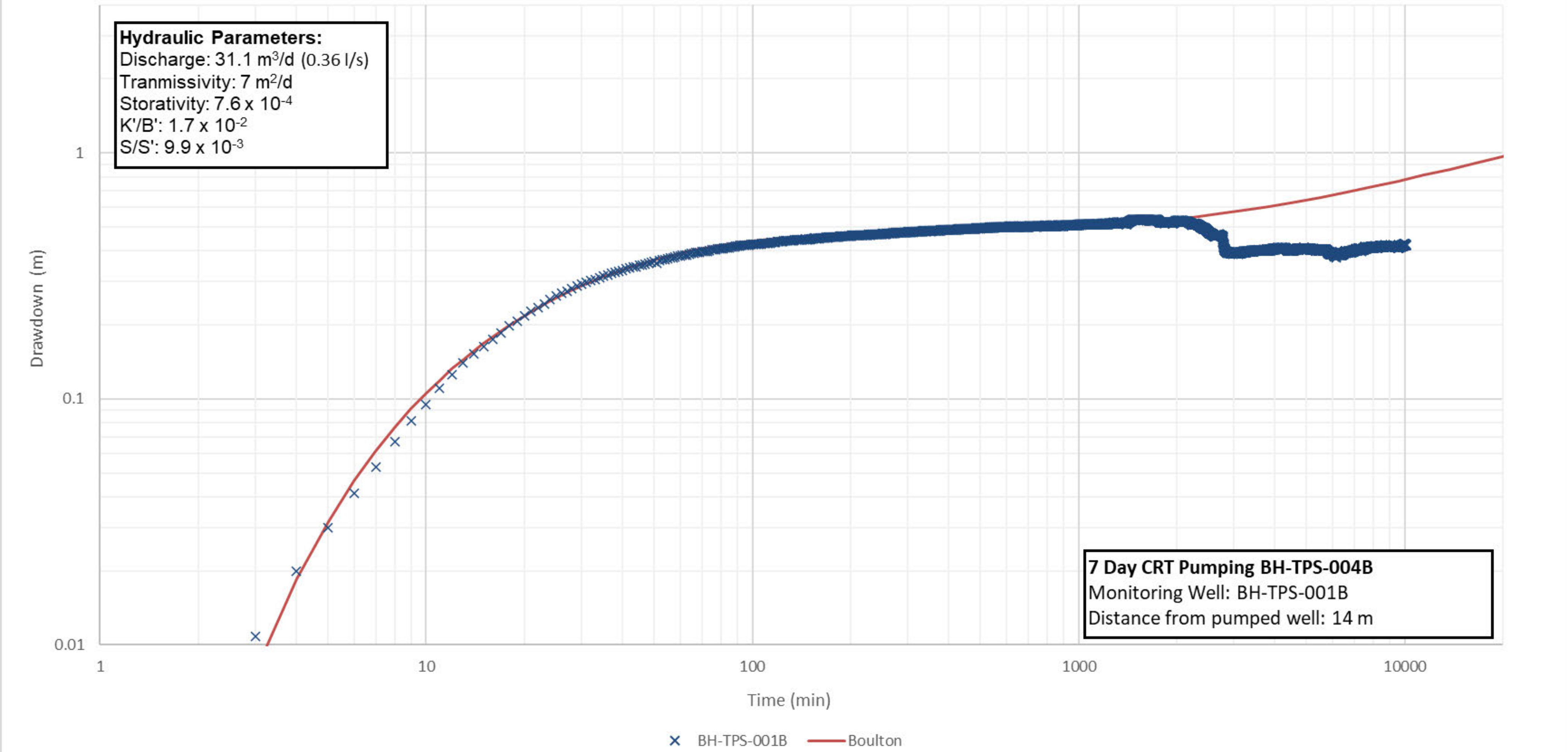


**Figure 5.9: Distance drawdown plot (seven days)**



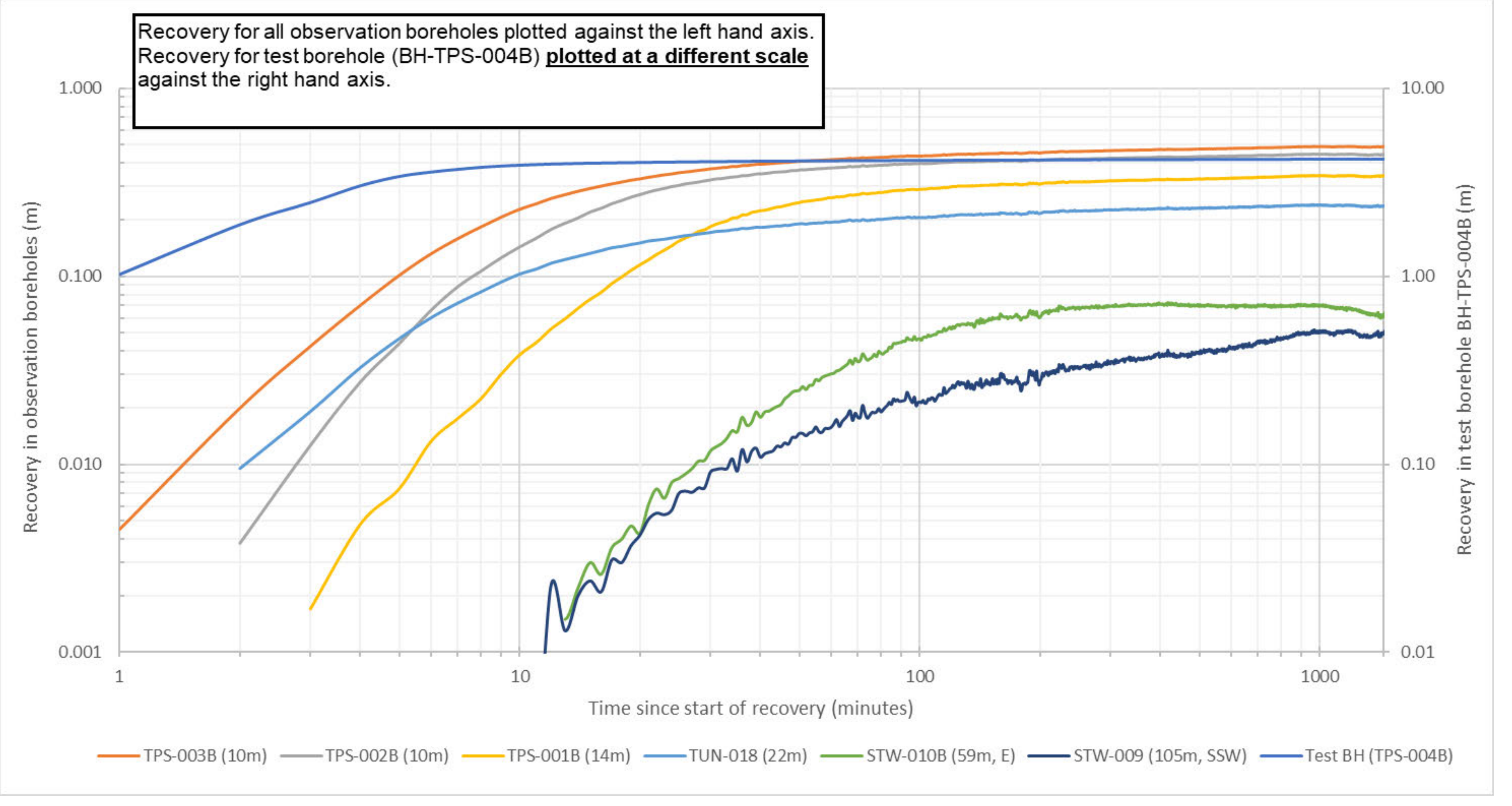
MOTT MACDONALD

**Figure 5.10: Boulton analysis method example plot (BH-TPS-001B)**



MOTT MACDONALD

**Figure 5.11: Recovery following CRT – logarithmic scales**



MOTT MACDONALD

**Figure 5.12: Boulton recovery analysis method example plot (BH-TPS-001B)**

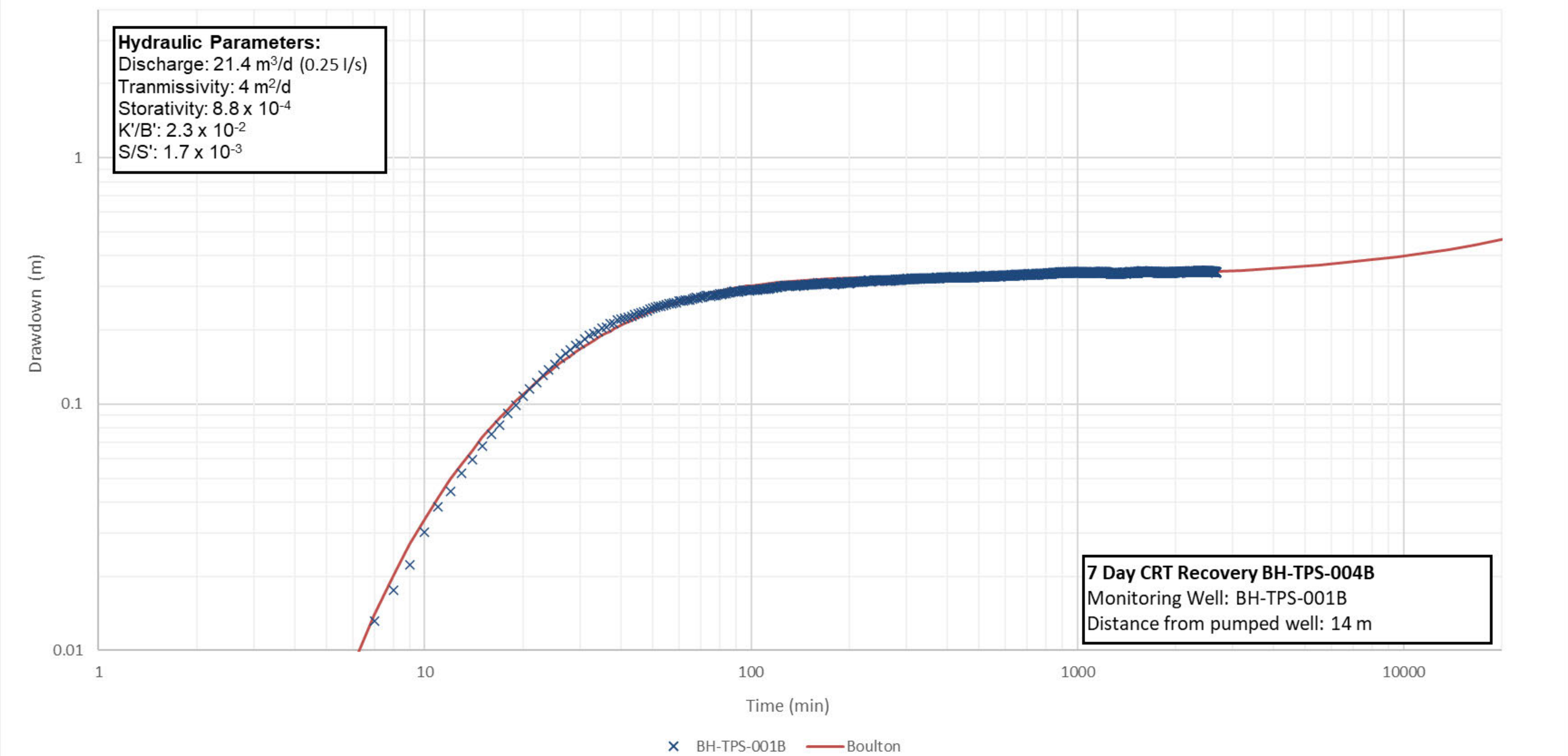
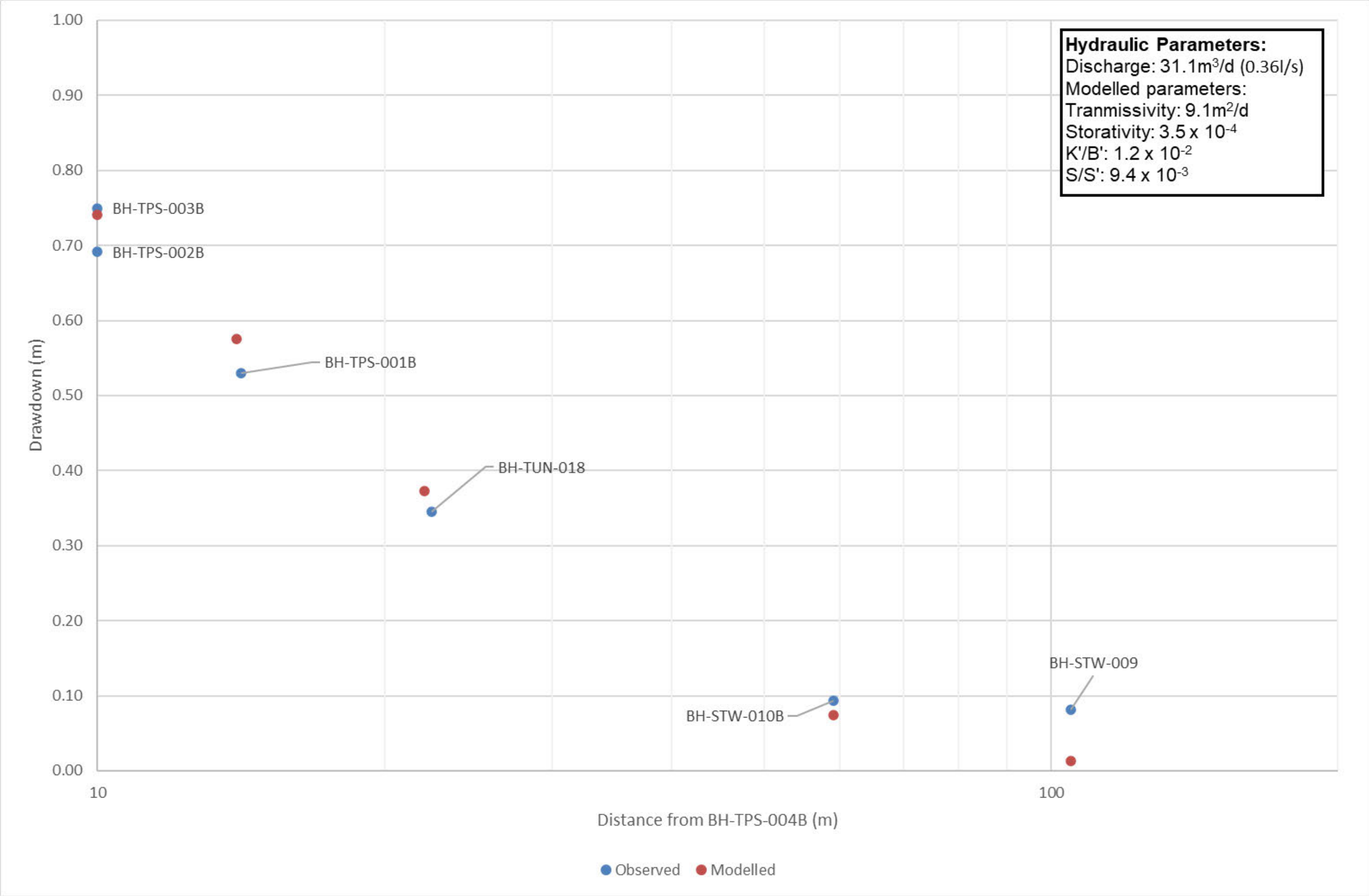


**Figure 5.13: Modelled distance drawdown (1 day)**



MOTT MACDONALD

**Figure 5.14: Modelled distance drawdown (7 days)**

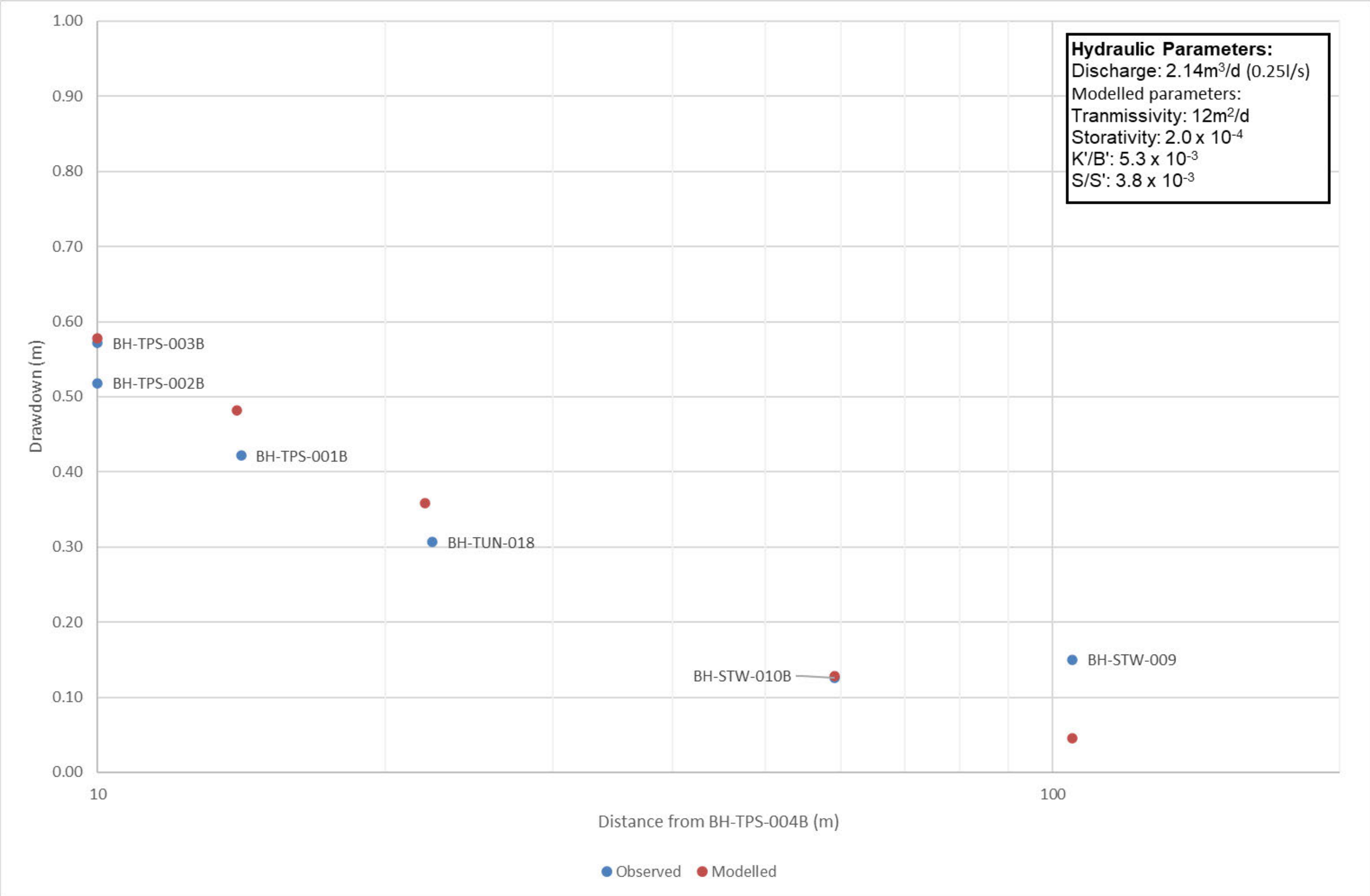
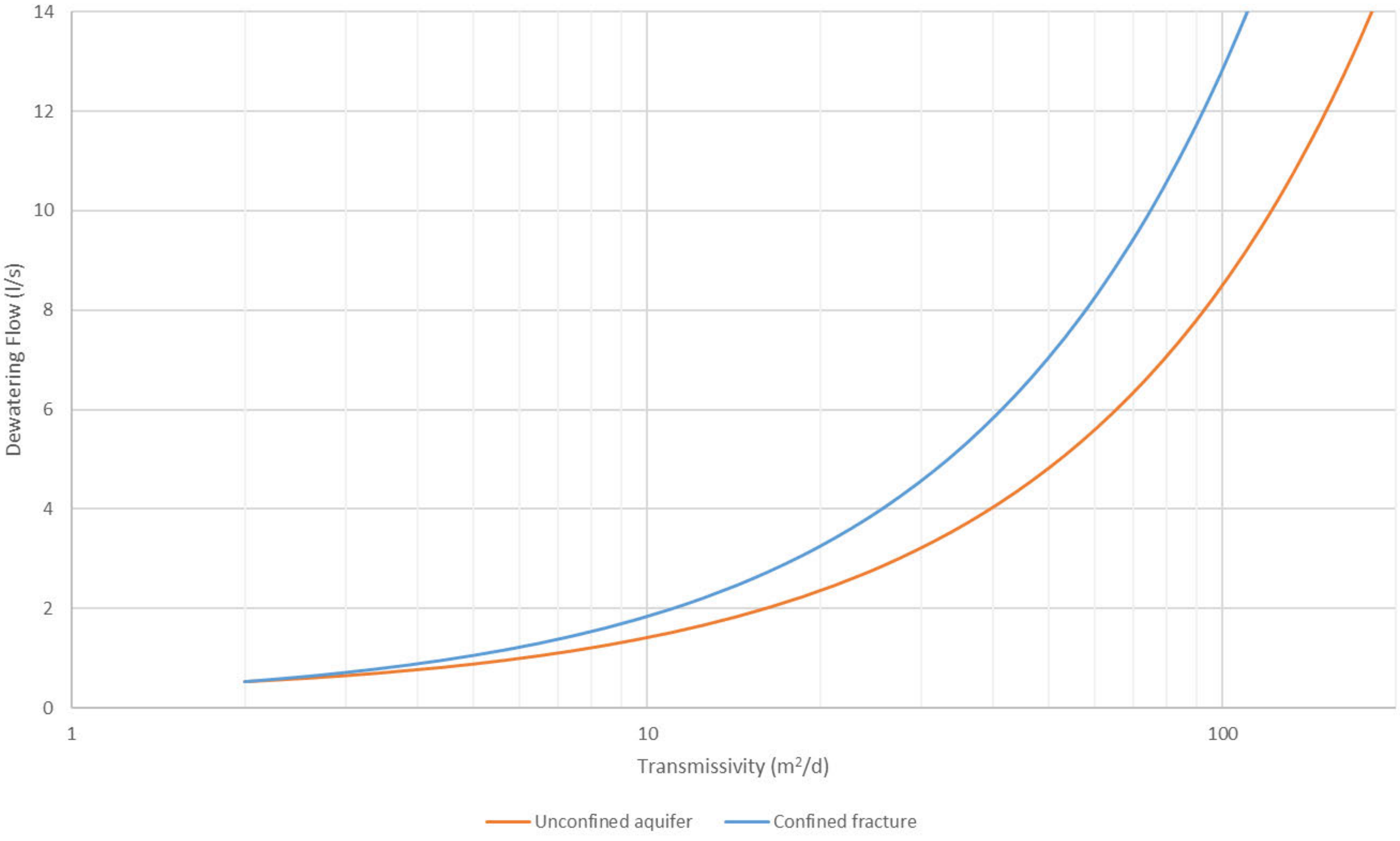


**Figure 5.15: Dewatering rate vs transmissivity**



## 5.2 Tables

**Table 5.1: Aquifer properties**

| Borehole/ data set | Distance from BH-TPS-004B | Transmissivity value from analysis of data (m²/d) | | | | | Storage coefficient | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Step discharge tests | | Constant rate test BH-TPS-004B | | | | | |
| | | Step 1 (Jacob method) | using aquifer constant (B) | Jacob method | Boulton's method | | Jacob method | Boulton's method | |
| | | | | | test data | recovery data | | test data | recovery data |
| BH-TPS-004B | - | 10 | 32 | 11 | N/A | N/A | N/A | N/A | N/A |
| BH-TPS-003B | 10 | 10 | 34 | 13 | 9 | 3 | 0.0003 | 0.0003 | 0.0005 |
| BH-TPS-002B | 10 | 2 | 7 | 7 | 6 | 4 | 0.0008 | 0.0006 | 0.0008 |
| BH-TPS-001B | 14 | 1 | - | 13 | 7 | 4 | 0.0007 | 0.0008 | 0.0009 |
| BH-TUN-018 | 22 | N/A | | 34 | 22 | 7 | 0.0001 | 0.0002 | 0.0002 |
| BH-STW-009 | 105 | | | 285 | 34 | 34 | 0.0003 | 0.0002 | 0.0003 |
| BH-STW-010B | 59 | | | 67 | 25 | 15 | 0.0006 | 0.0005 | 0.0004 |
| **Distance/drawdown analysis** | | | | | | | | | |
| 1 day | | | | 17 | | | | | |
| 7 days | | | | 19 | | | | | |

**Table 5.2: Range of transmissivity and permeability for shaft dewatering assessment**

| Values | Transmissivity (T) | Permeability (k)* | |
|---|---|---|---|
| | m²/d | m/d | m/s |
| very low | 2 | 0.3 | $3.4x10^{-06}$ |
| low | 20 | 3 | $3.4x10^{-05}$ |
| mid-range | 65 | 10 | $1.1x10^{-04}$ |
| high | 100 | 15 | $1.7x10^{-04}$ |
| highest | 250 | 37 | $4.2x10^{-04}$ |

* Based on saturated Grey Cha k thickness of 6.8m at the time of testing.

MOTT MACDONALD

**Table 5.3: Reassessment of trench section dewatering in Grey Chalk**

| Pipeline | | Transmissivity | Hydraulic conductivity, k | | Dewatering rate, Q | |
|---|---|---|---|---|---|---|
| | | $m^2/d$ | m/d | m/s | $m^3/d$ | l/s |
| Waterbeach transfer | lower limit | 9 | 1.3 | 1.5E-05 | 146 | 1.7 |
| | best estimate | 18 | 2.5 | 2.9E-05 | 206 | 2.4 |
| | upper limit | 34 | 4.8 | 5.5E-05 | 284 | 3.3 |
| Treated effluent transfer | lower limit | 9 | 1.3 | 1.5E-05 | 58 | 0.7 |
| | best estimate | 18 | 2.5 | 2.9E-05 | 82 | 0.9 |
| | upper limit | 34 | 4.8 | 5.5E-05 | 112 | 1.3 |

# 6 References

British Standards Institute. (2012). *BS EN ISO 22282-4:2012. Geotechnical investigation and testing — Geohydraulic testing — Part 4: Pumping tests.*

Mott MacDonald. (2021). *Cambridge WWTP Relocation Hydrogeological Impact Assessment.*

Soil Engineering. (2021). *Report on a Ground investigation for Cambridge Waste Water Treatment Plan Relocation. Issue 01. Document Reference: TE8364/DRpt01.*

Stuart Wells Limited. (2021). *Cambridge WwTW Pumping Test Report. Report No: SWL21-122-01-PT-01.*

# Get in touch

**You can contact us by:**

Emailing at **info@cwwtpr.com**

Calling our Freephone information line on **0808 196 1661**

Writing to us at **Freepost: CWWTPR**

Visiting our website at [redacted]

You can view all our DCO application documents and updates on the application on The Planning Inspectorate website:

https://infrastructure.planninginspectorate.gov.uk/projects/eastern/cambridge-waste-water-treatment-plant-relocation/