British Geological Survey

Drilling and as-built borehole design report for the UK Geoenergy Observatory in Cheshire

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Geobore coring assembly ready to be run.

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Foreword

The UK Geoenergy field observatories comprising the Cheshire and Glasgow field Observatories are world class facilities for research and innovation in shallow geothermal energy, thermal energy storage, rock volume characterisation and monitoring of the subsurface environment.

This report provides as-built design details for the 20 boreholes drilled during the main phase of the Cheshire Observatory construction works. It details how each of the wells was drilled including the hole sizes, casing design, grout used and the equipment that has been installed in each borehole to provide the research capabilities for the site.

Acknowledgements

The UK Geoenergy Observatories were delivered by British Geological Survey on behalf of UKRI-NERC with £31 million capital funding provided by BEIS. The Geoenergy Observatories have been realised through the skill and dedication of a great many colleagues from BGS, NERC and the staff of Aecom (the principal contractors), Marriott Geotechnical Drilling and specialist engineering subcontractors which included Fox Owmby, Silixa, European Geophysical Services, Geopro, Geokon and RS Hydro to mention a few.

A special mention is needed for David Buckley and Sunday Okunuwadje who were the BGS representatives onsite during the drilling phase reporting and overseeing the operation throughout.

The author would also like to thank the members of the UKGEOS Science Advisory Group, University of Chester and experts from the UK and international subsurface research community who have advised on different aspects of the Observatory design.

Summary

This report details work undertaken during the main drilling phase of the UK Geoenergy Observatory in Cheshire, which is a unique, at-scale field laboratory for research and innovation in aquifer thermal energy storage, rock volume characterisation and the monitoring of subsurface processes.

The Observatory, which entered into operation in April 2024, comprises 21 vertical boreholes drilled to 100 m depth and permanent surface equipment for heating, cooling and groundwater flow control. Boreholes are equipped with a high-resolution array of electrical resistance tomography electrodes, hybrid fibre-optic distributed temperature and acoustic sensing (DTS & DAS) cables and multilevel groundwater monitoring to allow subsurface change to be observed in close to real time. Extensive rock volume characterisation was performed during Observatory construction including the scanning of 1,800 m of drill core, geophysical wireline logging, porewater profiling and hydraulic testing.

The Cheshire Observatory boreholes were drilled in two phases: an initial ground investigation borehole (TH0424) was drilled from the 8th to the 30th of November 2021 to provide data to inform the Observatory design. A further 20 boreholes were then drilled between 15th August 2022 and the 25th July 2023. Both phases of drilling were undertaken by Marriott Geotechnical Drilling.

The Geoenergy Observatories are operated by the British Geological Survey and are NERC/ UKRI facilities. They are available to the whole of the UK science community for research, innovation and training activities.

The drilling report and appendices include:

- Details of the drilling of each of the boreholes and well construction specifications.
- Details of each of the installations run and the material used.
- Borehole schematics.
- Details of the data collected during the drilling phase including wireline logs, core, sub cores, fluid samples etc.
- Well instrumentation and sensor positions.
- Issues encountered and lessons learned.

The Cheshire site is located within Thornton Science Park (TSP), approximately 10 km north of Chester. It is well placed to support energy storage research by energy-intensive industries in the Cheshire Science Corridor Enterprise Zone.

For the latest information on the UKGEOS facility, available datasets and research access please refer to the UKGEOS website: https://ukgeos.ac.uk

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1 Introduction

1.1 PROJECT BACKGROUND

The UK Geoenergy Observatories (UKGEOS) capital project was initiated in response to the government's announcement in the 2014 Autumn Statement that it would allocate £31 million to create world-class sub-surface geoenergy research centres. In 2016 the Science Advisory Group for the UKGEOS project published a report that identified four intrinsically coupled Science Challenges that are critical to understanding the effects of subsurface technologies:

1. How fluids flow through the rock mass, how the chemical interactions between fluids and minerals modify the fluid flow and mechanical properties of the rock mass, and how fluid chemistry can be used to monitor the evolving structure of the rock mass, fluid flow and biological processes and mechanical processes such as cracking.
2. How stress changes either because of injecting, producing or mobilising fluids, or imposed deliberately, cause mechanical responses.
3. How the nature of the subsurface biosphere responds to perturbations caused by fluid flow and mechanical changes.
4. Whether and how anthropogenic perturbations in the subsurface alter the links and feedback between the deep subsurface and the shallow subsurface and surface; for example, whether they affect the near subsurface (e.g. potable aquifers and other groundwater) or surface (e.g. subsidence, emissions).

The British Geological Survey (BGS) has built field research sites in both Glasgow and Cheshire that will enable researchers to undertake the at-scale experiments needed to address these challenges. The Glasgow site, which is focussed on subsurface interactions associated with thermal energy storage in flooded mine workings, entered full operation in 2022. The Cheshire Observatory, which is focused on aquifer thermal energy storage, rock volume characterisation and the monitoring of subsurface processes was completed and handed over in April 2024.

1.2 ROLES AND RESPONSIBILITIES

The roles of the various parties involved in the works are described in **Table 1** below:

Table 1 Project roles and responsibilities

Employee	Role
UK Research and Innovation (UKRI)	Client
NERC External Science Advisory Group (GSAG)	NERC Science Advice and Assurance
British Geological Survey (BGS)	Client
Ramboll	Principal Designer
AECOM	Principal Contractor
Fox	Civils Subcontractor
Marriott Geotechnical Drilling (MGD)	Drilling Subcontractor
Silixa, IBT, EGS, ITASCA, Solinst, RST, Enercret, WJ Groundwater, Haka Gerodur, Grundfos	Engineering subcontractors & suppliers

2 Site Description

2.1 LOCATION

The Cheshire Observatory is located within Thornton Science Park (TSP). **Figure 1** below shows the precise location and documents RAM-TSP-ZZ-DR-Z-00001 and RAM-TSP-ZZ-DR-Z-00002 (**Appendix 4.1**) show the access route and the observatory location within TSP.

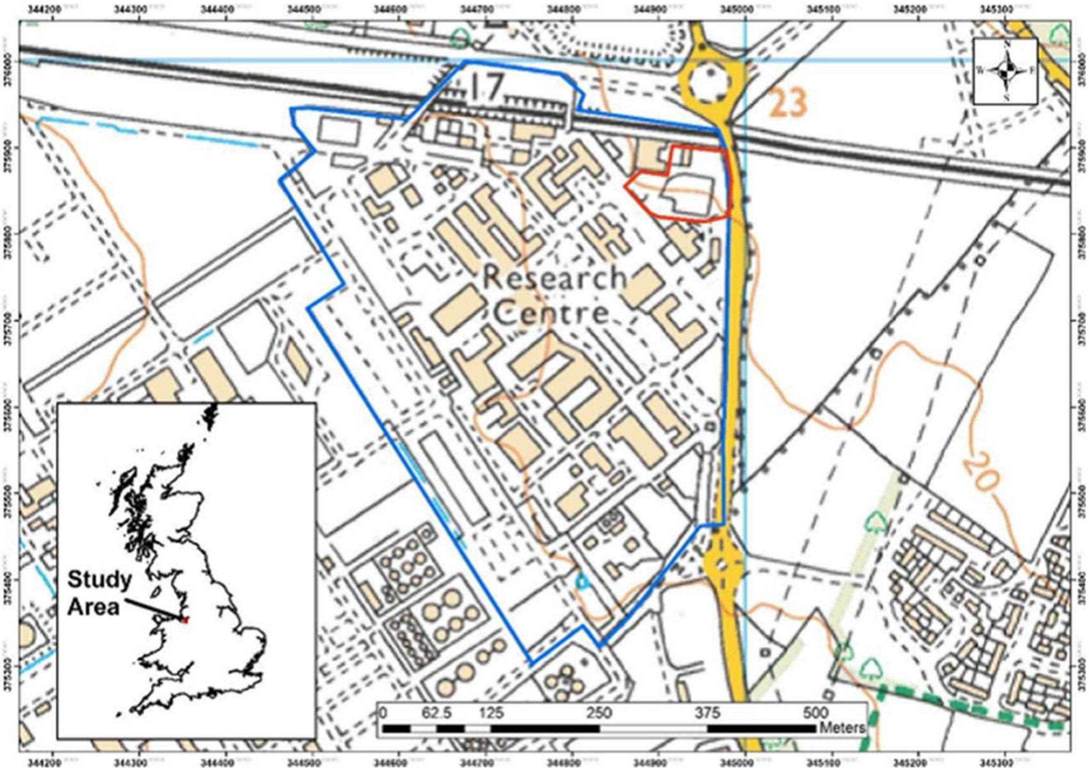


Figure 1 Location of the Cheshire Observatory Site (red), and Thornton Science Park (Blue). Includes Ordnance Survey data © Crown Copyright and database rights 2022 Ordnance Survey AC0000824781.

The site is bounded to the east by the north-south orientated B5132 Pool Lane Road, and to the north by the east-west orientated Ellesmere Port branch railway line. The remainder of the site is bounded by the surrounding Thornton Science Park with Stanlow Oil Refinery to the south and west.

The site address is:

UKGEOS Cheshire
Pool Lane,
Chester
CH2 4NU

The Observatory is centred on National Grid Reference SJ 44938 75845

2.2 TOPOGRAPHY AND SITE SETTING

The site is located within a former car park (**Figure 2** below) in the north-eastern corner of Thornton Science Park. The site is generally flat, sitting at approximately 20.0 m Above Ordnance Datum (AOD). The overall area covered by the red line boundary is approximately 0.42 hectares (ha). Figure RAM-TSP-ZZ-DR-Z-00003 (**Appendix 6.1**) shows the site boundaries.

Figure 2 Aerial photo of TSP showing the location of the UKGEOS site. Maps Data: Google, © May 2023.

2.3 ARRAY DESIGN

The Cheshire Observatory comprises a symmetrical array of 21 boreholes drilled to ~100.0 m below ground level (bgl) and instrumented to either ~15.0 m or ~100.0 m with fibre optic cable, resistance tomography electrodes and thermistor strings (**Figure 3**). It has five borehole types arranged on approximately north- south and east- west axes, see **Figure 3**. Working outwards from the centre these are as follows:

- Central borehole with PVC casing to 20.0 m and then open in the bedrock to 100.0 m (TH0410).
- Four Waterloo 401 type multilevel groundwater monitoring wells (TH0418, TH0419, TH0420, TH0421).
- Four boreholes with single loop HakaGerodur GEROtherm®-RT borehole heat exchangers (TH0416, TH0417, TH0422, TH0423).
- Four abstraction- reinjection wells with depth adjustable packers for control of groundwater flow velocity (TH0406, TH0408, TH0412, TH0414).
- Four deep piezometer wells (TH0407, TH0409, TH0411, TH0413).
- Four boreholes with PVC casing to 15.0 m and then open in the bedrock to 100.0 m (TH0404, TH0405, TH0415, TH0424).

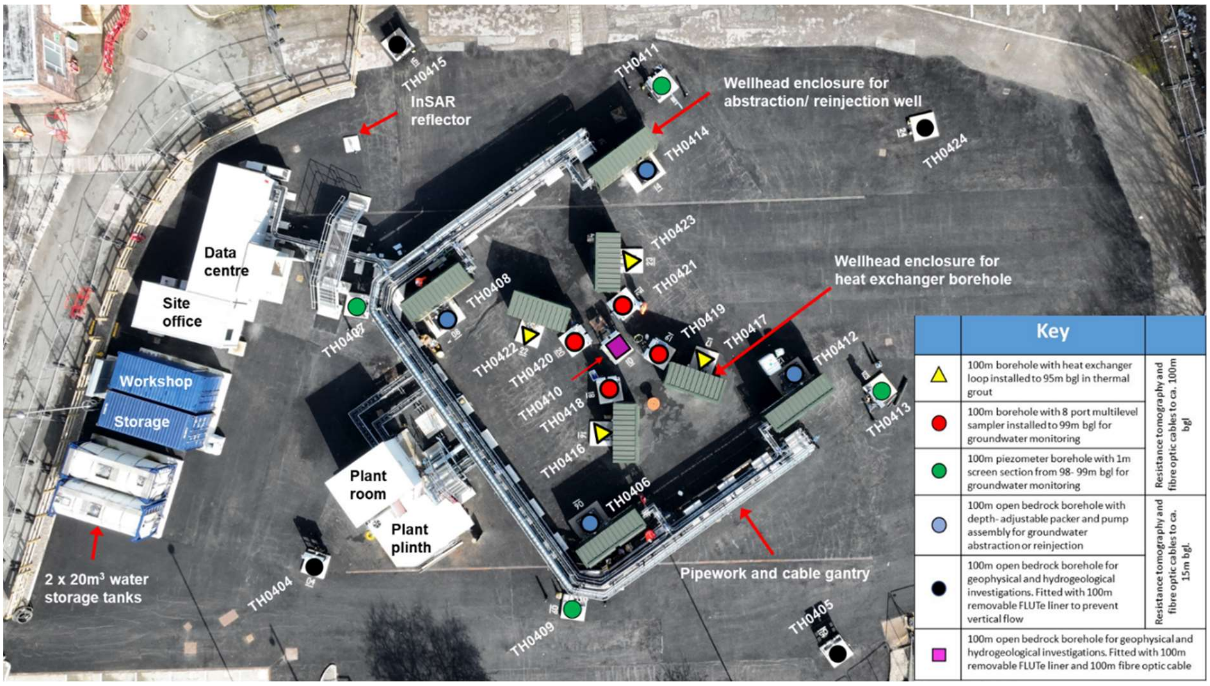


Figure 3 Aerial photo of the Cheshire site with the borehole array identifiers overlaid

Boreholes equipped with permanent fibre optic, resistance tomography and thermistor cables are connected to interrogators and loggers in the Observatory data centre. Additional information can be found in the Guidance Manual for UKGEOS Cheshire.

2.4 GEOLOGICAL SETTING

The Cheshire Observatory boreholes are in the Chester formation of the Sherwood sandstone, which is an important regional aquifer and a good prospect for shallow geothermal energy and thermal energy storage.

2.4.1 Quaternary geology

The Cheshire Observatory is located on elevated ground adjacent to the low- lying Ince Marches, which comprise estuarine marshes and tidal flats on the southern bank of the Mersey Estuary. Rockhead is close to surface and so superficial deposits are absent. Further to the east Quaternary deposits reach a thickness up to 60.0 m where the upper surface of the bedrock was deeply incised during the Quaternary, with thicker accumulations of alluvium deposits in filling a series of broadly north-trending buried channels.

2.4.2 Bedrock and structural setting

The site is located on the northern margin of the Cheshire Basin. Made ground and a variable thickness of Quaternary deposits unconformably overlay faulted Permo-Triassic sandstone bedrock, which varies in thickness from approximately 250 m to over 1,000 m. This comprises the Triassic Sherwood Sandstone Group, which is underlain in some locations by the Permian Collyhurst Sandstone Formation and/or the Manchester Marl Formation. Below the Permo-Triassic succession are older Carboniferous strata, with deep boreholes proving sedimentary rocks of the Warwickshire Group, Coal Measures, Millstone Grit and Craven Group at depth.

Analysis of seismic-reflection data indicates that the bedrock structure is characterised by a north-trending horst block that is 1–2 kilometres wide in the Thornton area (**Figure 4**). The horst is defined by the Waverton fault zone to the west, and the Dungeon Banks fault zone to the east. Evidence from deep boreholes sunk for hydrocarbon exploration gives information on bedrock stratigraphy in the area. The Ince Marshes 1 borehole proves the succession on the horst, while the succession in the Kemira graben to the east is proved by the Kemira 1 borehole (**Table 2**).

Table 2 Stratigraphic depths on the horst and eastern graben.

Stratigraphy (depths quoted in metres to base of unit)	Bedrock geology: horst, as proved by the Ince Marshes 1 borehole	Bedrock geology: eastern graben, as proved by the Kemira 1 borehole
Permo-Triassic	272 m	1,042 m
Carboniferous Warwickshire Group	331 m	1,221 m
Carboniferous Pennine Coal Measures Group	945 m	1,438 m (terminal depth)
Carboniferous Millstone Grit Group	1,577 m (terminal depth)	Not proved

2.4.3 Sherwood Sandstone geology

The Cheshire Observatory is underlain by the Chester Formation of the Sherwood Sandstone Group (Lower Triassic). This typically comprises brown and red-brown, medium-grained sandstone with occasional small pebbles and subordinate, impersistent beds of red-brown mudstone. While the Chester Formation is estimated to be in excess of 200 m in thickness at Thornton Science Park, the depth to the top of the Carboniferous has not been confirmed in the Elton graben to the west.

The Waverton Fault, which is mapped approximately 1,250 m to the east of TSP, throws sandstone of the Chester Formation down west against sandstone of the early Permian Collyhurst Sandstone Formation of the Appleby Group. Small, unmapped faults and deformation bands (zones of grain-size reduction formed in response to stress) may be present within the Chester Formation in the vicinity of TSP.

Further information is available from Hannis and Gent (2017) and Fellgett et al. (2017).

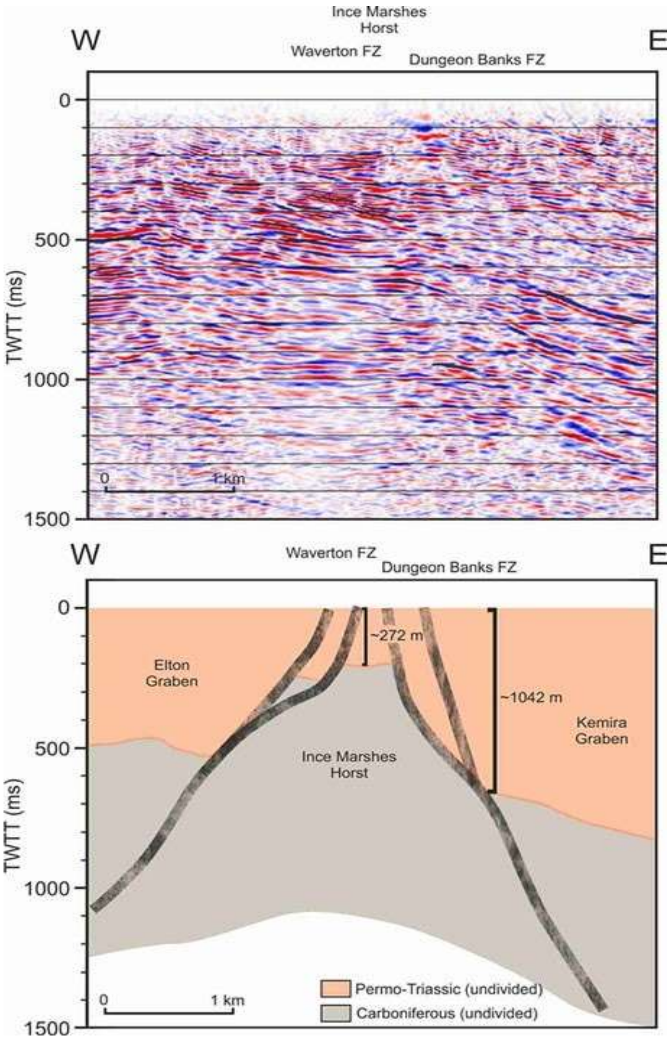


Figure 4 General structure of the area, based on interpretation of seismic reflection line SC-83-128V (seismic data courtesy of UKOGL)

Figure 4 illustrates the Ince Marshes horst structure defined by the Waverton fault zone to the west and Dungeon Banks fault zone to the east. FZ = fault zone. (Seismic data courtesy of UKOGL).

2.5 HYDROGEOLOGY OF THE BEDROCK

The Sherwood Sandstone Group is a principal aquifer. Groundwater abstraction is important in this region for public water supply, for example at Plemstall 5 kms south of Elton, as well as industry and agriculture. A key feature of this aquifer is its slow response to change, with observation wells showing a dampened response to recharge and abstraction. Groundwater levels have been modified over time by large abstractions.

The Permo-Triassic sandstones have moderate matrix permeability, with fractures providing secondary permeability. The hydraulic conductivity is highly anisotropic, with considerably higher horizontal hydraulic conductivity than vertical, due mainly to the presence of marl horizons within the sandstones. Bulk permeability declines with increasing depth and salinity increases, thus the effective aquifer is considered to be about 200 m thick. The aquifer has high storativity, which accounts for its slow response to perturbations (e.g. abstraction) compared to other UK aquifers.

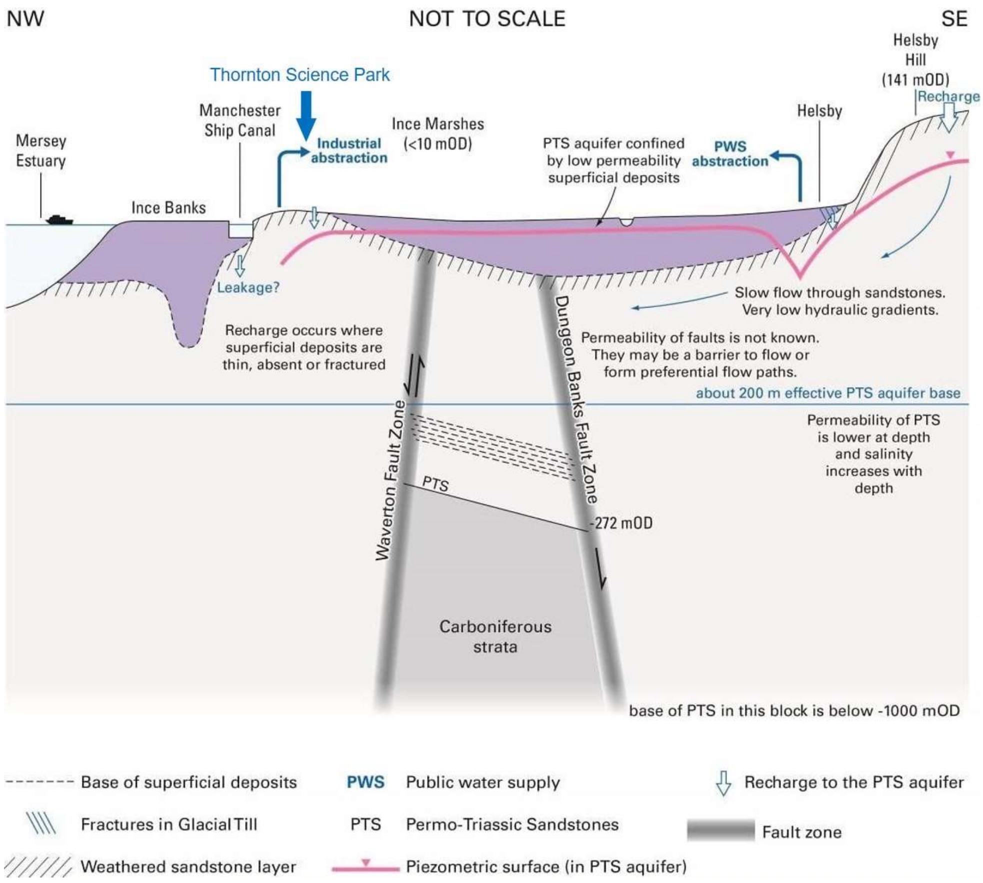


Figure 5 Schematic cross-section identifying key hydrogeological features of the Permo-Triassic sandstone aquifer in the vicinity of Thornton Science Park.

3 Drilling Phase Summary

3.1 PLANNING CONSENTS

Planning consent for the works was obtained by the BGS and granted by Cheshire West and Chester Council (Application Number: 21/04323/FUL).

The Consent to Investigate a Groundwater Source under Section 42(3) of the Water Resources Act was granted by the Environment Agency (pertaining to the abstraction / reinjection boreholes, consent number: GMMC0039).

3.2 SERVICES IDENTIFICATION AND CLEARANCE

BGS undertook an extensive geophysical survey of the site prior to final site selection. This survey included underground utilities detection, topographic survey and ultra-wide band ground penetrating radar. This data along with historic maps and service plans provided by TSP were used to confirm the site suitability. Any anomalies were investigated during a ground investigation undertaken by Socotec between 12th and 22nd July 2021. This comprised several trial pits and 2 shallow monitoring boreholes. All the data generated during this stage was provided to the Principal Contractor as part of the Pre-Construction Information (PCI) package.

When work commenced onsite services clearance was undertaken in accordance with HSG47 – Avoiding Danger from Underground Services.

A permit to dig system was used for the avoidance of underground services. For all excavations the PCI was reviewed for the presence of known buried services. At each exploratory hole location, a visual check was undertaken for absence of services. Excavations were then scanned with a Cable Avoidance Tool (CAT) and Signal Generator (Genny) prior to a permit to dig being issued and machine excavation.

Unrecorded services encountered as part of the works were recorded and their location recorded.

3.3 EXPLORATORY HOLE SET-OUT AND POSITION

At the start of the enabling works undertaken by Fox (Ownby) Ltd each borehole location was surveyed in using a Zenith 25 Pro Series GPS to a horizontal accuracy of 5 mm on British National Grid coordinates (**Table 3)**. Once the locations were marked out 24” diameter surface casings were installed to a depth of 2 m. This operation occurred between the 15th August 2022 and the 14th September 2022. Verticality of the surface casing was critical as future temporary casing would be centralised off this as the boreholes advanced deeper. If the surface casing wasn’t set perfectly vertical, then the borehole was at increased risk of deviating beyond allowable limits. With the verticality tolerance in the Scope being 1 in 100 m, time was taken to get this correct before casings were cemented in place.

Figure 6 Installed 24” surface casing and smaller sump used during drilling phase only

It should be noted that the top of the 24” surface casing was used as the primary depth reference for all drilling, coring and wireline logging throughout the entire operation. The depths have subsequently been worked back to AOD where needed (**Table 3)**.

All depths stated in this report are referenced to the top of the 24” surface casing unless otherwise stated.

Table 3 Definitive borehole locations and depth reference

Borehole	Easting (Lat)	Northing (Long)	Top of 24" to AOD (m)	Top of 24” to GL (m)	Elevation GL to AOD
TH0404 Uncased Bedrock Borehole	344919.21	375835.62	19.694	0.130	19.824
TH0405 Uncased Bedrock Borehole	344953.26	375823.90	20.018	0.130	20.148
TH0406 Abstraction / reinjection borehole	344938.18	375835.40	20.031	0.055	20.086

Borehole	Easting (Lat)	Northing (Long)	Top of 24" to AOD (m)	Top of 24" to GL (m)	Elevation GL to AOD
TH0407 ERT/DTS borehole	344925.07	375852.64	19.962	0.115	20.077
TH0408 Abstraction / reinjection borehole	344930.72	375850.69	20.086	0.085	20.171
TH0409 ERT/DTS borehole	344936.22	375829.73	19.928	0.108	20.036
TH0410 Central Borehole	344942.09	375846.77	20.181	0.090	20.271
TH0411 ERT/DTS borehole	344947.95	375863.77	20.547	0.023	20.570
TH0412 Abstraction / reinjection borehole	344953.44	375842.84	20.288	0.070	20.358
TH0413 ERT/DTS borehole	344959.09	375840.92	20.331	0.146	20.477
TH0414 Abstraction / reinjection borehole	344946.00	375858.12	20.404	0.070	20.474
TH0415 Uncased bedrock borehole	344930.93	375869.66	20.496	0.118	20.614
TH0416 Closed loop heat exchanger borehole	344940.13	375841.08	20.095	0.070	20.165
TH0417 Closed loop heat exchanger borehole	344947.76	375844.80	20.251	0.056	20.307
TH0418 8 Port Multi-Level sampling borehole	344941.09	375843.92	20.082	0.125	20.207
TH0419 8 Port Multi-Level sampling borehole	344944.91	375845.77	20.197	0.088	20.285
TH0420 8 Port Multi-Level sampling borehole	344939.22	375847.76	20.030	0.196	20.226
TH0421 8 Port Multi-Level sampling borehole	344943.05	375849.59	20.211	0.086	20.297
TH0422 Closed loop heat exchanger borehole	344936.43	375848.71	20.065	0.126	20.191
TH0423 Closed loop heat exchanger borehole	344944.05	375852.44	20.174	0.159	20.333
TH0424 Uncased Bedrock Borehole	344964.96	375857.91	20.526	0.143	20.669

Note: the borehole coordinates and 24” casing top elevations were surveyed again following completion of the works and it is this final survey data that is presented above.

3.4 KEY DATES DURING THE DRILLING PHASE

The main phase of the drilling was undertaken by Marriott Drilling between 31st August 2022 and 24th July 2023. Well installations occurred from 13th October 2022 to 25th July 2023. Prior to drilling commencement, temporary sound hoarding was erected around the site boundary.

3.5 SPECIALIST SERVICES

The ground works and drilling were supported by several specialist contractors. **Table 4** below lists the main companies used:

Table 4 Specialist services used

Company	Service provided
Marriott Drilling	Drilling contractor
European Geophysical Services (EGS)	Wireline logging
Fox (Ownby) Ltd	Enabling works / ground works
Silixa	Fibre Optics
BGS	Client oversight. Provided NEC4 Site Supervision, the borehole and installation designs Electro-Resistivity Tomography (ERT) sensors equipment and installation guidance
RS Hydro & Solinst	Solinst Waterloo MLS borehole equipment
GeoScience	installation of Heat Exchanger Borehole equipment
RST Instruments (Terra Insights)	Beadedstream™ digital temperature (thermistor) cables

3.6 DRILLING PHASE SUMMARY

The main drilling phase utilised both a Comacchio 405 and a Soilmec PSM-16GT rig to deliver the 20 boreholes. Boreholes comprised of an Upper Section (where the surface 24" casing was installed) to 2.0 m, an Intermediate Section (where permanent PVC casing was installed if the well design required or temporary steel casing was run) and a Lower Section down to the target depth in the required hole size.

The boreholes were primarily drilled via rotary methods using a Geobore S wireline retrievable coring system incorporating semi-rigid plastic liner. Boreholes were cored with either a 146 mm or a 152 mm diameter coring assembly, dependent on the final hole size required.

Where the borehole section needed to be opened out to a larger diameter a reamer of the correct size was used with a pilot bit 0.5 m below. This was done to ensure the

original cored hole was followed without the risk of deviation as the borehole was reamed out and enlarged.
Table 5 summarises the drilling operations for each borehole including drilled depths, drilled diameters, casing diameters run and setting depths and drilling dates.

Final as- built borehole schematics are included in this report. These detail the borehole construction and installation details including instrumentation and sensor locations along the borehole length.

3.7 BOREHOLE SUMMARY TABLE

Table 5 Summary of drilling operations

Borehole	Drilling Start Date	Intermediate Section cored depth (m BCT)	Intermediate Section Final Reamed Diameter (mm)	Final Reamed Intermediate Section Depth (m BCT)	Permanent Casing Installation Depth (m BCT)	Permanent Casing Diameter (mm)	Lower Section Cored Depth (m BCT)	Lower Section Cored Diameter (mm)	Final Reamed Lower Section Depth (m BCT)	Final Reamed Lower Section Diameter (mm)	Drilling End date
TH0404	08/02/2023	16.25	311	15.2	15	200mm OD x 180.8mm ID	100.5	152	NA	NA	20/04/2023
TH0405	06/02/2023	16.1	311	15.0	15	200mm OD x 180.8mm ID	100.5	152	NA	NA	09/05/2023
TH0406	22/02/2023	16.2	444	15.5	15	330mm OD x 292mm ID	100.5	146	100.0	222	09/05/2023
TH0407	29/11/2022	10.8	311	6.1	NA	NA	106.4	152	105.0	200	22/12/2022
TH0408	20/03/2023	16.1	444	15.5	15	330mm OD x 292mm ID	100.5	146	100.0	222	12/05/2023
TH0409	31/08/2022	17.1	311	6.1	NA	NA	105.9	146	101.0	200	25/11/2022
TH0410	21/09/2022	21.2	311	20.2	20.2	200mm OD x 180.8mm ID	102.7	152	NA	NA	13/10/2022
TH0411	08/12/2022	7.0	311	6.1	NA	NA	105.7	146	105.0	200	15/12/22 (Airlifting to 21/12/22)
TH0412	05/04/2023	16.2	444	15.5	15	330mm OD x 292mm ID	100.5	146	100.0	222	02/05/23 (Airlifting to 16/05/2023)
TH0413	07/09/2022	17.1	311	6.4	NA	NA	105.7	146	105.0	200	06/12/22 (Airlifting to 07/12/22)
TH0414	27/03/2023	16.1	444	15.5	15	330mm OD x 292mm ID	100.5	146	100.0	222	10/05/2023

Borehole	Drilling Start Date	Intermediate Section cored depth (m BCT)	Intermediate Section Final Reamed Diameter (mm)	Final Reamed Intermediate Section Depth (m BCT)	Permanent Casing Installation Depth (m BCT)	Permanent Casing Diameter (mm)	Lower Section Cored Depth (m BCT)	Lower Section Cored Diameter (mm)	Final Reamed Lower Section Depth (m BCT)	Final Reamed Lower Section Diameter (mm)	Drilling End date
TH0415	17/02/2023	16.1	311	15.5	15.5	200mm OD x 180.8mm ID	100.4	152	NA	NA	24/04/2023
TH0416	28/03/2023	7.4	222	6.0	NA	NA	101.9	152	NA	NA	12/04/2023
TH0417	13/03/2023	7.4	222	6.0	NA	NA	101.9	152	NA	NA	21/03/2023
TH0418	31/05/2023	8.1	311	6.0	NA	NA	104.1	146	103.6	200	06/06/2023
TH0419	12/09/2022	18.6	311	6.0	NA	NA	99.0	146	99.0	200	27/06/2023
TH0420	20/09/2022	18.6	304 mm (273 mm prior to over drilling to remove stuck 10”)	18.2	NA	NA	104.2	152 mm to 39.1 m then 146 mm to TD	100.8	222	09/11/2022
TH0421	08/09/2022	18.6	311	6.0	NA	NA	104.2	146	103.7	200	16/05/2023
TH0422	25/01/2023	7.4	222	6.0	NA	NA	101.4	152	NA	NA	03/02/2023
TH0423	13/02/2023	7.4	222	6.0	NA	NA	100.4	152	NA	NA	28/02/2023

3.8 SAMPLING AND CORING REQUIREMENTS

3.8.1 Core curation

Table 6 below details the coring requirements set out in the tendered drilling specification. Six boreholes were identified as being "In scope" for core recovery with "additional" core recovery proposed should time and resources permit. The drilling contractor Marriott in fact opted to core all 20 boreholes due to the tight borehole verticality constraint and the more rigid nature of the coring assembly. Following discussions internally and with GSAG the decision was taken on the 27th February 2023 to retain all recovered core onsite pending a decision on the level of processing and which cores would be retained for the longer term. The 6 original "in-scope" cores were curated to the required length, boxed and manifested by Marriotts and then stored in a refrigerated container unit before being shipped back to the NGR in Keyworth. All other core was curated by BGS staff onsite and then sent back to Keyworth for scanning.

Table 6 Coring requirements as per Scope

Asset Code	Borehole type	Cored interval top	Cored interval base	Anticipated core recovery	In scope or optional?	Position in drilling schedule
		(m bgl)	(m bgl)	(m)		
TH0410	Flute liner multilevel sampler	2	100	98	In scope	First borehole drilled
TH0420	Waterloo 401 multilevel sampler	2	100	98	In scope	Second borehole drilled
TH0413	ERT &DTS monitoring well	2	100	98	In scope	Order flexible
TH0407	ERT &DTS monitoring well	2	100	98	In scope	Order flexible
TH0417	GSH test well	2	100	98	In scope	Order flexible
TH0423	GSH test well	2	100	98	In scope	Order flexible
TH0422	GSH test well	2	100	98	Additional core (Option #1)	Order flexible
TH0416	GSH test well	2	100	98	Additional core (Option #2)	Order flexible
TH0409	ERT &DTS monitoring well	2	100	98	Additional core (Option #3)	Order flexible
TH0411	ERT &DTS monitoring well	2	100	98	Additional core (Option #4)	Order flexible
TH0404	Uncased bedrock borehole	90	100	10	Additional core (Option #5)	Order flexible
TH0405	Uncased bedrock borehole	90	100	10	Additional core (Option #6)	Order flexible
TH0415	Uncased bedrock borehole	90	100	10	Additional core (Option #7)	Order flexible

3.8.2 Subsampling of drill core for chemical and microbiological analysis

Drill core from 4 boreholes was subsampled by BGS in an onsite containerised laboratory. Samples were collected from boreholes drilled at the start and end of the programme so that the effect of drilling operations on the aquifer chemistry and microbiology could be assessed. The boreholes sampled were TH0410 (the first borehole drilled), TH0420 (the second drilled) and TH0418 (0 - 20 m) + TH0419 (20 - 100 m) (last two drilled).

Core was processed using a sub-coring drill press and a diamond wheel cutoff saw (Figures 7 and 8 respectively). A gravity feed of deionised water from an IBC was used to cool and flush away cuttings from the sub coring drill and cut-off saw to minimise sample contamination. Core samples were collected every ca. 3.0 m at TH0410 and every ca. 6 m in the other boreholes. Additional samples were collected adjacent to a fracture zone at ~80 m bgl in TH0419 to check for gradients in the porewater chemistry and microbiology (Figure 21).

Figure 7 Sub- coring drill press and example sub-core

Figure 8 Water- cooled diamond wheel cutoff saw located in entrance porch to core processing container. Core cradle and jig developed and made by BGS

1.5 m lengths of recovered core were initially cut into 100 cm and 50 cm sections (100 cm is maximum that NGR can accommodate). A 50 cm section was then cut from the base of the core using the cutoff saw. This section was further divided into a 6 cm section, a 20 cm section and a 24 cm offcut. The 6, 20 and 24 cm core sections were processed as follows:

- **6 cm section -** this section was quartered and preserved for microbiological analysis.
- **20 cm section -** this section was sub- cored down its axis to recover a 20 cm long, 1 ½ inch diameter, sub- core section. This was then divided into two 10 cm sections and each section wrapped with clingfilm, heat sealed inside a vacuum bag and then heat sealed inside an outer aluminised bag.
- **24 cm section** - If intact, this section was heat sealed inside a vacuum bag and then heat sealed inside an outer aluminised bag.

Core material was preserved by freezing, vacuum bagging and refrigeration or using chemical preservatives, as shown in **Figure 9**. Core that was not used for sub-sampling was returned to the original liner with wood or polystyrene spacers inserted, to show where the sub-samples had been removed. The liners were then sealed by taping on end caps, placed in core boxes and stored at 4°C prior to transport to BGS Keyworth for refrigerated storage.

Table 7 summarises the core sample collection (note that core sampling frequency was reduced at stages to ensure preservation (time dependant) targets could be achieved.

Table 7 Summary of core sub samples collected

Sample type	Dimensions of sample	Borehole	Sampling interval (m bgl)	Analyse/storage/disposal of sample
Microbiology subsample	100 mm diameter, 60 mm height (quartered)	TH0410	Every 3.0 m from 4.4 m to 100.3 m	1 quarter vacuum sealed and 4C storage,
		TH0420	Every 6.0 m from 8.0 m to 100.9m	
		TH0418	Every 1.5 m from 2.7 m to 19.5 m	2 quarters bagged and -80 ºC storage,
		TH0419	Every 6.0 m from 20.8 m to 97.6m + High resolution sampling from 75.0 m to 85.0 m	1 quarter partial preservation in glutaraldehyde
Pore water chemistry subsample	2 x 38 mm plugs each 100 mm in height	TH0410	Every 3.0 m from 4.4 m to 100.3 m	Sub-cored, vacuum sealed and 4 ºC storage
		TH0420	Every 6.0 m from 8.0 m to 100.9 m	
		TH0418	Every 1.5 m from 2.7 m to 19.5 m	
		TH0419	Every 6.0 m from 20.8 m to 97.6 m + High resolution sampling from 75.0 m to 85.0 m	
Off cut	100 mm diameter – 24 cm length	TH0410	Every 3.0 m from 4.4 m to 100.3 m	Double bagged and returned to position in core box
		TH0420	Every 6.0 m from 8.0 m to 100.9 m	
		TH0418	Every 1.5 m from 2.7 m to 19.5 m	
		TH0419	Every 6.0 m from 20.8 m to 97.6 m + High resolution sampling from 75.0 m to 85.0 m	

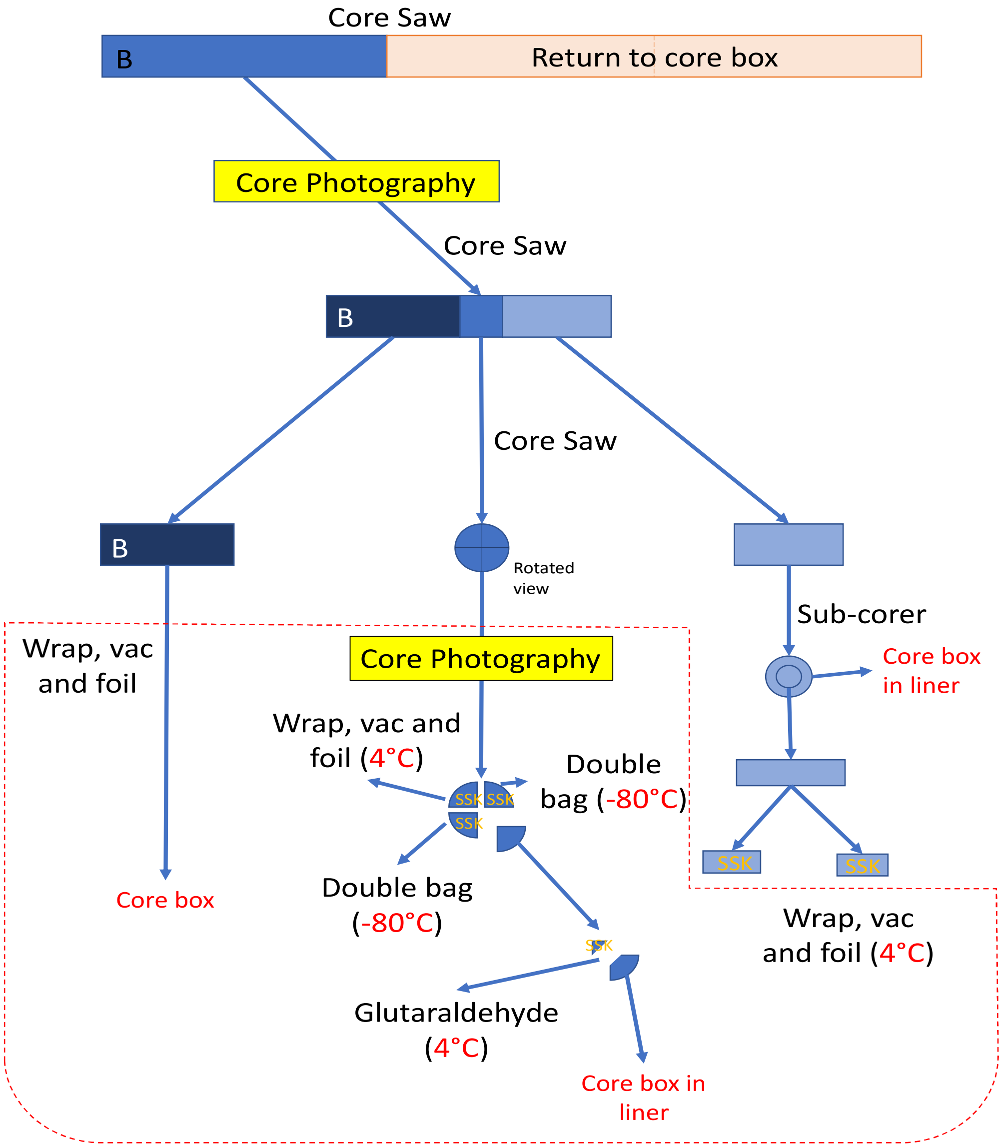


Figure 9 Flow diagram showing the core sampling process. Core photography and sample processing procedures are circled in red

3.8.3 Additional samples collected

Throughout the drilling phase numerous samples were collected that could be used for future analysis and as reference samples to confirm the properties of the borehole construction materials. The samples collected were as follows:

- **Drilling mud samples** – 2 x 1 litre bottles were collected at set intervals throughout. The wells that were sub sampled had a drilling mud sample collected after every 1.5 m core run so the drilling mud composition could be cross checked if needed to that in any specific core liner.
- **Mud additives (dry)** – any mud additives or loss circulation materials introduced into the wells were retained for future analysis. This was required to confirm the additives used didn't have a lasting effect on the ground water chemistry.

- **Cement samples (wet and dry)** – samples of all grout batches that were mixed and pumped were retained along with spot samples of the dry grout used. This was for all surface casing string, all intermediate casing strings and all wells where the installations were back filled with grout.
- **Back fill materials** – samples for all filter pack mediums, Bentonite pellets and anything used in the installations was also retained.

3.8.4 Summary of drilling additives used

Most wells were drilled with water only however some wells required a different approach to achieve the final install objectives. Various drilling additives were used during the drilling of specific boreholes. Mud additives were introduced to alter properties of the water-based drilling fluid to help with hole cleaning by increasing the viscosity and to control losses to achieve a static well. Lost Circulation Materials (LCM) were used to seal problematic fractures. On specific occasions, Geotherm-X GR or Ordinary Portland Cement (OPC) with a 1.5% Bentonite content was used to grout back zones of significant loss where LCM treatment had been unsuccessful and had to be drilled out.

The main reasons for the inclusion of these mud additives were:

- Reduce drilling fluid losses by increasing the viscosity and attenuate flow into fractures within the bedrock.
- Achieve a better lift of cuttings and improve hole cleaning during drilling.
- Reduce quantity of drill cuttings being lost to the formation.
- Reduce number of grout lifts required to finish installations thereby improving grout quality (of particular importance for heat exchanger boreholes where a single lift with uniform grout quality across the installation was required).
- Reduce grout loss to the formation resulting in fractures being permanently sealed.
- Allow drilling of two boreholes simultaneously within a tight array of boreholes. Use of drilling additives and LCM reduced the likelihood of cross-borehole transmission of sediments and drilling produced fines. This reduced the risk of drilling assemblies becoming stuck when two boreholes were being progressed simultaneously, ultimately with goal of improving project programme.
- Mud additives were used on the following wells:
  - The coring of intermediate and lower sections of heat exchanger ('ground source heat') boreholes TH0416, TH0417, TH0422, TH0423.
  - The intermediate sections of abstraction/ reinjection wells TH0406, TH0408, TH0412, TH0414.
  - The intermediate sections hydraulic testing/ geophysics ('open bedrock') boreholes TH0404, TH0405, TH0415.

The products used during the drilling phase are summarised in **Table 8** below. Product data sheets are included within **Appendix 6.3.**

Table 8 Drilling additives and LCM used during drilling

Product name	Purpose
Purebore	Viscosifier, fluid loss control, clay encapsulation
Ultrabore	Sodium Bentonite powder – filter cake producer, viscosifier, fluid loss control, clay encapsulation
Clear Stab	Wellbore stabiliser
Nut Plug	Lost circulation material
Flaked Mica	Lost circulation material

Quantities of materials used in each borehole are included under individual wells in this report. Compositions of the drilling mud, typical LCM pill and grout mixed used are summarised below:

Polymer Based Drilling Mud:

- Ultrabore - 14.25 kg/m^3
- Purebore – 8.2 kg

Typical 100L, 40 pounds per barrel (ppb) LCM Pill:

- Purebore - 0.855 kg
- Clear Stab - 4.1 kg
- Nut Plug – (LCM) - 8.2 kg
- Flaked Mica - 1.35 kg

Geotherm-X GR thermal grout (per 100 L water-based mix):

- Geotherm-X GR: 7.5 bags at 24 kg/bag = 180 kg

Ordinary Portland Cement (OPC) with 1.5% Bentonite powder (per 100 L water-based mix):

- OPC – 75 kg
- Bentonite – 6 kg

3.8.5 Well verticality and techniques utilised

The Scope provided a verticality tolerance that had to be achieved due to the close borehole spacing especially in the centre of the array. The tolerance stated within the Scope was 1/100 (i.e., 1.0 m lateral deviation at 100.0 m). Several techniques were deployed to ensure borehole verticality was achieved. These included:

- 24” surface starter pit casing was set true and checked prior to cementing.
- Accurate-centralisation of 7” temporary technical steel casing within 24” starter string (for purpose of guiding the Geobore-S coring string) prior to commencing the drilling of the intermediate section pilot hole.
- Verticality of the intermediate casing was confirmed prior to any further casing being run or the wells being advanced deeper.
- Systematically undertake gyro surveys on all wells as they advanced deeper. An NOV E-Totco tool was deployed to confirm the inclination at a given depth. The E-Totco tool is an electronic drift survey tool that is run inside the drill pipe and

calculates the precise inclination of the borehole at that depth. A digital and hard copy readout is provided and the tool has a 1% reading accuracy (±0.1°)

- In boreholes TH0407, TH0409, TH0410, TH0411 and TH0413 the Scope required that the intermediate hole section be wireline logged, part of the logging suite included an acoustic borehole imager which has the capacity to provide a fully orientated inclination and azimuth survey.
- Verticality of the permanent intermediate PVC casing installed into the Abstraction/Reinjection wells was assessed using the “Crosswires” method. The “Crosswire” method comprises of a weighted plumbing cage with 6 mm radial clearance that is lowered into the un grouted casing on a line suspended from a fixed point on a tripod or the drill rig mast. The compass points are marked on the circumference of the casing and offset measurements recorded at the wellhead as the plumbing cage is lowered in three metre depth increments. The resultant deviation at each depth increment is calculated using the similar triangle concept and the casing adjusted to rectify any deviation.
- Detailed inclination checks were undertaken during geophysical wireline logging completed by EGS as required by Scope. Due to concern over the tight spacing between boreholes at the site, and possibility of borehole convergence/divergence EGS determined total vertical deviation and azimuth which is visually displayed on “Bullseye-Plots” for each borehole within this report.

All 20 wells were drilled within tolerance.

4 Drilling Operations

4.1 CENTRAL BOREHOLE – TH0410 SUMMARY OF OPERATIONS

4.1.1 Key Well Data

Table 9 TH0410 Key well data

Well name	TH0410		
Well classification	Central Borehole – FLUTe liner installed		
Depth measurement units	Metres		
Depth reference point	Top of 24” casing		
Depth reference details	Top 24" depth ref - 20.181 m AOD Top 24" to GL - 0.09 m		
Start date	Intermediate section started on the 21/09/22 to 03/10/22. Lower section started on the 04/10/22.		
End of drilling date	13/10/22		
Install dates	The first FLUTe liner was installed in September 2022. This was compromised during drilling and was replaced in July 2023.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24” Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 311 mm	Cored to 21.2 m Reamed to 20.2 m	8” Boode PVC casing 200 mm OD 180.8 mm ID	20.2 m
Final section to TD Cored in 152 mm	102.7 m	n/a	n/a
Installation	n/a	FLUTe liner – 6” / 840 denier nylon liner	100.15 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344942.088 Northing Y: 375846.772	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″N Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44942 75847	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344941.81 Northing Y: 375846.47 Step out - 0.41 m (inclination 0.3 deg / azimuth 254 deg)	

4.1.2 Summary of Drilling Operations

Operations on TH0410 commenced on the 22nd September 2022. The rig and associated equipment were rigged up, and 2 x 500 ml bottles of sodium fluorescein solution were added to the active mud tank (**Figure 10**). Fluorescein was added as a tracer to assess the degree of drilling fluid contamination in TH0410 drill core subsamples collected for pore water and microbiological analysis.

Figure 10 Sodium Fluorescein being added to the active tank system.

The upper section was cored using the Geobore S wireline retrievable system down to 21.2 m. A review of the recovered core confirmed the position of the intermediate casing string at 20.2 m, positioned away from any major fractures to reduce grout loss as much as possible and achieve a competent shoe. The hole was opened out down to this depth using a 311 mm reamer assembly and circulated clean.

The permanent PVC intermediate (200 x 180 mm ID) casing was run to 20.2 m and checked with the crosswire technique for verticality before grouting with a standard mix of 150 kg Ordinary Portland Cement + 2.3 kg Bentonite powder to 100 L of water. Grouting occurred over two days (30th September 2022 and 3rd October 2022). Full details of this operation can be found in the daily activity summary.

Once the grout had achieved a sufficient hardness the 152 mm Geobore S assembly was made up and RIH. The cement plug pre-installed in the shoe joint of the intermediate casing string was drilled out before coring ahead to 30.1 m where excessive vibration in the string was experienced. The decision was taken to recover the string and change out the assembly for the 146 mm Geobore assembly as excessive vibration is not desirable for both drilling and recovered core quality.

Continued to core ahead in 146 mm taking verticality surveys every 6.0 m down to 47.2 m where total losses occurred. The decision was taken to core ahead. This was possible because most of the material from the well was being recovered in the core barrel. Successfully cored down to 102.7 m with no returns but with no drilling issues, overpull or tight spots being reported.

The assembly was POOH and replaced with a slightly larger 152 mm reamer assembly. This was RIH and the well opened out to the required diameter from 30.1 m to total depth. The well was circulated clean before POOH. On recovery of the assembly the 146 mm pilot bit below the reamer had been lost in hole. This was successfully fished before lowering the mast and preparing for wireline logging operations. See **Section 4.1.5** for full details of the wireline logging undertaken by EGS and the tools run.

Borehole cleaning was undertaken as per Scope. The aim of the cleaning was to remove, as far as practicable, any drilling fluids, sediment or other debris generated during the drilling process. For TH0410, this cleaning took the form of a submersible pump, lowered to ~18.0 m and pumped at a low rate (rate monitored as no more than 20 cm drawdown). Water quality meters were used to monitor the progress. BGS were onsite throughout monitoring and confirmed when the water quality was acceptable.

4.1.3 Materials, Flush and Drilling Additive Used

TH0410 was drilled with water only with fluorescein added to the drilling mud to assess the degree of drilling fluid contamination in core subsamples. A high viscosity sweep was needed to achieve total depth and lift the remaining cuttings from the hole.

4.1.4 Core sub sampling

Core from TH0410 was sub- sampled to determine the aquifer porewater chemistry and microbiology at the start of drilling operations.

Subsamples were collected at 3.0 m intervals (i.e. every 2nd core run) from 4.4 to 100.3 m. Cores were subsampled within 24 hours of core recovery to minimise drilling fluid ingress and oxidation. The sampling protocol was as described in **Section 3.8.2**.

4.1.5 Geophysical Logging Undertaken

Table 10 Geophysical logging summary – TH0410

Wireline logging undertaken	Tools run
Upper section logged in 152 mm to 18.1 m before reaming out. (23/09/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW, VP, VS
Lower section logged in 152 mm to 102.7 m (17/12/21)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Repeat logged after all drilling had been completed (12/10/22)	GR, CALI, ACBI, TEMP, COND, FLOW, BMR

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below (**Figure 11**). The maximum step out recorded was 0.41 m and within the 1/100 tolerance.

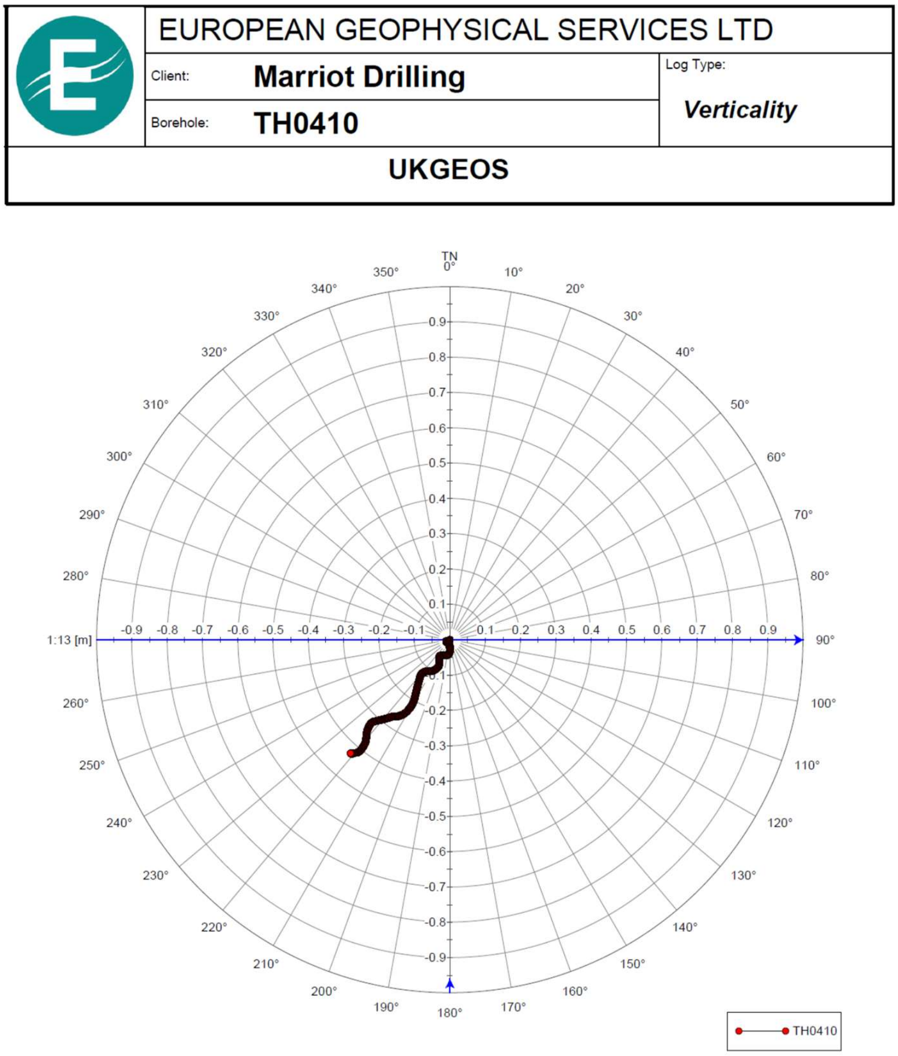


Figure 11 Verticality bullseye plot TH0410, © European Geophysical Services Ltd

4.1.6 Summary of Installation Operations

Installation criteria for TH0410:

- Run a single fibre optic cable to total depth.
- Deploy a FLUTe nylon liner to seal the well and prevent vertical flow in the borehole.
- Protect the borehole for future research opportunities.

Summary of initial FLUTe liner installation operations:

Bentonite was introduced to bring the total depth of the well up to 100.0 m for the FLUTe liner install. The well was dipped at 100.5 m and accepted by BGS. A spooling apparatus supplied by FLUTe called a “Green Machine” and other equipment needed for liner deployment were rigged up before installing the liner as per the manufacturer’s instructions (**Figure 12**). The liner and tether were secured at surface before making the well safe and rigging down.

Figure 12 FLUTe liner deployment into TH0410 using “Green Machine”

Summary of later FLUTe liner recovery and replacement operations:

Later inspection of the FLUTe liner installed in TH0410 revealed that the liner had collapsed due to an influx of sediment associated with the drilling of subsequent nearby boreholes. This meant that an internal dip couldn’t be achieved deeper than 80.0 m.

The Green machine was rigged up, and an attempt was made to pull the liner (via the liner base tether rope) with no success. A pump was rigged up and lowered to 20.0 m and the water level inside the liner dropped to below the water table. A second attempt to pull with the Green Machine was also unsuccessful. A further 1,300 L of water was then pumped from the inside of the liner to depressurise it but there was still no movement, and the liner could only be dipped to 33.0 m.

The Green Machine was rigged down, and a drilling rig mobilised over the well. An air lift apparatus was then RIH to 51.5 m and a further 500 L of water was pumped however the liner then collapsed around the air lift string and it became stuck. The liner was refilled with water to allow string to be recovered.

Additional air lift runs were attempted but with no success, so the decision was taken to work down the outside of the liner with drill rods and wash and work to bottom and remove any sediment from the well that had migrated in via open fractures during the drilling of other wells in the vicinity. The drill rods were slowly worked down to 100 m removing a large amount of fine sediment.

The drillers rigged up a weight indicator to the top drive, attached the FLUTe liner and commenced pulling the liner out of hole (indicator showed 330 kg pull). It was pulled using a 2-strop technique using the main top drive and the rig winch. The liner was successfully recovered on the 22nd June 2023 but with damage in several locations.

On the 7th July 2023 the Comacchio rig was mobilised back over the well, and a cleanout run was performed. The string was RIH to 60.0 m and then washed down to bottom removing further sediment from the well before POOH.

Airlifting was then undertaken to remove sediment from the fractures. Three stations were completed at 60.0 m (5,000 L pumped), 80.0 m (5,000 L pumped) and 100.0 m (10,000 L pumped). On completion of air lifting operations, the assembly was recovered and the well dipped at 101.2 m.

The Green Machine was rigged up and Bentonite pellets introduced to the base to bring the total depth up to 100.0 m. A replacement liner was successfully deployed to depth on the 13th July 2023.

4.1.7 TH0410 Borehole Well Schematic

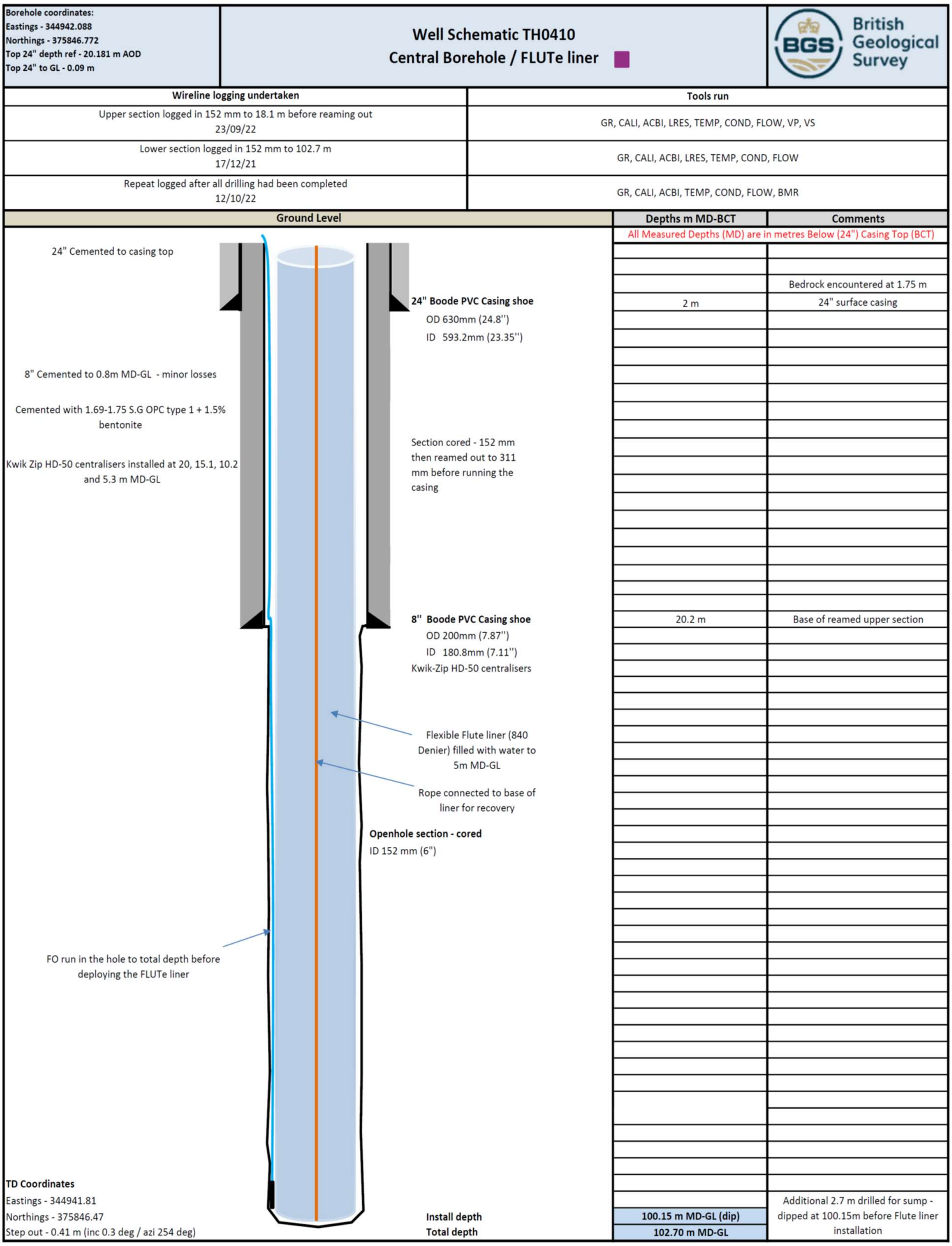


Figure 13 TH0410 Well Schematic

4.1.8 Wellhead / Well Chamber Status

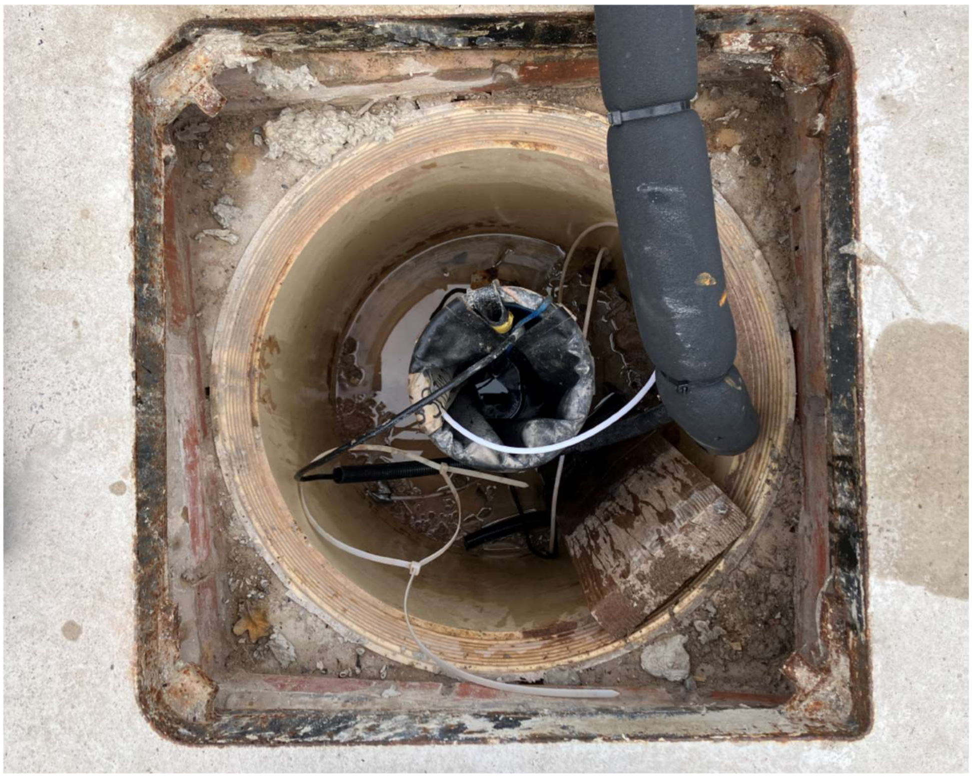


Figure 14 Wellhead chamber image TH0410

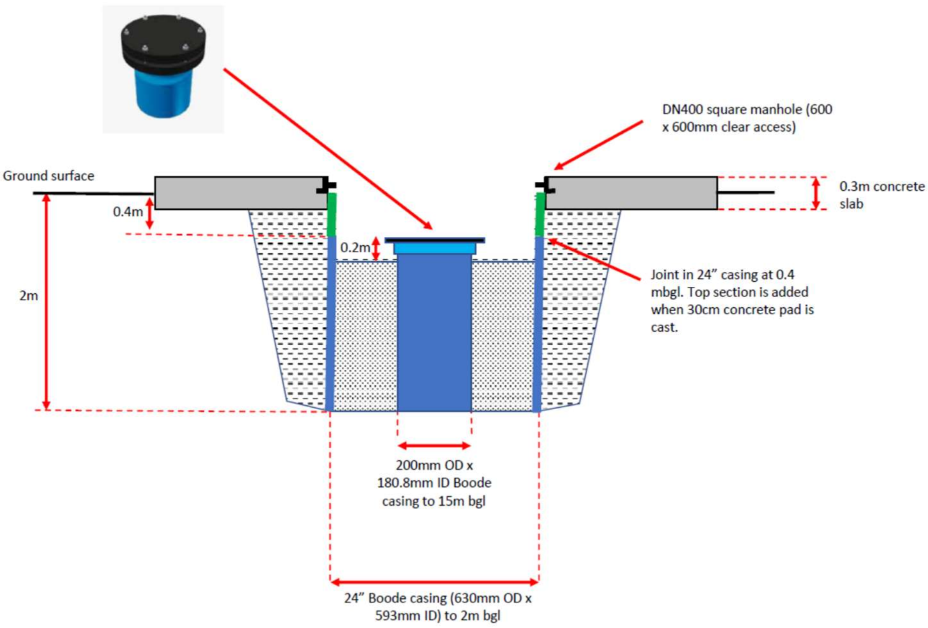


Figure 15 Wellhead chamber schematic TH0410

Note the Boode wellhead shown in the schematic has not been installed due to the FLUTe liner and fibre optic cable being deployed.

4.1.9 Daily Activity Summary

Table 11 Daily activity summary TH0410

Date	Depth M BGL	Operation	Parameters	Issues
22/09/22	2.1 m to 13.7 m	Prepared active mud tanks system for coring. Added 2 x 500 ml of sodium fluorescein solution to the 5,600 L of water as TH0410 to be sub sampled. Commenced coring from 2.1 m at 10:50 am to 13.7 m taking inclination reading with E Totco tool. BGS commenced sub sampling of core in onsite laboratory.	Each core run (1.5 m) taking between 3 and 4 minutes to complete. Verticality checks: 0.20 deg @ 4.6 m. 0.32 deg @ 6.6 m. 0.25 deg @ 10.6 m.	Losses commenced from 6.6 m with an average loss rate of 200 L per core. Total losses of 1,000 L recorded.
23/09/22	18.2 m	Continued to core ahead from 13.7 m to 18.2 m. Circulated the hole clean and POOH the coring assembly. EGS mobilised to site and setup over the well and completed geophysical logging as per Scope. Logged to 18.1 m before rigging down.	Each core run (1.5 m) taking between 2 and 5 minutes to complete. Verticality checks: 0.33 deg @13.0 m. 0.14 deg @16.0 m. Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW, OPTICAL SCANNER.	Unable to run VP / VS log due to insufficient fluid level – optical scanner run instead.
26/09/22	21.2 m	Decision taken to core deeper, so the assembly was picked backup and RIH. Continued to core from 18.2 m to 21.2 m.		Decision taken to core deeper due to fractures noticed at planned casing depth in recovered core.
27/09/22	21.2 m	Following casing setting depth meeting the decision was made to set at 20.2 m. Most of the day was used repairing the rig. Recovered the Geobore S assembly and 7" casing. 311 mm reamer made up in readiness.		Mechanical issue with the rig – fitter mobilised and filter changed out – NPT 10 hours.
28/09/22	21.2 m	RIH and reamed out the hole to 311 mm down to 20.2 m before circulating the well clean of cuttings. Pulled out the assembly before dipping the well. Well dipped shallow (2.0 m of cuttings still in the well). Reamer run back in hole and re flushed the well before pulling but well still dipping shallow.		Marriott flushed out cuttings from the hole but lost ~ 4,000 L into formation. After circulation, the dip depth was measured at 18.0 m, indicating ~ 2.0 m of suspended cuttings had fallen back to the hole, necessitating re-flushing. Unfortunately, the re-flushing effort was unsuccessful in removing the cuttings.
29/09/22	21.2 m	Decision taken to mix and pump a high viscosity pill. Mixed a pure-bore polymer pill and circulated. 0.4 m of material was lifted from the well. Viscosity of a second pill was increased by adding additional Pure Bore polymer and circulated. The well was dipped at the required depth of 20.2 m. The reaming assembly was recovered.	RIH the PVC casing – 200 mm OD x 180.8 mm ID with plastic centralisers at 3.0 m intervals.	Flushed in stages. The first pill - 1 m^3 of high viscosity pill was pumped. POOH and dipped the well to 18.4 m. The pill consisted of a more viscous pill. Dipped the well and confirmed hole has been cleaned

Date	Depth M BGL	Operation	Parameters	Issues
		Rigged up and ran the 200 mm OD x 180.8 mm PVC casing to 20.2 m. Verticality was checked with the crosswire technique.		out to the required depth of 20.2 m.
30/09/22	21.2 m	Marriott rigged up and commenced grouting operations of the 200 mm casing. The first cement plug was pumped bringing the TOC back to circa 15.0 m. Waited on cement and dipped the borehole. Top of cement had dropped 1.0 m to 16.0 m. Waited on cement to ensure a hard base for the second plug. Second cement plug pumped back to 11.7 m.	Grout mixed used: 150 kg OPC Type 1 2.3 kg Bentonite Powder 100 L (kg) Water This gives a Bentonite content of 1.5% as per the specification.	
03/10/22	21.2 m	Marriott measured dip depth at 11.0 m. Continued grouting operations, mixed and pumped the 3rd grout stage bringing the TOC to 3.1 m. Waited on cement. 4th grout stage pumped bringing TOC to surface.	Grout mix used and volumes: 3rd stage 150 kg OPC type 1 = 99 L (150 x 0.66) 2.3 kg Bentonite = 1.5 L (2.3 x 0.66) 100 L (kg) Water = 100 L (100 x 1) Gives: Mix 1 = 201 L – 1.69 sg Mix 2 = 201 L – 1.75 sg Mix 3 = 201 L – 1.76 sg Mix 4 = 201 L – 1.75 sg 4th stage: Mix 1 = 201 L – 1.69 sg Mix 2 = 201 L – 1.85 sg	Rig swivel bushing changed out as developed a leak, completed during grouting operations.
04/10/22	24.1 m	Marriott set up for coring. 2 x 500 ml of required dye (sodium fluorescein solution) was poured into the active tanks. RIH Geobore-S string at 15:00 hrs, drilled through cement plug/shoe and cored from 21.2 m to 24.1 m.		Blockage in shaker tank valve stopped drilled commencing. Present when mobilised to site – 7 hours NPT whilst blockage removed. Rig winch became stuck and needed repair – 1 hour NPT.
05/10/22	32.2 m	Cored ahead down to 30.1 m taking verticality reading as required. At 30.1 m it was noted 20% of the flush had been lost. Continued to core ahead but excessive vibration noted through top drive which would result in poor core recovery, so the operation was stopped. The assembly was pulled out and reconfigured removing an extended barrel section being used to aid verticality and changing the core head from 152 mm to 146 mm. Ran back in hole and continued to core to 32.2 m.	ROP – 3 to 5 minutes per 1.5 m core run. Verticality checks: 0.24 deg @23.0 m. 0.29 deg @29.0 m.	Further winch repairs and issues with the generator – 4 hours NPT. BHA changed due to excessive vibration to 146 mm assembly which means the lower section will need to be reamed out once drilling has reached TD to achieve the Scope requirement of 152 mm final hole size.
06/10/22	54.7 m	Continued to core ahead from 32.2 m to 47.2 m with up to 50% losses. At 47.2 m total losses were encountered.	ROP - 4-10 minutes per run and average flush loss of 50% until 47.2	Despite having no flush returns, water was used to continue coring as sufficient water was in

Date	Depth M BGL	Operation	Parameters	Issues
		Decision made to core ahead see comments about water management in issues column. Core to 54.7 m.	m. where total losses were encountered. Verticality checks every 6.0 m: 0.26 deg @ 35.2 m. 0.46 deg @ 40.0 m. 0.27 deg @ 46.0 m. 0.43 deg @ 52.0 m.	the driller's tank that fed from the 32 mm water pipe. Considering the loss rate, a larger water pipe (54 mm) has been proposed to support the existing 32 mm water pipe feeding the driller's tank.
07/10/22	77.2 m	Continued to core from 54.7 m to 77.2 m with good recovery throughout. Still no returns but no issues drilling ahead and no overpull or tight spots reported. Inclination and drift to be checked after each reading going forward as drifting close to tolerance.	Verticality checks every 6.0 m: 0.48 deg @ 58.0 m. 0.49 deg @ 64.0 m. 0.52 deg @ 70.0 m. 0.48 deg @ 76.0 m.	Recovered 40 cm section of lost core. No returns.
10/10/22	102.7 m	Continued to core from 77.2 m to 102.7 m. Still no returns, but no issues drilling ahead, and no overpull or tight spots reported. BGS completed sub sampling of the core from TH0410.	ROP - 6 minutes per core run. Verticality checks every 6 m: 0.43 deg @ 82.0 m. 0.37 deg @ 88.0 m. 0.36 deg @ 94.0 m. 0.15 deg @ 100.0 m.	No returns. 2.7 m sump drilled to accommodate cuttings in hole and suspended fines.
11/10/22	102.7 m	RIH 152 mm reamer assembly and opened out the final section as per Scope down to 100.0 m. Circulated hole clean and pulled out. When on surface it was noticed the 146 mm pilot assembly below the reamer had been lost in hole. Commenced fishing operations and successfully recovered.		Fishing operations – 146 mm pilot bit and bit sub below reamer lost in hole. Recovered but 2.5 hours of NPT.
12/10/22	100.5 m	The rig mast was lowered and EGS (wireline) were rigged up, and the hole was logged. Wireline was rigged down, and a submersible pump run to 16.0 m and ran at 30 L/min until parameters were accepted by BGS (1 hr 10 mins). Well backfilled with Bentonite pellets to 100.0 m. Dipped at 100.5 m but left overnight.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND, and FLOW The BMR tool was not available, but the VS and VP tools were run (not instructed). Water sample was collected every 5 min and measured for Temp (°C), ORP (mV), pH, EC (µs/cm), TDS (ppm), and Turbidity (ntu). Initial depth to water level = 15.3 m. Instantaneous draw down depth = 15.4 m. Final depth after pumping = 15.2 m.	

Date	Depth M BGL	Operation	Parameters	Issues
13/10/22	100.15 m	Well dipped at 100.15 m and accepted by BGS. Rigged up and ran the FLUTe liner using the Green Machine.	FLUTe install data: Dip measured depth to borehole bottom = 100.15 m. Static water level depth before installation = 14.9 m. Total water pumped = 1,180 L. Static water level depth in the liner after installation = 12.0 m.	
FLUTe liner recovery and replacement				
02/06/23	100.0 m	Prepared equipment (Green Machine, pulley System etc) for removal of the Flute liner. Attempted to pull Flute liner free using the tether line that runs through the middle of the liner down to the bottom of the hole. Green Machine with manual capstan was used to apply tension. Managed to move upwards about 15 cm-but no more progress. This movement is likely stretch in the tether, and the liner is immobile. Made further attempts but unsuccessful.		FLUTe liner stuck in the hole due to sediment inflow through fractures during drilling pinning liner in place.
05/06/23	100.0 m	Rigged up pancake compressor and hose and RIH to 20.0 m. Pumped water from inside the liner, water level still at water table at approx. 15.0 m. Attempted to pull the liner using the Green Machine without success. Resumed pumping and removed 1,300 L of water from inside liner. FLUTe liner still wouldn't move. Decision taken to suspend operation and reinflate liner.		The liner was dipped to ~ 33.0 m. This was different to previous where the liner was dipped at ~ 80.0 m. This could indicate that the liner was collapsing as water was removed. Still not possible to pull the liner.
14/06/23	100.0 m	Levelled out location around TH0410. Moved Comacchio rig over TH0410 and setup.		FLUTe liner stuck.
15/06/23	100.0 m	Attempted to run air lift rods in hole and simultaneously pull liner but unable to grip liner with rod in hole. Decision taken to RIH airlifting rods (40 mm tremie pipe) with alkathene air lift pipe strapped to the outside to 51.5 m where the restriction in the liner was tagged. Pulled back and commenced air lifting (500 L recovered in 2 hours).	51.5 m restriction in liner tag depth.	FLUTe liner stuck.
16/06/23	100.0 m	Attempted to lift the tremie pipe by hand unable to move. Well dipped to 15.0 m tagging top of the collapsed liner. Refilled liner with water and dipped well. Managed to dip back to 50.0 m and ran tremie back to original depth with new air lift configuration. Commenced air lift. Initially rate was good with higher sediment content in the returns. Continue to air lift with a higher return rate than original however returns clearing after about 10 minutes of lifting. Decision taken to fill the well and recover the airlift assembly. Ran back in hole with the 40 mm blue tremie back to the blockage at 51.0 m. Attempted to circulate conventionally. Initially some sediment was removed but soon		FLUTe liner stuck.

Date	Depth M BGL	Operation	Parameters	Issues
		cleared. Tremie was worked but wouldn't advance deeper indicating no sediment remained inside and the liner had collapsed. Decision taken to try down the annulus. Airlift assembly rerun inside the liner to 51.0 m and airlifted collapsing the liner. Well dipped at 40.0 m. Ran 19 mm black pipe down annulus but hung up on ledge at the shoe.		
19/06/23	100.0 m	RIH open ended 40 mm tremie pipe down the annulus between FLUTe liner and the open hole. Held up at 51.96 m. Rigged up hose to flush through the tremie pipe. Commenced circulation with 500 L of water and observed water level rise in FLUTe liner which dropped immediately when pumping stopped. Observed a sudden drop in resistance. RIH 3 more joints giving a total of 21 in hole still no resistance. Pulled out of hole – only 8 recovered. Successfully re engaged fish at 12.0 m and recovered all 18 joints. Meeting held and decision taken to RIH with steel drill rods down annulus and clean out.		Fishing operations – 13 joints of 40 mm tremie pipe lost in hole – No damage to recovered pin end. Lost time 4.75 hours.
20/06/23	100.0 m	RIH with 70 mm flush jointed airlift rods. RIH to 54.0 m where resistance was noted. Pulled back 1 joint and installed crossover back to the rig top drive. Established circulation with returns coming to surface. Advanced slowly, recovering significant amounts of sand at surface. Started by RIH 1 m at a time then circulating until clean. Then moved to RIH complete drill rod continuously circulating and working the full rod length until returns ran clean. Progressed to ~63.0 m. Pulled out of hole. Filled FLUTe liner and recovered tremie pipe from the centre. choked the top of the liner and secured. Ran back in hole the steel rods down the annulus to 60.0 m.	Chamfered the end of the first rod in hole to reduce the risk of damaging the FLUTe liner.	FLUTe liner stuck.
21/06/23	100.0 m	Worked and circulated the string down the annulus to 96.0 m removing large volumes of sediment. Pulled back to 90.0 m for overnight.		FLUTe liner stuck, large volume of sediment on the outside of the liner which has caused it to collapse. Water management caused short delay.
22/06/23	100.0 m	Ran back to 96.0 m and continued to wash the string down to 100.0 m and circulated the hole clean. Pulled out the drill rods. Rigged up weight indicator and commenced pulling the liner. Liner recovered. Rig moved off location.	Liner recovery - weight indicator was showing 85 kg initially due to stretch. Then weight increased to 330 kg. Pulled the liner using 2 strop technique, using the main hook and the rig winch.	Liner was holed and split in multiple places and heavily damaged towards the base of the hole. Some of this damage is likely to be due to the recovery process adopted.

Date	Depth M BGL	Operation	Parameters	Issues
07/07/23	102.0 m	Moved Comacchio rig over to TH0410 and setup the surface circulating system including the shaker in preparation for circulating the hole clean. Ran in hole with Geobore string to 60.0 m then washed down through sediment to TD at 102.0 m. Circulated out the debris / sediment with 6,000 L of clean water. POOH. Fluid returns were 100% throughout.		
08/07/23	101.2 m	RIH airlifting rods and cleaned the borehole and fractures of any remaining sediment. Airlift rods stations were 60.0 m (5,000 L), 80.0 m (5,000 L) and 100.0 m (10,000 L). A data logger was deployed at each stage to monitor. POOH with airlifting rods and dipped well at 101.2 m. Moved rig off TH0410 and onto TH0412.	20 m^3 of water used during airlifting operation.	
13/07/23	100.0 m	Rigged up Green Machine for running replacement liner. Placed 1 bag of Bentonite pellets in the hole to bring base of the well up to 100.0 m. Silixa onsite and deployed a FO cable with bottom hole assembly and weight to the base of the well. Ran the Flute liner in hole as per manufacturers procedure to 100.0 m. Anchored the tether and filled the liner with clean water to 4.8 m. Rigged down Green Machine.		
17/07/23	100.0 m	EGS set up over well and ran BMR (Borehole Magnetic Resonance), but tool failed. EGS rigged down and returned to base to fix the issue.		EGS engineer reported that the issue was with the logging unit itself, not the tool, so the operation had to be stopped.
18/07/23	100.0 m	EGS set up over the well and attempted to run BMR log again but encountered intermittent technical issue with the tool. Operation cancelled.		Issue appears to be tool related not surface interface unit as originally thought. Replacement logging unit didn't fix the issue.
TH0410 complete				

4.2 WATERLOO MULTI-LEVEL SAMPLING WELL – TH0418 SUMMARY OF OPERATIONS

4.2.1 Key Well Data

Table 12 TH0418 Key well data

Well name	TH0418		
Well classification	Waterloo 401 8 port multilevel sampling well (MLS)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.082 m AOD Top 24" to GL - 0.125 m		
Start date	Intermediate section start date -30/05/23, end date - 31/05/23 Lower section started 31/05/23		
End of drilling date	06/06/23		
Install dates	Commenced on 07/06/23 with backfilling, completed by 14/06/23. Grouting of the top section was completed at the later date of the 06/07/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 8.1 m Reamed to 6.0 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.0 m
Final section to TD Cored in 146 mm then reamed out to 200 mm	Cored to 104.1 m Reamed to 103.6 m	n/a	n/a
Installation	n/a	Solinst Waterloo 8 port MLS completion run on 60.3 mm OD / 50 mm ID tubing	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344941.092 Northing Y: 375843.919	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44941 75844	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344940.19 Northing Y: 375843.56 Step out - 0.97 m (inclination 0.56 deg / azimuth 277 deg)	

4.2.2 Summary of Drilling Operations

The Soilmec rig was moved onto position and rigged up before running 7” temporary casing centralised inside the 24” and sealed to the base with Bentonite.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.1 m to 8.1 m. The hole was circulated clean before POOH the assembly. A 311 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m. On recovery of the reamer, it was noted that the pilot bit had been lost in hole resulting in a fishing operation. A magnet run was unsuccessful, so the decision was taken to run the temporary 10 ¾” casing and seal at the base with Bentonite before running in with a bit sub and re engaging the bit.

Made up and RIH the 146 mm Geobore assembly and cored ahead from 8.1 m to 68.1 m taking inclination readings every 6.0 m. Due to the inclination reading being higher than the projected 1/100 tolerance the frequency of surveys was increased to every 3.0 m and rate of penetration held back to try and rectify. Continued to core ahead to 73.1 m but with several miss core runs and dropped core. The decision was taken to recover the assembly and inspect the core barrel and catchers.

With the assembly out of hole EGS were mobilised and the well wireline logged down to 72.6 m. Full details of wireline logging programme undertaken can be found in **Section 4.2.5**.

Ran back in hole with the 146 mm coring assembly and cored to total depth at 104.1 m. Scope requires 100.0 m as a TD but Marriotts opted to drill deeper to provide a sump for any remaining cuttings that may remain in the well. The hole was circulated clean before POOH.

EGS were mobilised back to site and the lower section of the well wireline logged from 70.0 m to 100.0 m. On completion of logging operations EGS were rigged down and moved off the well.

Made up and RIH a 200 mm reamer assembly and opened out the hole down to 103.6 m before circulating the hole clean and POOH the assembly and recovering the temporary 10 ¾” casing string.

A cleanout run was completed to total depth and the well flushed with 15 m^3 of clean water from the TSP abstraction well. The hole was dipped at 103.4 m before POOH in preparation for the installation operation.

4.2.3 Materials, Flush and Drilling Additive Used

TH0418 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.2.4 Core sub sampling

TH0418 was the second to last borehole to be drilled and was sub- sampled to determine the aquifer porewater chemistry and microbiology at the end of drilling operations (vs the profiles from cores TH0410 and TH0420 collected at the start of drilling operations). TH0418 is only 3.0 m away from TH0410 and 4.2 m from TH0420 and so was hypothesised to have a similar pre-drilling porewater chemistry and microbiology profile.

The following subsamples were collected:

From 2.7 m to 19.5 m:

Subsamples were collected at 1.5 m intervals (i.e. every core run) to provide data for comparison with TH0410 and TH0420 and to produce a higher resolution profile of variation in aquifer chemistry and microbiology through the unsaturated zone. The sampling protocol was as described in **Section 3.8.2**.

4.2.5 Geophysical Logging Undertaken

Table 13 Geophysical logging summary table TH0418

Wireline logging undertaken	Tools run
Section logged in 146 mm from 6.0 m to 73.0 m. (02/06/23)	GR, CALI, ACBI, LRES, TEMP, COND
Lower section logged in 146 mm from 70.0 m to 104.0 m. (Logged in two sections due to inclination check being required at 70.0 m). (06/06/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.97 m and just within the 1/100 tolerance.

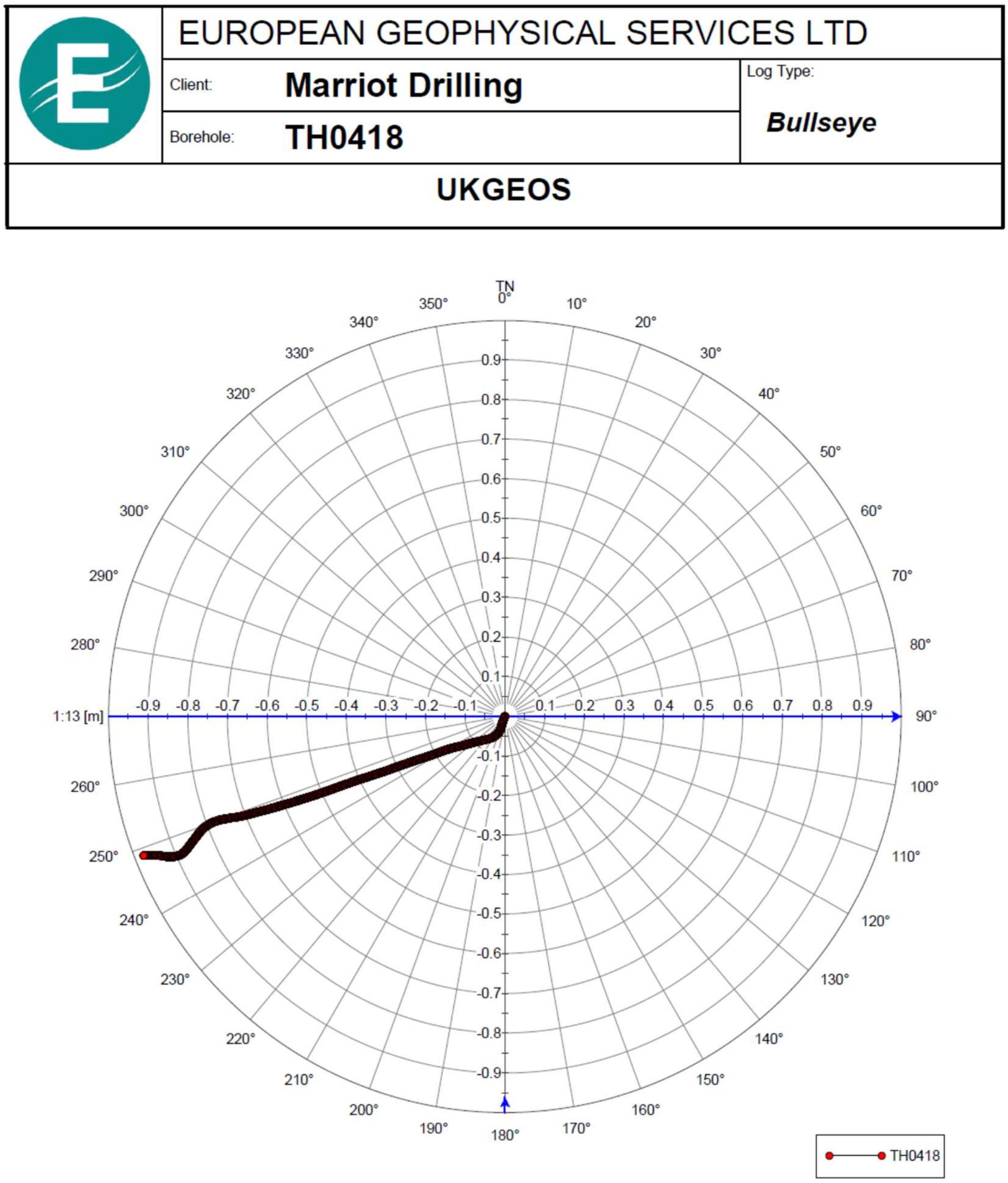


Figure 16 Verticality bullseye plot for TH0418, © European Geophysical Services Ltd

4.2.6 Summary of Installation Operations

Installation criteria for TH0418:

- Monitor groundwater level and quality at 8 different depths coinciding with identified geological features from wireline logs.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Backfill the multilevel well with sand gravel and Bentonite pellet to create hydraulically isolated filter packs around the pressure transducer and sampling ports.
- Prevent loss of backfill into open fractures.
- Match sand and gravel backfill carbonate concentration to aquifer.

- Run resistance tomography and fibre optic cables on the outside of the waterloo casing ensuring that ERT electrodes are at correct depths.
- Deploy centralisers to ensure the waterloo casing is central in the borehole before backfilling and maintain in tension.
- Accurately monitor the deployment.
- Emplace backfill material using tremie pipe to ensure accuracy, prevent bridging and within 15 cm tolerance of specified depths.

Summary of MLS installation operations:

The detailed design of each MLS well was finalised using geophysical wireline logging data. Wireline data was provided to BGS within 24 hours of collection and processed to identify major fractures and other features important to the MLS well design

The 8 MLS pneumatic double- valve groundwater sampling pumps were tested prior to installation to confirm that they functioned correctly. The 8 MLS pressure sensors (4,500 SOL vibrating wire transducers) were also checked to confirm that pressure readings were within 0.1% of the factory calibration values.

The installation bottom hole assembly (BHA) was prepared, and cable reel stands and other equipment deployed in preparation for running. MLS cables and tubing were laid out on a 100.0 m run around the site perimeter on a heavy-duty polyethylene sheet. The installation was then RIH to the final setting depth at 99.96 m with the casing assembly as per the install tally (Solinst Waterloo MLS tubing 60.3 mm OD / 50 mm ID), attaching all line and the ERT and FO cables to the MLS tubing. The ERT and FO cables were tested together with the groundwater sampling pumps before commencing the backfilling operation. See **Section 4.2.7** for the backfill materials, intervals and the 8 x MLS port depth. Once the final layer of filter pack had been emplaced the upper section of the well from 11.06 m was grouted back to surface with Geotherm X grout.

Figure 17 Images of the installation being run into TH0418 showing the MLS lines, the ERT and FO cables

4.2.7 Backfill and grouting operations

The backfill materials used in each of the 8 filter packs including thicknesses are detailed in **Table 14** below. Filter packs were constructed around the multilevel sample ports using 1-2 mm quartz filter sand. Gravel layers were emplaced within the filter packs in places to guard against loss of filter sand into large fractures observed in wireline logs. Medium swelling Mikolit 300 bentonite pellets were used to form seals between the filter packs, and the top ca. 11.0 m of the borehole was sealed into the unsaturated zone using Geotherm-X GR grout.

The gravel layers varied in composition, with 4-10 mm MGS gravel used in the deeper part of the well (below 40.0 m) and a low carbonate 6-10 mm Derby gravel used in the upper section where core scanning data indicated that the aquifer was depleted in carbonate. This was done to better match the gravel filter pack to the formation and so avoid it influencing the quality of sampled groundwater. The material specification sheets for each backfill material can be found in the appendices of this report.

Table 14 Backfill and grout summary table – TH0418

MLS Port depths M BGL	Material type	Depths from / to m BGL
	Geotherm-X GR grout	0.5 to 11.06 m
	Sharp sand	11.06 to 12.00 m
	Bentonite Pellets (Mikolit 300)	12.00 to 25.44 m
MLS Port 8 - 26.97 m	1 - 2 mm MGS filter sand	25.44 to 28.50 m
	6-10 mm Derby Gravel	28.50 to 29.91 m
	1 - 2 mm MGS filter sand	29.91 to 30.48 m
	Bentonite Pellets (Mikolit 300)	30.48 to 32.83 m
MLS Port 7 - 34.14 m	1 - 2 mm MGS filter sand	32.83 to 35.80 m
	6-10 mm Derby Gravel	35.80 to 37.27 m
	1 - 2 mm MGS filter sand	37.27 to 37.84 m
	Bentonite Pellets (Mikolit 300)	37.84 to 44.60 m
MLS Port 6 - 46.18 m	1 - 2 mm MGS filter sand	44.60 to 48.50 m
	4-10 mm MGS Gravel	48.50 to 50.10 m
	1 - 2 mm MGS filter sand	50.10 to 51.10 m
	Bentonite Pellets (Mikolit 300)	51.10 to 56.12 m
MLS Port 5 - 58.22 m	1 - 2 mm MGS filter sand	56.12 to 60.38 m
	4-10 mm MGS Gravel	60.38 to 62.28 m
	1 - 2 mm MGS filter sand	62.28 to 62.92 m
	Bentonite Pellets (Mikolit 300)	62.92 to 67.78 m
MLS Port 4 - 68.43 m	1 - 2 mm MGS filter sand	67.78 to 71.86 m
	Bentonite Pellets (Mikolit 300)	71.86 to 75.06 m
MLS Port 3 - 76.5 m	1 - 2 mm MGS filter sand	75.06 to 78.16 m
	4-10 mm MGS Gravel	78.16 to 80.16 m
	1 - 2 mm MGS filter sand	80.16 to 80.60 m
	Bentonite Pellets (Mikolit 300)	80.60 to 84.04 m
MLS Port 2 - 85.5 m	1 - 2 mm MGS filter sand	84.04 to 87.01 m
	Bentonite Pellets (Mikolit 300)	87.01 to 94.95 m
MLS Port 1 - 96.62 m	1 - 2 mm MGS filter sand	94.95 to 97.90 m
	4-10 mm MGS Gravel	97.90 m to TD

The Geotherm-X grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg.

Each batch was checked before pumping with a mud balance. The grout was delivered via a retractable tremie pipe. Dry and wet samples of the grout were taken for future analysis if needed. The below table summarises the grout batches pumped:

Table 15 Grout backfill summary table – TH0418

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	06/07/23	50	90	1.69
2	06/07/23	50	90	1.67
3	06/07/23	50	90	1.71
4	06/07/23	50	96	1.67
5	06/07/23	50	90	1.67
6	06/07/23	50	90	1.67
7	06/07/23	50	90	1.67
8	06/07/23	50	90	1.71
9	06/07/23	50	90	1.71
10	07/07/23	50	90	1.67
11	07/07/23	50	96	1.67
Total		550	1,002	1.68 avg

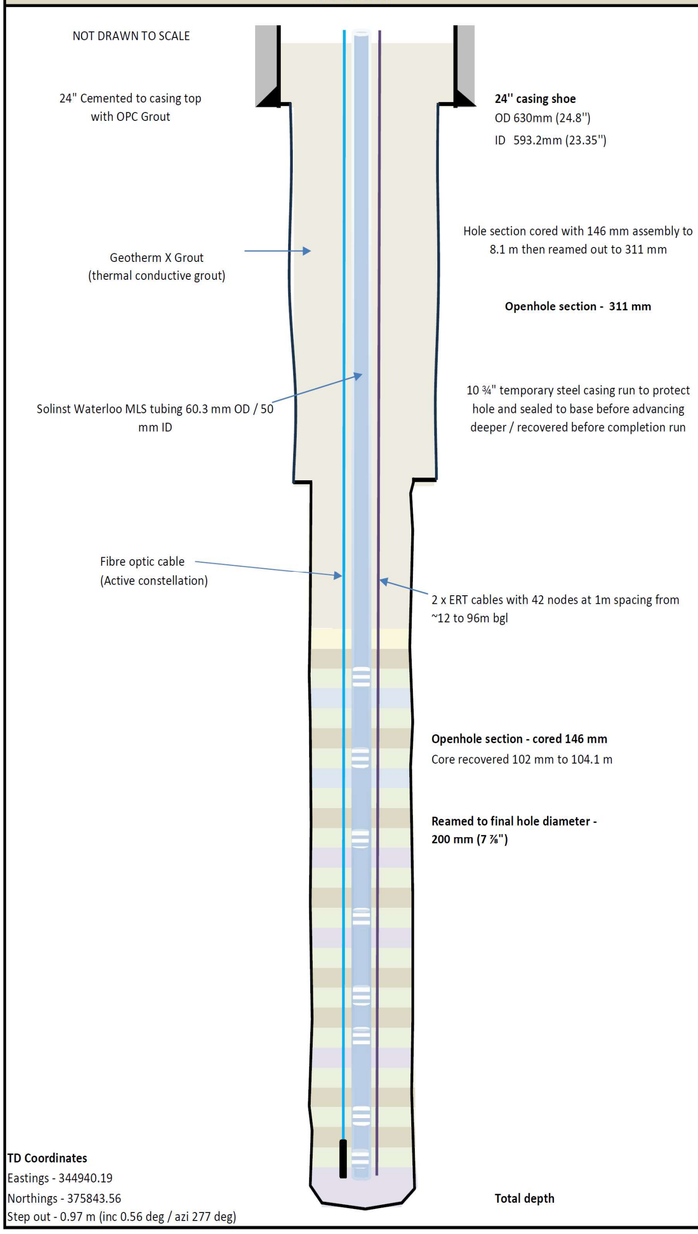
The final grout levels within the 24” surface casing were dipped and topped up to final levels during completion of the headworks.

4.2.8 TH0418 Borehole Well Schematic

Borehole coordinates: Eastings - 344941.092 Northings - 375843.919 Top 24" depth ref - 20.082 m AOD Top 24" to GL - 0.125 m	Well Schematic TH0418 MLS Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Section logged in 146 mm from 6 to 73 m. 02/06/23	GR, CALI, ACBI, LRES, TEMP, COND
Lower section logged in 146 mm from 70 to 104 m (Logged in two sections due to inc check being required at 70 m). 06/06/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



Depths m MD-BCT	Comments	Backfill depths
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)		
	Bedrock encountered at 1.75 m	Geotherm X Grout (thermal conductive grout)
2 m	24" shoe depth	
	273 x 250 mm temp casing	
6 m	Base of reamed upper section	
	Sharp sand	11.06 to 12.00 m
	Bentonite Pellets (Mikolit 300)	12.00 to 25.44 m
MLS Port 8 - 26.97 m	1 - 2 mm MGS filter sand	25.44 to 28.50 m
	6-10 mm Derby Gravel	28.50 to 29.91 m
	1 - 2 mm MGS filter sand	29.91 to 30.48 m
	Bentonite Pellets (Mikolit 300)	30.48 to 32.83 m
MLS Port 7 - 34.14 m	1 - 2 mm MGS filter sand	32.83 to 35.80 m
	6-10 mm Derby Gravel	35.80 to 37.27 m
	1 - 2 mm MGS filter sand	37.27 to 37.84 m
	Bentonite Pellets (Mikolit 300)	37.84 to 44.60 m
MLS Port 6 - 46.18 m	1 - 2 mm MGS filter sand	44.60 to 48.50 m
	4-10 mm MGS Gravel	48.50 to 50.10 m
	1 - 2 mm MGS filter sand	50.10 to 51.10 m
	Bentonite Pellets (Mikolit 300)	51.10 to 56.12 m
MLS Port 5 - 58.22 m	1 - 2 mm MGS filter sand	56.12 to 60.38 m
	4-10 mm MGS Gravel	60.38 to 62.28 m
	1 - 2 mm MGS filter sand	62.28 to 62.92 m
	Bentonite Pellets (Mikolit 300)	62.92 to 67.78 m
MLS Port 4 - 68.43 m	1 - 2 mm MGS filter sand	67.78 to 71.86 m
	Bentonite Pellets (Mikolit 300)	71.86 to 75.06 m
MLS Port 3 - 76.5 m	1 - 2 mm MGS filter sand	75.06 to 78.16 m
	4-10 mm MGS Gravel	78.16 to 80.16 m
	1 - 2 mm MGS filter sand	80.16 to 80.60 m
	Bentonite Pellets (Mikolit 300)	80.60 to 84.04 m
MLS Port 2 - 85.5 m	1 - 2 mm MGS filter sand	84.04 to 87.01 m
	Bentonite Pellets (Mikolit 300)	87.01 to 94.95 m
MLS Port 1 - 96.62 m	1 - 2 mm MGS filter sand	94.95 to 97.90 m
	4-10 mm MGS Gravel	97.90 m to TD
Reamed to 103.6 m	Additional m drilled for sump - debris in well and for logging tools	
Cored to 104.1 m		

Figure 18 TH0418 Well Schematic

4.2.9 Wellhead / Well Chamber Status

Figure 19 Wellhead chamber image TH0418

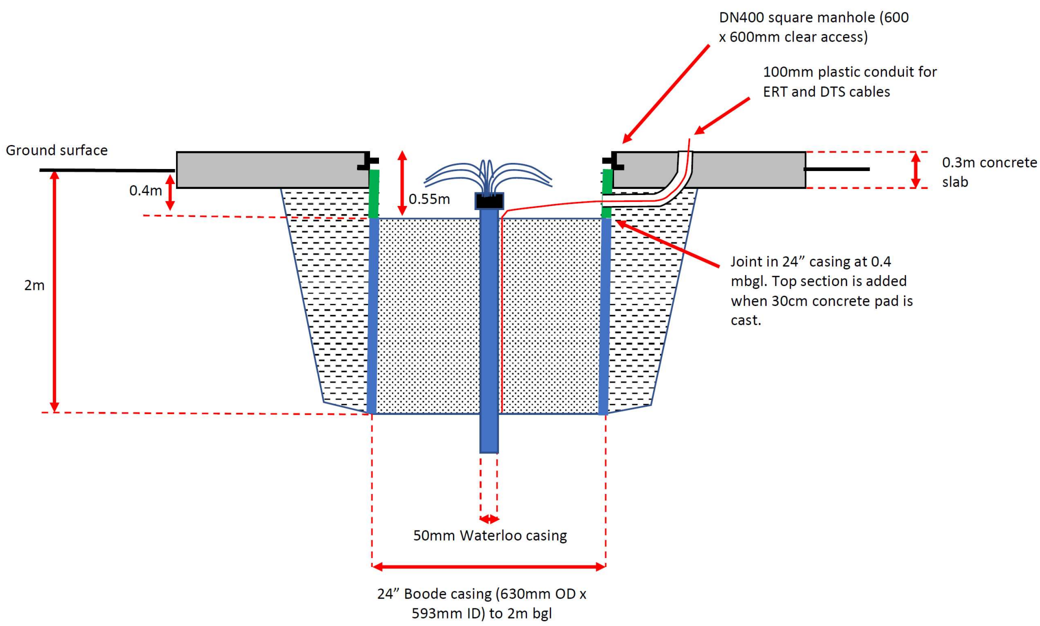


Figure 20 Wellhead chamber schematic TH0418

4.2.10 Daily Activity Summary

Table 16 Daily activity summary TH0418

Date	Depth M BGL	Operation	Parameters	Issues
30/05/23	2 m	Cleared the ground around the 24'' casing of well TH0418. Moved Soilmec rig from TH0421 to TH0418 and set up over location. Set 2.0 m of 7'' steel temporary casing, checked verticality and sealed.		
31/05/23	50.1 m	Commenced coring from 2.1 m to 8.1 m. Circulated the hole clean before POOH the Geobore string and recovering the 7" temporary casing. Made up the 311 mm reamer and pilot bit assembly and opened out the hole to 6.0 m. POOH the reamer but pilot bit lost in hole. Attempted to fish with magnet but unsuccessful and could screw back into due to debris. Decision taken to run temporary 273 mm OD (10 ¾") casing and seal annulus with Bentonite pellets. RIH with bit sub on drill rods and re engaged and recovered the pilot bit. Made up and RIH 146 mm Geobore string to 8.1 m and circulated well with clean water. Cored ahead to 50.1 m.	**Flush returns:** 90% at 23.1 m. 80% at 27.6 m. 70% at 33.6 m. 60% at 35.1 m. 30% at 38.1 m. 20% at 44.1 m. **E-Totco surveys:** 0.51 deg @ 5.1 m. 0.32 deg @ 8.1 m. 0.71 deg @ 14.1 m. 0.40 deg @ 20.1 m. 0.52 deg @ 26.1 m. 0.62 deg @ 32.1 m. 0.71 deg @ 38.1 m. 0.59 deg @ 44.1 m. 0.51 deg @ 50.1 m.	Pilot bit unscrewed from reamer and lost in hole resulting in fishing operations – NPT 1.5 hours.
01/06/23	73.1 m	Continued to core ahead from 50.1m to 68.1m. Due to concerns that inclination was getting close to tolerance additional inclination readings were taken as follows: Cored 2 runs and took E-Totco: 0.71 deg. Cored 2 runs and took E-Totco: 0.62 deg. Cored 4 runs and took E-Totco: 0.71 deg. Lost circulation at 63.6m. E-Totco @ 68.1 m of 0.80 deg. Continued to core from 68.1 m to 72.6 m, last core dropped (71.1 m to 72.6 m). Attempted to catch dropped core but no success. Dipped well but unable to retrieve dip tape and parted leaving end downhole. POOH with Geobore string. No recovery of dip tape weight. Decision taken to core 50 cm to 73.1 m. String recovered with 40 cm of core and lost dip tape end.		Maintained water hose running in TH0410. Below 63.6 m (when returns were lost) when core barrel was retrieved the fluid level in TH0410 dropped and when pumping resumes for the next core run, the level returns to surface confirming communication between boreholes. Majority of core run 71.1 m to 72.6 m was lost. Fishing NPT – 7 hours.
02/06/23	73.1 m	EGS mobilised and performed full wireline logging suite down to 72.6m, including trajectory survey.	Wireline tools run - GR, CALI, ACBI, LRES, TEMP, COND	Unable to produce Bullseye plot of the trajectory due to missing Software module (plot to be produced at EGS) but verbal assessment is that the borehole is trending to WSW, with the bottom of hole about 0.64 m from centre.
05/06/23	104.1 m	Made up and RIH 146 mm Geobore string and washed to TD at 73.1 m. Cored ahead with no returns to TD at 104.1 m.	E-Totco inclination surveys: 0.27 deg @ 74.1 m. 0.66 deg @ 80.1 m.	Observed water flow from TH0410 until 77.1 m when the water flow ceased

Date	Depth M BGL	Operation	Parameters	Issues
			0.71 deg @ 86.1 m. 0.52 deg @ 92.1 m. 0.47 deg @ 98.1 m.	At 84.6 m, water flow again observed from Flute liner. At 89.1 m, brown coloured water was observed from TH0410 Flute liner.
06/06/23	104.1 m	POOH Geobore coring string and rigged up wireline over the well and logged the lower section of the well from 70.0 m to 100.0 m. Made up and RIH the 200 mm reamer and opened out the hole to 103.6 m. Circulated the hole clean before pulling out the assembly and recovering the 273 mm OD (10 ¾") temporary casing. RIH Geobore string and circulated to remove any Bentonite that had fallen into the well when recovering the 10 ¾" casing.	Wireline tools run - GR, CALI, ACBI, LRES, TEMP, COND	While reaming, water was welling up out of TH0410 and during the course of the night a large quantity of fine sand was lifted from TH0410 and deposited around the borehole.
07/06/23	103.4 m	RIH with Geobore to TD. Flushed hole with 15,000 L of clean water. Dipped hole at 103.4 m. POOH with Geobore string. Prepared BHA and cable reels for the MLS install and hung the BHA in the mast ready to commence installation.		
TH0418 MLS install				
08/06/23	103.4 m	Laid out MLS port lines around the site on Heavy-duty polyethylene sheet. RIH with MLS assembly / tubing, spacing out to accommodate the sampling ports as per the installation plan. Install depth achieved 60.0 m.		
09/06/23	103.4 m	Continued RIH with MLS assembly as per detailed design from 60.0 m (pipe section No 43). Installation completed during night shift down to 99.96 m before weekend shutdown.		
12/06/23	59.7 m	Commenced back filling operations and installed filter packs as per the well schematic to 59.7 m.		
13/06/23	19.26 m	Continued back filling of the annulus and installing the filter packs as per the well schematic to 19.26 m.		
14/06/23	11.06 m	Completed back filling operations with final sharp sand layer being installed back to 11.06 m.		
06/07/23	1 m	Rigged up grout mixer and grouted the annulus from 11.06 m to 1.0 m below casing top as per Scope via the recoverable tremie pipe. Operation complete.	Geotherm X grout used.	
TH0418 complete				

4.3 WATERLOO MULTI-LEVEL SAMPLING WELL – TH0419 SUMMARY OF OPERATIONS

4.3.1 Key Well Data

Table 17 TH0419 Key well data

Well name	TH0419		
Well classification	Waterloo 401 8 port multilevel sampling well (MLS)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.197 m AOD Top 24" to GL - 0.088 m		
Start date	Intermediate section started on 09/09/22 and was completed on 26/06/23. Lower section started 26/06/23.		
End of drilling date	29/06/23.		
Install dates	Commenced on 03/07/23 with backfilling plus grouting completed on 06/07/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 18.6 m Reamed to 6.0 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.0 m
Final section to TD Cored in 146 mm then reamed out to 200 mm	Cored to 99.0 m Reamed to 99.0 m	n/a	n/a
Installation	n/a	Solinst Waterloo 8 port MLS completion run on 60.3 mm OD / 50 mm ID tubing	97.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344944.913, Northing Y: 375845.765		
Ordnance Survey Grid Reference	Latitude N: 53°16′36″ Longitude W: 002°49′38″		
12 Character National Grid Reference	SJ 44945 75846		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344945.13, Northing Y: 375845.41 Step out - 0.42 m (inclination 0.35 deg / azimuth 165 deg)		

4.3.2 Summary of Drilling Operations

Marriotts set the rig up over TH0419 and RIH a string of 7” temporary casing centralised inside the 24” surface casing and sealed to the base with Bentonite pellets.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.1 m to 18.6 m using water only. Flush losses increased with depth and by TD of the section the loss rate was at 80%. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The rig was moved off location on the 12th September 2022.

The Soilmec rig was mobilised back on the 23rd June 2023 and setup. The well was dipped at 9.85 m indicating a large volume of fine sediment had entered the well from drilling operating in the vicinity via shallow open fractures.

A 311 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m and the well circulated clean before POOH. The temporary 10 ¾” casing was run and sealed at the base with Bentonite.

Made up and RIH the 146 mm Geobore assembly and washed in hole down to 18.6 m removing all the cuttings / sediment from the well before coring ahead to 99.0 m and well TD. The shallower depth of 99.0 m was accepted by BGS.

The coring operation was influenced by the mitigations put in place against the possibility of sediment flowing into TH0419 from the adjacent TH0410 and causing the drill string to become stuck. The following was adopted:

1. Pull back the core assembly after each core run above the sediment depth in TH0410 before pulling out the core barrel.
2. Stopped taking verticality surveys to avoid leaving string stationery in the hole.

With the assembly out of hole EGS were mobilised and the well wireline logged down to 99.0 m. Full details of wireline logging programme undertaken can be found in **Section 4.3.5**. Due to log quality issues experienced in other wells that had already been opened out it was instructed that wireline logging be completed in the cored hole going forward. The issue and data quality noted was vertical lines on the acoustic image log. This was investigated but why this had occurred couldn’t be determined.

EGS were rigged down off the well, and a 200 mm reamer assembly was made up and RIH. The hole was opened out down to 99.0 m with returns throughout. Once TD had been reached the well was circulated clean before POOH the assembly and recovering the temporary 10 ¾” casing string.

The 311 mm reamer was picked up and RIH to 6 m to clean up the shoulder and remove any residual Bentonite following the recovery of the temporary casing.

A cleanout run was completed to total depth and the well flushed with 22 m^3 of clean water from the TSP abstraction well. The hole was dipped at 97.8 m before POOH in preparation for the installation.

4.3.3 Materials, Flush and Drilling Additive Used

TH0419 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.3.4 Core sub sampling

TH0419 was the last borehole to be drilled and was sub- sampled to determine the aquifer porewater chemistry and microbiology at the end of drilling operations (vs the profiles from cores TH0410 and TH0420 collected at the start of drilling operations). TH0419 is only 3.0 m away from TH0410 and 6.0 m from TH0420 and so was hypothesised to have a similar pre-drilling porewater chemistry and microbiology profile. The sampling protocol was as described in Section 3.8.2 The following subsamples were collected:

From 20.0 to 100.0 m:

Subsamples were collected at 6.0m intervals (i.e. every 4th core run) to provide data for comparison with TH0410 and TH0420.

From 75.0 m to 85.0 m:

Additional subsamples were collected on either side of a flowing fractures at ca. 80.0 m to check for gradients between the fracture water and the sandstone matrix, as shown in **Figure 21**.

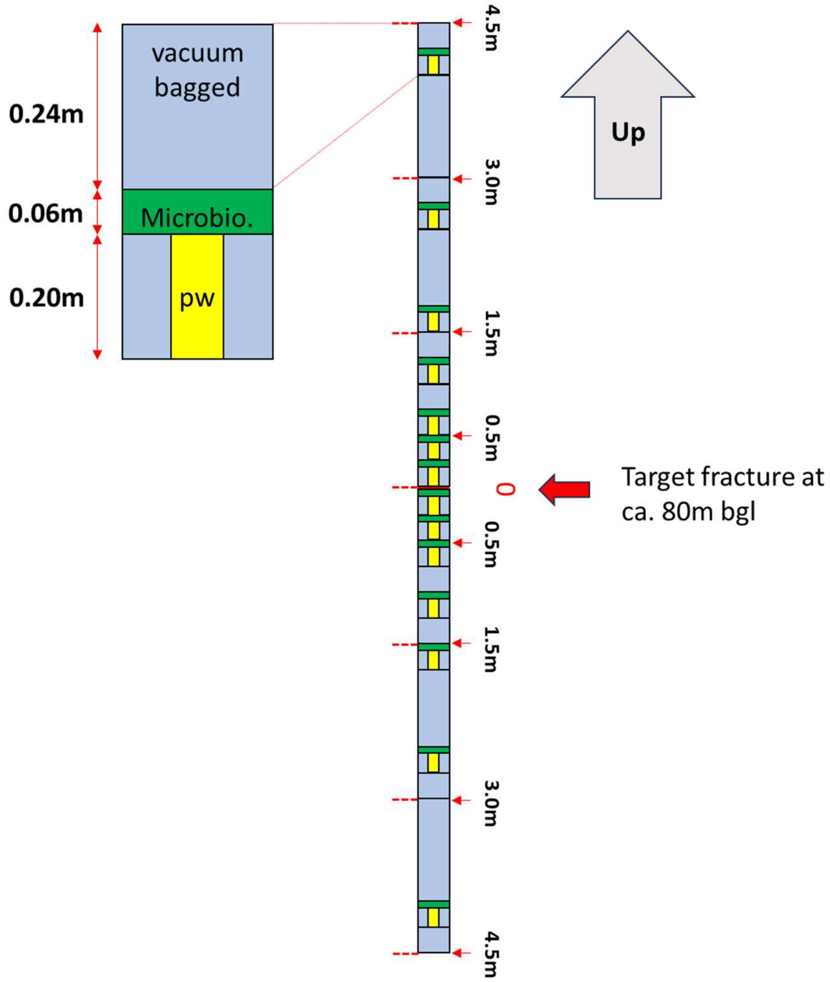


Figure 21 Illustration of higher resolution drill core sub- sampling around major fracture at ca. 80.0 m in TH0419. Location of subsampled sections are shown relative to the 1.5 m recovered core lengths.

4.3.5 Geophysical Logging Undertaken

Table 18 Geophysical logging summary TH0419

Wireline logging undertaken	Tools run
Section logged inside temp casing to 6.0 m then 146 mm from 6.0 m to 99.0 m. (28/06/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.42 m and within the 1/100 tolerance.

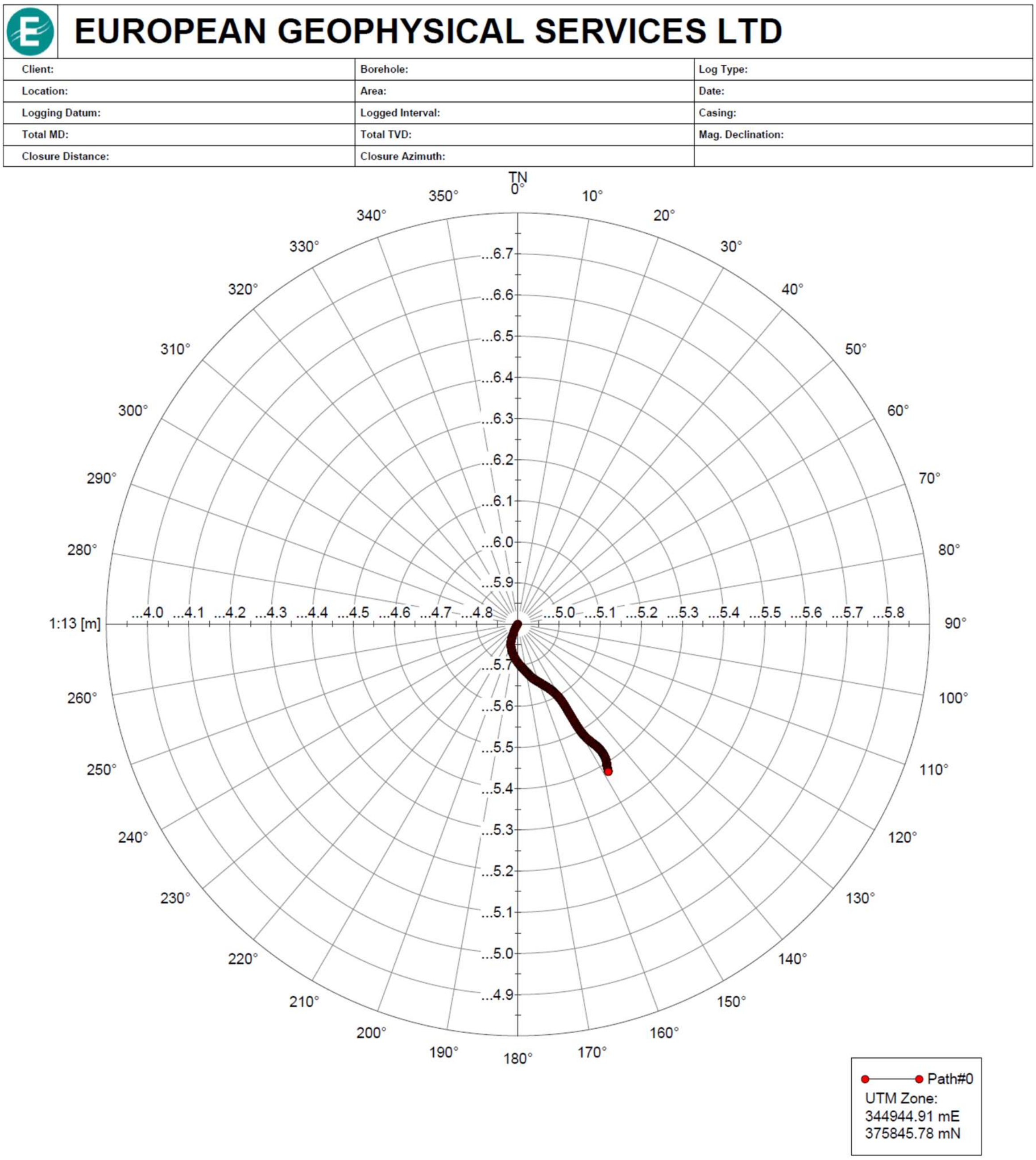


Figure 22 Verticality bullseye plot for TH0419, © European Geophysical Services Ltd

4.3.6 Summary of Installation Operations

Installation criteria for TH0419:

- Monitor groundwater level and quality at 8 different depths coinciding with identified geological features from wireline logs.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Backfill the multilevel well with sand gravel and Bentonite pellet to create hydraulically isolated filter packs around the pressure transducer and sampling ports.
- Prevent loss of backfill into open fractures.
- Match sand and gravel backfill carbonate concentration to aquifer.
- Run resistance tomography and fibre optic cables on the outside of the waterloo casing ensuring that ERT electrodes are at correct depths.
- Deploy centralisers to ensure the waterloo casing is central in the borehole before backfilling and maintain in tension.
- Accurately monitor the deployment.
- Emplace backfill material using tremie pipe to ensure accuracy, prevent bridging and within 15 cm tolerance of specified depths.

Summary of installation operations:

The detailed design of each MLS well was finalised using geophysical wireline logging data. Wireline data was provided to BGS within 24 hours of collection and processed to identify major fractures and other features important to the MLS well design

The 8 MLS pneumatic double- valve groundwater sampling pumps were tested prior to installation to confirm that they functioned correctly. The 8 MLS pressure sensors (4,500 SOL vibrating wire transducers) were also checked to confirm that pressure readings were within 0.1% of the factory calibration values. The well was dipped at 97.4 m and the depth accepted by BGS as the installation tally and final setting depth was 97.0 m.

The installation bottom hole assembly (BHA) was prepared, and cable reel stands and other equipment deployed in preparation for running. MLS cables and tubing were laid out on a 100.0 m run around the site perimeter on a heavy-duty polyethylene sheet. The installation was then RIH to the final setting depth at 97.0 m with the casing assembly as per the install tally (Solinst Waterloo MLS tubing 60.3 mm OD / 50 mm ID), attaching all line and the ERT and FO cables to the MLS tubing. The ERT and FO cables were tested together with the groundwater sampling pumps before commencing the backfilling operation. See **Section 4.3.7** for the backfill materials, intervals and the 8 x MLS port depth. Once the final layer of filter pack had been emplaced the upper section of the well from 12.15 m was grouted back to surface with Geotherm X grout.

4.3.7 Backfill and grouting operations

The backfill materials used in each of the 8 filter packs, including thicknesses, are detailed in **Table 19** below. Filter packs were constructed around the multilevel sample ports using 1-2 mm quartz filter sand. Gravel layers were emplaced within the filter packs in places to guard against loss of filter sand into large fractures observed in wireline logs. Medium swelling Mikolit 300 bentonite pellets were used to form seals between the filter packs and the top ca. 12.0 m of the borehole was sealed into the unsaturated zone using Geotherm-X GR grout.

The gravel layers varied in composition, with 4-10 mm MGS gravel used in the deeper part of the well (below 40.0 m) and a low carbonate 6-10 mm Derby gravel used in the upper section where core scanning data indicated that the aquifer was depleted in carbonate. This was done to better match the gravel filter pack to the formation and so avoid it influencing the quality of sampled groundwater. The material specification sheets for each backfill material can be found in the appendices of this report.

Table 19 Backfill and grout summary table – TH0419

MLS Port depths M BGL	Material type	Depths from / to m BGL
	Geotherm-X GR grout	0.5 to 12.15 m
	Sharp sand	12.15 to 13.05 m
	Bentonite Pellets (Mikolit 300)	13.05 to 14.93 m
	1 - 2 mm MGS filter sand	14.93 to 15.58 m
	6-10 mm Derby Gravel	15.58 to 18.43 m
MLS Port 8 - 19.81 m	1 - 2 mm MGS filter sand	18.43 to 20.86 m
	Bentonite Pellets (Mikolit 300)	20.86 to 23.40 m
	1 - 2 mm MGS filter sand	23.40 to 23.35 m
MLS Port 7 - 25.15 m	6-10 mm Derby Gravel	23.35 to 27.95 m
	1 - 2 mm MGS filter sand	27.95 to 28.57 m
	Bentonite Pellets (Mikolit 300)	28.57 to 31.37 m
	1 - 2 mm MGS filter sand	31.37 to 32.00 m
	6-10 mm Derby Gravel	32.00 to 35.15 m
MLS Port 6 - 36.28 m	1 - 2 mm MGS filter sand	35.15 to 38.04 m
	Bentonite Pellets (Mikolit 300)	38.04 to 48.90 m
MLS Port 5 - 50.44 m	1 - 2 mm MGS filter sand	48.90 to 53.03 m
	Bentonite Pellets (Mikolit 300)	53.03 to 56.10 m
MLS Port 4 - 57.91 m	1 - 2 mm MGS filter sand	56.10 to 59.80 m
	4-10 mm MGS Gravel	59.80 to 62.75 m
	1 - 2 mm MGS filter sand	62.75 to 63.25 m
	Bentonite Pellets (Mikolit 300)	63.25 to 66.56 m
MLS Port 3 - 68.43 m	1 - 2 mm MGS filter sand	66.56 to 70.35 m
	Bentonite Pellets (Mikolit 300)	70.35 to 74.97 m
MLS Port 2 - 76.81 m	1 - 2 mm MGS filter sand	74.97 to 79.10 m
	4-10 mm MGS Gravel	79.10 to 80.93 m
	1 - 2 mm MGS filter sand	80.93 to 81.58 m
	Bentonite Pellets (Mikolit 300)	81.58 to 90.10 m
MLS Port 1 - 92.51 m	1 - 2 mm MGS filter sand	90.10 to 95.05 m
	Bentonite Pellets (Mikolit 300)	95.05 to 97.40 m

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a retractable tremie pipe. Dry and wet samples of the grout were taken for future analysis if needed. The below table summarises the grout batches pumped:

Table 20 Grout backfill summary table – TH0419

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	06/07/23	50	96	1.67
2	06/07/23	50	96	1.71
3	06/07/23	50	96	1.70
4	06/07/23	50	96	1.67
5	06/07/23	50	96	1.71
6	06/07/23	50	96	1.67
7	06/07/23	50	96	1.67
8	06/07/23	50	96	1.67
9	06/07/23	50	96	1.67
10	07/07/23	50	96	1.70
11	07/07/23	50	96	1.67
Total		550	1,056	1.68 avg

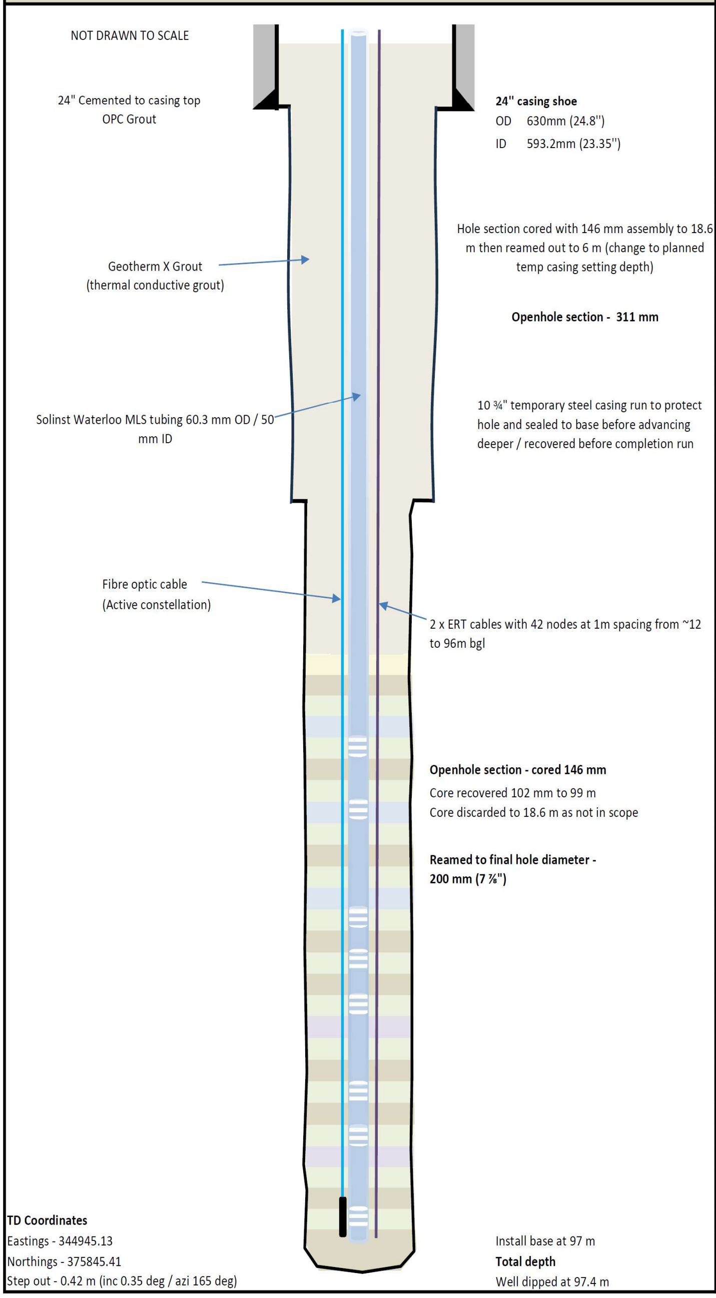
The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.3.8 TH0419 Borehole Well Schematic

Borehole coordinates:	Well Schematic TH0419	British Geological Survey
Eastings - 344944.913 Northings - 375845.765 Top 24" depth ref - 20.197 m AOD Top 24" to GL - 0.088 m	MLS Borehole	

Wireline logging undertaken	Tools run
Section logged inside temp casing to 6 m then 146 mm from 6 to 99 m. 28/06/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
	Bedrock encountered at 1.75 m	
2 m	24" shoe depth	
	273 x 250 mm temp casing	Geotherm X Grout (thermal conductive grout)
6 m	Base of reamed upper section	
	Sharp sand	12.15 to 13.05 m
	Bentonite Pellets (Mikolit 300)	13.05 to 14.93 m
	1 - 2 mm MGS filter sand	14.93 to 15.58 m
	6-10 mm Derby Gravel	15.58 to 18.43 m
MLS Port 8 - 19.81 m	1 - 2 mm MGS filter sand	18.43 to 20.86 m
	Bentonite Pellets (Mikolit 300)	20.86 to 23.40 m
MLS Port 7 - 25.15 m	1 - 2 mm MGS filter sand	23.40 to 26.35 m
	6-10 mm Derby Gravel	26.35 to 27.95 m
	1 - 2 mm MGS filter sand	27.95 to 28.57 m
	Bentonite Pellets (Mikolit 300)	28.57 to 31.37 m
	1 - 2 mm MGS filter sand	31.37 to 32.00 m
	6-10 mm Derby Gravel	32.00 to 35.15 m
MLS Port 6 - 36.28 m	1 - 2 mm MGS filter sand	35.15 to 38.04 m
	Bentonite Pellets (Mikolit 300)	38.04 to 48.90 m
MLS Port 5 - 50.44 m	1 - 2 mm MGS filter sand	48.90 to 53.03 m
	Bentonite Pellets (Mikolit 300)	53.03 to 56.10 m
MLS Port 4 - 57.91 m	1 - 2 mm MGS filter sand	56.10 to 59.80 m
	4-10 mm MGS Gravel	59.80 to 62.75 m
	1 - 2 mm MGS filter sand	62.75 to 63.25 m
	Bentonite Pellets (Mikolit 300)	63.25 to 66.56 m
MLS Port 3 - 68.43 m	1 - 2 mm MGS filter sand	66.56 to 70.35 m
	Bentonite Pellets (Mikolit 300)	70.35 to 74.97 m
MLS Port 2 - 76.81 m	1 - 2 mm MGS filter sand	74.97 to 79.10 m
	4-10 mm MGS Gravel	79.10 to 80.93 m
	1 - 2 mm MGS filter sand	80.93 to 81.58 m
	Bentonite Pellets (Mikolit 300)	81.58 to 90.10 m
MLS Port 1 - 92.51 m	1 - 2 mm MGS filter sand	90.10 to 95.05 m
	Bentonite Pellets (Mikolit 300)	95.05 to 97.40 m
Reamed to 99 m		
Cored to 99 m		

Figure 23 TH0419 Well Schematic

4.3.9 Wellhead / Well Chamber Status

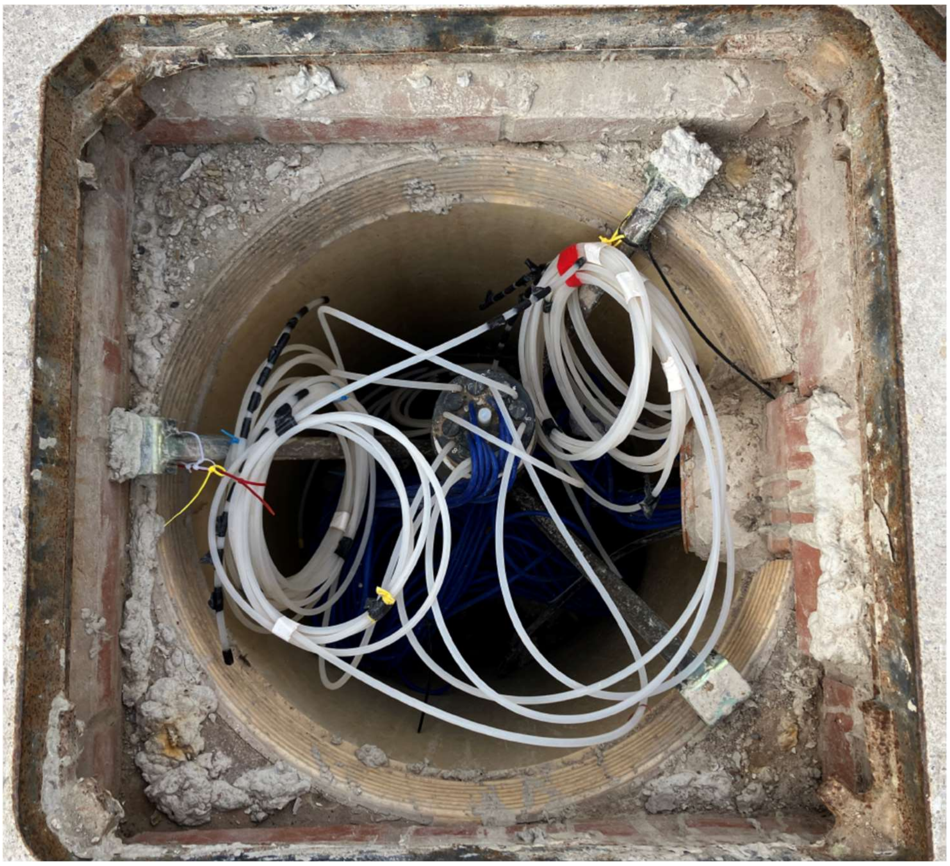


Figure 24 Wellhead chamber image TH0419

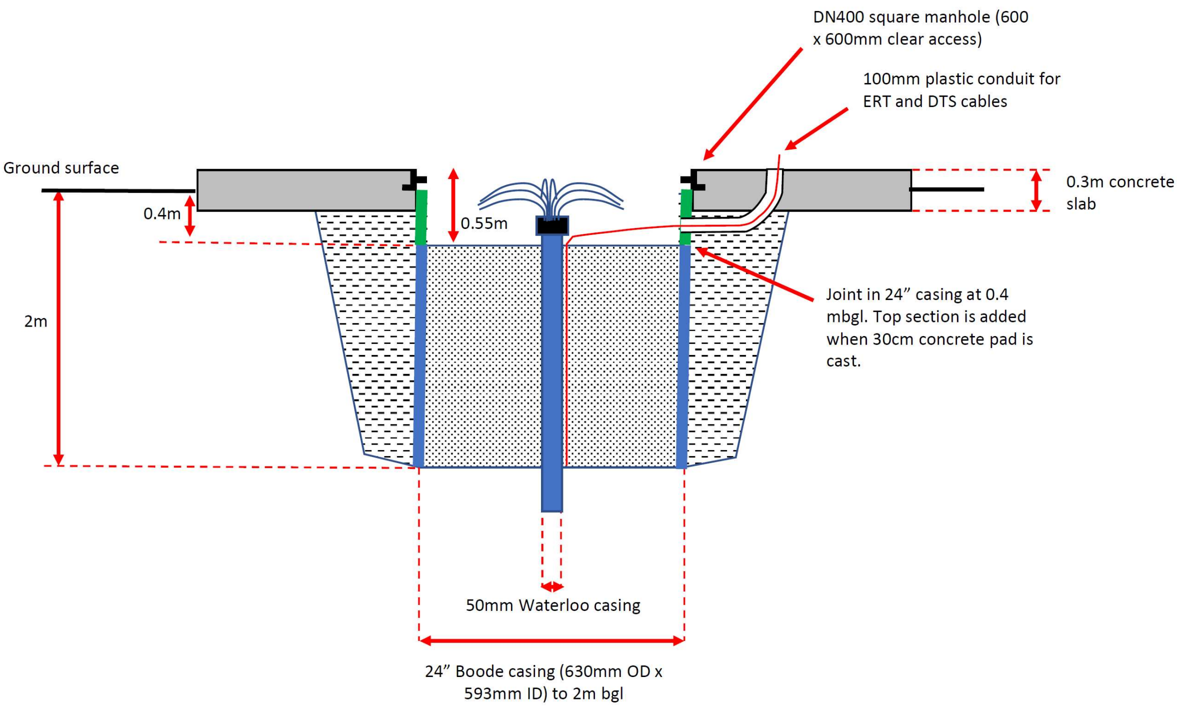


Figure 25 Wellhead chamber schematic TH0419

4.3.10 Daily Activity Summary

Table 21 Daily activity summary TH0419

Date	Depth M BGL	Operation	Parameters	Issues
12/09/22	18.6 m	Marriott set up on TH0419, RIH with 7" casing, added Bentonite to base and allowed time for it to swell and seal. Commenced coring from 2.1 m to 18.6 m taking E Totco reading. Loss rates increased toward the end of the section. Pilot drilled only; rig moved off location.	ROP - 4 to 5 minutes per 1.5 m core run Inclination readings: 0.17 deg @ 0.0 m. 0.34 deg @ 6.10 m. 0.45 deg @ 9.10 m. 0.47 deg @ 12.10 m. 0.27 deg @ 18.10 m.	Flush loss – 30% from 14.1 m to 16.5 m then increasing to 80% down to 18.6 m.
23/06/23	18.6 m	Moved the Soilmec rig across to TH0419 and set up over well. Emptied and cleaned tanks/skips in preparation for drilling.		
26/06/23	74.1 m	Well dipped at 9.85 m. Made up 311 mm reaming assembly and opened out the hole down to 6.0 m before circulating the hole clean and POOH. RIH with 10 ¾'' steel temporary casing to 6.0 m. Sealed the casing with Bentonite pellets and allowed to hydrate. Washed in hole with 146 mm Geobore string cleaning out the original pilot hole down to 18.6 m. Cored ahead from 18.6 m to 74.1 m.		
27/06/23	99.0 m	Continued to core ahead from 74.1 m to 99.0 m. Circulated the hole clean and pulled out of hole the coring assembly.		Operations influenced by mitigation against the possibility of sediment moving back into TH0419 wellbore from the adjacent TH0410 and causing the drill string to become stuck. The following was adopted: 1. Pull back the core assembly after each core run above the sediment depth in TH0410 before pulling out the core barrel with the assembly stationery. 2. stop taking verticality surveys to avoid leaving string stationery in the hole.
28/06/23	97.8 m	EGS mobilised and completed wireline logging down to 99.0 m. Once complete the area was cleared, and the 200 mm reamer assembly was picked up and RIH. The hole was opened out to 99.0 m with returns throughout. Circulated the hole clean before POOH. Recovered the 10 ¾" temporary casing and cleaned up the shoulder at 6.0 m of any remaining Bentonite with the 311 mm reamer. Once recovered the Geobore string was run to TD and the hole circulated and displaced to	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND	

Date	Depth M BGL	Operation	Parameters	Issues
		clean water (22,000 L pumped). Hole dipped at 97.8 m. POOH Geobore string to 50.0 m.		
29/06/23	97.5 m	Recovered remaining 50.0 m of pipe from the well.		
TH0419 MLS Install				
30/06/23	97.5 m	Cleared equipment from around TH0419 in preparation for the installation operation. Setup scaffolding tower with cable sheaves.		
03/07/23	97.4 m	Prepared location with Heavy-duty polyethylene sheeting to lay out the MLS lines. Dipped well to 97.4 m. Laid out MLS lines and FO cable. Ran 63 mm yellow tremie pipe to TD in preparation for backfilling. Commenced RIH with the MLS tubing, ERT, DTS and thermistor cables, spacing out each sample port as per install design spreadsheet to 30.0 m. Secured installation for the night.		
04/07/23	85.0 m	Continued running MLS installation from 30.0 m to 45.0 m – port 5. Tested port 5. Continued RIH from 45.0 m to final setting depth of 97.0 m. Carried out testing of ERT/DTS system before starting to backfill and emplace the filter packs as per the install sheet (see well schematic). Backfilled to 85.0 m before site closed.		
05/07/23	47.55 m	Continued to backfill the borehole to 47.55 m as per the install design sheet.		
06/07/23	1.0 m	Completed back filling operations with final layer being installed back to 12.0 m. Rigged up grout mixer and grouted the annulus from 12.0 m to 1.0 m below 24” casing top as per Scope via the recoverable tremie pipe.	Geotherm X grout used.	
TH0419 complete				

4.4 WATERLOO MULTI-LEVEL SAMPLING WELL – TH0420 SUMMARY OF OPERATIONS

4.4.1 Key Well Data

Table 22 TH0420 Key well data

Well name	TH0420		
Well classification	Waterloo 401 8 port multilevel sampling well (MLS)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.030 m AOD Top 24" to GL - 0.196 m		
Start date	Intermediate section started on 15/09/22 and was completed on 14/10/22. Lower section started 17/10/22.		
End of drilling date	09/11/22.		
Install dates	Commenced on 10/11/22 with backfilling plus grouting completed by 22/11/22.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 273.05 mm	Cored to 18.6 m Reamed to 18.2 m in 273.05 mm Over drilled (304.8 mm) to 12.0 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) became stuck and had to be over drilled with 304.8 mm assembly to recover	18.0 m
Final section to TD Cored in 152 mm to 39.1 m then switched to 146 mm. Reamed out to 222 mm (incorrect reamer picked up)	Cored to 104.2 m Reamed to 100.8 m	n/a	n/a
Installation	n/a	Solinst Waterloo 8 port MLS completion run on 60.3 mm OD / 50 mm ID tubing	98.99 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344939.223, Northing Y: 375847.755	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44939 75848	

Well TD Coordinates:	
Easting / Northing (OS GRID)	Easting X: 344939.50, Northing Y: 375847.63 Step out - 0.30 m (inclination 0.31 deg / azimuth 110 deg)

4.4.2 Summary of Drilling Operations

Marriotts levelled the work area with type 1 gravel and setup the rig before running in hole a string of 7” temporary casing centralised inside the 24” surface casing and sealed to the base with Bentonite.

Made up and RIH the Geobore S coring assembly and cored from 2.0 m to 18.6 m. Flush losses increased with depth. 30% by 11.1 m, 80% by 14.1 m and total losses by section TD. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The rig was moved off location on the 20th September 2022.

The Soilmec rig was mobilised back on the 14th October 2022 and setup.

A 273 mm reamer and pilot bit was made up and the hole opened out down to 18.2 m with good return. The well circulated before POOH. Temporary 273 mm (10 ¾”) casing was run with some resistance and temporarily packed off toward section TD. A high viscosity polymer sweep was pumped to remove cuttings and sediment and aid lubrication. The proposed well schematic and temporary casing size stated were followed however this should have been questioned before RIH and again when the string became tight. With the project being a 100% design contract, it didn’t allow for variation without instruction.

A 7” temporary casing was then run and centralised inside the 10 ¾” string to maintain well verticality and sealed at the base with Bentonite pellets. Made up and RIH the 146 mm Geobore assembly and washed in hole down to 18.6 m removing all the cuttings / sediment from the well before coring ahead to 28.6 m where the annulus seal between the 7” and 10 ¾” casing failed. POOH the 7” casing and introduced 25 kg of Bentonite before rerunning and bedding the casing into the Bentonite and providing the required seal.

Continued to core ahead from 28.6 m to 37.6 m where excessive vibration through the drill string was noticed. Coring operations were stopped and the issue investigated. On inspection it was found to be the main shaft within the top drive assembly. The Soilmec rig was rigged down and moved to the compound to undergo repairs and the Comacchio rig was moved into position and setup.

Coring recommenced with an average ROP of 15 m/hr and with total losses down to well and section TD at 101.1 m. All verticality reading were within tolerance.

The Comacchio 405 was rigged down and replaced with the repaired and larger Soilmec rig for the reaming phase.

Made up and RIH a 222 mm reamer assembly (picked up in error as the Scope required a 200 mm hole) and opened out the hole down to 100.8 m. Partial returns (60 to 70%) were regained during the reaming phase with a significant number of cuttings recovered from the well. Once TD had been reached the well was circulated clean before POOH. Well dipped at 99.7 m.

During the flushing at the end of the reaming operation resistance was encountered when working to TD. It was thought this may be a quantity of pebbles at the base of the hole that couldn't be lifted using water alone. The Geobore assembly was re-run in hole with a basket spring installed. The string was worked to 101.2 m and then one additional 1.5 m core run was taken. The well was circulated and dipped at 102.65 m before POOH. 1 m of core was recovered with nothing in the spring basket. When out of hole the well was dipped again, this time to 101.2 m.

Made up drive head to the 10 ¾" casing and attempted to recover. No progress casing stuck. Worked casing with up to 19 tons and attempted to initiate rotation with no success.

It became apparent the stuck casing was a result of confusion between OD and ID measurements. Marriotts had been referring to the ID of the casing at 10" and not the OD of the string. This is common for geotechnical and water well drilling and where well schematics differ when looking at oil and gas well schematics. With this being one of the first wells drilled all documents and schematics were updated to clearly state both the OD and ID of all items run in future boreholes. A key learning for the project.

Summary of casing recovery operations

Continued to work the casing string with the Soilmec rig but still with no movement or rotation. Rigged up a compressor and commenced hammering operations. The casing moved upwards by 30 cm when the weld on the drive head failed. Installed a joint of 10 ¾" casing and made up the backup drive head. Attempted to rotate with the rig tongs but without success.

Decision take to mobilise EGS and run wireline logs whilst waiting on additional equipment and a welder. The well was logged down to total depth along with a piston sampler taking a water sample from 96.0 m. Full details of wireline logging programme undertaken can be found in **Section 4.4.5**.

The drive head was welded back onto the 10 ¾" casing and hammering recommenced with no further progress. A jacking frame was mobilised, and 75 tonnes of pressure was applied via the frame but the casing remained stuck.

Additional equipment including the Marriott Liebherr rig was mobilised to site and rigged up. The Kelly drive was connected to the casing string and attempted to rotate. The casing coupling failed under the torque applied by the more powerful rig. Operation stopped to discuss the forward plan.

Decision taken to over drill the stuck 10 ¾" casing with a 12" wash pipe string. The string was worked down over the next 4 days (full details can be found in **Section 4.4.10**) to 16.5 m where high torque was seen. Gravel was introduced to add additional friction between the 10 ¾" casing and 12" wash pipe. The string was worked and confirmed the string had been freed. POOH both strings before rigging down the Liebherr rig.

Figure 26 Marriotts Liebherr rig casing recovery operation

The well was dipped at 82.5 m. RIH with the Geobore string while circulating down to flush out infilled material. Worked to bottom at 102.7 m. Continued to circulate the hole clean. An additional core run was completed to a new TD of 104.2 m to provide a larger sump. The well was circulated before POOH. Once the assembly was out of hole the well dipped at 99.7 m.

The rig was changed out for the Comacchio unit in preparation for running the installation. Marriotts preferred to use the smaller unit as it provided better speed control on the winch for running the MLS tubing.

4.4.3 Materials, Flush and Drilling Additive Used

TH0420 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.4.4 Core sub sampling

Core from TH0420 was sub- sampled to determine the aquifer porewater chemistry and microbiology at the start of drilling operations.

Subsamples were collected at 6.0 m intervals (i.e. every 4th core run) from 8.0 to 100.9 m. Cores were subsampled within 24 hours of core recovery to minimise drilling fluid ingress and oxidation. The sampling protocol was as described in **Section 3.8.2**.

4.4.5 Geophysical Logging Undertaken

Table 23 Geophysical logging summary TH0420

Wireline logging undertaken	Tools run
Section logged inside temp casing to 18.2 m then 222 mm hole from 0.0 m to 102.0 m. (28/10/22)	GR, CALI, ACBI, IRES, TEMP, COND

The acoustic image log quality was poor for this well. TH0420 was one of the first wells drilled and as per normal logging practices and as per Scope the hole was logged after it had been opened out with a reaming assembly. A full investigation of the reamer, pulling techniques for recovery and measurements of all BHA components was undertaken but it couldn't be confirmed what caused these vertical lines on the acoustic logs. As a result, it was instructed that all future wireline logging be undertaken in the cored hole to avoid this log quality issue. TH0420 logs show heavy vertical lines down to a depth of 50.0 m with much better acoustic signatures below this depth.

The inclination of the well was checked once total depth had been achieved, as shown in the bullseye plot below. The maximum step out recorded was 0.31 m and within the 1/100 tolerance.

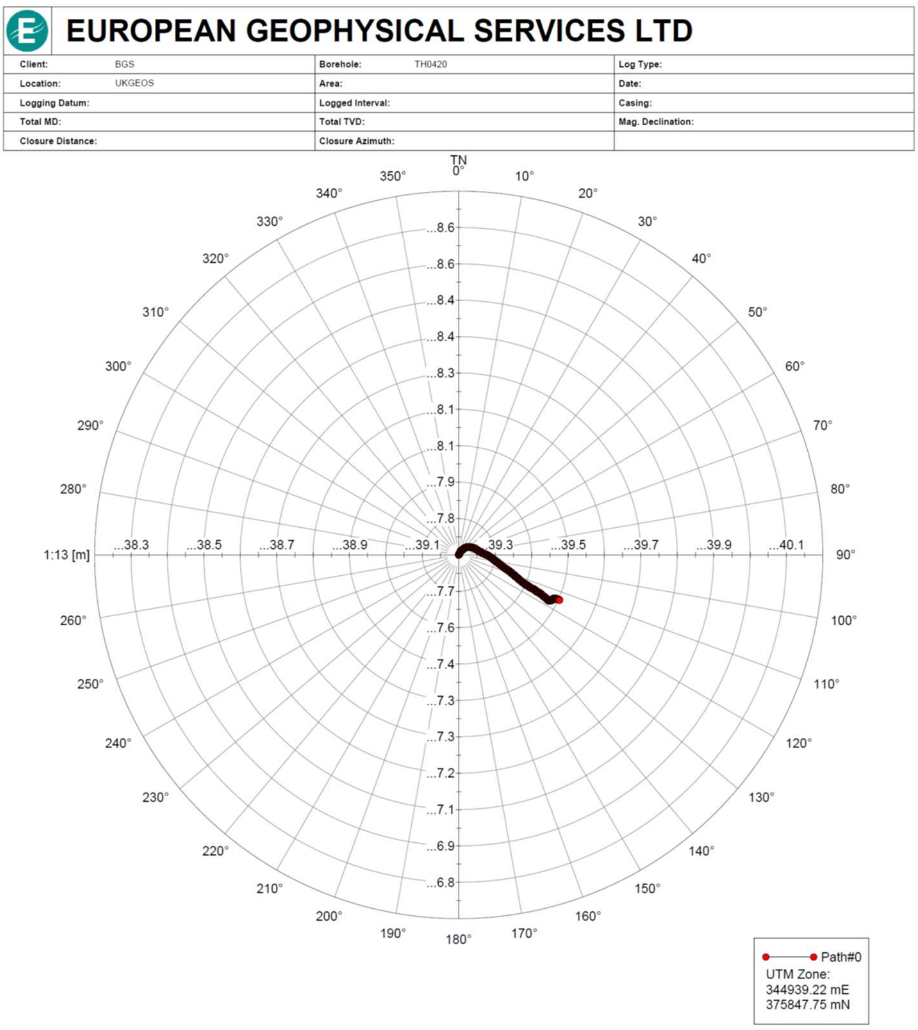


Figure 27 Verticality bullseye plot for TH0420, © European Geophysical Services Ltd

4.4.6 Summary of Installation Operations

Installation criteria for TH0420:

- Monitor groundwater level and quality at 8 different depths coinciding with identified geological features from wireline logs.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Backfill the multilevel well with sand gravel and Bentonite pellet to create hydraulically isolated filter packs around the pressure transducer and sampling ports.
- Prevent loss of backfill into open fractures.
- Match sand and gravel backfill carbonate concentration to aquifer.
- Run resistance tomography and fibre optic cables on the outside of the waterloo casing ensuring that ERT electrodes are at correct depths.
- Deploy centralisers to ensure the waterloo casing is central in the borehole before backfilling and maintain in tension.
- Accurately monitor the deployment.
- Emplace backfill material using tremie pipe to ensure accuracy, prevent bridging and within 15 cm tolerance of specified depths.

Summary of installation operations:

The detailed design of each MLS well was finalised using geophysical wireline logging data. Wireline data was provided to BGS within 24 hours of collection and processed to identify major fractures and other features important to the MLS well design

The 8 MLS pneumatic double- valve groundwater sampling pumps were tested prior to installation to confirm that they functioned correctly. The 8 MLS pressure sensors (4,500 SOL vibrating wire transducers) were also checked to confirm that pressure readings were within 0.1% of the factory calibration values. The well was dipped at 99.75 m and the depth accepted by BGS as the installation tally and final setting depth was 98.99 m.

Figure 28 left hand image showing preparation works for running, right hand image shows the end of the install, and all MLS ports run.

The installation bottom hole assembly (BHA) was prepared, and cable reel stands and other equipment deployed in preparation for running. MLS cables and tubing were laid out on a 100m run around the site perimeter on a heavy-duty polyethylene sheet. The installation was then RIH to the final setting depth at 98.99 m with the casing assembly as per the install tally (Solinst Waterloo MLS tubing 60.3 mm OD / 50 mm ID), attaching all line and the ERT and FO cables to the MLS tubing. The ERT and FO cables were tested together with the groundwater sampling pumps before commencing the backfilling operation. See **Section 4.4.7** for the backfill materials, intervals and the 8 x MLS port depth. Once the final layer of filter pack had been emplaced the upper section of the well from 8.45 m was grouted back to surface with Connect Plus grout.

Note: this is the only well that used Connect Plus grout. A change of grout was instructed due to concern this none setting thermal enhanced grout may be washed away because of communication between open fractures from other wells during subsequent drilling operations. The risk of this occurring increases with depth and why a setting grout was selected for all other wells (Geotherm X).

4.4.7 Backfill and grouting operations

The backfill materials used in each of the 8 filter packs, including thicknesses, are detailed in **Table 24** below. Filter packs were constructed around the multilevel sample ports using 1-2 mm quartz filter sand. Gravel layers were emplaced within the filter packs in places to guard against loss of filter sand into large fractures observed in wireline logs. Medium swelling Mikolit 300 bentonite pellets were used to form seals between the filter packs and the top ca. 8.0 m of the borehole was sealed into the unsaturated zone using Connect Plus grout.

The gravel layers varied in composition, with 4-10 mm MGS gravel used in the deeper part of the well (below 40.0 m) and a low carbonate 6-10 mm Derby gravel used in the upper section where core scanning data indicated that the aquifer was depleted in carbonate. This was done to better match the gravel filter pack to the formation and so avoid it influencing the quality of sampled groundwater. The material specification sheets for each backfill material can be found in the appendices of this report.

Table 24 Backfill and grout summary table – TH0420

MLS Port depths M BGL	Material type	Depths from / to m BGL
	Connect Plus grout	0.5 to 8.45 m
	Sharp sand	8.45 to 9.47 m
	1 - 2 mm MGS filter sand	9.47 to 10.55 m
	Bentonite Pellets (Mikolit 300)	10.55 to 12.55 m
	1 - 2 mm MGS filter sand	12.55 to 13.10 m
	6-10 mm Derby Gravel	13.10 to 15.50 m
MLS Port 8 - 16.38 m	1 - 2 mm MGS filter sand	15.50 to 18.10 m
	Bentonite Pellets (Mikolit 300)	18.10 to 23.05 m
MLS Port 7 - 24.46 m	1 - 2 mm MGS filter sand	23.05 to 26.50 m
	6-10 mm Derby Gravel	26.50 to 28.00 m
	1 - 2 mm MGS filter sand	28.00 to 28.45 m
	Bentonite Pellets (Mikolit 300)	28.45 to 34.08 m
MLS Port 6 - 35.59 m	1 - 2 mm MGS filter sand	34.08 to 37.05 m
	6-10 mm Derby Gravel	37.05 to 40.00 m
	1 - 2 mm MGS filter sand	40.00 to 40.45 m
	Bentonite Pellets (Mikolit 300)	40.45 to 48.10 m
MLS Port 5 - 50.37 m	1 - 2 mm MGS filter sand	48.10 to 52.05 m
	Bentonite Pellets (Mikolit 300)	52.05 to 55.90 m
MLS Port 4 - 57.53 m	1 - 2 mm MGS filter sand	55.90 to 59.60 m
	4-10 mm MGS Gravel	59.60 to 62.05 m
	1 - 2 mm MGS filter sand	62.05 to 62.60 m
	Bentonite Pellets (Mikolit 300)	62.60 to 66.46 m
MLS Port 3 - 68.35 m	1 - 2 mm MGS filter sand	66.46 to 70.60 m
	Bentonite Pellets (Mikolit 300)	70.60 to 75.05 m
MLS Port 2 - 76.43 m	1 - 2 mm MGS filter sand	75.05 to 78.06 m
	4-10 mm MGS Gravel	78.06 to 79.56 m
	1 - 2 mm MGS filter sand	79.56 to 80.06 m
	Bentonite Pellets (Mikolit 300)	80.06 to 89.96 m
MLS Port 1 - 92.43 m	1 - 2 mm MGS filter sand	89.96 to 95.05 m
	Bentonite Pellets (Mikolit 300)	95.05 to 97.41 m
	1 - 2 mm MGS filter sand	97.41 to 97.96 m
	4-10 mm MGS Gravel	97.96 to 99.75 m

The Connect+ grout used was mixed with a ratio of 1 bag (25 kg each) of grout to 5 bags (125 kg) of Silica sand. This grout mix had previously been checked and trialled by Marriotts before mobilising to site to ensure it could be pumped without any issues via a tremie pipe. No slurry weights were taken as a result. The grout was delivered via a retractable tremie pipe. The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks. Dry and wet samples of the grout were taken for future analysis if needed. The below table summarises the grout batches pumped:

Table 25 Grout backfill summary table – TH0420

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
8	21/11/22	800	200 Connect+ and 1,000 kg of silica sand	NA
Total			1,200	Not taken

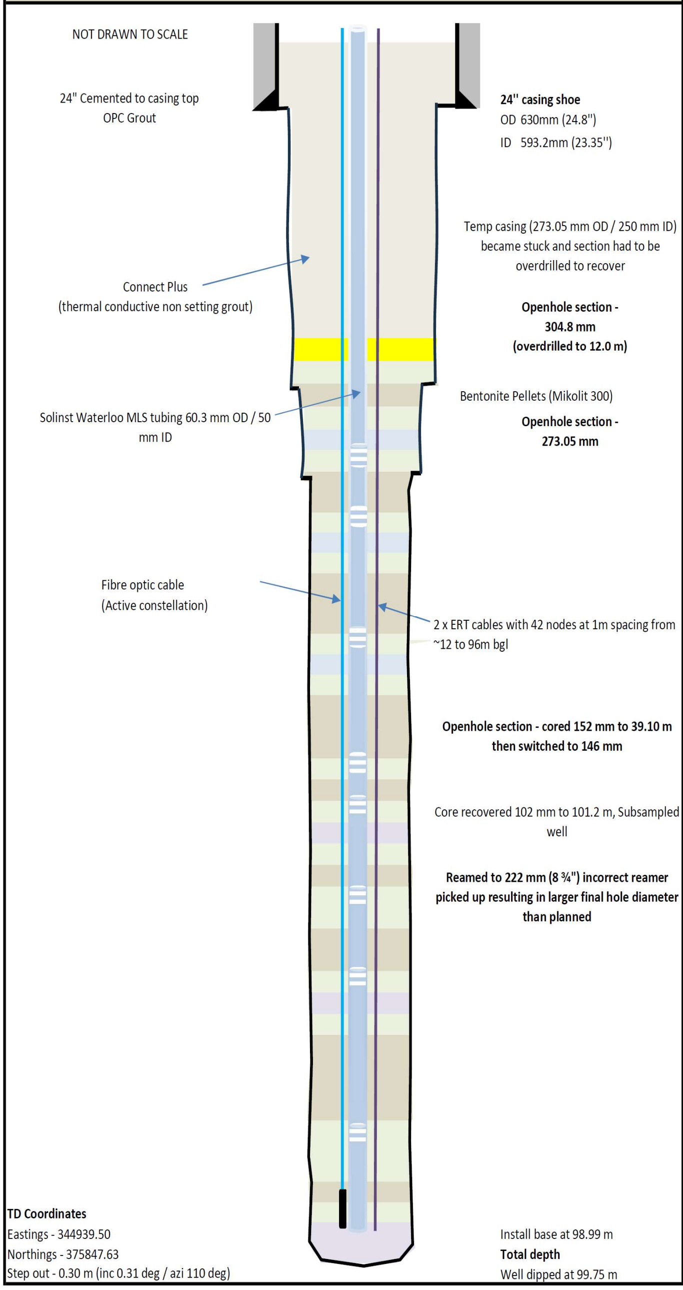
This was the first well that was grouted and as drilling continued it became apparent this thermal grout mix wasn’t optimal for the ground conditions due to the large number of open fractures encountered. The switch to a setting Geotherm-X GR thermal grout was made after this well was completed.

4.4.8 TH0420 Borehole Well Schematic

Borehole coordinates: Eastings - 344939.223 Northings - 375847.755 Top 24" depth ref - 20.030 m AOD Top 24" to GL - 0.196 m	Well Schematic TH0420 MLS Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Section logged inside temp casing to 18.2 m then 222 mm hole from 0 to 102 m. 28/10/22	GR, CALI, ACBI, IRES, TEMP, COND

Ground Level



All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
	Bedrock encountered at 1.75 m	Connect plus grout (thermal conductive non setting grout)
2 m	24" shoe depth	
	Sharp sand	8.45 to 9.47 m
	1 - 2 mm MGS filter sand	9.47 to 10.55 m
	Bentonite Pellets (Mikolit 300)	10.55 to 12.60 m
	1 - 2 mm MGS filter sand	12.60 to 13.10 m
	6-10 mm Derby Gravel	13.10 to 15.50 m
MLS Port 8 - 16.38 m	1 - 2 mm MGS filter sand	15.50 to 18.10 m
18.20 m	Base of reamed lower section	
	Bentonite Pellets (Mikolit 300)	18.10 to 23.05 m
MLS Port 7 - 24.46 m	1 - 2 mm MGS filter sand	23.05 to 26.50 m
	6-10 mm Derby Gravel	26.50 to 28.00 m
	1 - 2 mm MGS filter sand	28.00 to 28.45 m
	Bentonite Pellets (Mikolit 300)	28.45 to 34.08 m
MLS Port 6 - 35.59 m	1 - 2 mm MGS filter sand	34.08 to 37.05 m
	6-10 mm Derby Gravel	37.05 to 40.00 m
	1 - 2 mm MGS filter sand	40.00 to 40.45 m
	Bentonite Pellets (Mikolit 300)	40.45 to 48.10 m
MLS Port 5 - 50.37 m	1 - 2 mm MGS filter sand	48.10 to 52.05 m
	Bentonite Pellets (Mikolit 300)	52.05 to 55.90 m
MLS Port 4 - 57.53 m	1 - 2 mm MGS filter sand	55.90 to 59.60 m
	4-10 mm MGS Gravel	59.60 to 62.05 m
	1 - 2 mm MGS filter sand	62.05 to 62.60 m
	Bentonite Pellets (Mikolit 300)	62.60 to 66.46 m
MLS Port 3 - 68.35 m	1 - 2 mm MGS filter sand	66.46 to 70.60 m
	Bentonite Pellets (Mikolit 300)	70.60 to 75.05 m
MLS Port 2 - 76.43 m	1 - 2 mm MGS filter sand	75.05 to 78.06 m
	4-10 mm MGS Gravel	78.06 to 79.56 m
	1 - 2 mm MGS filter sand	79.56 to 80.06 m
	Bentonite Pellets (Mikolit 300)	80.06 to 89.96 m
MLS Port 1 - 92.43 m	1 - 2 mm MGS filter sand	89.96 to 95.05 m
	Bentonite Pellets (Mikolit 300)	95.05 to 97.41 m
	1 - 2 mm MGS filter sand	97.41 to 97.96 m
	4-10 mm MGS Gravel	97.96 to 99.75 m
Reamed to 100.8 m	Additional metres drilled for sump - debris in well and for logging tools	
Cored to 104.2 m		

Figure 29 TH0420 Well Schematic

4.4.9 Wellhead / Well Chamber Status

Figure 30 Wellhead chamber image TH0420

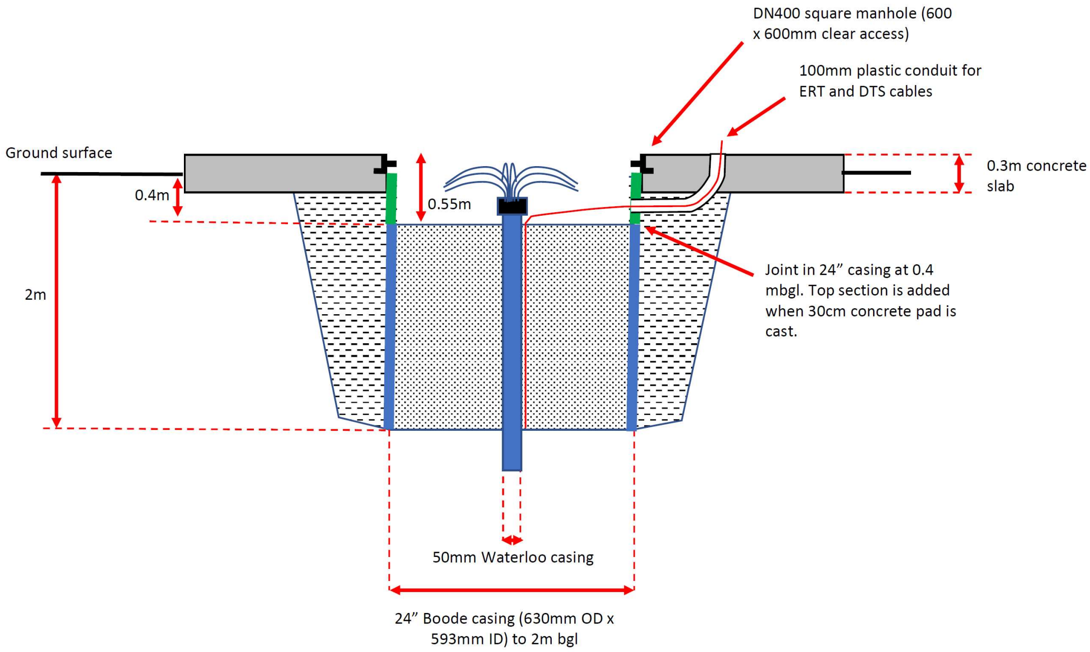


Figure 31 Wellhead chamber schematic TH0420

4.4.10 Daily Activity Summary

Table 26 Daily activity summary TH0420

Date	Depth M BGL	Operation	Parameters	Issues
20/09/22	18.6 m	Marriott levelled the rig work area with type 1 gravels and ran temp 7" casing, centralised inside the 24" to 2.0 m. Made up the coring assembly and commenced coring from 2.0 m to 18.6 m before POOH. Recovered temp 7" casing. BGS curated the core in the onsite laboratory and processing unit.	ROP – 3 to 4 minutes per 1.5 m core run. Inc reading for TH0420: 0.29 deg @ 6.10 m. 0.21 deg @ 9.10 m. 0.26 deg @ 12.10 m. 0.30 deg @ 15.10 m. 0.10 deg @ 18.10 m. Losses - 10% at 8.1m, increased to 30% by 11.1m, 80% by 14.1m, and total loss from 15.6 m.	
14/10/22	18.6 m	Made up 10 ¾" (273 mm) reamer assembly and opened out the pilot hole down to 18.0 m with good returns throughout. Assembly recovered. 10" flush joint temporary casing RIH to 18.0 m, rotating the casing down with resistance. Worked casing to setting depth. Temporarily packed off but high viscosity pill pumped to aid lubrication and lift cuttings.	100% fluid returns down to 12.0 m reducing to 75%-80% after this depth.	Polymer was pumped as mitigation against the risk of casing becoming stuck. Proposed well schematic was followed but casing size used should have been questioned due to difficulties to RIH.
17/10/22	30.1 m	Commenced coring from 18.6 m with the 146 mm Geobore assembly, cored to 28.6 m with an average penetration rate of 5 mins/core run. At 28.6 m the Bentonite seal between the 7" and 10" casings failed resulting in drilling flush ingress into the annulus. POOH the 7" casing and introduced 25 kg of Bentonite to seal the casing base. Casing reran and resumed coring down to 30.1 m. BGS curated the core in the onsite laboratory and processing unit.	The 10" casing was set at 18.2 m and the 7" casing was set at 18.6 m. The 7" temporary steel casing was run to aid verticality. Checked with crosswire technique. Losses were stable from 18.60 m but recorded 10% flush loss (~ 100L) at 24.1 m, which increased to 20% losses by 28.6 m. Verticality checks: 0.51 @ 23.0 m. 0.46 @ 29.0 m.	Cored with the 146 mm Geobore assembly due to the 152 mm assembly possibly causing vibrations in the drive head. Failed sealed at base of 10" casing resulting in flush coming up the annulus of the 2 x strings.
18/10/22	37.6 m	Continued to core from 30.1 m to 37.6 m. BGS curated the core in the onsite laboratory and processing unit.	ROP – 6 minutes avg per 1.5 m core run. Flush loss increased to 30% from 31.6 m-33.1 m, 40% from 33.1 m -34.6 m, and 60% from 34.6 to 37.6 m. Verticality inc: 0.36 @ 36.1 m.	Coring stopped due to vibrations of the rig's shaft @ 10:10 hrs. Engineer mobilised to fix. NPT – 7 hours as a result.
19/10/22	44.2 m	Engineer couldn't fix the shaft issue on the Soilmec rig, so the rig was removed off the well and changed out with the Comacchio.	Average ROP of 6 min /core run, with no flush returns (total losses).	Rig repairs and change out – 5 hours NPT.

Date	Depth M BGL	Operation	Parameters	Issues
		Setup Comacchio on location and resumed coring from 37.6 m to 39.1 m where excessive drill string vibration was seen. Recovered the 152 mm coring assembly, reconfigured the BHA and ran back in hole with 146 mm core bit and cored to 44.2 m. BGS curated the core in the onsite laboratory and processing unit.	Verticality inc: 0.25 @ 38.0 m. 0.40 @ 42.0 m.	Total losses.
20/10/22	78.7 m	Continued coring from 44.2 m to 78.7 m.	Average ROP of 4 mins/core run, still total losses. Verticality inc: 0.51 @ 48.0 m. 0.22 @ 54.0 m. 0.18 @ 60.0 m. 0.46 @ 66.0 m. 0.45 @ 72.0 m. 0.09 @ 78.0 m.	Total losses.
21/10/22	101.2 m	Continued coring from 78.7 m to 101.2 m with no returns. Dipped well at 101.2 m. Pulled back 6 rods to leave assembly 10.0 m off bottom. Secured site for the weekend. BGS processed final core from TH0420.	Average ROP of 5 mins/core run. Verticality inc: 0.22 @ 84.0 m. 0.36 @ 100.0 m.	Total losses. Water usage was approximately 1,000 L/m giving an approximate volume of 22,000 L for the day.
24/10/22	101.1 m	Dipped the well at 101.1 m before pulling out the rod and rigging down the Comacchio 405 off location. Moved over the Soilmec Rig 40 and made up 200 mm reamer assembly. Reamed out the hole from 18.6 m to 62.7 m with no returns.	Reaming progress +/- 10 m/hr.	Total losses, no returns. Water usage for the day ~ 30,000 L.
25/10/22	101.1 m	Reamed out the hole to 200 mm from 67.2 m to 100.8 m before circulating the well clean and POOH assembly.		Regained 60-70% partial returns and significant cuttings returns from the well.
26/10/22	101.2 m	Borehole dipped at 99.7 m (see issues column). RIH Geobore assembly to 101.2 m. Cored 1.5 m to give a new TD of 102.7 m. Circulated the well before dipping at 101.8 m. Continued to circulate and dipped the well at 102.65 m. POOH the assembly and confirmed the borehole depth at 101.2 m. Made up drive head to the 10'' casing (later confirmed as 10 ¾" OD). Attempted to pull 10'' temporary casing free, no progress. Worked on the casing, pulled up to ~19 tons with the hoist and attempted to initiate rotation without success.	1 m of core was recovered with nothing in the spring basket.	During the flushing at the end of the reaming operation resistance was encountered when working to TD suggesting a quantity of pebbles on the bottom of the hole that couldn't be lifted by water alone. A basket spring will be run in the cleanout assembly to catch larger pebbles and debris. 10" temporary casing stuck. Later confirmed as 10 ¾" OD.

Date	Depth M BGL	Operation	Parameters	Issues
27/10/22	101.2 m	Continued working on releasing 10'' casing using various parameters without success. No movement observed. Rigged up compressor and surface equipment for air hammering operations. Commenced hammering, casing moved 30 cm when weld on drive head failed. Installed a joint of 10'' casing to the top of the well and made up a backup drive head. Attempted to rotate the casing with the rig make up/breakout clamps but without success.		Airline swivel on top drive came unscrewed – repaired same. Weld on drive head parted due to hammering. 10" temporary casing remains stuck. Later confirmed as 10 ¾" OD.
28/10/22	101.2 m	EGS arrive and rigged up over the well. A piston sampler was run to collect water samples from 96 m BGL before completing the wireline logging programme. Marriott welders arrived and welded the drive head that parted and welded on the 10" casing section to bring the string above GL. Resumed casing recovery with no success.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND, Verticality.	Decision taken to run wireline whilst waiting on equipment / welder for casing recovery operations. 10" temporary casing remains stuck. Later confirmed as 10 ¾" OD.
29/10/22	101.2 m	Attempted to jack the casing out without success over the weekend.	Up to 75 tonnes applied to the jacks.	10" temporary casing remains stuck. Later confirmed as 10 ¾" OD.
30/10/22	101.2 m	Attempted to jack the casing out without success over the weekend.	Up to 75 tonnes applied to the jacks.	10" temporary casing remains stuck. Later confirmed as 10 ¾" OD.
31/10/22	101.2 m	Offloaded and rigged up Marriott Liebherr rig. Raised the mast, installed the Kelly drive and prepared the top of the 10'' casing. Commenced rotating the casing. Casing joint failed. Stopped operation and discussed next steps.		The torque applied with the Liebherr rig resulted in the failure of a casing coupling. To avoid further damage to the stuck string the operation was suspended. 10" temporary casing remains stuck. Later confirmed as 10 ¾" OD.
01/11/22	101.2 m	Marriott prepared for over-drilling operation. This operation involves drilling down over the 10 ¾" OD stuck casing with a 12'' wash pipe and carbide dressed wash over shoe. The aim is to free the 10 ¾" from the borehole wall and lift both sections the 10 ¾" and the 12'' from the well together. Commenced over-drilling of the 10 ¾" temporary casing to 6.0 m where another section of 12" wash pipe had to be welded on. Continued ahead until no progress could be made (circa 6.5 m). POOH wash pipe and managed to recover a 6.0 m section of 10 ¾" casing.		POOH with 12'' wash pipe and 10 ¾" casings together. A 6 m length of 10 ¾" was recovered and the bottom of the 12'' wash pipe was heavily crimped at the base.

Date	Depth M BGL	Operation	Parameters	Issues
02/11/22	101.2 m	Continued rotating the over-drilling assembly. Unable to make progress. Stopped rotation, retracted the Kelly drive, attached the winch and recovered the 12'' wash pipe section. Observed cutting structure worn away. Re-dressed the 12'' wash over shoe and RIH to resume the over-drilling but no progress due to metal-on-metal contact. Worked string. Stopped rotation and pulled back to surface with the 12'' wash pipe. Recovered a metal 'ring' or 'doughnut' at surface. Checked cutting structure was OK for another run. RIH and managed to work and washed over down to 18.0 m (re dressing cutting shoe at 11.5 m).	Washing over rate: 2.5hrs from 6.5 m to 11.5 m.	It was immediately clear from the noise level that there was metal/metal contact between the over-drill assembly and something in the hole. Recovered a metal 'ring' or 'doughnut' at surface, unclear what the item was from. **Stuck casing OD confirmed as 10 ¾'' and not 10'' as stated.**
03/11/22	101.2 m	Re dressed the 12" cutting shoe with new carbide cutters overnight before running back in hole to 11.5 m. Raised additional 6.0 m length of 12'' wash pipe and welded to the existing section in the hole. Advanced assembly ahead to 13.0 m where high torque was experienced. Operation stopped and 12'' cut to see if the 10 ¾'' was caught inside – it wasn't. Re welded and continue to 14.5 m where no further progress could be made. POOH.	Approx 1 m/hr progress rate.	High periodic torque observed. 10 ¾'' temporary casing remains stuck.
04/11/22	101.2 m	Re-dressed wash over shoe with new carbide cutting structure before RIH and continuing to over drill to 16.5 m where the string was seeing high torque. Added gravel to create additional friction between the 10 ¾" and 12" casing. Worked the string and confirm the 10 ¾" casing had been caught. POOH and laid down section of 12'' wash pipe with the 10 ¾'' inside. Rigged down Liebherr rig from TH0420 and demobbed Marriott crew.	**Stuck casing recovered.**	Cleanout run was planned with the Soilmec rig, but filter developed a leak (resolved over weekend).
07/11/22	101.2 m	EGS were mobilised and rigged up over the well and completed wireline logging operations (details in parameters column). Once clear the Geobore string was RIH to 82.5 m to circulate back to bottom but the engine on the water-cooling pump failed. Operations stopped.	Wireline summary - EGS logged with CCTV, CALI, and Casing Column indicator. The CALI log and CCTV image suggest good borehole conditions with rare tight spots in places. Also, casing column indicators provide no apparent evidence of metallic materials in the borehole.	Failure of the rig engines water cooling pump resulting in operations being suspended from 15:00 hrs.
08/11/22	104.2 m	Liebherr rig removed from site at 11:00 hrs. Water pump part arrived site at 12:30 hrs, installed and tested ok at 14:00 hrs. RIH with Geobore string while circulating down to flush out infilled material. Worked to bottom at 102.7 m. Continued to circulate the hole clean. An additional core run was completed to a new TD of 104.2 m to provide a larger sump.	Well dipped at 82.5 m before the clean out run commenced.	Large number of fines and debris in the well had to be cleaned out following over drilling operations.

Date	Depth M BGL	Operation	Parameters	Issues
09/11/22	99.7 m	Marriott resumed flushing with returns diverted to waste tanks. First borehole flush resulted in a dip measurement of 100.7 m. Second flush resulted in dip measurement of 102.0 m. POOH the Geobore assembly. Borehole dipped at 99.8 m. After 1 hour borehole dipped shallower at 99.7 m. Rig changed out for the Comacchio before proceeding with the setup for the installation. Tremie pipe RIH to 93.45 m and clamped at surface.		Marriott preferred the Comacchio rig because it is more flexible in controlling the speed of the winches during installation.
TH0420 MLS Install				
10/11/22	99.75 m	Borehole dipped at 99.75 m. FO and ERT cables laid out. Commenced RIH the FO/ERT cable on the 60.3 mm PVC casing from the winches with plastic centralizers placed across PVC segment every 10.0 m. At joint 25 (37.2 m) the string became buoyant. Water was run into the PVC casing before continuing RIH to joint no 33 at ~ 44.0 m.		Cable tangling was occasionally observed but was resolved.
11/11/22	99.75 m	Continued running the MLS installation from 44.0 m. at port 4 the deeper ERT sensors were tested ok. After RIH port 6 (~ 62.0 m), observed defect in one of the white tubes, traced tubing/wire lines, but found no subsequent defects. As a result, installation POOH back to port 4 and damaged tubing replaced. Ran back in hole to port 6 and ~ 62.0 m. Installation secured overnight.		Cable tangling was observed while pulling the tubing/wire line through the 60.3 mm PVC casing, resulting in binding them into bundles with black duct tape. However, the black duct taping was removed before the cable lines were RIH.
14/11/22	99.75 m	Continued running MLS installation from 62.0 m to final depth of 99.06 m. Carried out testing of ERT/DTS systems before pump testing the tubing lines – all tested good.		
15/11/22	97.56 m	Tested all the installed cable ports from port 1. All tested ok. Mobilized backfilling materials to wellhead in preparation for backfilling. Commenced backfill of the borehole as per the install design sheet to 97.56 m.		
16/11/22	80.26 m	Continued to backfill the borehole to 80.26 m as per the install design sheet.		On several occasions, the tremie pipe for back filling became blocked. Blockage removed by running water constantly through the pipe.
17/11/22	59.6 m	Continued to backfill the borehole to 59.6 m as per the install design sheet.		
18/11/22	8.45 m	Completed back filling operations with final layer being installed back to 8.45 m.		

Date	Depth M BGL	Operation	Parameters	Issues
		Rigged up grout mixer and grouted the remainder via the recoverable tremie pipe. Last mix was un pumpable, so operations suspended for the weekend.	Grout mix used - • 125 kg of high silica sand. • 25 kg Connect+. • 100 litres of potable water.	
21/11/22	1.0 m	Completed grouting operations and grouted back to 1.0 m below casing top as per Scope.	Grout mix used - • 125 kg of high silica sand. • 25 kg Connect+. • 100 litres of potable water.	
TH0420 complete				

4.5 WATERLOO MULTI-LEVEL SAMPLING WELL – TH0421 SUMMARY OF OPERATIONS

4.5.1 Key Well Data

Table 27 TH0421 Key well data

Well name	TH0421		
Well classification	Waterloo 401 8 port multilevel sampling well (MLS)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.211 m AOD Top 24" to GL - 0.086 m		
Start date	Intermediate section started on 08/09/22 and completed on 12/05/23. Lower section started 15/05/23.		
End of drilling date	16/05/23.		
Install dates	Commenced on 22/05/23 with backfilling plus grouting completed by 30/05/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 18.6 m Reamed to 6.0 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.0 m
Final section to TD Cored in 146 mm then reamed out to 200 mm	Cored to 104.2 m Reamed to 103.7 m	n/a	n/a
Installation	n/a	Solinst Waterloo 8 port MLS completion run on 60.3 mm OD / 50 mm ID tubing	99.97 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344943.05 Northing Y: 375849.585		
Ordnance Survey Grid Reference	Latitude N: 53°16′36″ Longitude W: 002°49′38″		
12 Character National Grid Reference	SJ 44943 75850		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344943.19 Northing Y: 375849.50 Step out - 0.16 m (inclination 0.09 deg / azimuth 167 deg)		

4.5.2 Summary of Drilling Operations

Marriotts levelled the area around TH0421 with type 1 gravel and setup the rig. Ran in hole a string of 7” temporary casing centralised inside the 24” and sealed to the base with Bentonite.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 18.6 m. Flush losses increased with depth and by 16.1 m total losses were observed. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The rig was moved off location on the 09th September 2022.

The Soilmec rig was mobilised back to TH0421 on the 12th May 2023 and setup. A 311 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m and the well circulated before POOH. The temporary 10 ¾” casing was run and sealed at the base with Bentonite.

Made up and RIH the 146 mm Geobore assembly and washed in hole down to 18.6 m removing all the cuttings / sediment from the well before displacing the well to clean water. The well was then cored down to 104.2 m and well TD with circa 60% returns. The hole was circulated clean before POOH.

EGS were mobilised and the well wireline logged from 6.0 m to 103.5 m. Full details of wireline logging programme undertaken can be found in **Section 4.5.4**. Due to log quality issues experienced in other wells that had already been opened out it was instructed that wireline logging be completed in the cored hole going forward. The issue noted was vertical lines on the acoustic image log. This was investigated but a conclusion as to why this was occurring couldn’t be confirmed.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

A 200 mm reamer assembly was then made up and RIH. The well was opened out down to 103.7 m with no return until the assembly reached 70.0 m. Once TD had been reached the well was circulated clean before POOH the assembly. The well dipped at 102.45 m and the temporary 10 ¾” casing string was recovered. The well was dipped again at 101.9 m indicating Bentonite had fallen in the well from the temporary casing recovery.

A Bentonite collar was observed at 1.3 m below the top of 24” casing (70 cm inside the 24” casing and the rest within the 200 mm hole). A jetting assembly was RIH and the area flushed clean inside the 24” surface casing before recovering the assembly.

The 311 mm reamer was picked backup and RIH to 6.0 m to clean up the shoulder. The well was dipped at 100.8 m (17th May 2023) and the 99.25 m (19th May 2023).

A cleanout run was completed to total depth with sand and cuttings in the returns. The hole was dipped at 102.4 m before POOH in preparation for the installation.

4.5.3 Materials, Flush and Drilling Additive Used

TH0421 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.5.4 Geophysical Logging Undertaken

Table 28 Geophysical logging summary TH0421

Wireline logging undertaken	Tools run
Section logged inside temp casing to 6.0 m then 146 mm from 6.0 m to 103.5 m. (16/05/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.09 m and within the 1/100 tolerance.

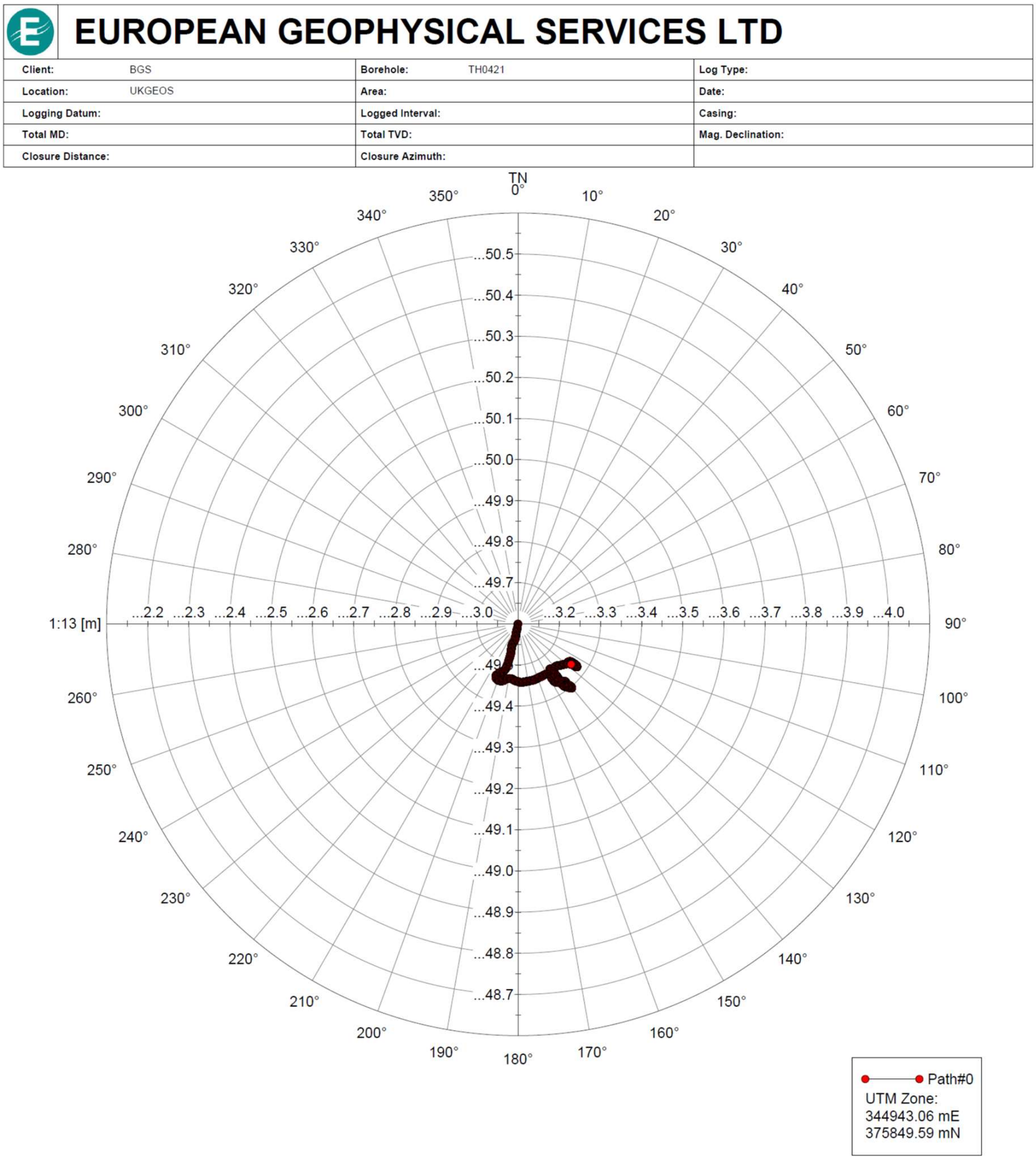


Figure 32 Verticality bullseye plot for TH0421, © European Geophysical Services Ltd

4.5.5 Summary of Installation Operations

Installation criteria for TH0421:

- Monitor groundwater level and quality at 8 different depths coinciding with identified geological features from wireline logs.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Backfill the multilevel well with sand gravel and Bentonite pellet to create hydraulically isolated filter packs around the pressure transducer and sampling ports.
- Prevent loss of backfill into open fractures.
- Match sand and gravel backfill carbonate concentration to aquifer.
- Run resistance tomography and fibre optic cables on the outside of the waterloo casing ensuring that ERT electrodes are at correct depths.
- Deploy centralisers to ensure the waterloo casing is central in the borehole before backfilling and maintain in tension.
- Accurately monitor the deployment.
- Emplace backfill material using tremie pipe to ensure accuracy, prevent bridging and within 15 cm tolerance of specified depths.

Summary of operations:

The detailed design of each MLS well was finalised using geophysical wireline logging data. Wireline data was provided to BGS within 24 hours of collection and processed to identify major fractures and other features important to the MLS well design

The 8 MLS pneumatic double- valve groundwater sampling pumps were tested prior to installation to confirm that they functioned correctly. The 8 MLS pressure sensors (4,500 SOL vibrating wire transducers) were also checked to confirm that pressure readings were within 0.1% of the factory calibration values.

The installation bottom hole assembly (BHA) was prepared, and cable reel stands and other equipment deployed in preparation for running. MLS cables and tubing were laid out on a 100m run around the site perimeter on a heavy-duty polyethylene sheet. The installation was then RIH to the final setting depth at 99.97 m with the casing assembly as per the install tally (Solinst Waterloo MLS tubing 60.3 mm OD / 50 mm ID), attaching all line and the ERT and FO cables to the MLS tubing. The ERT and FO cables were tested together with the groundwater sampling pumps before commencing the backfilling operation. See **Section 4.5.6** for the backfill materials, intervals and the 8 x MLS port depth. Once the final layer of filter pack had been emplaced the upper section of the well from 12.35 m was grouted back to surface with Geotherm X grout.

4.5.6 Backfill and grouting operations

The backfill materials used in each of the 8 filter packs, including thicknesses, are detailed in **Table 29** below. Filter packs were constructed around the multilevel sample ports using 1-2mm quartz filter sand. Gravel layers were emplaced within the filter packs in places to guard against loss of filter sand into large fractures observed in wireline logs. Medium swelling Mikolit 300 bentonite pellets were used to form seals between the filter packs and the top ca. 12.0 m of the borehole was sealed into the unsaturated zone using Geotherm-X GR grout.

The gravel layers varied in composition, with 4-10 mm MGS gravel used in the deeper part of the well (below 40.0 m) and a low carbonate 6-10 mm Derby gravel used in the upper section where core scanning data indicated that the aquifer was depleted in carbonate. This was done to better match the gravel filter pack to the formation and so avoid it influencing the quality of sampled groundwater. The material specification sheets for each backfill material can be found in the appendices of this report.

Table 29 Backfill and grout summary table – TH0421

MLS Port depths M BGL	Material type	Depths from / to m BGL
	Geotherm-X GR grout	0.5 to 12.35 m
	Sharp sand	12.35 to 13.05 m
	Cement Bentonite Pellets	13.05 to 18.55 m
	Bentonite Pellets (Mikolit 300)	18.55 to 27.35 m
	1 - 2 mm MGS filter sand	27.35 to 30.34 m
	6-10 mm Derby Gravel	30.34 to 35.10 m
MLS Port 8 - 28.62 m	1 - 2 mm MGS filter sand	35.10 to 35.65 m
	Bentonite Pellets (Mikolit 300)	35.65 to 38.10 m
	1 - 2 mm MGS filter sand	38.10 to 38.40 m
	6-10 mm Derby Gravel	38.40 to 40.00 m
MLS Port 7 - 41.57 m	1 - 2 mm MGS filter sand	40.00 to 43.01 m
	Bentonite Pellets (Mikolit 300)	43.01 to 46.75 m
	1 - 2 mm MGS filter sand	46.75 to 47.33 m
	4 - 10 mm MGS Gravel	47.33 to 48.70 m
MLS Port 6 - 50.56 m	1 - 2 mm MGS filter sand	48.70 to 51.90 m
	Bentonite Pellets (Mikolit 300)	51.90 to 56.06 m
MLS Port 5 - 57.42 m	1 - 2 mm MGS filter sand	56.06 to 59.60 m
	4 - 10 mm MGS Gravel	59.60 to 61.90 m
MLS Port 4 - 68.24 m	1 - 2 mm MGS filter sand	61.90 to 62.55 m
	Bentonite Pellets (Mikolit 300)	62.55 to 66.10 m
	1 - 2 mm MGS filter sand	66.10 to 70.55 m
	Bentonite Pellets (Mikolit 300)	70.55 to 74.95 m
MLS Port 3 - 76.62 m	1 - 2 mm MGS filter sand	74.95 to 77.95 m
	4-10 mm MGS Gravel	77.95 to 79.40 m
MLS Port 2 - 85.31 m	1 - 2 mm MGS filter sand	79.40 to 79.90 m
	Bentonite Pellets (Mikolit 300)	79.90 to 84.10 m
	1 - 2 mm MGS filter sand	84.10 to 87.10 m
	Bentonite Pellets (Mikolit 300)	87.10 to 95.00 m
MLS Port 1 - 96.44 m	1 - 2 mm MGS filter sand	87.10 to 98.00 m
	4 - 10 mm MGS Gravel	98.00 to 102.00 m

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a retractable tremie pipe. Dry and wet samples of the grout were taken for future analysis if needed. The below table summarises the grout batches pumped:

Table 30 Grout backfill summary table – TH0421

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	30/05/23	50	96	1.68
2	30/05/23	50	96	1.70
3	30/05/23	50	96	1.72
4	30/05/23	50	90	1.68
5	30/05/23	50	90	1.68
6	30/05/23	50	90	1.68
7	30/05/23	50	90	1.69
8	30/05/23	50	90	1.69
9	30/05/23	50	90	1.69
Total		450	828	1.69 avg

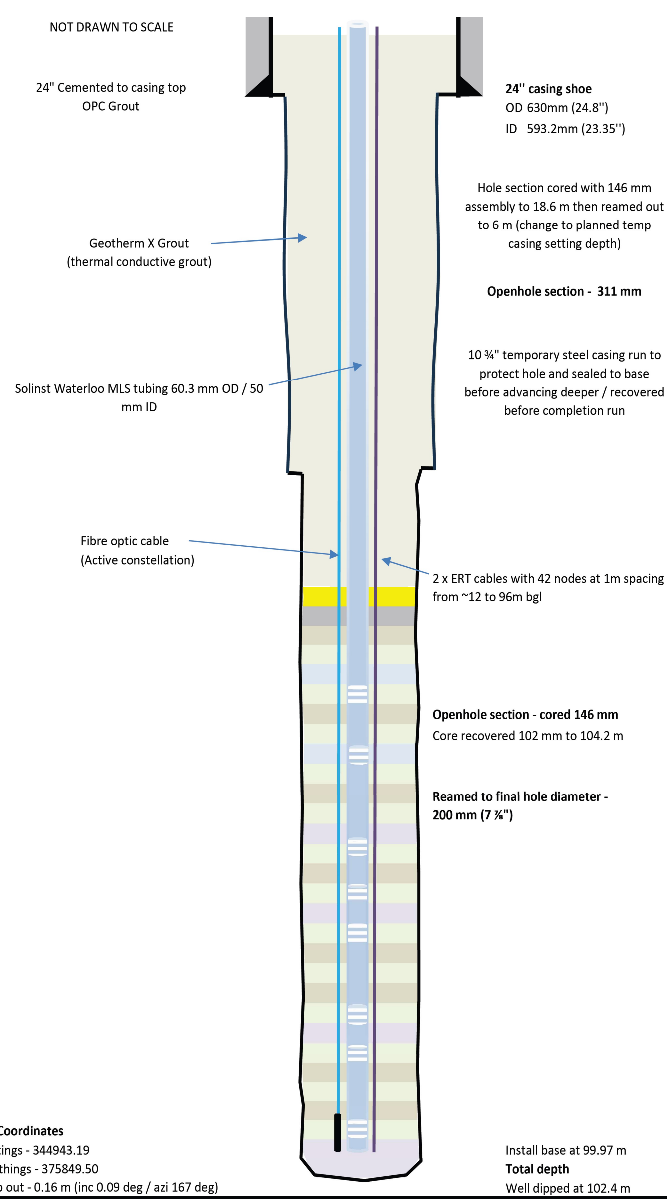
The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.5.7 TH0421 Borehole Well Schematic

Borehole coordinates: Eastings - 344943.05 Northings - 375849.585 Top 24" depth ref - 20.211 m AOD Top 24" to GL - 0.086 m	Well Schematic TH0421 MLS Borehole ●	British Geological Survey

Wireline logging undertaken	Tools run
Section logged inside temp casing to 6 m then 146 mm from 6 to 103.5 m. 16/05/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



TD Coordinates
Eastings - 344943.19
Northings - 375849.50
Step out - 0.16 m (inc 0.09 deg / azi 167 deg)

Depths m MD-BCT	Comments	Backfill depths
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)		
	Bedrock encountered at 1.75 m	
2 m	24" shoe depth	
	273 x 250 mm temp casing	Geotherm X Grout (thermal conductive grout)
6 m	Base of reamed upper section	
	Sharp sand	12.35 to 13.05 m
	Cement Bentonite Pellets	13.05 to 18.55 m
	Bentonite Pellets (Mikolit 300)	18.55 to 27.35 m
	1 - 2 mm MGS filter sand	27.35 to 30.34 m
	6-10 mm Derby Gravel	30.34 to 35.10 m
MLS Port 8 - 28.62 m	1 - 2 mm MGS filter sand	35.10 to 35.65 m
	Bentonite Pellets (Mikolit 300)	35.65 to 38.10 m
	1 - 2 mm MGS filter sand	38.10 to 38.40 m
	6-10 mm Derby Gravel	38.40 to 40.00 m
MLS Port 7 - 41.57 m	1 - 2 mm MGS filter sand	40.00 to 43.01 m
	Bentonite Pellets (Mikolit 300)	43.01 to 46.75 m
	1 - 2 mm MGS filter sand	46.75 to 47.33 m
	4-10 mm MGS Gravel	47.33 to 48.70 m
MLS Port 6 - 50.56 m	1 - 2 mm MGS filter sand	48.70 to 51.90 m
	Bentonite Pellets (Mikolit 300)	51.90 to 56.06 m
MLS Port 5 - 57.42 m	1 - 2 mm MGS filter sand	56.06 to 59.60 m
	4-10 mm MGS Gravel	59.60 to 61.90 m
MLS Port 4 - 68.24 m	1 - 2 mm MGS filter sand	61.90 to 62.55 m
	Bentonite Pellets (Mikolit 300)	62.55 to 66.10 m
	1 - 2 mm MGS filter sand	66.10 to 70.55 m
	Bentonite Pellets (Mikolit 300)	70.55 to 74.95 m
MLS Port 3 - 76.62 m	1 - 2 mm MGS filter sand	74.95 to 77.95 m
	4-10 mm MGS Gravel	77.95 to 79.40 m
MLS Port 2 - 85.31 m	1 - 2 mm MGS filter sand	79.40 to 79.90 m
	Bentonite Pellets (Mikolit 300)	79.90 to 84.10 m
	1 - 2 mm MGS filter sand	84.10 to 87.10 m
	Bentonite Pellets (Mikolit 300)	87.10 to 95.00 m
MLS Port 1 - 96.44 m	1 - 2 mm MGS filter sand	87.10 to 98.00 m
	4-10 mm MGS Gravel	98.00 to 102.00 m
Reamed to 103.7 m	Additional metres drilled for sump - debris in well and for logging tools	
Cored to 104.2 m		

Figure 33 TH0421 Well Schematic

4.5.8 Wellhead / Well Chamber Status

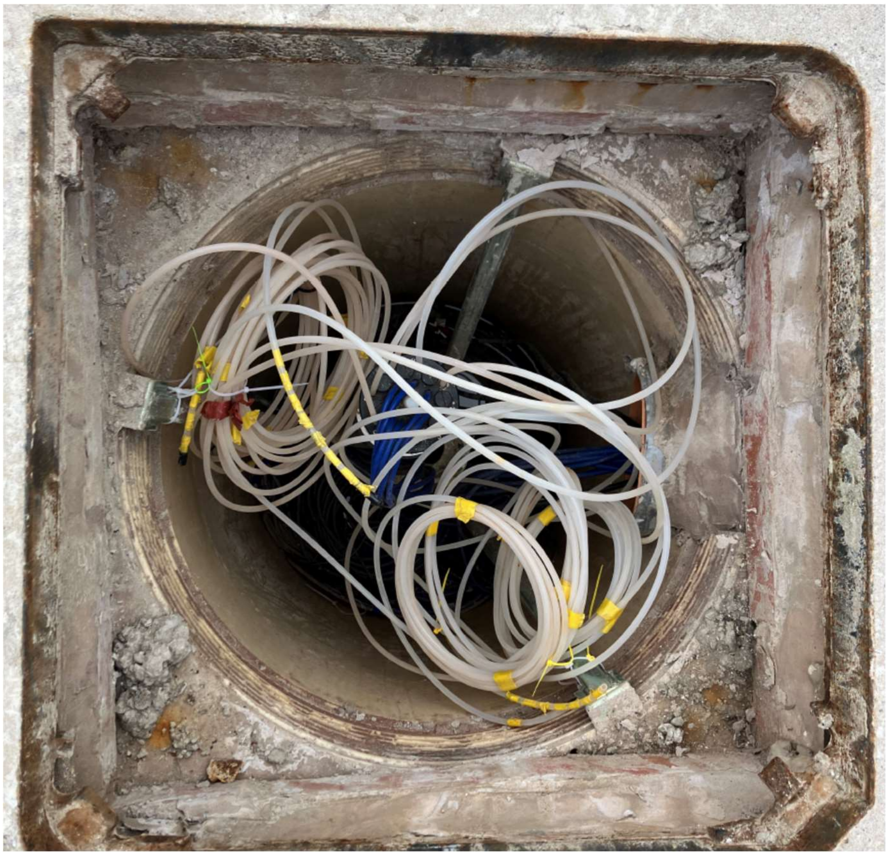


Figure 34 Wellhead chamber image TH0421

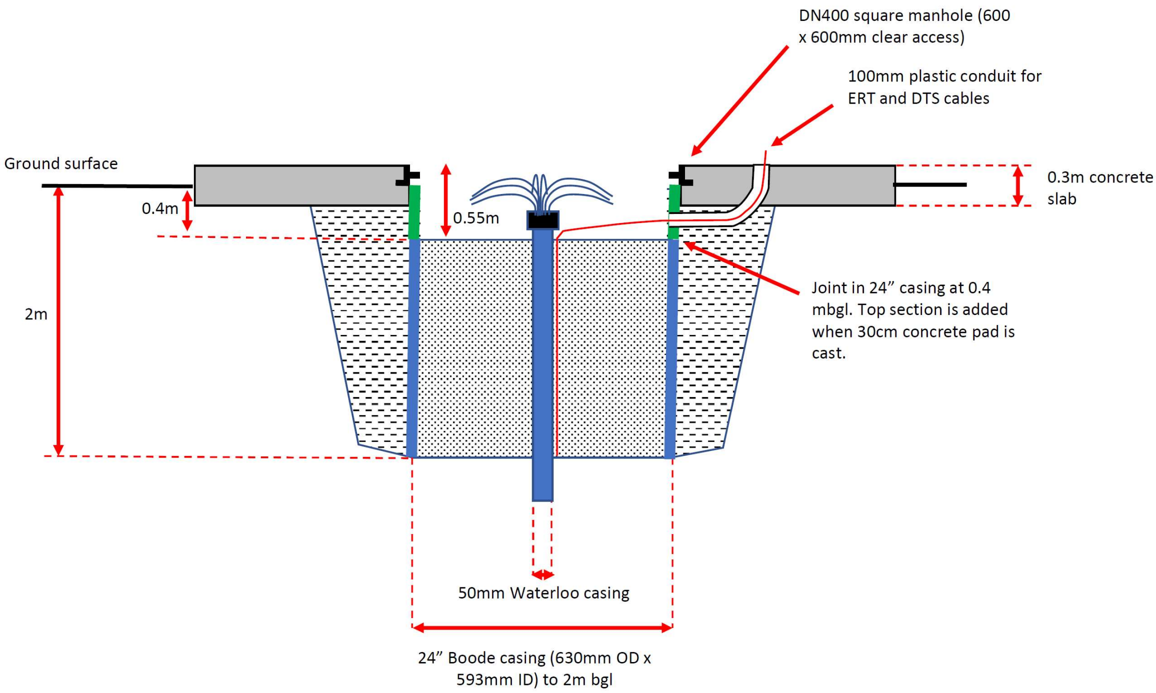


Figure 35 Wellhead chamber schematic TH0421

4.5.9 Daily Activity Summary

Table 31 Daily activity summary TH0421

Date	Depth M BGL	Operation	Parameters	Issues
08/09/22	2.0 m	Marriott levelled the rig work area with type 1 gravels and ran temp 7” casing centralised inside the 24” to 2.0 m and sealed with Bentonite at base.		Rig developed hydraulic filter leak. Rig crew attempted to fix and meanwhile mobilised engineer. 3 hours NPT.
09/09/22	18.6 m	Made up coring assembly and commenced coring from 2.0 m to 18.6 m before POOH. Recovered temp 7” casing.	ROP – 5 to 6 minutes per 1.5 m core run. Inc reading for TH0421: 0.42 deg @ 5.0 m. 0.17 deg @ 9.0 m. 0.36 deg @ 12.1 m. Losses – slowly increased to 60% and total loss were experienced from 16.1 m.	
12/05/23	18.6 m	The Soilmec rig was moved on to position over TH0421 and setup. The top section was reamed out to 311 mm down to 6.0 m before POOH. 10 ¾” temporary casing was run, centralised and the base sealed with Bentonite. Made up Geobore string and run in hole before displacing the well to clean water. Pulled back off bottom and setup surface hoses to shaker system in readiness for recommencing after weekend shutdown.		
15/05/23	98.2 m	Commenced coring from 18.6 m with the 146 mm Geobore assembly, cored to 51.7 m with good penetration rate and flush returns throughout. Night shift continued to core to 98.2 m with flush returns between 50 and 60%. Verticality readings all within tolerance.	Losses – good returns throughout reducing towards the base. returns confirmed to be between 50 and 60% by 98.0 m. Verticality checks: 0.40 deg @ 20.2 m. 0.18 deg @ 26.2 m. 0.07 deg @ 32.2 m. 0.17 deg @ 38.2 m. 0.34 deg @ 44.2 m. 0.11 deg @ 50.2 m. 0.27 deg @ 56.2 m. 0.26 deg @ 62.2 m. 0.28 deg @ 68.2 m. 0.24 deg @ 74.2 m. 0.18 deg @ 80.2 m. 0.21 deg @ 86.2 m. 0.21 deg @ 92.2 m. 0.30 deg @ 98.2 m.	
16/05/23	102.45 m	Ran back to bottom and continued to core ahead from 98.2 m to 104.2 m and total depth. Once TD was reached the hole was circulated clean before pulling out the Geobore string in preparation for wireline logging.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged from 6.0 m to 103.5 m.	Wireline - Interface surface box failed for the main tool suite to be run, mobilised replacement whilst

Date	Depth M BGL	Operation	Parameters	Issues
		EGS arrived and setup over the well but an issue with the surface interface box in the wireline unit was identified. Logged the borehole as per Scope running the acoustic imager first whilst waiting for a replacement surface box. All tools successfully run once box changed out. Made up and RIH the 200 mm reaming assembly and opened out the hole to total depth. Well circulated clean and displaced to clean water. Hole dipped at 102.45 m. Reamer assembly POOH.	Returns reported at the end of the coring however total losses occurred during reaming and didn't return until circa 70.0 m.	acoustic imager was being run.
17/05/23	100.8 m	Broke out the reamer assembly and laid down. Pulled out of hole the 10 ¾" casing and dipped the well to 101.9 m. Bentonite collar at 1.3 m below top of 24" casing (70 cm inside the 24" and the rest within the 200 mm hole). Jetting assembly RIH and flushed Bentonite from inside the 24" surface casing. POOH jetting BHA. Reran the 311 mm reamer to 6.0 m and cleaned the ledge of any remaining Bentonite before POOH. Well dipped at 100.8 m.		1 hour NPT waiting on a forward plan from Aecom to resolve Bentonite collar issue.
18/05/23	100.8 m	No well operations on TH0421.		
19/05/23	105.0 m	Well dipped at 99.25 m. Decision taken to run in hole with the Geobore pipe and attempt to flush the hole clean. Assembly washed down to 105.0 m into the pilot hole with visible signs of sand and debris in returns. Recovered the Geobore string. Started to prepare for the installation.		
TH0421 MLS Install				
22/05/23	102.4 m	Well dipped at 102.4 m. Commenced RIH the FO/ERT cable on the 60.3 mm PVC casing from the winches with plastic centralizers placed across PVC segment every 10.0 m. Install ran to 15.0 m before being suspended in the hole overnight.		
23/05/23	95.0 m	Continued running the MLS installation from 15.0 m to total depth. Carried out testing of ERT/DTS systems before pump testing the tubing lines – all tested good. Commenced backfill of the borehole as per the install design sheet to 95.0 m. When emplacing the first Bentonite layer the tremie became blocked. Attempted to remove blockage – see issues column for details.		Bentonite formed a bridge at ~ 36.0 m. Made attempts to clear the blockage – lowered blue 40 mm tremie pipe inside, ran water through the 60 mm tremie, repeated process with blue tremie pipe followed by water but no success.
24/05/23	70.55 m	Continued efforts to remove Bentonite blockage from inside yellow tremie pipe at 36.0 m. Managed to clear by pumping water down narrow alkathene pipe.		Second blockage in tremie at 82.0 m – cleared successfully.

Date	Depth M BGL	Operation	Parameters	Issues
		Continued to backfill the borehole to 70.55 m as per the install design sheet.		
25/05/23	38.4 m	Continued to backfill the borehole to 38.4 m as per the install design sheet.		
26/05/23	18.55 m	Continued to backfill the borehole to 18.55 m as per the install design sheet.		
30/05/23	1.0 m	Completed back filling operations with final layer being installed back to 12.35 m. Rigged up grout mixer and grouted the annulus from 12.35 m to 1.0 m below casing top via the recoverable tremie pipe.	Grout mix used per batch: • 4 x 24 kg bags of Geotherm X. • 50 Litres of water. Mixes pumped: 1: 1.68 sg. 2: 1.70 sg. 3: 1.72 sg. 4: 1.68 sg. 5: 1.68 sg. 6. 1.68 sg. 7. 1.69 sg. 8: 1.69 sg. 9. 1.69 sg.	Grout in place at 15:30 hrs. Samples placed in fridge. Decision to wait at least 6 hrs before commencing coring in TH0418 due to proximity and possible communication between boreholes (depending on firmness of the grout in the well and the samples).
TH0421 complete				

4.6 ISSUES ENCOUNTERED AND SOLUTIONS – MLS WELLS AND CENTRAL BOREHOLE

Table 32 Summary table of issues encountered – MLS and central borehole

Well number	Issue	Solution / lessons learned
TH0410	Vibration in coring assembly.	The drillers chose to use the 146 mm coring assembly instead of the planned 152 mm assembly due to excessive vibrations encountered. This resulted in TH0410 having to be reamed open by 6 mm. This process resulted in cuttings at the base of the borehole. Due to the flush losses encountered, removal of these cuttings from the well by flushing alone was not possible. The borehole was over-drilled to allow cuttings to fall into base sump allowing the target depth to be achieved. Worn rig parts (drive head shaft and bushings) replaced with more frequent plant inspections going forward. Consideration of drilling of sumps to avoid airlifting operations. Use of 146 mm lead Geobore lead length with 152 mm reaming shell believed by drillers to reduce vibration.
TH0410	Stuck FLUTe liner.	Liner level allowed to drop initially reducing the hydrostatic pressure on the borehole. This may have been a contributing factor however borehole proximity and open fractures would still have meant cuttings build up behind the liner which is the primary cause of the liner becoming pinned. Stuck liner had to be recovered by working drill rods down the outside of the liner and flushing the sediment from the annulus down to the bottom of the well. A learning from the process was to drill and cleanout TH0410 once all other boreholes in the vicinity has been drilled instead of relying on a liner. Have a replacement liner onsite for any liner recovery operations in the event the installed liner is damaged during recovery.
TH0420	Flush Loss.	LCM pills to be considered at the base of the intermediate casing to seal any loss zones. This would prevent the migration of thermal grout backfill away from the borehole. From the intermediate casing to total depth, the boreholes were cored and reamed using water flush only. If cuttings couldn't be recovered, use of air lift was adopted to remove cuttings from the hole and cleanup open fractures.
TH0420	Stuck temporary casing.	Casing of a similar OD to the diameter of the hole was run. This was due to internal diameters being referenced by the drilling contractor and not the outside diameter. The contractor should have flagged the tight tolerance between the annulus before running and asked for clarification. Ensure all components to be run into boreholes are checked and the OD/ID confirmed in advance. This can then be cross checked against the well geometry and clearances confirmed before proceeding. This should be

Well number	Issue	Solution / lessons learned
		completed by the Principal Contractor and witnessed by BGS. Procedural issue. For subsequent holes, the following method was used: Open out the existing Geobore pilot hole to 311 mm (12 ¼”) down to 6.0 m. Run in 10 ¾” temp steel casing and centralise within the surface casing. Seal around the base using a thin layer of Bentonite pellets. Centralise 7” Geobore casing within 10 ¾” casing. Core using Geobore to target depth (with verticality checks), open out borehole to larger diameter.
TH0420	Incorrect diameter hole.	Incorrect diameter reamer picked up and run (222 mm rather than 200 mm as stated in the Scope). Hole openers diameters colour coded following the above to assist the rig crew in identification onsite and reduce the chance of this reoccurring.
Wireline / geophysical logging	Vertical scoring on wireline logs undertaken in reamed holes.	Although the exact cause is unknown (measurement taken of reamer and pulling techniques changed), the acoustic wireline logging run within reamed boreholes has resulted in visual “scoring” of the acoustic image resulting in a poor-quality log. Geophysical logging was undertaken in the cored borehole prior to reaming where possible on all later wells.
All MLS wells	Blocked tremie pipe when back filling.	Speed of delivery of each back fill material was key. It was also learned that constantly running water through the 60 mm tremie helped to remove most blockages. A smaller 40 mm tremie and alkathene pipe were available if needed to run inside and work any blockages.

4.7 GROUND SOURCE HEAT BOREHOLE – TH0416 SUMMARY OF OPERATIONS

4.7.1 Key Well Data

Table 33 TH0416 Key well data

Well name	TH0416		
Well classification	Closed loop ground source heat well (GSH)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.095 m AOD Top 24" to GL - 0.070 m		
Start date	Intermediate section started on 28/03/23 and was completed on 29/03/23. Lower section started 29/03/23.		
End of drilling date	12/04/23.		
Install dates	Install 12/04/23 to 13/04/23, Grouted 14/04/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 222 mm	Cored to 7.4 m Reamed to 6.0 m	Temporary 168.3mm OD x 155.7mm ID casing, recovered before completion run	6.0 m
Final section to TD Cored in 152 mm	Cored to 101.9 m Base of the well cemented and drilled out to 101.5 m	n/a	n/a
Installation	n/a	40 mm OD Haka heat exchanger loop with EZ Snap 60125 XT centralisers at 3.0 m spacing	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344940.132 Northing Y: 375841.083	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44940 75841	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344939.81 Northing Y: 375840.66 Step out - 0.53 m (inclination 0.33 deg / azimuth 191 deg)	

4.7.2 Summary of Drilling Operations

The Comacchio rig was mobilised and rigged up over TH0416. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled, to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 7.4 m with 100% returns. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered and replaced with a string of 10 ¾” casing, sealed with Bentonite at the base.

A 222 mm reamer and pilot bit was made up, and the hole was opened out down to 6.0 m and the well circulated with full returns before POOH. The temporary 10 ¾” casing was recovered and replaced with the 7” string down to 6.0 m. The annulus was sealed again with Bentonite pellets.

Made up and RIH the 152 mm Geobore assembly and cored ahead to 11.5 m where total losses were encountered. Continued to core down to 13.4 m before treating the well with LCM to stem the losses before advancing deeper.

Continued to core treating loss zones with LCM as the assembly advanced deeper. All LCM pills were deployed via a 40 mm tremie pipe and after being allowed to soak for a determined length of time the well was circulated and any returning LCM material diverted into a waste tank. This process was needed to avoid circulating LCM through the rig pumps and drill bit which could cause either to become blocked. Details of products used can be found in **Section 4.7.3**.

The well was successfully cored to total depth at 101.9 m and treated with LCM (80 ppb pills). The well was confirmed to be static before POOH.

The 7” casing was recovered before running a cleanout assembly (222 mm reamer assembly) down to the shoulder at 6.0 m and removed any remaining Bentonite before POOH. A cleanout BHA was run to total depth and circulated out any remaining LCM material. The well was monitored but the well wouldn’t stand full with the fluid level dropping to between 6.0 m and 7.0 m below GL. The 40 mm tremie pipe was run to bottom and a further 80 ppb LCM pill was pumped and allowed to soak. Excess LCM material was circulated out before dipping the well at 6.1 m. POOH the cleanout assembly in preparation for wireline logging.

EGS were mobilised and the well wireline logged from 6.0 m to 101.8 m. Full details of wireline logging programme undertaken can be found in **Section 4.7.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The decision was taken to seal the fractures at the base of the well with grout. A total of 2 x 160 L OPC grout mixes were pumped. Both mixes were delivered via a tremie pipe. After the first pill had been pumped and allowed to set the well dipped at 100.3 m and the water level was down at the water table at approx. 14.0 m. After the second pill the well dipped at 95.5 m.

The 146 mm Geobore assembly was run back in hole and hard cement tagged at 98.3 m which was drilled out to 101.5 m with good returns. The tremie pipe was RIH to bottom and 1,000 L of residual LCM was pumped before POOH.

Due to the wrong Geobore assembly being picked up the 152 mm assembly was RIH and the section between 98.3 m and 101.5 m was opened out to achieve Scope.

The string was pulled back to 70.0 m, and a falling head test was conducted to check if the grout level could be monitored during the back filling of the installation. The fluid level was observed to be rising at 1.0 cm per minute inside the 24’’ casing with a pump rate of ~15 L/minute to simulate the grout pumping rate. POOH in preparation for the installation.

4.7.3 Materials, Flush and Drilling Additive Used

A water and LCM approach was taken to drill TH0416. This decision was made based on information obtained using a polymer mud system in other closed loop wells. Maintaining the polymer mud at the required specification and also building new mud offline was time consuming. The well was successfully drilled but as detailed above the well did not stand full when total depth had been reached meaning that during the grouting stage the volumes pumped couldn’t be monitored based on returning volumes to ensure grout wasn’t being lost into fracture and sealing off preferential flow paths permanently. The solution was to utilise the ERT system which was very successful. Full details on this can be found in **Section 4.7.6**.

Table 34 Drilling fluid summary table – TH0416

	TH0416
Type of drilling mud used	Water
Section of well used	Intermediate and lower sections
Recorded drilling mud losses (L)	26,712
Ultrabore additive lost (kg)	n/a
Purebore additive lost (kg)	n/a

The below table summarise the lost circulation materials used, and the number of pills pumped whilst drilling both the intermediate and lower sections of the well. Each pill was 100 L in volume with various concentration of products based on loss rates being experienced and an understanding on how known fractures at given depths reacted.

Table 35 LCM pills deployed – TH0416

	TH0416
Section of well used	Intermediate and lower sections
LCM pills pumped	14
Volume of LCM pills pumped	1,400
Purebore additive used (kg)	20.5
Clear Stab additive used (kg)	98.4
Nut Plug (kg)	196.8
Flaked Mica (kg)	32.4

Note: volumes stated above are the volumes of LCM pumped. Each pill was allowed to soak on depth before circulating to confirm if the treatment had been successful. A large percentage of each LCM pills pumped were circulated out and disposed of.

Due to large fractures being encountered that couldn't be controlled with LCM alone, the decision was taken to emplace two cement plugs at the base of the well as detailed below in **Table 36**.

Table 36 Summary table of grouting operations to stem losses – TH0416

	TH0416
Grout pills pumped to stem losses	1 x OPC grout plug (6 bags grout, 3 kg Bentonite (1.5%) and 100 L of water at 101.9 m. 1 x OPC grout plug (6 bags grout, 3 kg Bentonite (1.5%) and 100 L of water at 100.3 m.
Water volume (L)	200
OPS grout (kg)	300
Bentonite (kg)	6
Geotherm-X GR grout (kg)	0

The LCM pills deployed and grout to the base allowed the well to remain static and full whilst the installation was run and grouted.

4.7.4 Geophysical Logging Undertaken

Table 37 Geophysical logging summary TH0416

Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 101.8 m. 05/04/23	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.53 m and within the 1/100 tolerance.

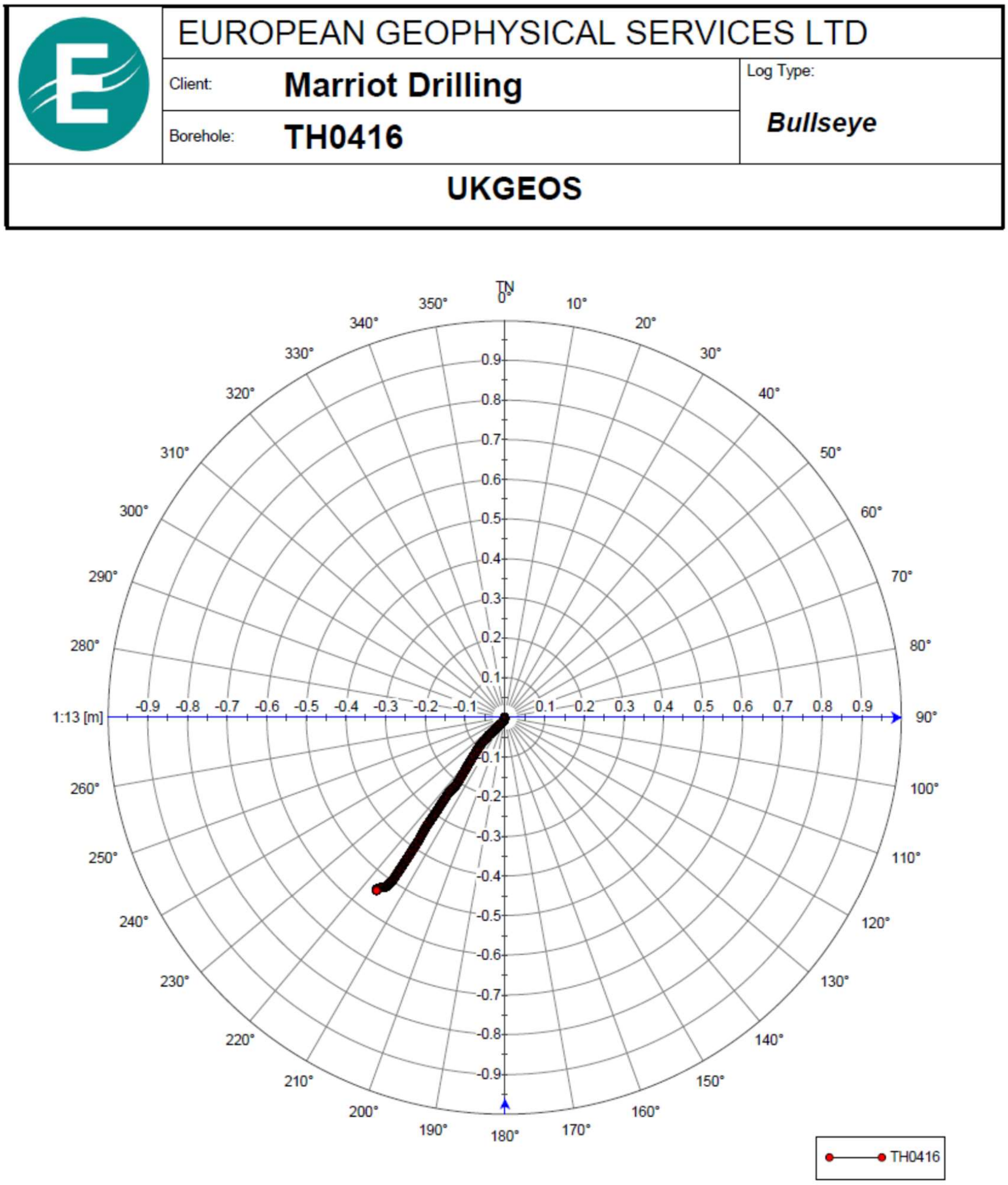


Figure 36 Verticality bullseye plot for TH0416, © European Geophysical Services Ltd

4.7.5 Summary of Installation Operations

Installation criteria for TH0416:

- Ensure well is standing full and static before commencing the installation.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography, Beaded stream thermistor cables and fibre optic cables on the outside of the borehole heat exchanger ensuring that ERT electrodes are at correct depths.
- Run passive fibre optic cable through the centre of the heat exchanger.
- Deploy heat exchanger with EZ snap centralisers to ensure heat exchanger is in contact with the borehole wall before grouting operations.

- Accurately monitor the deployment.
- Maintain heat exchanger in tension during backfill using insulated base weights to counteract buoyancy during running.
- Grout the borehole in a single stage if possible but with contingency of a backup tremie in the event of any issues.
- Backfill with a continuous column of grout, with uniform density to ensure consistent thermal properties as per suppliers' specifications.
- Prevent loss of grout into open fractures and monitor grout returns throughout.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared for running the installation. Spotted the cable reel stands and equipment. Moved the telehandler into position with the Loop Master with the heat exchanger spooled already. The passive FO cable was threaded through the centre of the heat exchanger, tested by Silixa and pressure tested to 7.5 bar following the GSHPA guidelines in advance of the installation operation.

The BHA assembly was made up, however due to the residual bend of the heat exchanger loop the lower section had to be tie wrapped and additional short length of tremie pipe used to act as a splint. The heat exchanger weights were encapsulated inside a section of 60 mm yellow PVC pipe and sealed at the top and bottom to avoid any chance of interference with the ERT array.

The heat exchanger was run in hole as per the installation sheet securing all the cables to the permanent tremie and heat exchanger loop with tie wraps. See **Figure 37**. Centralisers were placed every 3.0 m to ensure the correct standoff from the borehole wall was achieved. The centralisers used were EZ Snap 60125 XT for the 40 mm OD Haka heat exchanger loop.

As the last few metres of the 100.0 m heat exchanger loop were spooled off the Loop Master the loop became snagged resulting in a kinked section of pipe. The operation was stopped and the damage assessed but it became apparent that this section was excess and would be removed when the final termination would be made. The Loop Master was lowered to the ground and the damaged section removed. All cable strings were tested (FO, ERT and thermistor strings) before rigging up and pressure testing the heat exchanger loop to 7.5 bars for a second time, again following the GSHPA guidelines and in accordance with the SN EN80. A good test was observed.

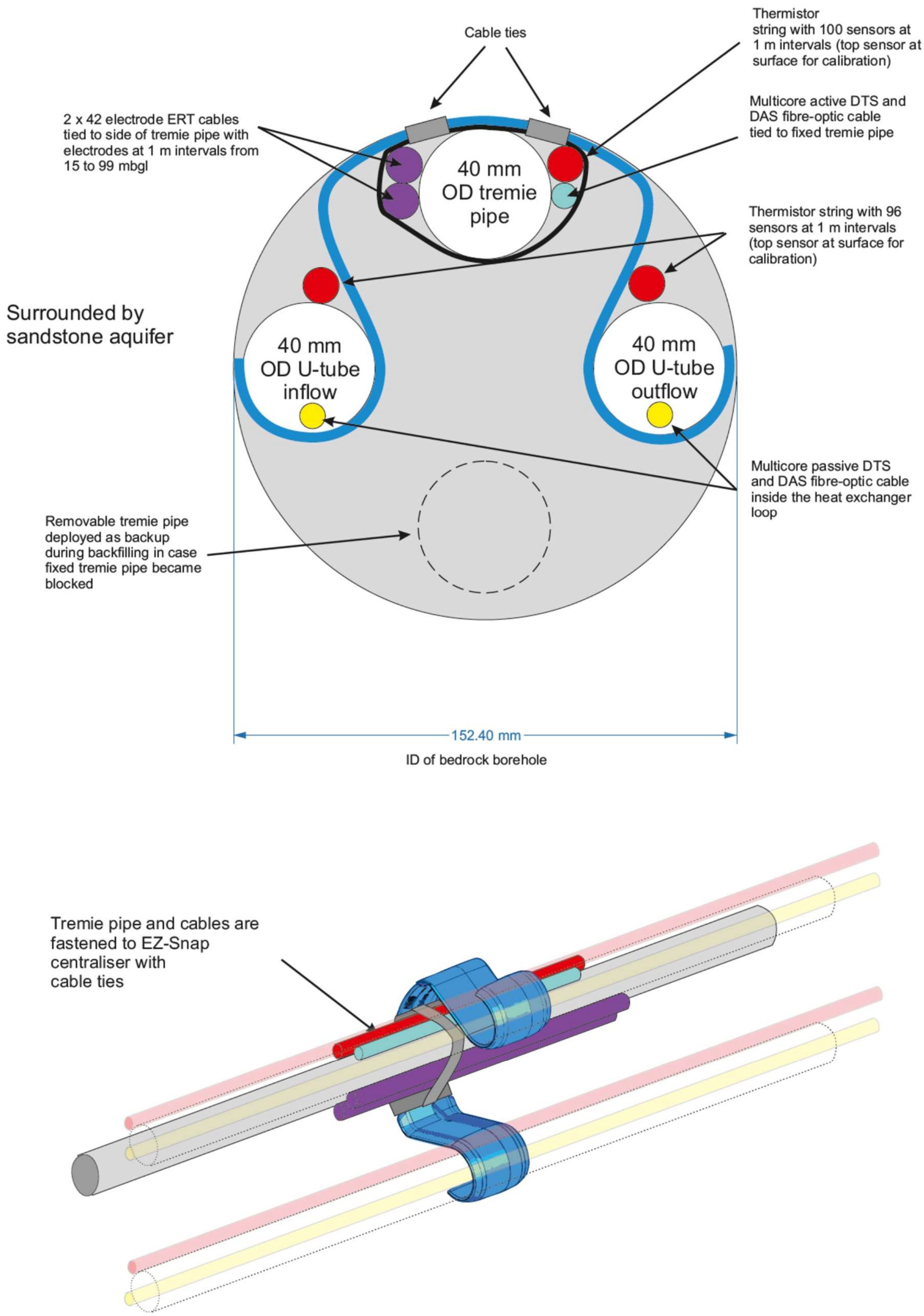


Figure 37 Schematic showing the placement of the various sensor cables on and within the installation for TH0416

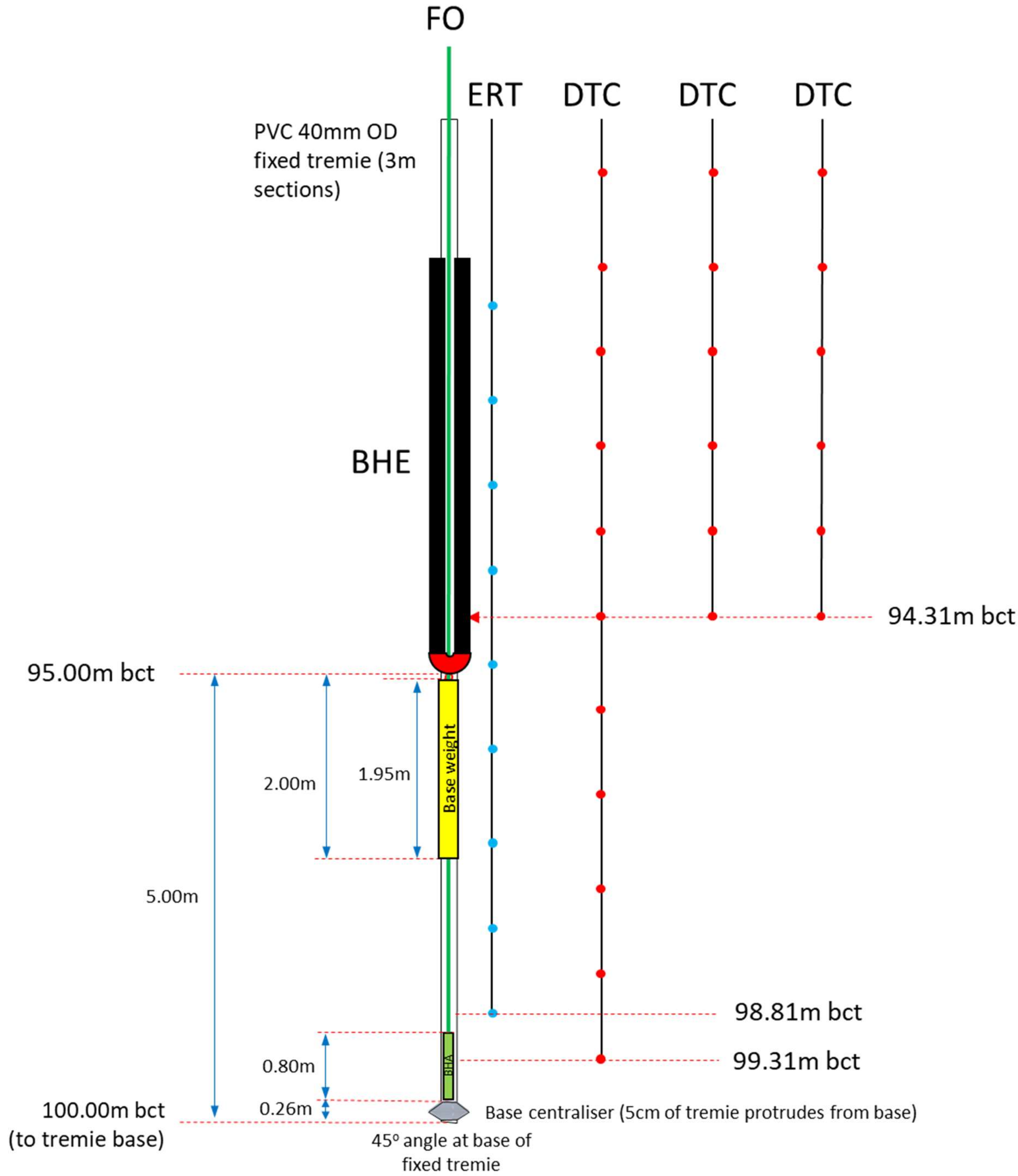


Figure 38 TH0416 bottom hole assembly schematic showing the depth of the install and bottom of each sensor string.

Figure 39 Image showing the Loop Master in operation as the installation is run.

The grouting equipment was rigged up which comprised of a batch mixer and screed pumper. This setup allowed the continuous delivery of grout into the well with each grout batch being mixed offline until the correct weight and viscosity was achieved before transferring over to the active grout pump. Grouting operations commenced and progressed without any issues until the 10th mix was pumped and the primary tremie pipe became blocked. This resulted in the backup tremie having to be used which happened seamlessly with only a short pause in the operation. A total of 14 mixes were pumped before grout returns were seen on surface. The ERT system was utilised to monitor the cement migration up the well and ensure no lateral migration of grout into the fractures was occurring due to no returns until the latter stages of the cement job. The LCM strategy had successfully sealed off the loss zones and the installation successfully grouted back to surface. Full details of the grouting operation including the mixes used are detailed in **Section 4.7.6**.

4.7.6 Backfill and grouting operations

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via permanent sacrificial tremie pipe. A backup retractable tremie was also deployed to total depth before the completion was run and pulled back in stages during the grouting operation, always keeping above the top of cement (TOC). This backup tremie was only used in the event a blockage occurred in the primary.

Real-time data were collected from the thermistor cables and ERT sensors by BGS during the grouting operations. This was observed to track the upward progress of the grout via temperature and conductivity change respectively as the grout moved up the annulus.

This was to give forewarning of significant grout loss to formation and pressures were monitored at the cement unit to signs of blockages occurring. If the temperature and conductivity remained stationary at a given depth, then this would indicate grout was flowing laterally outwards into fractures which was to be avoided at all costs.

The Geotherm X grout was found to have a range of weights per bag from the supplier, so all bags were pre weighed and stacked in batches ready for mixing to ensure a more consistence grout weight and viscosity.

The grouting rig up consisted of two grout units; the primary was used to deliver the grout into the well, and the secondary allowed the next batch to be mixed offline before being transferred to the primary unit. This ensured a constant delivery of grout without having to stop which would have increased the risk of the tremie pipe becoming blocked. The two-unit system was developed due to the limitations on grouting equipment and the size of mix hoppers available.

The backup tremie had to be used due to blockage occurring in the primary fixed tremie after the 10^{th} batch of grout had been pumped. The backup tremie pipe had been RIH before the installation and retracted during the grouting operation and maintained above TOC. The distance the tremie pipe had to be pulled back was calculated based on a gauge hole and volumes of grout pumped. Fluid returns were monitored throughout to ensure grout continued to fill the well and not travel laterally into fractures. The LCM pills pumped had successfully sealed off the problematic loss zones.

Dry and wet samples of the grout were taken for future analysis if needed. The below table **(Table 38)** summarises the grout batches pumped:

Table 38 Grout backfill summary table – TH0416

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	14/04/23	100	180	1.71
2	14/04/23	102	180	1.70
3	14/04/23	100	180	1.71
4	14/04/23	100	180	1.70
5	14/04/23	100	180	1.71
6	14/04/23	100	180	1.69
7	14/04/23	100	180	1.69
8	14/04/23	100	180	1.70
9	14/04/23	100	180	1.69
10	14/04/23	100	180	1.69
11	14/04/23	100	180	1.69
12	14/04/23	100	180	1.68
13	14/04/23	100	180	1.80
14	14/04/23	100	180	1.69
Total		1,402	2,520	1.70 avg

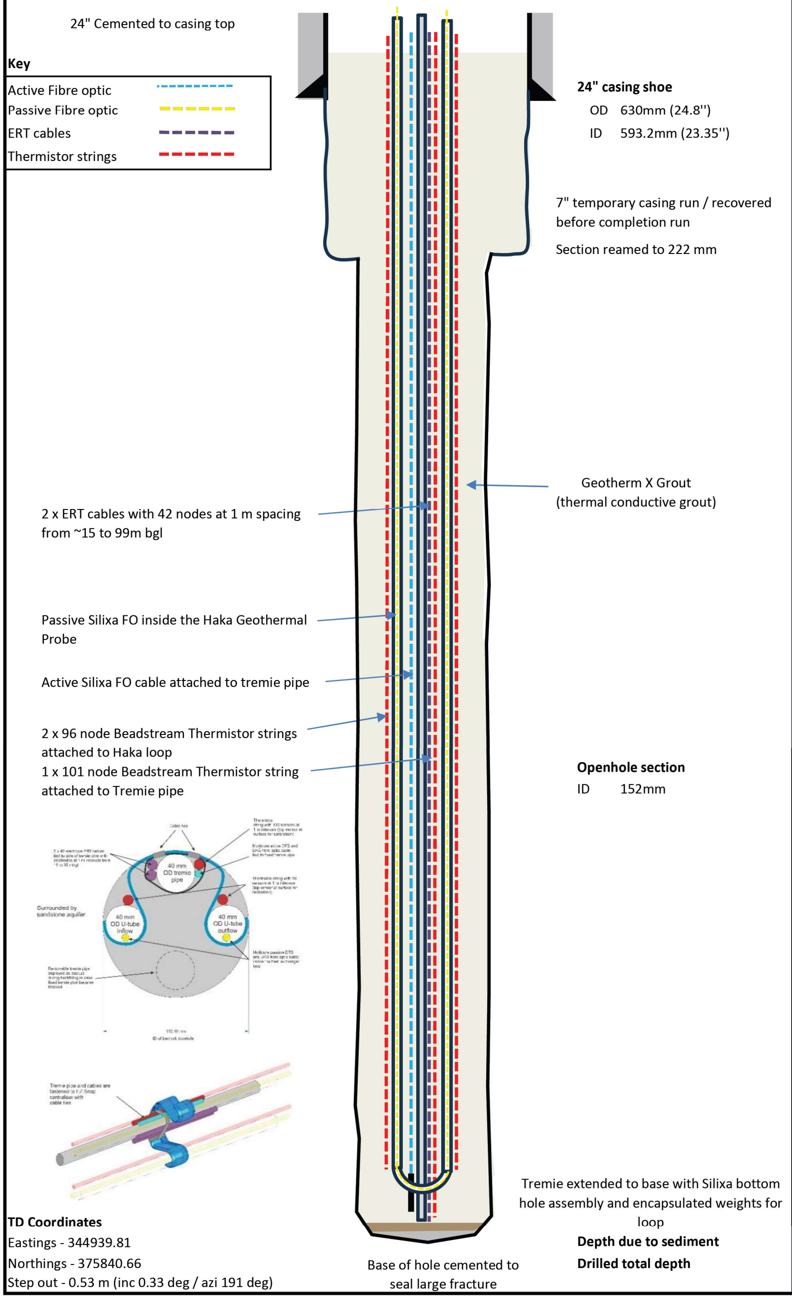
The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.7.7 TH0416 Borehole Well Schematic

Borehole coordinates:	Well Schematic TH0416 GSH Borehole	British Geological Survey
Eastings - 344940.132 Northings - 375841.083 Top 24" depth ref - 20.095 m AOD Top 24" to GL - 0.070 m		

Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 101.8 m. 05/04/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



TD Coordinates
Eastings - 344939.81
Northings - 375840.66
Step out - 0.53 m (inc 0.33 deg / azi 191 deg)

Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
0.95 m	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
	Well drilled with water
6 m	Base of reamed upper section
	Loss zones were cured as they occurred with LCM
	Centralisers used on the install were EZ Snap 60125 XT at 3 m spacing for the 40 mm OD Haka heat exchanger loop
100.0 m	Install depth
100.4 m	
101.5 m	Additional metres drilled for sump - debris in well and for logging tools

Figure 40 TH0416 Well Schematic

4.7.8 Wellhead / Well Chamber Status

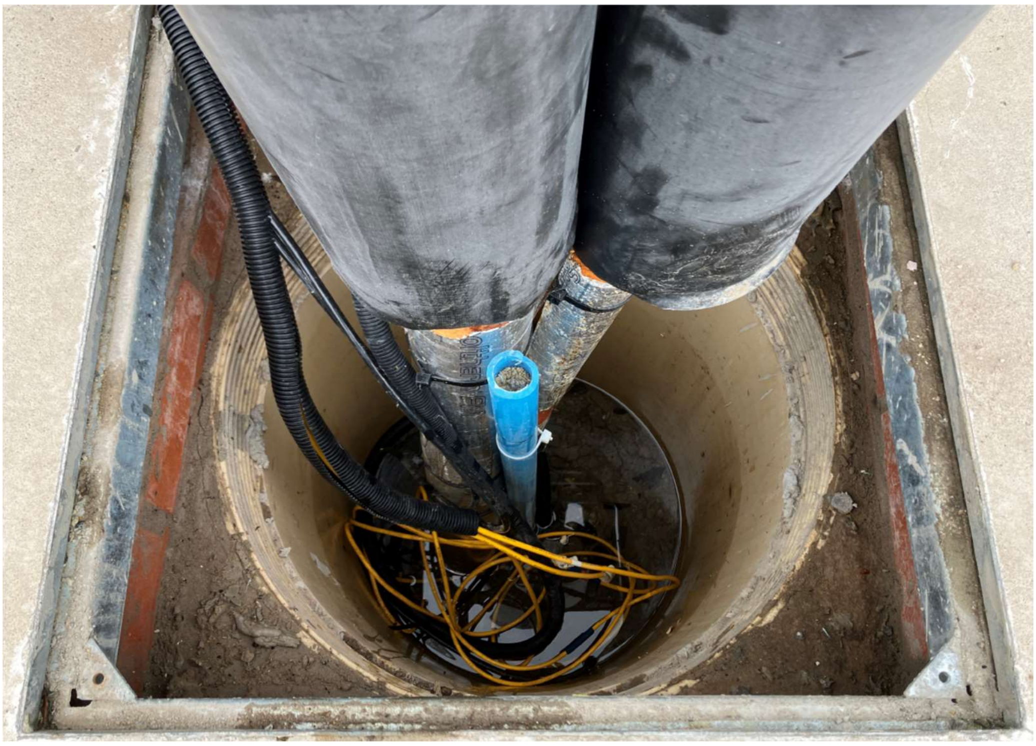


Figure 41 Wellhead chamber image TH0416

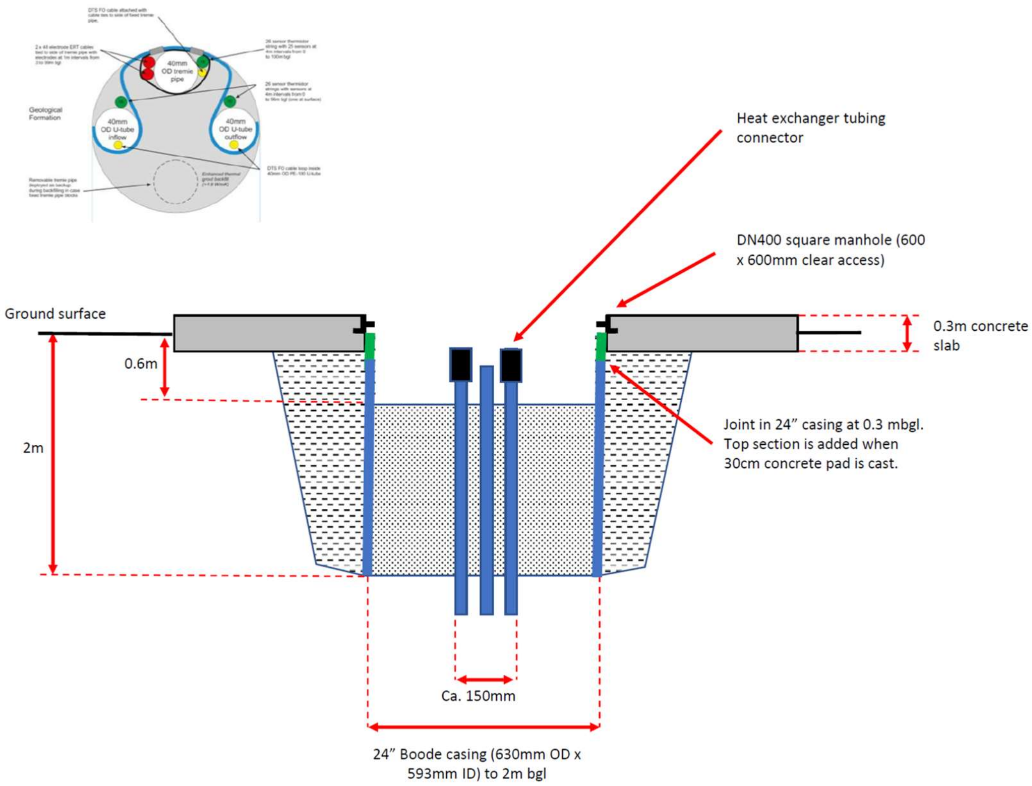


Figure 42 Wellhead chamber schematic TH0416

4.7.9 Daily Activity Summary

Table 39 Daily activity summary TH0416

Date	Depth m bgl	Operation	Parameters	Issues
28/03/23	7.4 m	Comacchio rig moved over TH0416 and rigged up. Ran temp 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite at base. Made up and RIH the 146 mm coring assembly and cored to 7.4 m with 100% returns. Recovered the coring assembly and the 7" temporary casing.	100% returns. Verticality checks: 0.53 deg @ 4.4 m. 0.13 deg @ 7.4 m.	Note: 146 mm Geobore used for the top-hole section because of hardcore in the 24'' casing. 146 mm standard bits are less expensive than the 152 mm version.
29/03/23	26.9 m	Picked up and set 10 ¾'' casing at 2.0 m. Sealed the casing with Bentonite at the base. Made up and RIH the 222 mm reaming assembly and opened out the section down to 6.0 m with full returns. POOH and laid out assembly. Recovered the 10 ¾" temporary casing and ran 7" casing down to 6.0 m and sealed annulus with Bentonite pellets at the base. Made up and RIH the 152 mm coring assembly and cored ahead to 11.5 m where total losses were encountered. Cored to 13.4 m before treating loss zone with LCM pill. Continued to core ahead treating fractures with LCM pills down to 26.9 m.	Verticality checks: 0.4 deg @ 13.4 m. 0.12 deg @ 19.4 m. 0.49 deg @ 25.4 m. 4 x 100 L LCM pills pumped from 11.5 to 26.9 m. Note: all LCM pills pumped via 40 mm tremie pipe not through drill string.	Fractures difficult to seal with LCM pills being pumped.
30/03/23	55.4 m	RIH Geobore assembly and pumped out residual LCM at 26.9 m. Flow checked the well and observed 7 cm drop in well fluid level. Decision made to continue coring. Cored ahead treating fractures with LCM pills down to 55.4 m.	Verticality checks: 0.32 deg @ 31.4 m. 0.13 deg @ 37.4 m. 0.24 deg @ 43.3 m. 5 x 100 L LCM pills pumped from 26.9 to 55.4 m.	Fractures difficult to seal with LCM pills being pumped.
31/03/23	82.4 m	Continued to core ahead treating fractures with LCM pills down to 82.4 m. Pulled back assembly and made safe for the weekend.	Verticality checks: 0.41 deg @ 61.4 m. 0.42 deg @ 67.4 m. 2 x 100 L LCM pills pumped from 55.4 to 82.4 m.	Fractures difficult to seal with LCM pills being pumped.
03/04/23	101.9 m	RIH with Geobore to ~79.4 m. Washed down to TD at 82.4 m. Established returns at approx. 50% before continuing to core ahead. Cored ahead treating fractures with LCM pills down to well TD at 101.9 m where total losses occurred. RIH with 40 mm tremie pipe to TD and pumped an 80 ppb LCM pill. POOH with tremie pipe and allowed LCM to soak. POOH with Geobore assembly before recovering the 7" temporary casing installed to 6.0 m. RIH with 222 mm reamer and washed/cleaned down to the 222 x 152 mm shoulder at 6.0 m before POOH the reamer. Ran back to bottom and circulated out any excess LCM material.	Verticality checks: 0.32 deg @ 85.4 m. 0.36 deg @ 91.4 m. 2 x 100 L LCM pills pumped from 82.4 to 101.9 m. Pills pumped were 80 ppb.	Total losses occurred on the final core run which was drilled for a sump.

Date	Depth m bgl	Operation	Parameters	Issues
04/04/23	101.9 m	RIH with Geobore to TD and attempted to fill the well. Unable to bring fluid level to surface, level remained between 6.0 m and 7.0 m after 30 minutes of pumping. Pulled back Geobore and ran a 40 mm tremie pipe to TD before spotting an 80 ppb LCM pill on bottom. After leaving to soak, RIH Geobore assembly to TD and circulated out excess LCM. Continued pumping, fluid level only at 6.1 m. POOH assembly in preparation for wireline logging.	1 x LCM pill pumped to seal fracture at the base of the well.	Well fluid level standing at 6.1 m after LCM treatment.
05/04/23	101.9 m	EGS arrived and setup over the well. Logged the borehole as per Scope before rigging down and leaving site. Positioned grouting equipment at TH0416. Meanwhile held meeting to decide way forward. RIH with tremie pipe to TD at 101.9 m. Mixed and pumped 1 batch of OPC grout at 1.68 sg with 100L of water 6 bags of grout, 3 kg of Bentonite powder. Pulled back 3 lengths of tremie pipe and flushed through the hose/tremie pipe with water. Continued POOH tremie pipe to surface. Wait on cement.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged from 6.0 m to 101.8 m. Note:1 batch of grout fully mixed with product gives approx. 160 L of grout volume which at 18 L/m in 152 mm hole gives approx. 9.0 m coverage in open hole (not allowing for seepage into the fracture(s)).	
06/04/23	95.5 m	Dipped the well and found the grout level at 100.3 m. Attempted to fill the well with water at the 15 L/min (grout pumping rate). After pumping the equivalent of 12.5 m of hole volume, the water level rose by only 0.38 cm. Standing water level was at the water table approx. 14.0 m below GL. RIH the 40 mm tremie pipe to 100.3 m to repeat the grout treatment. Mixed and pumped a second batch of OPC grout at 1.68 sg with 100L of water 6 bags of grout, 2 kg of Bentonite powder. Pulled back 3 lengths of tremie pipe and flushed through the hose/tremie pipe with water. Continued POOH tremie pipe to surface. Wait on cement. Dipped well at 95.5 m. RIH Geobore to 70.0 m in readiness to drill out after the weekend.	Second cement pill appears to have sealed the fractures at the base of the well.	The grout pill pumped appears to have mostly flowed into a fracture, possibly at the very bottom of the hole which was not seen by the acoustic imager. The TOC does not appear to have reached the fracture seen on the log at ~100.0 m.
11/04/23	101.5 m	Dipped the well and found the grout level at 98.3 m. Performed flow check on the well before RIH with Geobore from 70.0 m to 93.0 m and cored out the cement to 101.5 m. Added polymer to residual LCM in IBC. RIH with tremie pipe to 101.5 m. Pumped 1,000 L of the residual LCM mixture downhole from IBC before POOH tremie. Made up and RIH 152 mm assembly and washed / reamed in hole opening out the hole from 146 mm to 152 mm to TD.	Constant returns seen from approx. 96.5 m to TD with slow water level drop inside the 24'' casing.	Note: The 146 mm core barrel was used in error. There will be an additional operation to ream out the grouted section from 146 mm to 152 mm.

Date	Depth m bgl	Operation	Parameters	Issues
12/04/23	100.3 m	Circulated the hole clean before POOH the 152 mm assembly back to 70.0 m. Conducted 'falling head' test to check if grout level can be monitored during the job. Observed fluid level rising at 1 cm/minute inside the 24'' surface casing when pumping at a rate of ~15 L/minute to simulate the grout pumping rate. POOH. Prepared for running the installation. Spotted cable spoolers and associated equipment for running the GSH installation including the Loop Master. Lifted the BHA up over the well and attached ERT and FO cables. RIH installation as per the install design sheet to 12.0 m.		Well dipped at 100.3 m before commencing running installation. Tie wrapped the centraliser tremie, base weight and strengthening tremie together. This was needed to straighten the residual bend of the GSH loop to allow it to be RIH without snagging.
13/04/23	100.3 m	Continued RIH the GSH installation from 12.0 m to 100 m as per design sheet. Lowered Loop Master to ground and prepared to test cables. Cut off damaged section of BHE loop. Tested thermistor, ERT and FO cables.	Checked fixed tremie #34 in correct position 47 cm above top of 24'' surface casing.	The heat exchanger loop became snagged on the Loop Master as the last few metres were being unreeled. This resulted in kinks in the loop. Fortunately, the kinked section is above ground level when the installation is on depth and can be terminated without affecting the install.
14/04/23	100.3 m	Rigged up to pressure test BHE loop. Performed pressure test to 7.5 bar following testing schedule in accordance with SN EN 80. Spotted grout mixing equipment (mixer and screed pumper), grout bags and rigged up hoses. Commenced mixing grout. Water level approx. 12.7 m below GL prior to pumping grout. Pumped 1st batch @ 10:50 hrs and final batch @ 13:00 hrs. 14 batches pumped in total. Final grout position estimated to be ~1.5 m. After pulling tremie No. 27 the level in the 24'' was observed receding although pumping was ongoing. Pump pressure increased and pumping was stopped. Disconnected wellhead hose connection – clear. Pumped through hose from screed mixer – clear. Downhole blockage in fixed tremie suspected. Changed over to temporary tremie and continued pumping/pulling tremie as per schedule (every 3 minutes) for the remaining 4 lengths. Washed down all equipment and secured site for the weekend.	The combined use of batch mixer and screed pumper allows a continuous feed of grout into the well. Water level recorded through temporary tremie throughout cementing operations.	Blockage in primary tremie pipe occurred during grouting resulting in the backup being needed for the remaining 4 grout lifts. Grouting operations were only paused for a short duration during the switchover which occurred seamlessly.
TH0416 complete				

4.8 GROUND SOURCE HEAT BOREHOLE – TH0417 SUMMARY OF OPERATIONS

4.8.1 Key Well Data

Table 40 TH0417 Key well data

Well name	TH0417		
Well classification	Closed loop ground source heat well (GSH)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.251 m AOD Top 24" to GL - 0.056 m		
Start date	Intermediate section started 13/03/23, completed on the 13/03/23. Lower section started 13/03/23.		
End of drilling date	22/03/23.		
Install dates	Install 22/03/23, Grouted 24/03/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 222 mm	Cored to 7.4 m Reamed to 6.0 m	Temporary 168.3 mm OD x 155.7 mm ID casing, recovered before completion run	6.0 m
Final section to TD Cored in 152 mm	Cored to 101.9 m	n/a	n/a
Installation	n/a	40 mm OD Haka heat exchanger loop with EZ Snap 60125 XT centralisers at 3.0 m spacing	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344947.757 Northing Y: 375844.796	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′37″	
12 Character National Grid Reference		SJ 44948 75845	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344947.63, Northing Y: 375844.75 Step out - 0.14 m (inclination 0.47 deg / azimuth 268 deg)	

4.8.2 Summary of Drilling Operations

The Comacchio 405 rig was mobilised and rigged up over TH0417. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

The approach to drill TH0417 was changed from running a polymer mud system and LCM to drilling with water only and treating fractures as needed with LCM. This change was made based on other GSH wells and the volumes of fluid being lost and the time required to build new polymer mud and maintain.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 7.4 m with 100% returns. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered and replaced with a string of 10 ¾” casing, sealed with Bentonite at the base.

A 222 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m and the well circulated with full returns before POOH. The temporary 10 ¾” casing was recovered and replaced with the 7” string down to 6.0 m. The annulus was sealed with Bentonite pellets.

Made up and RIH the 152 mm Geobore assembly and cored ahead to 19.4 m where losses were encountered that needed to be treated with LCM.

Continued to core ahead treating loss zones with LCM pills (80 ppb pills) as the assembly advanced deeper. All LCM pills were deployed via a 40 mm tremie pipe and after being allowed to soak were circulated out and any returning LCM material diverted into a waste tank to avoid circulating through the rig pumps and drill bit. Details of products used can be found in **Section 4.8.3**.

Cored to a depth at 82.4 m where the fractures became increasingly difficult to seal. The assembly was picked off bottom, and an 80-ppb pill was pumped followed by 6 x bags of Bentonite pellets. The thinking was the Bentonite pellets would aid the sealing of the borehole and provide a type of filter cake. Washed back to bottom and continued to core ahead. Initially returns were seen but quickly stopped. The decision was taken to core ahead to TD at 101.9 m.

At TD the well was treated with a 1,200 L LCM (80 ppb pills) and allowed to soak. The coring assembly was POOH.

The 7” casing was recovered before running a cleanout assembly (222 mm reamer assembly) down to the shoulder at 6.0 m and removed any remaining Bentonite before POOH. A cleanout BHA was run to total depth and circulated out any remaining LCM material. The well was monitored but the well wouldn’t stand full, with the fluid level dropping rapidly.

EGS were rigged up over TH0417 and the well wireline logged from 6.0 m to 101.5 m. Full details of wireline logging programme undertaken can be found in **Section 4.8.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The decision was taken to seal the fractures at the base of the well with grout. A total of 4 x 100 L OPC grout mixes were pumped (100 L of water, 6 x 25 kg bags of OPC grout with 3 kg of Bentonite). All mixes were delivered via a tremie pipe. The cement was allowed time to set before dipping the well at 84.25 m (short of intended height). The tremie pipe was run back to bottom and one additional 100 L grout mix was introduced before waiting on cement. Well dipped at 80.2 m which was slightly lower than planned so a bag of cement Bentonite pellets was put on top. Well dipped at 77.5 m.

Reran the 7” temporary casing (not sealed at base) before picking up the 146 mm Geobore assembly. Ran back in hole to 75.0 m and washed down the last few metres tagging hard cement at 78.0 m. Well still on losses with circa 30% returns seen at surface. Cored out the cement down to 101.9 m with returns increasing and estimated at 70%. The well was flow checked at TD before POOH.

Flow check results – pumped into the 7’’ casing at ~15 L/minute to simulate the grout pumping rate and measured the level with a dip tape. Level rose from 11.2 m to 4.1 m in 15 minutes. The level then dropped 2.9 m to 7.0 m in about 5 minutes after the pumping trial had stopped.

Due to the wrong Geobore assembly being picked up the 152 mm assembly was RIH and the section between 78.0 m and 101.9 m was opened out to achieve Scope. The well was circulated clean before POOH.

Well dipped at 101.4 m prior to running the installation.

4.8.3 Materials, Flush and Drilling Additive Used

A water and LCM approach was taken to drill TH0417. This decision was made based on information obtained using a polymer mud system in other closed loop wells. Maintaining the polymer mud at the required specification and building new mud offline was time consuming. The well was successfully drilled but as detailed above the well did not stand full when total depth had been reached meaning that during the grouting stage the volumes pumped couldn’t be monitored based on returning volumes to ensure grout wasn’t lost into fracture and sealing off preferential flow paths permanently. The solution was to utilise the ERT system which was very successful. Full details on this can be found in **Section 4.8.5**.

Table 41 Drilling fluid summary table – TH0417

	TH0417
Type of drilling mud used	Water
Section of well used	Intermediate and lower sections
Recorded drilling mud losses (L)	18,804
Ultrabore additive lost (kg)	NA
Purebore additive lost (kg)	NA

The below table summarise the lost circulation materials used, and the number of pills pumped whilst drilling both the intermediate and lower sections of the well. Each pill was 100 L in volume with various concentration of products based on loss rates being experienced and an understanding on how known fractures at given depths reacted. The majority of pills pumped had a concentration of 80 ppb of LCM products.

Table 42 LCM pills deployed – TH0417

	TH0417
Section of well used	Intermediate and lower sections
LCM pills pumped	10
Volume of LCM pills pumped	1,000
Purebore additive used (kg)	15.4
Clear Stab additive used (kg)	73.8
Nut Plug (kg)	147.6
Flaked Mica (kg)	24.3

Note: volumes stated above are the volumes of LCM pumped. Each pill was allowed to soak on depth before circulating to confirm if the treatment had been successful. The large percentage of the LCM pills pumped were circulated out and disposed of.

Due to large fractures being encountered that couldn't be controlled with LCM alone, the decision was taken to emplace cement at the base of the well and drill out as detailed below in **Table 43**.

Table 43 Summary table of grouting operations to stem losses – TH0417

	TH0417
Grout pills pumped to stem losses	4 x mixes of OPC grout (6 x bags of grout, 3 kg (1.5% Bentonite) and 100 L of water) set at 101.4 m 1 x mix of OPC grout (6 x bags of grout, 3 kg (1.5% Bentonite) and 100 L of water) set at 84.25 m
Water volume (L)	500
OPS grout (kg)	750
Bentonite (kg)	15
Geotherm-X GR grout (kg)	0

The LCM pills deployed and grout to the base allowed the well to be in a suitable state for when the install was run and grouted.

4.8.4 Geophysical Logging Undertaken

Table 44 Geophysical logging summary TH0417

Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 101.5 m. (17/03/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.14 m and within the 1/100 tolerance.

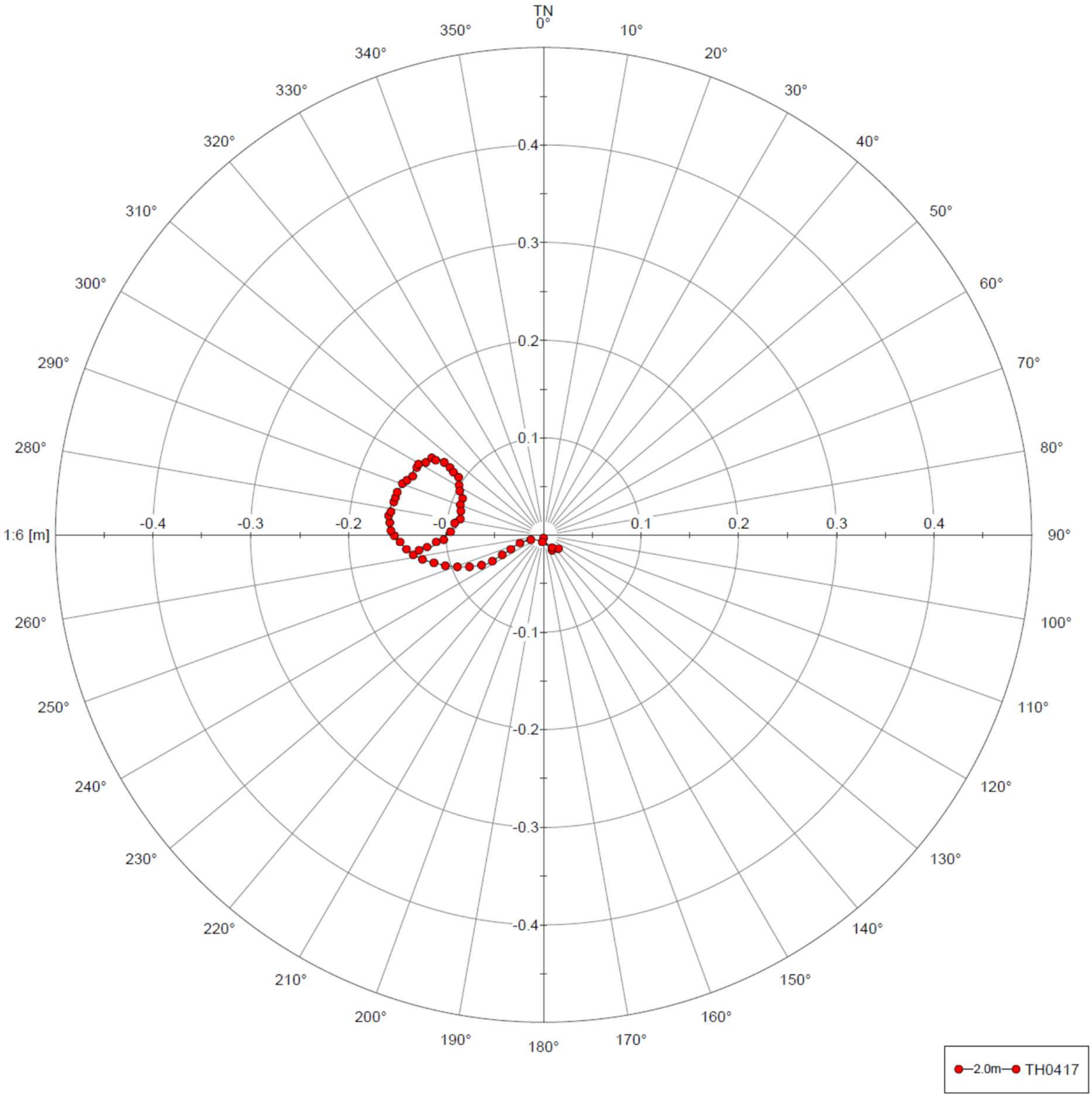


Figure 43 Verticality bullseye plot for TH0417, © European Geophysical Services Ltd

4.8.5 Summary of Installation Operations

Installation criteria for TH0417:

- Ensure well is standing full and static before commencing installation.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography, Beaded stream thermistor cables and fibre optic cables on the outside of the borehole heat exchanger ensuring that ERT electrodes are at correct depths.
- Run passive fibre optic cable through the centre of the heat exchanger.
- Deploy heat exchanger with EZ snap centralisers to ensure heat exchanger is in contact with the borehole wall before grouting operations.

- Accurately monitor the deployment.
- Maintain heat exchanger in tension during backfill using insulated base weights to counteract buoyancy during running.
- Grout the borehole in a single stage if possible but with contingency of a backup tremie in the event of any issues
- Backfill with a continuous column of grout, with uniform density to ensure consistent thermal properties as per suppliers' specifications.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared for running the installation. Spotted the cable reel stands and equipment. Moved the telehandler into position with the Loop Master with the heat exchanger spooled already. The passive FO cable was threaded through the centre of the heat exchanger, tested by Silixa and pressure tested to 7.5 bar following the GSHPA guidelines in advance of the installation operation.

The BHA assembly was made up however due to the residual bend of the heat exchanger loop the lower section had to be tie wrapped and additional short length of tremie pipe used to act as a splint. The heat exchanger weights were encapsulated inside a section of 60 mm yellow PVC pipe and sealed at the top and bottom to avoid any chance of interference with the ERT array.

The heat exchanger was run in hole as per the installation sheet to 100.0 m, securing all the cables to the permanent tremie and heat exchanger loop with tie wraps. See **Figure 44**. Centralisers were placed every 3.0 m to ensure the correct standoff from the borehole wall was achieved. The centralisers used were EZ Snap 60125 XT for the 40 mm OD Haka heat exchanger loop.

The Loop Master was lowered to the ground, and all cable strings were tested (FO, ERT and thermistor strings) before rigging up and pressure testing the heat exchanger loop to 7.5 bars, again following the GSHPA guidelines and in accordance with the SN EN80. A good test was observed that was within the pass test criteria.

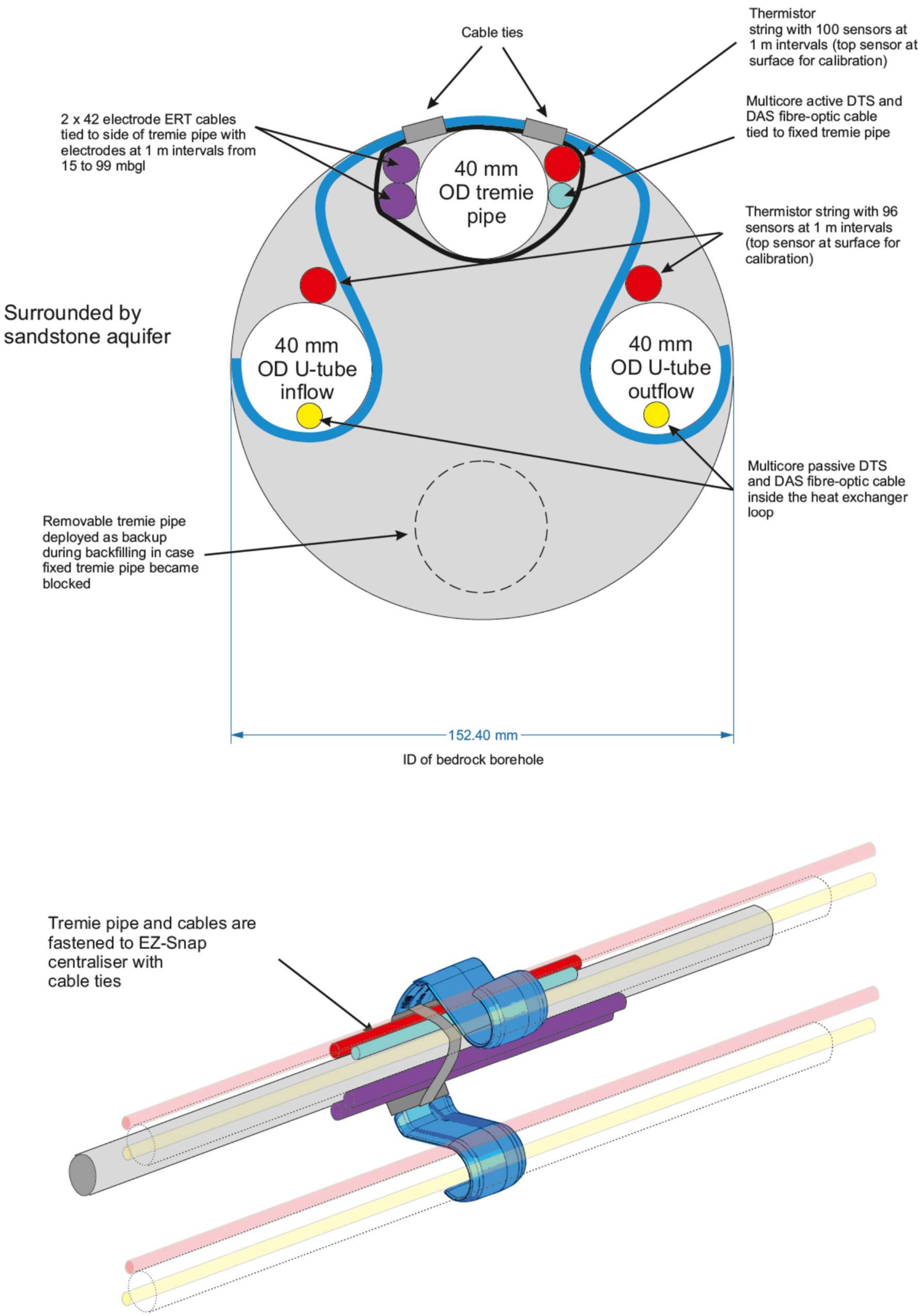


Figure 44 Schematic showing the placement of the various sensor cables on and within the installation for TH0417

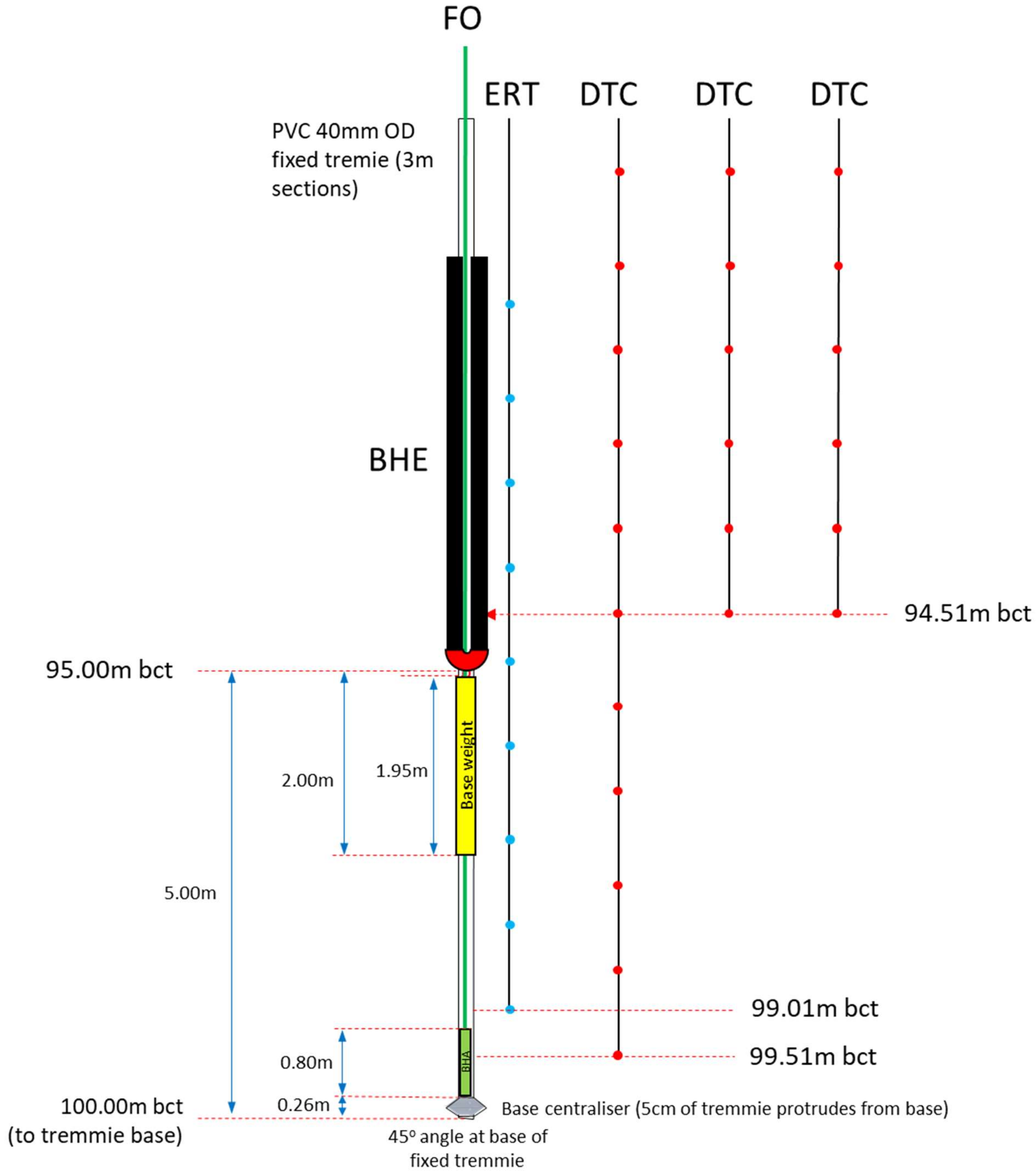


Figure 45 Bottom hole assembly schematic for TH0417 showing depth of install and each sensor string

The grouting equipment was rigged up which comprised of a batch mixer and screed pumper. This setup allowed the continuous delivery of grout into the well with each grout batch being mixed offline until the correct weight and viscosity was achieved before transferring over to the active grout pump. The tremie pipe was circulated with water and confirmed free before commencing with the grouting operation. The fluid level was monitored throughout with a dip tape through the backup tremie pipe to confirm the fluid level was rising in the well. The ERT was used and monitored throughout to identify the interface between the water and the heavier grout. This worked well and gave additional confidence the grout wasn't being lost to the fractures. After the 7.5 mixes had been pumped the permanent tremie pipe became blocked. This was identified by a dropping fluid level, increase in the cement unit pressure and a static ERT trace. The operation was stopped with the TOC estimated from the ERT trace to be at 38.0 m. 2 x mixes of grout had to be disposed of before pulling back the temporary tremie pipe to circa 23.0 m (15.0 m above TTOC). The cement line to the permanent tremie was broken and lumps of cement were noticed in the surface connection and the cause of blockage.

At the same time the blockage occurred the hydraulic drive of the primary cement unit failed. A noise change was noted onsite, but this was not linked to the blockage as this unit was not feeding the grout into the well.

Grouting operations were suspended on the 24th March 2023 whilst repairs could be made.

Resumed grouting operations on the 28th March 2023. Positioned the backup tremie pipe just above the TOC at 42.0 m. Checked the circulation path through the tremie pipe. Commenced mixing grout at 1.67 sg and transferring to the screed pumper. Pumped a further 6 x 100 L batches of grout into the well, pumping for a 3-minute periods then disconnecting the hose and recovering 1 x joint of tremie pipe then reconnecting the hose and repeating the process. The grout level was monitored via the ERT system throughout. All remaining tremie pipe sections were recovered, and grouting operations were completed successfully. A total of 13.5 mixes were pumped. Grout was not observed inside the 24'' casing as this was full of water, but the fluid level rose steadily throughout, ending at approximately 0.5 m below the top of Boode 24'' surface casing.

Washed down all equipment and cleared site. TOC tagged at 1.7 m.

Full details of the grouting operation including the mixes used are detailed in **Section 4.8.6**.

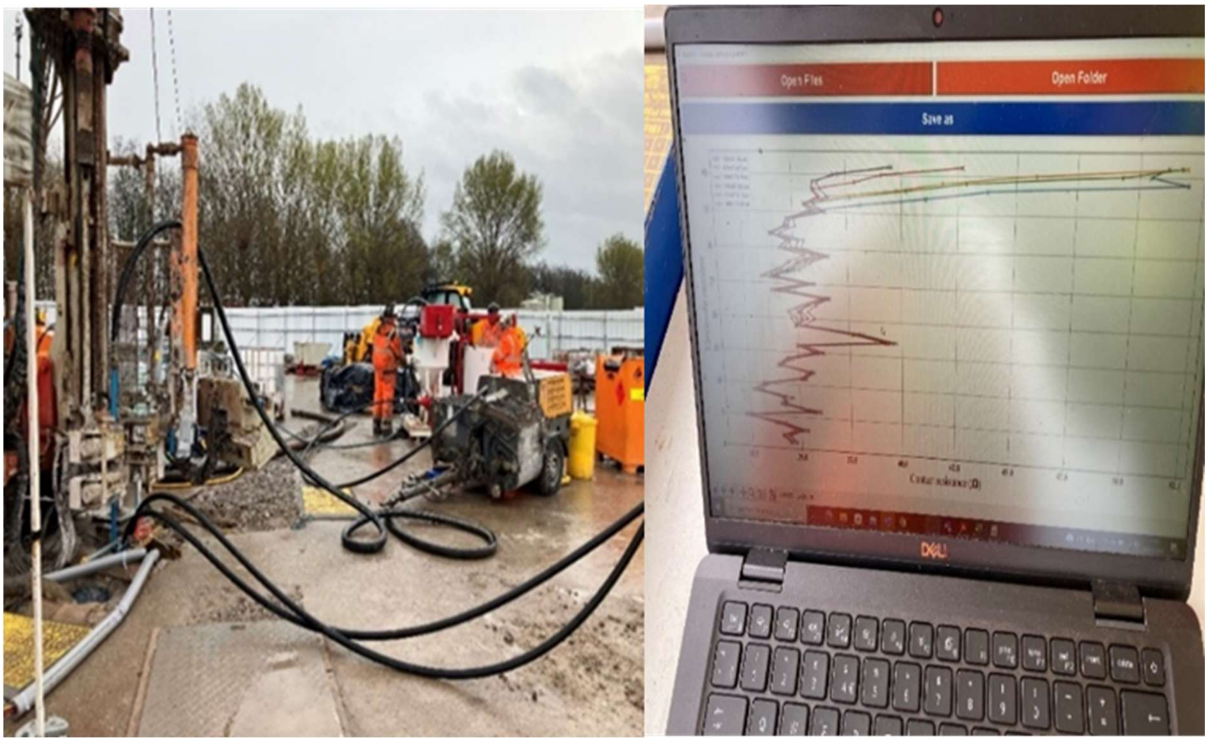


Figure 46 Grouting setup at TH0417 showing both mixing units and the ERT trace showing clear grout migration up the well with no returns at surface

4.8.6 Backfill and grouting operations

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via permanent sacrificial tremie pipe. A backup retractable tremie was also deployed to total depth before the completion was run and pulled back in stages during the grouting operation, always keeping above the top of cement (TOC). This backup tremie was only used in the event a blockage occurred in the primary.

Real-time data were collected from the thermistor cables and ERT sensors by BGS during the grouting operations. This was observed to track the upward progress of the grout via temperature and conductivity change respectively as the grout moved up the annulus. This was to give forewarning of significant grout loss to formation and pressures were monitored at the cement unit to warn of any signs of blockages occurring. If the temperature and conductivity remained stationary at a given depth, then this would indicate grout was flowing laterally outwards into fractures which was to be avoided at all costs.

The Geotherm X grout was found to have a range of weights per bag from the supplier, so all bags were pre weighed and stacked in batches ready for mixing to ensure a more consistence grout weight and viscosity.

The grouting rig up consisted of two grout units; the primary was used to deliver the grout into the well and the secondary allowed the next batch to be mixed offline before being transferred to the primary unit. This ensured a constant delivery of grout without having to stop which would have increased the risk of the tremie pipe becoming blocked. The two-unit system was developed due to the limitations on grouting equipment and the size of mix hoppers available.

During the grouting of TH0417 the permanent / primary tremie became blocked after 7.5 mixes being pumped. The backup tremie had to be used for the remaining 6 mixes which proves the importance of running a backup in the well before the install is run. It would be difficult to run once the install was in the ground due to the number of cables, centralisers etc that had to be run.

Dry and wet samples of the grout were taken for future analysis if needed.

The below table summarises the grout batches pumped:

Table 45 Grout backfill summary table – TH0417

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	24/03/23	100	180	1.70
2	24/03/23	100	180	1.71
3	24/03/23	100	180	1.72
4	24/03/23	100	180	1.71
5	24/03/23	100	180	1.71
6	24/03/23	100	180	1.70
7	24/03/23	100	180	1.70
7.5	24/03/23	50	90	1.70
Permanent tremie became blocked				

8.5	28/03/23	100	180	1.67
9.5	28/03/23	100	180	1.67
10.5	28/03/23	100	180	1.67
11.5	28/03/23	100	180	1.67
12.5	28/03/23	100	180	1.67
13.5	28/03/23	100	180	1.67
Total		1,350	2,430	1.69 avg

The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.8.7 TH0417 Borehole Well Schematic

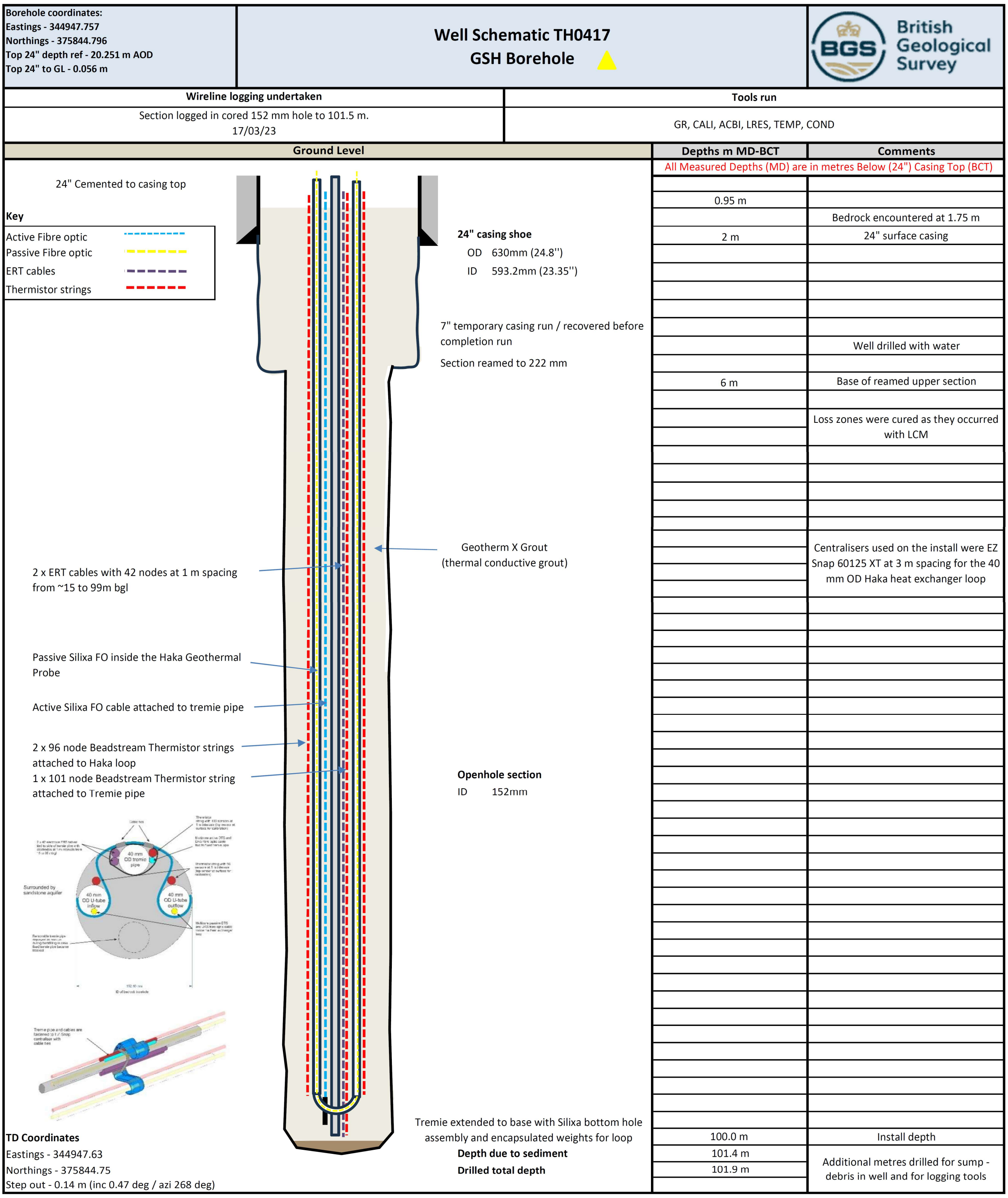


Figure 47 TH0417 Well Schematic

4.8.8 Wellhead / Well Chamber Status

Figure 48 Wellhead chamber image TH0417

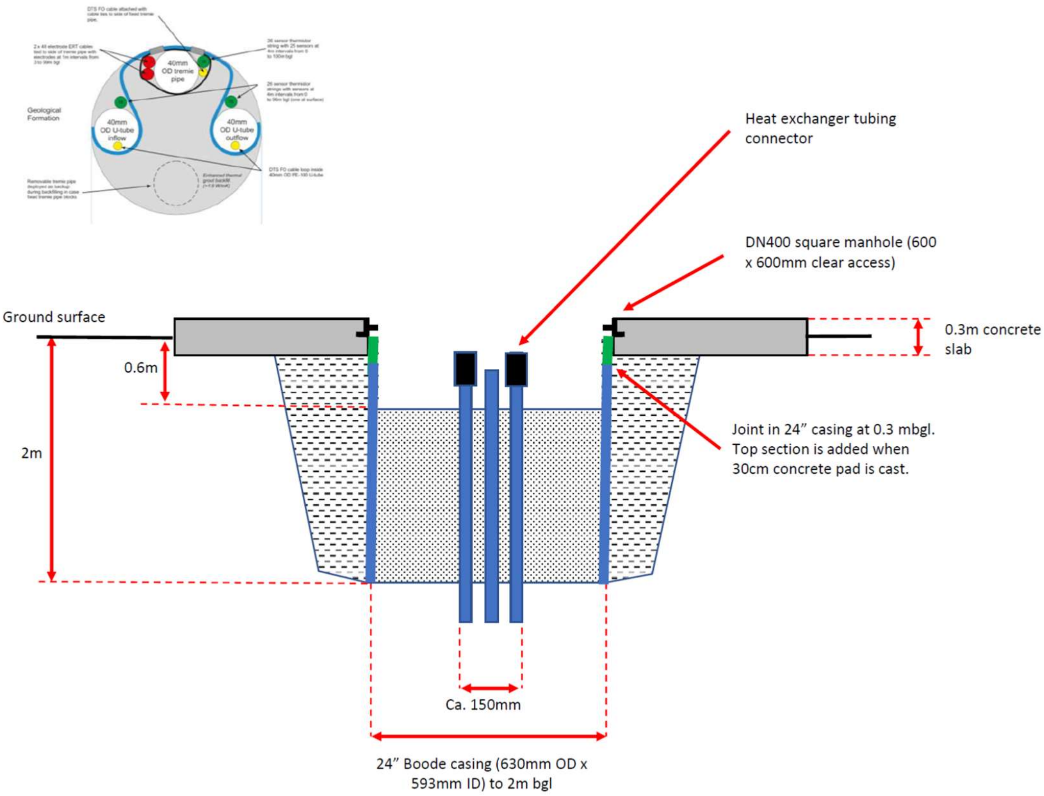


Figure 49 Wellhead chamber schematic TH0417

4.8.9 Daily Activity Summary

Table 46 Daily activity summary TH0417

Date	Depth M BGL	Operation	Parameters	Issues
09/03/23	2.0 m	Comacchio 405 rig moved over TH0417 and rigged up. Ran temp 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite at base.		
10/03/23	2.0 m	Site shutdown due to snow.		NPT due to weather – 10 hrs assuming 07:30 to 17:30 hrs day shift only.
13/03/23	32.9 m	Made up and RIH the 152 mm coring assembly and cored to 7.4 m with 100% returns. Recovered the coring assembly and the 7" temporary casing. Picked up and set 10 ¾'' casing at 2.0 m. Sealed the casing with Bentonite at the base. Made up and RIH the 222 mm reaming assembly and opened out the section down to 6.0 m with full returns. POOH and laid out assembly. Recovered the 10 ¾" temp casing and reran the 7" temporary casing down to 6.0 m and sealed annulus with Bentonite pellets. Made up and RIH the 152 mm coring assembly and cored ahead to 19.4 m where loss rate increased. Spotted a 40 ppb LCM pill (via 40 mm tremie pipe) and allowed to soak before coring ahead to 25.4 m. A second LCM pill, this time 40 ppb was pumped. Cored ahead to 32.9 m.	Cores being collected and curated into 1.0 and 0.5 m lengths, boxed and labelled by Marriott. Fluid sample every 6.0 m and verticality check every 3.0 m. Verticality checks: 0.20 deg @ 5.9 m. 0.28 deg @ 8.9 m. ROP - 3-4 minutes per 1.5 m core run. 2 x 100 L LCM pills pumped. Note all LCM pills pumped via 40 mm tremie pipe not through drill string.	This well is planned to be cored with water only and not polymer mud. LCM pills will be pumped as required to maintain fluid returns to surface to enable grouting during the installation to be completed in one stage. Using shale shaker system and tanks for a closed recirculating system.
14/03/23	53.9 m	Continued to core ahead treating fractures with LCM pills down to 53.9 m where total losses were seen.	Verticality checks: 0.16 deg @ 38.9 m. 0.18 deg @ 44.9 m. 0.18 deg @ 50.9 m. 5 x 100 L (80 ppb) LCM pills pumped from 32.9 to 53.9 m.	Fractures difficult to seal with LCM pills being pumped.
15/03/23	82.4 m	Dipped water level at 13.3 m. Filled hole using the rig pump. RIH with 152 mm Geobore string and circulated out residual LCM material into a waste IBC. Performed flow check and observed 8 cm drop in fluid level in the tank – acceptable. Continued to core ahead treating fractures with LCM pills down to 82.4 m.	Verticality checks: 0.20 deg @ 62.9 m. 2 x 100 L (80 ppb) LCM pills pumped from 53.9 m to 82.4 m. 80 ppb pill consisting of: Pure-Bore Powder Mica M10 Nut Plug Med Clear-Stab ULI All pills pumped in this well have used the above.	Observed section of core on worktable not boxed overnight. Unable to reconcile missing section which is from interval 49.4 m to 53.9 m. Fractures difficult to seal with LCM pills being pumped.
16/03/23	101.9 m	RIH with Geobore to bottom and circulated but no returns.	Verticality checks: 0.25 deg @ 86.9 m.	

Date	Depth M BGL	Operation	Parameters	Issues
		Pulled back Geobore assembly to above the estimated top of the last loss zone at ~ 76.0 m. RIH with tremie pipe to TD. Mixed and pumped 80 ppb LCM pill. Allowed pill to soak. Introduced 6 bags of Bentonite pellets via the drill string. See issues column. Allowed to soak for 45 minutes. Washed assembly to bottom and continued to core from 82.4 m. Initially returns were seen but these quickly stopped. Decision taken to core ahead. Cored to TD at 101.9 m. POOH with Geobore assembly. Ran 40 mm tremie pipe and pumped a 1,200 L LCM pill (LCM previously circulated out) and allowed to soak. POOH tremie. Recovered the 7" temporary casing installed to 6.0 m. RIH with 222 mm reamer and washed/cleaned down to the 222 x 152 mm shoulder at 6.0 m before POOH the reamer. Ran back to bottom and circulated out any excess LCM material.	0.21 deg @ 92.9 m. 0.21 deg @ 98.9 m. 1 x 100 L LCM pill pumped at 82.4 m. 1 x 1,200 L LCM pill pumped at TD. Pills pumped were 80 ppb. An additional core run was made to provide a sump to receive any material not lifted from the well when the 7'' temporary casing is recovered, possible Bentonite dropping in the well.	The LCM was chased with Bentonite pellets to enhance the LCM. The idea was that the Bentonite would swell and smear the borehole as it was washed through.
17/03/23	101.4 m	Checked water level – 14.3 m. Well dipped at 101.4 m (0.5 m of fill). Ran rig pump and filled the well with water. Level rapidly dropped back to 13.5 m. EGS arrived and setup over the well. Logged the borehole as per Scope before rigging down and leaving site. Based on results from the data from the calliper and acoustic logs decision taken to grout up lower section to seal fractures identified back to 80 m. Ran 40 mm tremie pipe to TD. Mixed and pumped 4 x 100 L batches of OPC grout. Pulled back tremie pipe. WOC for 3 hours. Dipped the well, not possible to give definitive TOC but change in running resistance noted at 87.0 m. Wait on cement.	Wireline tools ran - GR, GR, CALI, ACBI, LRES, TEMP, COND. Logged to 101.5 m.	Unable to keep well full when pumping at 150L/min, normal coring flowrate.
20/03/23	77.5 m	Dipped the well and found the grout level at 84.25 m. Grout short of intended height. RIH the 40 mm tremie pipe to top of grout. Mixed and pumped 1 x batch of OPC grout with 100 L of water 6 bags of grout, 3 kg of Bentonite powder. Pulled back 3 lengths of tremie pipe and flushed through the hose/tremie pipe with water. Continued POOH tremie pipe to above TOC. Wait on cement. Dipped well at 80.2 m. Introduced a bag of Bentonite cement pellets and dipped at 77.5 m.		Grout short of intended height, decision taken to pump another grout pill.
21/03/23	101.9 m	Well dipped at 78.0 m. POOH 40 mm tremie pipe. RIH and set 7'' casing to 6.0 m but did not seal with Bentonite.	Carried out post grouting checks on all ERT cables. No issues reported.	Note: The 146 mm core barrel was used in error. There will be an additional operation to ream out the grouted section from 146 mm to

Date	Depth M BGL	Operation	Parameters	Issues
		RIH with Geobore assembly to 75.0 m and carried out flow check, well still on losses. Washed down with 30% returns and commenced coring out the cement from 78.0 m. Cored down to 101.9 m. Returns estimated at 70% apart from a short period where returns were not observed. Flow checked at TD before POOH the 146 mm assembly. Made up and RIH 152 mm assembly and washed / reamed in hole from 75.0 m opening out the hole from 146 mm to the required 152 mm to TD.	Flow checked well - pumped at approx. 15 L/min into the 7'' casing and measured the level with dip tape. Level rose from 11.2 m to 4.1 m in 15 minutes. The level then dropped 2.9 m to 7.0 m in about 5 minutes after the water was turned off.	152 mm. NPT 2.5 hours.
TH0417 GSH Install				
22/03/23	101.4 m	Well dipped at 101.4 m with the water level in well at 13.7 m. Prepared for running the installation. Spotted cable spoolers and associated equipment for running the GSH installation including the Loop Master. Lifted the BHA up over the well and attached ERT and FO cables. RIH installation as per the install design sheet to 35.0 m.		Well dipped at 101.4 m before commencing running installation. Tie wrapped the centraliser tremie, base weight and strengthening tremie together. This was needed to straighten the residual bend of the GSH loop to allow it to be RIH without snagging.
23/03/23	101.0 m	Well dipped at 101.0 m. Continued RIH the GSH installation from 35.0 m to 100.0 m as per design sheet. Lowered Loop Master to ground and prepared to test cables. Tested thermistor, ERT and FO cables.		
24/03/23	38.0 m	Rigged up to pressure test BHE loop. Performed pressure test to 7.5 bar following testing schedule in accordance with SN EN 80. Good test. Prepare for grouting of TH0417. Both grout mixers setup and tested, permanent and temp tremie pipes circulated to confirm free and no blockages caused by running in hole and Geotherm X grout moved into location. Grout bags all pre weighted due to bag discrepancies and stacked on dedicated pallets. Commenced mixing Geotherm X grout and filling hopper with 2 x mixes and second grout unit. Water level dipped at 15.3 m prior to pumping grout. Commenced mixing and pumping grout. Fluid levels monitored throughout with dip tape through temp tremie to confirm fluid rising. ERT	Pressure test of heat exchanger as per guidelines and criteria for a successful test. Brough pressure to 7.5 bar and dropped to 6.4 bar over 1 hour. Repeated drop test and both within pass criteria. Grout weight checked and confirmed in spec. First mix 1.67 sg. Grout mix 7.5 bags of Geotherm X to 100 L of water.	

Date	Depth M BGL	Operation	Parameters	Issues
		also monitored throughout with reasonable success. A total of 7.5 mixes pumped before the permanent tremie became blocked. Indications from dropping fluid levels, increase in cement unit pressure to 10 bar and static ERT trace. Operations stopped. Top of cement estimated at 38.0 m from ERT trace. Dumped 2 x mixes of grout. Pulled back another joint of the temporary tremie pipe to circa 23.0 m (15.0 m above top of cement) and ran the dip tape and confirmed clear before clamping. 8 x joints left in hole. Broke out the cement line to the permanent tremie and noted lumps of cement in connection which were the likely cause of the pressure increase. Washed down all equipment.		Hydraulic drive of the primary cement unit failed. Change in noise noted during last batch pumped. This failure was at the same time the pipe became plugged but not linked as the primary unit was feeding into the secondary unit that was delivering the grout to the well.
28/03/23	1.7 m	Prepared for resuming grout operations– positioning equipment, rigging up hoses. Positioned tremie pipe just above the top of grout at 42.0 m. Checked circulation path through the tremie pipe. Commenced mixing grout at 1.67 sg and transferring to the screed pumper. Pumped grout into the well, pumping for a 3-minute period then disconnecting the hose and recovering 1 joint of tremie pipe then reconnecting the hose and repeating the process. Mixed and pumped a total of 6 x 100L batches at 1.67 sg (giving a total for the well to date of 13.5 mixes). Monitored the grout level via ERT sensors while pumping. POOH all remaining tremie pipe. Did not observe grout in the 24’’ casing as there was a layer of water above but the fluid level rose steadily throughout the cement job, ending at approximately 0.5 m below the top of Boode 24’’ surface casing. Washed down all equipment and cleared site. TOC tagged at 1.7 m.	6 x 100L batches of grout pumped at 1.67 sg (giving a total for the well to date of 13.5 mixes). The ERT monitoring was successful with a clear indication of the grout level.	
TH0417 complete				

4.9 GROUND SOURCE HEAT BOREHOLE – TH0422 SUMMARY OF OPERATIONS

4.9.1 Key Well Data

Table 47 TH0422 Key well data

Well name	TH0422		
Well classification	Closed loop ground source heat well (GSH)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.065 m AOD Top 24" to GL - 0.126 m		
Start date	Intermediate section started on 25/01/23 and was completed on 25/01/23. Lower section started 25/01/23.		
End of drilling date	03/02/23.		
Install dates	Install 06/02/23 to 09/02/23, Grouted 10/02/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 222 mm	Cored to 7.4 m Reamed to 6.0 m	Temporary 168.3mm OD x 155.7mm ID casing, recovered before completion run	6.0 m
Final section to TD Cored in 152 mm	Cored to 101.4 m	n/a	n/a
Installation	n/a	40 mm OD Haka heat exchanger loop with EZ Snap 60125 XT centralisers at 3 m spacing	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344936.425 Northing Y: 375848.714	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44936 75849	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344936.38 Northing Y: 375849.41 Step out - 0.70 m (inclination 0.74 deg / azimuth 349 deg)	

4.9.2 Summary of Drilling Operations

TH0422 was the first of the GSH wells to be drilled. A mud system comprising of Purebore and Ultrabore was adopted with LCM available as needed to stem losses. This approach was taken to ensure the well was standing full and not on losses when the installation was run and grouted back to surface in a single stage. This was a key criterion for this well type to give the best possible thermally enhanced grout coverage from TD back to surface.

The rig was mobilised and rigged up over TH0422 and the drilling mud prepared. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. The initial seal failed so the 7” was pulled and reseated with additional Bentonite pellets being required. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 7.4 m with no losses reported. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered and replaced with a string of 10 ¾” temporary casing, sealed with Bentonite at the base.

A 222 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m and the well circulated with full returns before POOH. The temporary 10 ¾” casing was recovered and replaced with the 7” string down to 6.0 m. The annulus was sealed with Bentonite pellets.

Made up and RIH the 152 mm Geobore assembly and cored ahead to 15.0 m where losses were encountered that needed to be treated with LCM.

Continued to core ahead treating loss zones with LCM pills (40 ppb pills) as the assembly advanced deeper. All LCM pills were deployed via a 40 mm tremie pipe and after being allowed to soak were circulated out and any returning LCM material diverted into a waste tank to avoid circulating through the rig pumps and drill bit. Details of products used can be found in **Section 4.9.3**.

Cored to a depth at 64.4 m where the inclination started to drift out of the allowed tolerance. The frequency of E Totco inclination surveys was increased and the ROP / WOB was reduced to try and correct. The mud was also noted as becoming thick due to an increase in solids / drilling fines remaining in the system resulting in the shaker screens blinding. This made fluid loss monitoring difficult.

Continued to core to 82.4 m where it became increasing difficult to treat and seal the fractures and remain within the loss rates stated within the Site Instruction issued to the Principal Contractor as a requirement of the NEC 4 contract. The decision was taken to add Bentonite to the active system to provide a filter cake to reduce seepage losses. As the well advanced deeper and more open hole was exposed the seepage losses were contributing to the fluid loss threshold stated within the introduction for an LCM pill to be pumped to treat a fracture zone. This approach did not allow the drillers flexibility and to make judgement calls based on the depth of hole and how the well was reacting.

Figure 50 Coring ahead in TH0422

Continued to core ahead treating fractures with LCM to total depth at 100.4 m. The well was displaced to clean mud before flow checking. The flow check was within the allowable loss rate, so the assembly was POOH.

The 7” temporary casing was recovered before preparing the area for wireline logging. EGS were rigged up, and the well was wireline logged from 6.0 m to 98.6 m. Full details of wireline logging programme undertaken can be found in **Section 4.9.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

A cleanout assembly (222 mm reamer) was RIH down to the shoulder at 6.0 m and removed any remaining Bentonite before POOH. A second slimmer cleanout BHA was RIH and washed down to total depth cleaning out sediment that had settled to the base. The assembly was worked to 100.4 m before circulating bottoms up and POOH.

4.9.3 Materials, Flush and Drilling Additive Used

A viscosified drilling mud and lost circulation material approach was taken to drill TH0422. The reason was to ensure the well was standing full of fluid and static for the completion to be installed and achieve a single stage grouting operation. This was key to the well design to achieve a single column of grout from base to surface of a uniform density to ensure consistent thermal properties from the thermally enhanced grout. The grouting operation could be monitored accurately and the volume pumped checked against the returning volumes to ensure grout wasn't being lost into fracture and sealing off preferential flow paths permanently.

TH0422 was the first GSH well drilled and the mud system adopted comprised of Purebore and Ultrabore. It became apparent as the well advanced deeper that controlling losses was difficult and time consuming. The issues were related to the mud system available for this type of rig which have limited monitoring and mixing capabilities and trying to keep the mud in specification was not possible. There were also limitations on what drilling mud additives and LCM products could be used from an environmental and science standpoint. All products had to be inert, removable by acid or biodegradable so not to permanently seal fracture or alter the ground water chemistry.

The contract also required loss rates to be specified under a site instruction which triggered the deployment of an LCM pill. This removed all control from the drillers and didn't consider seepage losses etc as the well advanced deeper. This was reviewed for future boreholes which
ultimately resulted in mud systems being phased out due to complexity and contract limitations.

The products and LCM pills deployed are summarised in the below tables. All LCM pills deployed in TH0422 had a 40 ppb LCM concentration.

Table 48 Drilling fluid summary table – TH0422

	TH0422
Type of drilling mud used	Polymer mud
Section of well used	Intermediate and lower sections
Recorded drilling mud losses (L)	8,454
Ultrabore additive lost (kg)	120.5
Purebore additive lost (kg)	60.2

Table 49 summarise the lost circulation materials used, and the number of pills pumped whilst drilling both the intermediate and lower sections of the well. Each pill was mixed with various concentration of products based on loss rates being experienced and an understanding on how known fractures at given depths reacted.

Table 49 LCM pills deployed – TH0422

	TH0422
Section of well used	Intermediate and lower sections
LCM pills pumped	13
Volume of LCM pills pumped	2,400
Purebore additive used (kg)	11.1
Clear Stab additive used (kg)	53.3
Nut Plug (kg)	106.6
Flaked Mica (kg)	17.6

Note: volumes stated above are the volumes of LCM pumped. Each pill was allowed to soak on depth before circulating to confirm if the treatment had been successful. The large percentage of the LCM pills pumped were circulated out and disposed of.

Bentonite was introduced into the mud system toward the base of the well to reduce the seepage losses and produce a filter cake. As the well advanced deeper and more open hole was exposed the seepage losses were contributing to the fluid loss threshold stated within the introduction for an LCM pill to be pumped to treat a fracture zone. This had limited success as the concentration introduced couldn't be maintained at the optimum level as mud checks weren't being undertaken.

Figure 51 A 100 L 40 ppb LCM pill prepared ready to be pumped.

No fractures were grouted up during the drilling phase with all loss zones being controlled with LCM.

4.9.4 Geophysical Logging Undertaken

Table 50 Geophysical logging summary TH0422

Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 98.6 m. (03/02/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.80 m and within the 1/100 tolerance.

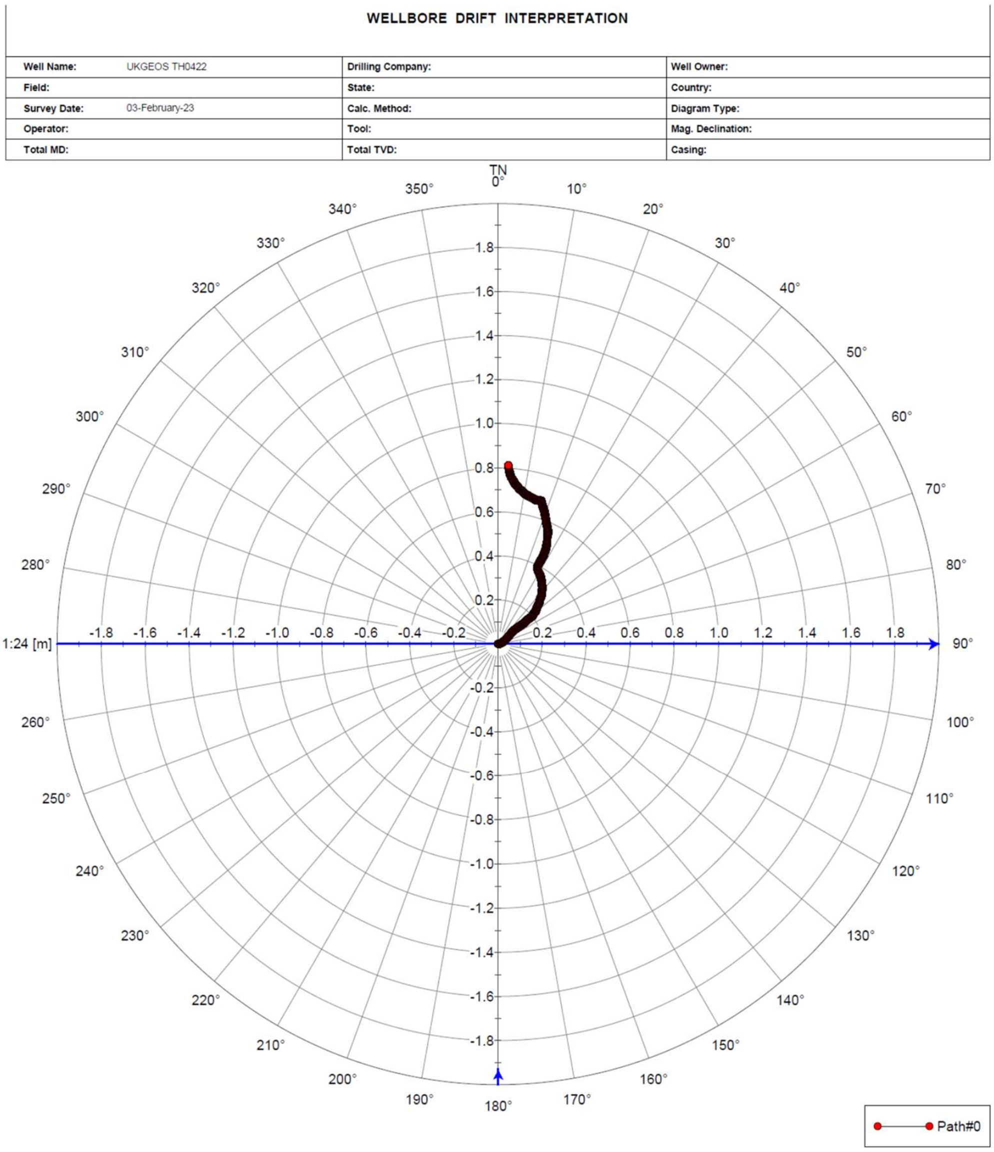


Figure 52 Verticality bullseye plot for TH0422, © European Geophysical Services Ltd

4.9.5 Summary of Installation Operations

Installation criteria for TH0422:

- Ensure well is standing full and static before commencing installation.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography, Beaded stream thermistor cables and fibre optic cables on the outside of the borehole heat exchanger ensuring that ERT electrodes are at correct depths.
- Run passive fibre optic cable through the centre of the heat exchanger.
- Deploy heat exchanger with EZ snap centralisers to ensure heat exchanger is in contact with the borehole wall before grouting operations.
- Accurately monitor the deployment.
- Maintain heat exchanger in tension during backfill using insulated base weights to counteract buoyancy during running.
- Grout the borehole in a single stage if possible but with contingency of a backup tremie in the event of any issues
- Backfill with a continuous column of grout, with uniform density to ensure consistent thermal properties as per suppliers' specifications.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

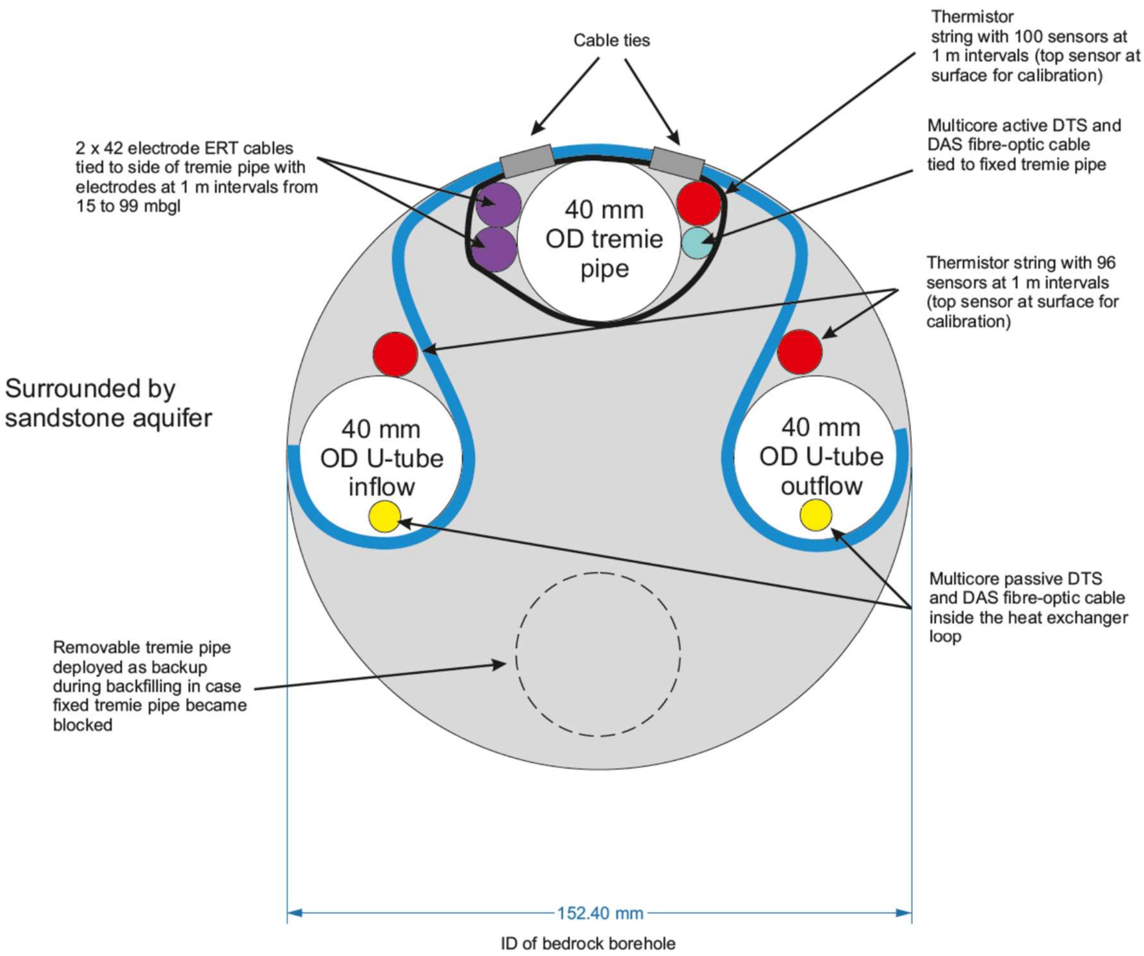
Summary of operations:

Prepared for running the installation. Spotted the cable reel stands and equipment. Moved the telehandler into position with the Loop Master with the heat exchanger spooled already. The passive FO cable was threaded through the centre of the heat exchanger, tested by Silixa and pressure tested to 7.5 bar following the GSHPA guidelines in advance of the installation operation.

The BHA assembly was made up however due to the residual bend of the heat exchanger loop the lower section had to be tie wrapped and additional short length of tremie pipe used to act as a splint. The heat exchanger weights (31 kg) were encapsulated inside a section of 60 mm yellow PVC pipe and sealed at the top and bottom to avoid any chance of interference with the ERT array.

The heat exchanger was run in hole as per the installation sheet to 100.0 m (neutral buoyancy point reached at 30.0 m so water was introduced into the loop), securing all the cables to the permanent tremie and heat exchanger loop with tie wraps. See **Figure 53**. Centralisers were placed every 3.0 m to ensure the correct standoff from the borehole wall was achieved. The centralisers used were EZ Snap 60125 XT for the 40 mm OD Haka heat exchanger loop.

The Loop Master was lowered to the ground, and all cable strings were tested (FO, ERT and thermistor strings) before rigging up and pressure testing the heat exchanger loop for a second time to 7.5 bars, following the GSHPA guidelines and in accordance with the SN EN80. Good test observed.



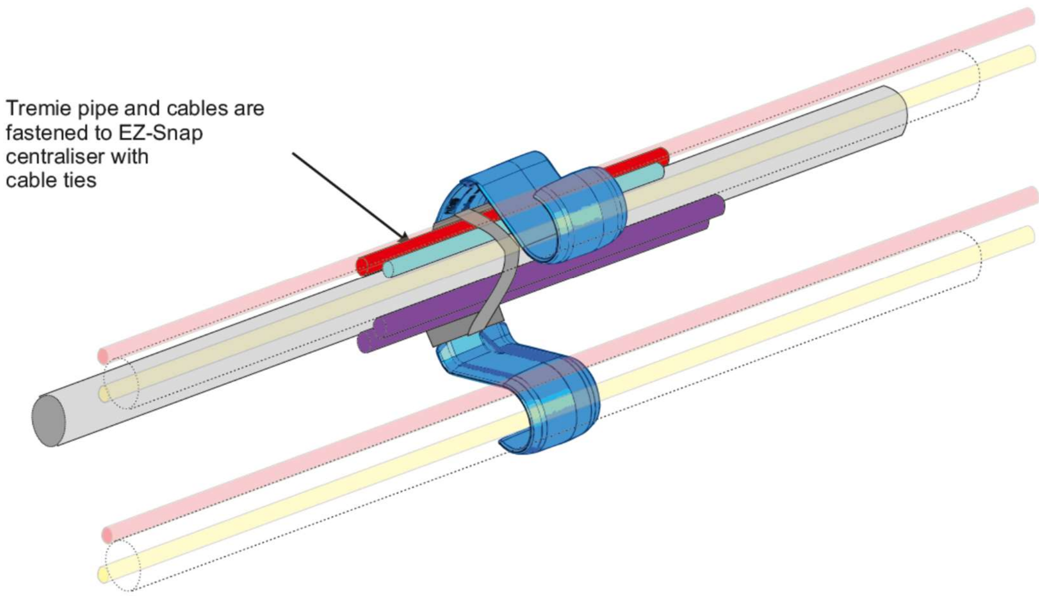


Figure 53 Schematic showing the placement of the various sensor cables on and within the installation for TH0422

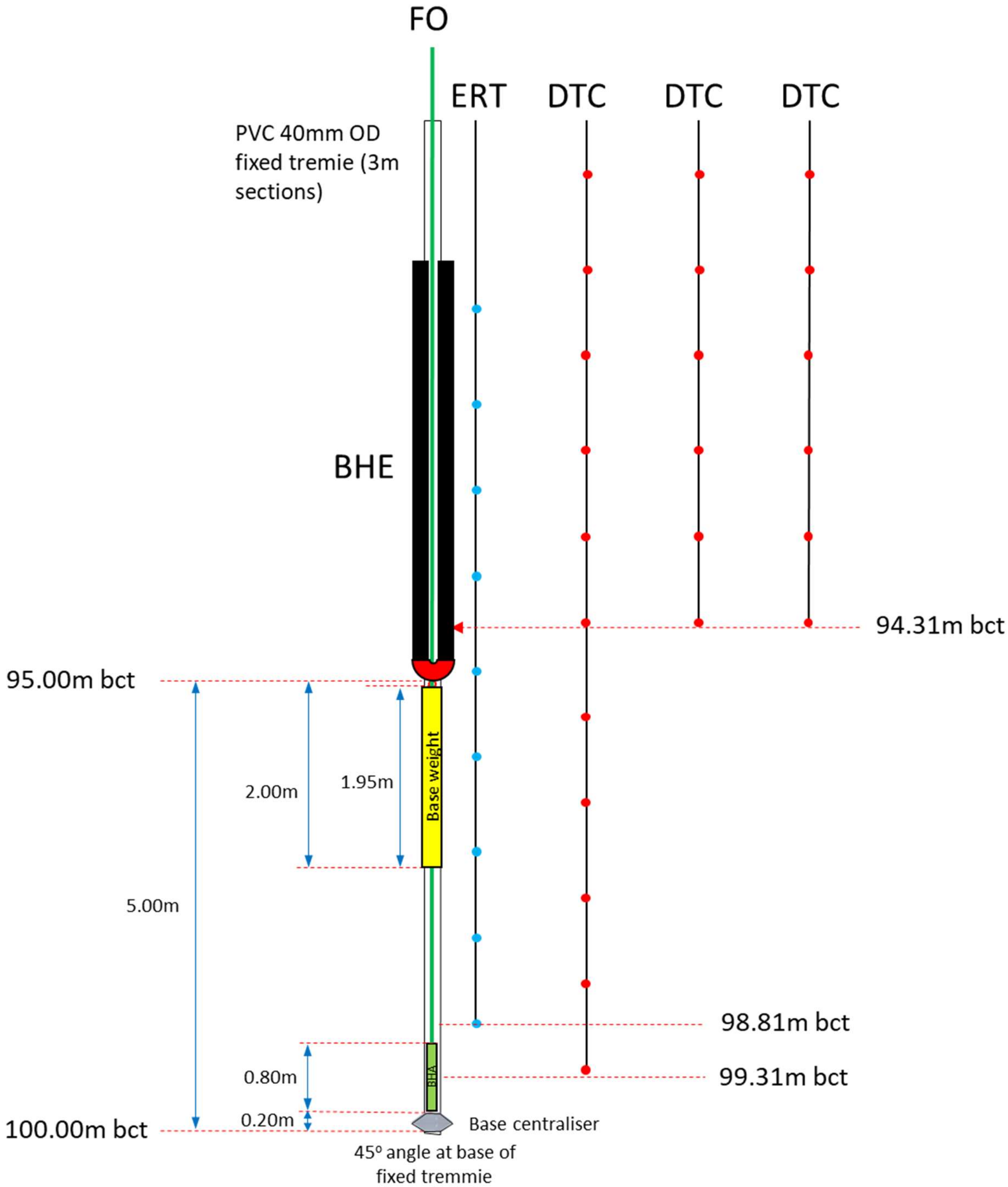


Figure 54 Bottom hole assembly schematic for TH0422 showing depth of install and each sensor string

The grouting equipment was rigged up which comprised of a batch mixer and screed pumper. This setup allowed the continuous delivery of grout into the well with each grout batch being mixed offline until the correct weight and viscosity was achieved before transferring over to the active grout pump. The tremie was circulated with water and confirmed free before commencing with the grouting operation. A total of 14 x 100 L mixes of grout were pumped.

Mud returns from the well occurred about halfway through the job as the grout level rose.

Excess grout was removed from inside the 24” surface casing to give a TOC at 1.0 m below casing top.

Full details of the grouting operation including the mixes used are detailed in **Section 4.9.6**.

4.9.6 Backfill and grouting operations

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via permanent sacrificial tremie pipe. A backup retractable tremie was also deployed to total depth before the completion was run and pulled back in stages during the grouting operation, always keeping above the TOC. The backup tremie would only be used in the event a blockage occurred in the primary string.

The Geotherm X grout was found to have a range of weights per bag from the supplier, so all bags were pre weighed and stacked in batches ready for mixing to ensure a more consistence grout weight and viscosity.

The grouting rig up consisted of two grout units; the primary was used to deliver the grout into the well, and the secondary allowed the next batch to be mixed offline before being transferred to the primary unit. This ensured a constant delivery of grout without having to stop which would have increased the risk of the tremie pipe becoming blocked. The two-unit system was developed due to the limitations on grouting equipment and the size of mix hoppers available.

Dry and wet samples of the grout were taken for future analysis if needed.

The below table summarises the grout batches pumped:

Table 51 Grout backfill summary table – TH0422

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	10/02/23	100	180	Not taken / continuous mixing
2	10/02/23	103	180	1.69
3	10/02/23	103	180	Not taken / continuous mixing
4	10/02/23	103	180	1.76
5	10/02/23	106	180	1.70
6	10/02/23	106	180	Not taken / continuous mixing
7	10/02/23	106	180	1.69
8	10/02/23	106	180	1.67
9	10/02/23	106	180	1.67
10	10/02/23	106	180	1.67
11	10/02/23	106	180	1.67
12	10/02/23	106	180	1.69
13	10/02/23	106	180	1.65
14	10/02/23	106	180	Not taken / continuous mixing
Total		1,469	2,520	1.69 avg

The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.9.7 TH0422 Borehole Well Schematic

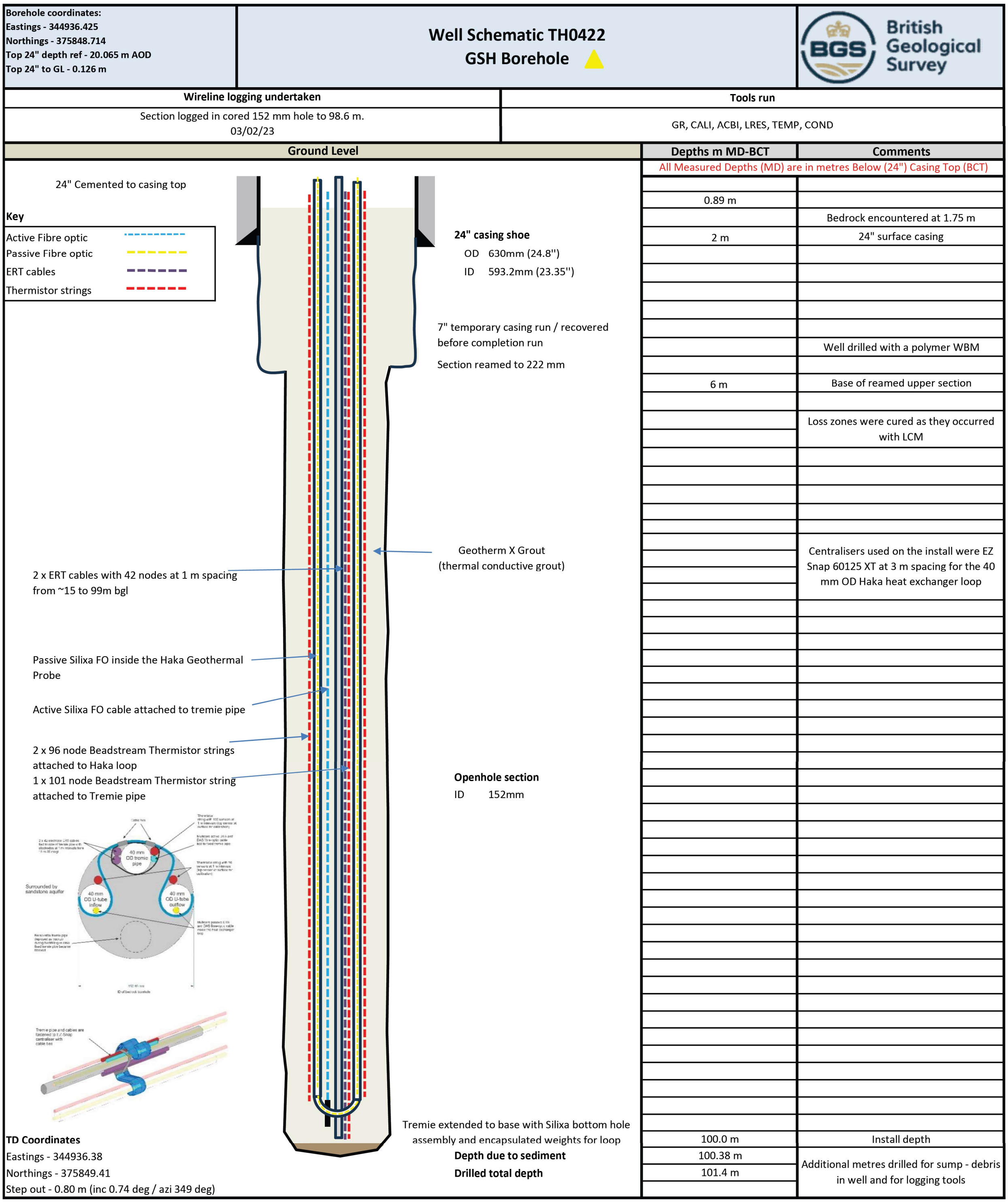


Figure 55 TH0422 Well Schematic

4.9.8 Wellhead / Well Chamber Status

Figure 56 Wellhead chamber image TH0422

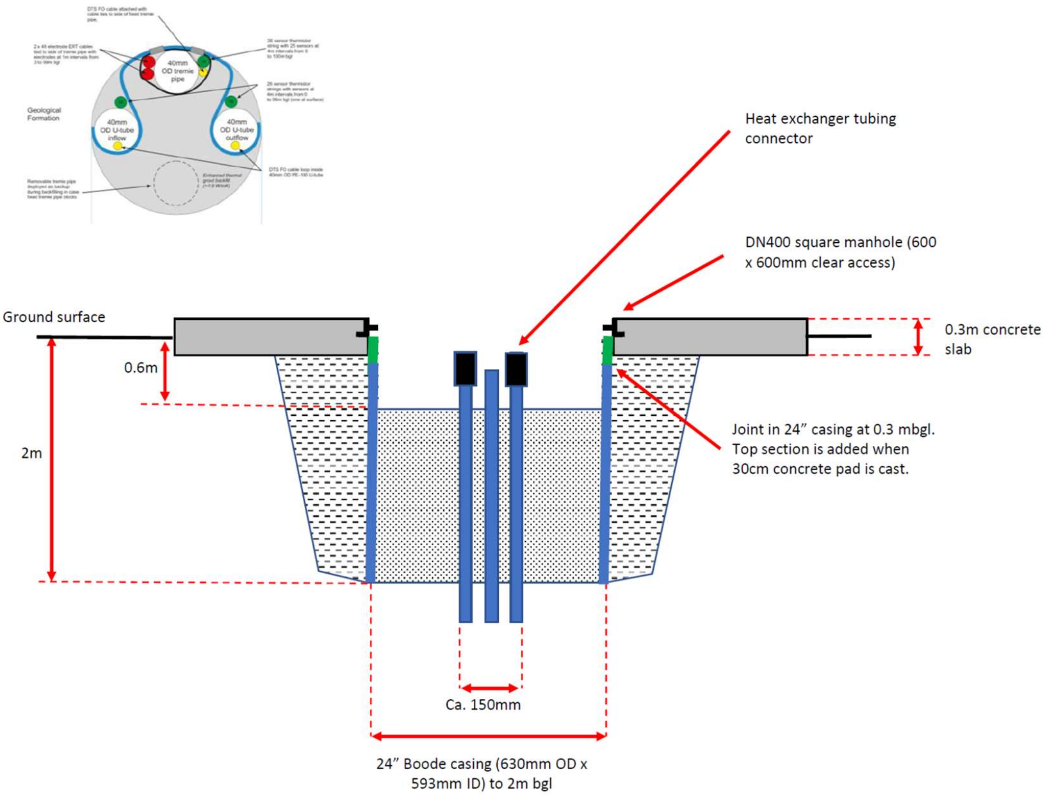


Figure 57 Wellhead chamber schematic TH0422

4.9.9 Daily Activity Summary

Table 52 Daily activity summary TH0422

Date	Depth M BGL	Operation	Parameters	Issues
25/01/23	10.4 m	Prepared to commence coring in TH0422, filled surface system with Purebore/Ultrabore drilling fluid and started to circulate. Observed a leak through the Bentonite seal at the base of the 7'' temporary casing. Decision made to pull the 7'' and reseal with additional Bentonite pellets. POOH the Geobore and 7'' temporary casing. Introduced 4 bags of Bentonite and allowed to hydrate. Ran back in hole the 7'' casing to just above the Bentonite layer and lowered into the Bentonite to achieve a seal. Commenced coring with 152 mm Geobore string from 2.0 m to 7.4 m, no losses reported. Circulated well clean removing cuttings and sediment. POOH with coring assembly. Recovered the coring assembly and the 7" temporary casing. Picked up and set 10 ¾'' temporary casing at 2.0 m. Sealed the casing with Bentonite at the base. Made up and RIH the 222 mm reaming assembly and opened out the section down to 6.0 m with full returns. POOH and laid out assembly. Recovered the 10 ¾" casing and ran 7" temporary casing down to 6.0 m and sealed annulus with Bentonite pellets. Mixed new mud. Made up and RIH the 152 mm coring assembly and cored ahead to 10.4 m. No losses reported.	Verticality checks: 0.25 deg @ 3.0 m. 0.26 deg @ 6.0 m. 0.59 deg @ 7.0 m. Repeat survey at 7.0 m: 0.25 deg. No losses reported.	Leak through the Bentonite seal at the base of the 7'' temporary casing allowing fluid to be lost to the surface formation below the 24'' surface casing shoe (flow also returning up the annulus between the 24'' casing and the 7'' string).
26/01/23	28.40 m	Continued to core ahead treating fractures with LCM pills down to 28.40 m. Losses started at 15.0 m.	Verticality checks: 0.52 deg @ 11.9 m. 0.48 deg @ 17.9 m. The LCM recipe consists of polymer base fluid, Bentonite powder, mica and walnut shells. The solids concentration is 25 pounds/barrel (ppb) for a standard pill and for a heavier pill at 40 ppb. 1 x 100 L (25 ppb) LCM pills pumped at 15.0 m. 1 x 100 L (40 ppb) LCM pills pumped at 22.4 m. Each pill pumped through a 40 mm tremie pipe RIH each time to spot on bottom.	

Date	Depth M BGL	Operation	Parameters	Issues
27/01/23	47.9 m	Continued to core ahead treating fractures with LCM pills down to 47.9 m.	Verticality checks: 0.29 deg @ 35.0 m. 0.22 deg @ 41.0 m. 0.33 deg @ 47.0 m. 2 x 100 L (40 ppb) LCM pills pumped from 28.4 m to 47.9 m. 40ppb pill consisting of: Pure-Bore Powder Mica M10 Nut Plug Med Clear-Stab ULI	Fractures difficult to seal and each time LCM pill is pumped time is lost running tremie pipe in and allow pill to soak.
30/01/23	64.4 m	Checked well status and observed the fluid level had dropped 5.0 m over the weekend. Topped up the well and monitored loss rate: level in well dropped ~60 cm in 10 minutes. Continued to core ahead treating fractures with LCM pills down to 64.4 m. The well inclination began to build so survey frequency was increased, and the ROP reduced to try and correct the inclination trend.	Verticality checks: 0.54 deg @ 53.9 m. 0.63 deg @ 59.9 m. 2 x 100 L (40 ppb) LCM pills pumped from 47.9 m to 64.4 m.	Core run from 52.4 m to 53.9 m, only 0.5 m was recovered. Attempted to pick up the missing core without success. Observed drilling fluid thickening considerably as drilled solids increase. Marriott is not using shaker system as it is believed that the screens will be blinded resulting in mud loss and complications with monitoring losses.
31/01/23	77.9 m	Continued to core ahead treating fractures with LCM pills down to 77.9 m.	Verticality checks: 0.40 deg @ 65.9 m. ROP - Average run times with the polymer mud are around 10-12 minutes per 1.5 m core. 3 x 100 L (40 ppb) LCM pills pumped from 64.4 m to 77.9 m.	Poor core recovery experience, core not being caught and section of core dropped (71.9 to 73.4 m) where only 0.5 m was recovered.
01/02/23	82.4 m	Continued to core ahead treating fractures with LCM pills down to 82.4 m. Added Bentonite to the mud system as per site instruction CSI026 – Updated drilling mud for GSH wells to provide a filter cake to the borehole and reduce seepage losses.	Verticality checks: 0.32 deg @ 80.9 m 4 x 100 L (40 ppb) LCM pills pumped from 64.4 m to 77.9 m.	Bentonite added to the mud system to prevent seepage losses and build a filter cake. Because loss rates must be instructed for an LCM pill to be pumped as the well was drilled deeper seepage losses contribute to the flow check volumes thresholds being exceeding. No flexibility allowed under the contract which caused delays.
02/02/23	100.3 m	Monitored well fluid level for 15 minutes. Recorded 1.99 m drop.	Verticality checks: 0.65 deg @ 86.9 m.	Loss threshold increased to 2.0 m to

Date	Depth M BGL	Operation	Parameters	Issues
		Continued to core ahead treating fractures with LCM pills down to 100.4 m and well TD. Losses over the last two runs exceeded the threshold so well flow checked – 1.6 m of drawdown inside the Geobore string over 15 minutes. Mixed mud to displace well. Dipped well to 100.3 m. A short section of core lost during final run.	0.47 deg @ 92.9 m. 0.58 deg @ 98.9 m. 1 x 100 L (40 ppb) LCM pills pumped at 89.9 m.	allow coring to proceed without the need for an LCM treatment at the start of the shift. Lost core from 85.4 to 86.9 m. Attempted to recover however 10 cm section became jammed in barrel resulting in assembly having to be POOH. Inner barrel had not latched within the outer barrel therefore the core is not captured in the inner barrel and not recovered.
03/02/23	100.4 m	Displaced the well to clean mud before flow checking the well for 15 minutes. Flow check within spec so continued to recover the Geobore assembly. Recovered the 7" temporary casing installed to 6.0 m. EGS arrived and setup over the well. Logged the borehole as per Scope down to 98.6 m (short of TD) before rigging down and leaving site. RIH with 222 mm reamer and washed/cleaned down to the 222 x 152 mm shoulder at 6.0 m before POOH the reamer. Made up and RIH 152 mm assembly and washed to TD at 100.4 m. Circulated the hole cleaned before POOH.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged to 98.6 m.	No sump drilled, decision taken by Aecom and Marriotts.
TH0422 GSH Install				
06/02/23	100.4 m	Prepared for running the installation. Spotted cable spoolers and associated equipment for running the GSH installation including the Loop Master.		Tie wrapped the centraliser tremie, base weight and strengthening tremie together. This was needed to straighten the residual bend of the GSH loop to allow it to be RIH without snagging.
07/02/23	100.4 m	Lifted the BHA up over the well and attached ERT and FO cables. RIH installation as per the install design sheet to 30.0 m.	Weight on loop is 31 kg and is required to overcome buoyancy and enable the completion to be run until there is sufficient string weight to overcome the buoyancy.	Hydraulic problem between the Loop Master and Telehandler had to be fixed – 1 hour NPT.
08/02/23	100.4 m	Installation weight is approx. at neutral point – water introduced into the loop to facilitate RIH. Continued RIH the GSH installation from 30.0 m to 75.0 m as per design sheet.		

Date	Depth M BGL	Operation	Parameters	Issues
09/02/23	100.4 m	Continued RIH the GSH installation from 75.0 m to 100.0 m as per design sheet. Lowered Loop Master to ground and prepared to test cables. Tested thermistor, ERT and FO cables. Rigged up to pressure test BHE loop. Performed pressure test to 7.5 bar following testing schedule in accordance with SN EN 80. Good test. Filled permanent tremie with water and observed level drop confirming communication through the tremie pipe.	Sorting grout bags according to bag weight – there is up to a 2 kg difference in bag weights. This will speed up the grouting procedure as weight checks will be less frequent.	There was an issue with Thermistor and ERT sensors when activated together. This delayed the start of the heat loop pressure testing. Approx 0.5 hrs NPT.
10/02/23	1.0 m	Prepare for grouting of TH0422. Both grout mixers setup and tested, permanent and temp tremie pipes circulated to confirm free and no blockages caused by running in hole and Geotherm X grout moved into location. Grout bags all pre weighted due to bag discrepancies and stacked on dedicated pallets. Commenced mixing Geotherm X grout and filling hopper with 2 x mixes and second grout unit. Pumped a total of 14 x 100 L mixes of grout. Started mixing grout at 10:08 hrs, first batch pumped at 10:21 hrs and finished at 13:00 hrs. Started seeing mud returns from the well approx. halfway through the job as the grout level rose. Final grout level at the top of the 24'' Boode casing (continued pumping grout until pure grout was observed in the Boode casing and all drilling mud removed). Excess grout was removed to give a top of grout 1.0 m below top of 24'' casing.	Grout mix 7.5 bags of Geotherm X to 100 L of water.	
TH0422 complete				

4.10 GROUND SOURCE HEAT BOREHOLE – TH0423 SUMMARY OF OPERATIONS

4.10.1 Key Well Data

Table 53 TH0423 Key well data

Well name	TH0423		
Well classification	Closed loop ground source heat well (GSH)		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.174 m AOD Top 24" to GL - 0.159 m		
Start date	Intermediate section started on 13/02/23 and was completed the same day. Lower section started 13/02/23.		
End of drilling date	01/03/23.		
Install dates	Install 06/03/23 to 09/03/23, Grouted 09/03/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 222 mm	Cored to 7.4 m Reamed to 6.0 m	Temporary 168.3mm OD x 155.7mm ID casing, recovered before completion run	6.0 m
Final section to TD Cored in 152 mm	Cored to 100.4 m	n/a	n/a
Installation	n/a	40 mm OD Haka heat exchanger loop with EZ Snap 60125 XT centralisers at 3 m spacing	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344944.045 Northing Y: 375852.444	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44944 75852	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344943.91 Northing Y: 375852.50 Step out - 0.15 m (inclination 0.31 deg / azimuth 273 deg)	

4.10.2 Summary of Drilling Operations

TH0423 was the second GSH wells to be drilled. A mud system comprising of Purebore and Ultrabore was adopted with LCM available as needed to stem losses. This approach was taken to ensure the well was standing full and not on losses when the installation was run and grouted back to surface in a single stage. This was a key criterion for this well type to give the best possible thermally enhanced grout coverage from base to TD.

The Comacchio 405 rig was mobilised and rigged up over TH0423 and the drilling mud prepared. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. The initial seal failed so the 7” was pulled and reseated with additional Bentonite pellets being required. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 7.4 m with no losses reported downhole however losses were seen over the shakers due blinding, so adjustments and screen change out was needed to the viscosified drilling mud. Inclination readings remained within the Scope tolerance. The hole was circulated clean before POOH the assembly.

The 7” casing was recovered and replaced with a string of 10 ¾” temporary casing, sealed with Bentonite at the base.

A 222 mm reamer and pilot bit was made up and the hole opened out down to 6.0 m and the well circulated with full returns before POOH. The temporary 10 ¾” casing was recovered and replaced with the 7” string down to 6.0 m. The annulus was sealed with Bentonite pellets.

Made up and RIH the 152 mm Geobore assembly and cored ahead to 20.9 m where losses were encountered that needed to be treated with LCM.

Continued to core ahead treating loss zones with LCM pills (40 ppb pills) as the assembly advanced deeper. All LCM pills were deployed via a 40 mm tremie pipe and after being allowed to soak were circulated out and any returning LCM material diverted into a waste tank to avoid circulating through the rig pumps and drill bit. Details of products used can be found in **Section 4.10.3**.

Cored to a depth at 46.4 m with slight return at the start of the core run but no returns by 47.9 m. Inspected core once recovered and fracture identified at 46.6 m. Due to difficulties sealing fractures previously the decision was taken to seal with grout. The coring assembly was pulled back and the 40 mm tremie pipe RIH. Mixed and pumped a 50 L Geotherm X pill (50 L water, 4.75 bags of Geotherm X grout at 1.7 sg) and monitored fluid level in the well, level dropping so a second cement pill was pumped. WOC.

Borehole dipped at 35.6 m. Ran back in hole the coring assembly and washed through the grout with no resistance until 44.9 m (3 m off bottom). Cored through the cement and recovered in the core barrel.

Figure 58 Cored out Geotherm X cement plug from 44.9 m to 47.9 m

Continued to core ahead treating fractures with LCM down to 62.6 m where it became difficult to treat and seal a fracture, so the decision was taken to seal with grout for a second time. The 40 mm tremie pipe was RIH and 4 x mixes (OPC grout with 1.5% Bentonite) were pumped ranging from 1.72 sg to 1.76 sg. WOC.

Top of cement was dipped at 37.15 m, and the coring assembly was advanced back in hole recovering cement down to 43.4 m. The cement was still friable and slightly soft, so the well was flow checked and observed to have seepage losses only, so the cement was allowed to cure overnight before advancing.

Continued to core ahead through the remainder of the cement (recovered cement was hard) before displacing the well to clean polymer mud. Cored to TD treating any remaining fractures with LCM to a depth of 100.4 m. A 40 ppb LCM pill was spotted on bottom before POOH.

The 7” temporary casing was recovered, and a cleanout assembly (222 mm reamer) was RIH down to the shoulder at 6.0 m and removed any remaining Bentonite before POOH. A cleanout BHA was RIH and washed down to total depth and circulated out the LCM pill that had been left to soak. The well was flow checked (30 cm drop in 15 minutes) before POOH.

EGS were mobilised and the well was wireline logged from 6.0 m to 100.4 m. Full details of wireline logging programme undertaken can be found in **Section 4.10.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

4.10.3 Materials, Flush and Drilling Additive Used

A viscosified drilling mud and lost circulation material approach was taken to drill TH0423. The reason was to ensure the well was standing full of fluid and static for the completion to be installed and achieve a single stage grouting operation. This was key to the well design to achieve a single column of grout from base to surface of a uniform density to ensure consistent thermal properties from the thermally enhanced grout. The grouting operation could be monitored accurately and the volume pumped checked against the returning volumes to ensure grout wasn't being lost into fracture and sealing off preferential flow paths permanently.

The products and LCM pills deployed are summarised in the below tables.

Table 54 Drilling fluid summary table – TH0423

	TH0423
Type of drilling mud used	Polymer mud
Section of well used	Intermediate and lower sections
Recorded drilling mud losses (L)	20,518
Ultrabore additive lost (kg)	292.4
Purebore additive lost (kg)	146.2

Table 55 summarise the lost circulation materials used, and the number of pills pumped whilst drilling both the intermediate and lower sections of the well. Each pill was 100 L in volume with various concentration of products based on loss rates being experienced and an understanding on how known fractures at given depths reacted.

Table 55 LCM pills deployed – TH0423

	TH0423
Section of well used	Intermediate and lower sections
LCM pills pumped	16
Volume of LCM pills pumped	1,600
Purebore additive used (kg)	14.5
Clear Stab additive used (kg)	69.7
Nut Plug (kg)	147.0
Flaked Mica (kg)	24.0

Note: volumes stated above are the volumes of LCM pumped. Each pill was allowed to soak on depth before circulating to confirm if the treatment had been successful. The large percentage of the LCM pills pumped were circulated out and disposed of.

Due to large fractures being encountered that couldn't be controlled with LCM alone, the decision was taken to emplace two cement plugs to seal as detailed below in **Table 56**.

Table 56 Summary table of grouting operations to stem losses – TH0423

	TH0423
Grout pills pumped to stem losses	Cement plug #1 at 47.90 m – 2 x 50 L Geotherm-X GR mixes. Cement plug #2 at 62.9 m - 4 x 1.5% Bentonite and OPC grout mixes.
Water volume (L)	Cement plug #1 = 100 Cement plug #2 = 200
Geotherm-X GR grout (kg)	228
OPS grout (kg)	300
Bentonite (kg)	6

The LCM pills and grout pumped to seal fractures allowed the well to be in a suitable state for when the install was run and grouted back to surface in a single stage.

4.10.4 Geophysical Logging Undertaken

Table 57 Geophysical logging summary TH0423

Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 100.4 m. (02/03/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.15 m and within the 1/100 tolerance.

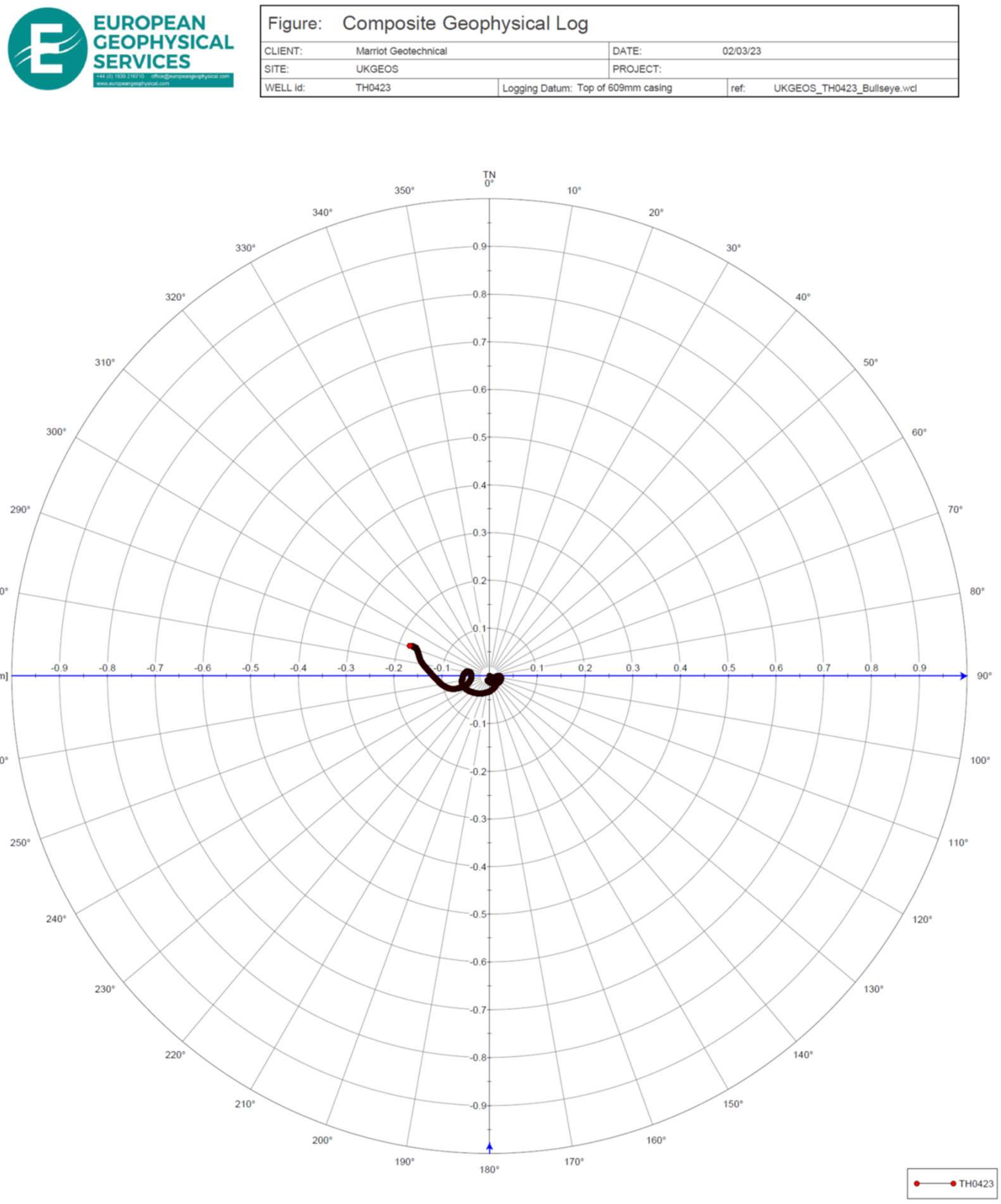


Figure 59 Verticality bullseye plot for TH0423, © European Geophysical Services Ltd

4.10.5 Summary of Installation Operations

Installation criteria for TH0423:

- Ensure well is standing full and static before commencing installation.
- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography, Beaded stream thermistor cables and fibre optic cables on the outside of the borehole heat exchanger ensuring that ERT electrodes are at correct depths.
- Run passive fibre optic cable through the centre of the heat exchanger.
- Deploy heat exchanger with EZ snap centralisers to ensure heat exchanger is in contact with the borehole wall before grouting operations.
- Accurately monitor the deployment.

- Maintain heat exchanger in tension during backfill using insulated base weights to counteract buoyancy during running.
- Grout the borehole in a single stage if possible but with contingency of a backup tremie in the event of any issues
- Backfill with a continuous column of grout, with uniform density to ensure consistent thermal properties as per suppliers' specifications.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared for running the installation. Spotted the cable reel stands and equipment. Moved the telehandler into position with the Loop Master with the heat exchanger spooled already. The passive FO cable was threaded through the centre of the heat exchanger, tested by Silixa and pressure tested to 7.5 bar following the GSHPA guidelines in advance of the installation operation.

The BHA assembly was made up however due to the residual bend of the heat exchanger loop the lower section had to be tie wrapped and additional short length of tremie pipe used to act as a splint. The heat exchanger weights (31 kg) were encapsulated inside a section of 60 mm yellow PVC pipe and sealed at the top and bottom to avoid any chance of interference with the ERT array.

The heat exchanger was run in hole as per the installation sheet to 100.0 m, securing all the cables to the permanent tremie and heat exchanger loop with tie wraps. See **Figure 61**. Centralisers were placed every 3.0 m to ensure the correct standoff from the borehole wall was achieved. The centralisers used were EZ Snap 60125 XT for the 40 mm OD Haka heat exchanger loop.

Figure 60 Installation images of the heat exchanger loop, primary and backup tremie pipes and all the cables / cable management as its RIH

The Loop Master was lowered to the ground, and all cable strings were tested (FO, ERT and thermistor strings) with no issues apart from a single thermistor node reading 99 deg C. The pressure testing equipment was rigged up and the heat exchanger loop tested to 7.5 bars, for a second time following the GSHPA guidelines and in accordance with the SN EN80. A good test was observed.

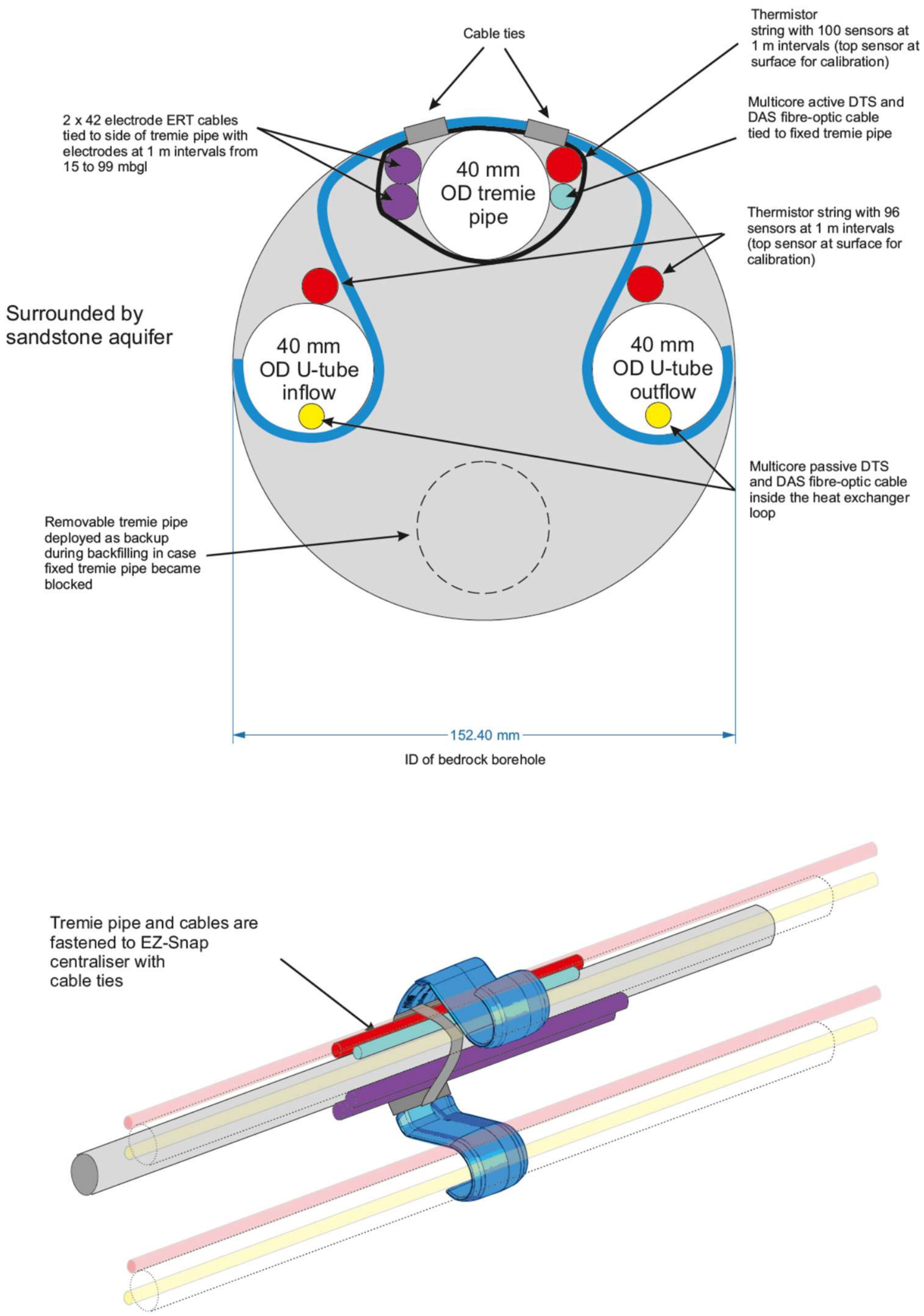


Figure 61 Schematic showing the placement of the various sensor cables on and within the installation for TH0423

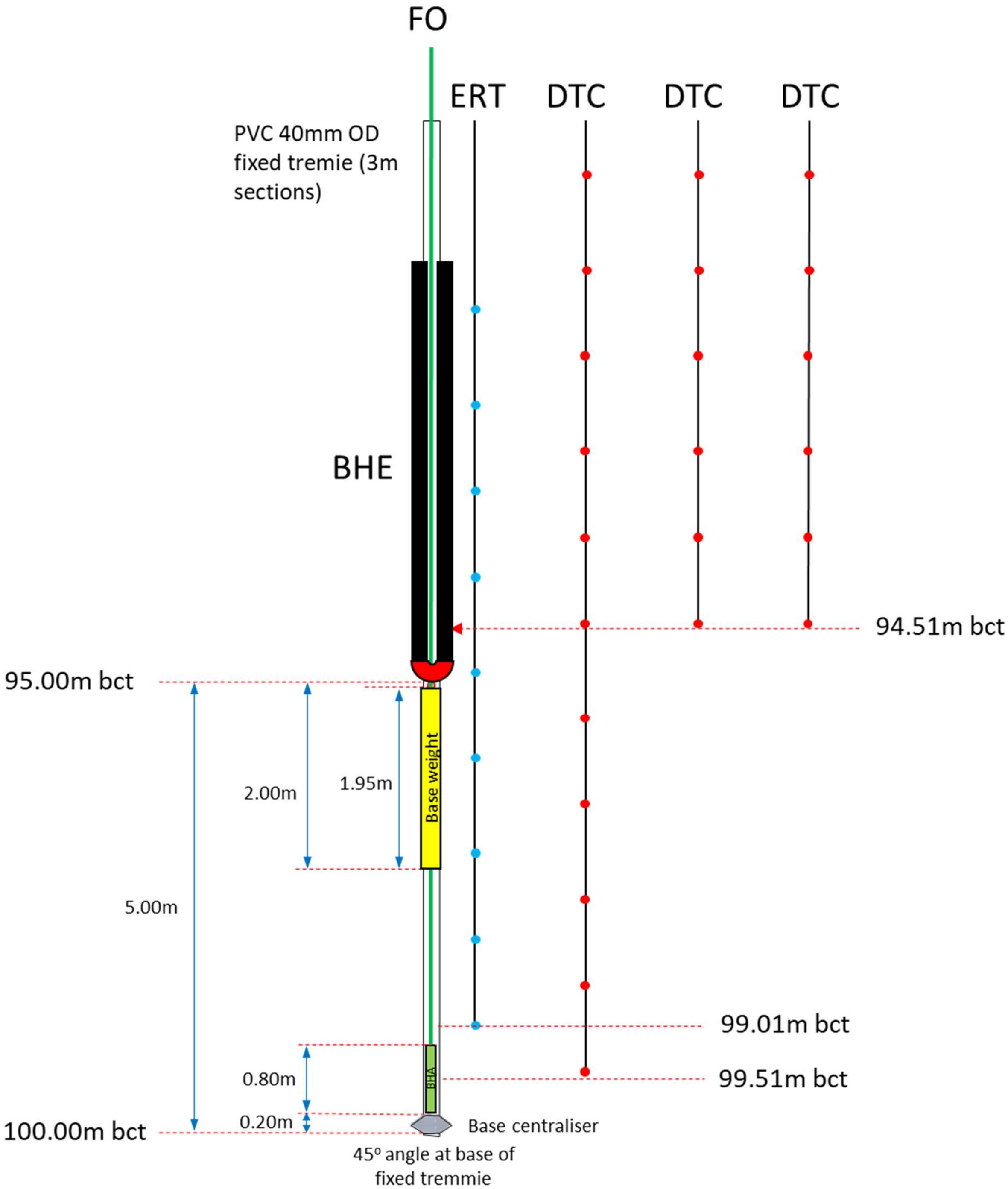


Figure 62 Bottom hole assembly schematic for TH0423 showing depth of install and each sensor string

The grouting equipment was rigged up which comprised of a batch mixer and screed pumper. This setup allowed the continuous delivery of grout into the well with each grout batch being mixed offline until the correct weight and viscosity was achieved before transferring over to the active grout pump. Two laptops were setup at the wellsite, one to monitor the ERT sensors and the other to monitor the RST thermistor strings. The tremie was circulated with water and confirmed free before commencing with the grouting operation. A total of 13 x 100 L mixes of grout were pumped at 15 L/min until grout was seen inside the 24” surface casing.

Full details of the grouting operation including the mixes used are detailed in **Section 4.10.6.**

4.10.6 Backfill and grouting operations

The Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a permanent sacrificial tremie pipe. A backup retractable tremie was also deployed to total depth before the completion was run and pulled back in stages during the grouting operation, always keeping above the top of cement (TOC). This backup tremie was only used in the event of a blockage occurred in the primary string.

Real-time data were collected from the thermistor cables and ERT sensors by BGS during the grouting operations. This was observed to track the upward progress of the grout via temperature and conductivity change respectively as the grout moved up the annulus. This was to give forewarning of significant grout loss to formation and pressures were monitored at the cement unit to warn of any signs of blockages occurring. If the temperature and conductivity remained stationary at a given depth, then this would indicate grout was flowing laterally outwards into fractures which was to be avoided at all costs.

The Geotherm X grout was found to have a range of weights per bag from the supplier, so all bags were pre weighed and stacked in batches ready for mixing to ensure a more consistence grout weight and viscosity.

The grouting rig up consisted of two grout units; the primary was used to deliver the grout into the well, and the secondary allowed the next batch to be mixed offline before being transferred to the primary unit. This ensured a constant delivery of grout without having to stop which would have increased the risk of the tremie pipe becoming blocked. The two-unit system was developed due to the limitations on grouting equipment and the size of mix hoppers available.

Dry and wet samples of the grout were taken for future analysis.

The grouting operation in TH0423 was completed successfully utilising only the primary tremie pipe. The below table summarises the grout batches pumped:

Table 58 Grout backfill summary table – TH0423

Batch number	Date	Volume of water (L)	Dry grout mass (kg)	Grout weight (sg)
1	09/03/23	100	180	1.68
2	09/03/23	100	180	1.68
3	09/03/23	100	180	Not taken / continuous mixing
4	09/03/23	100	180	1.70
5	09/03/23	100	180	1.65
6	09/03/23	100	180	1.69
7	09/03/23	100	180	1.68
8	09/03/23	100	180	1.68
9	09/03/23	100	180	1.69
10	09/03/23	100	180	1.68
11	09/03/23	100	180	1.68
12	09/03/23	100	180	1.70
13	09/03/23	100	180	1.67
Total		1,300	2,340	1.68 avg

The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.10.7 TH0423 Borehole Well Schematic

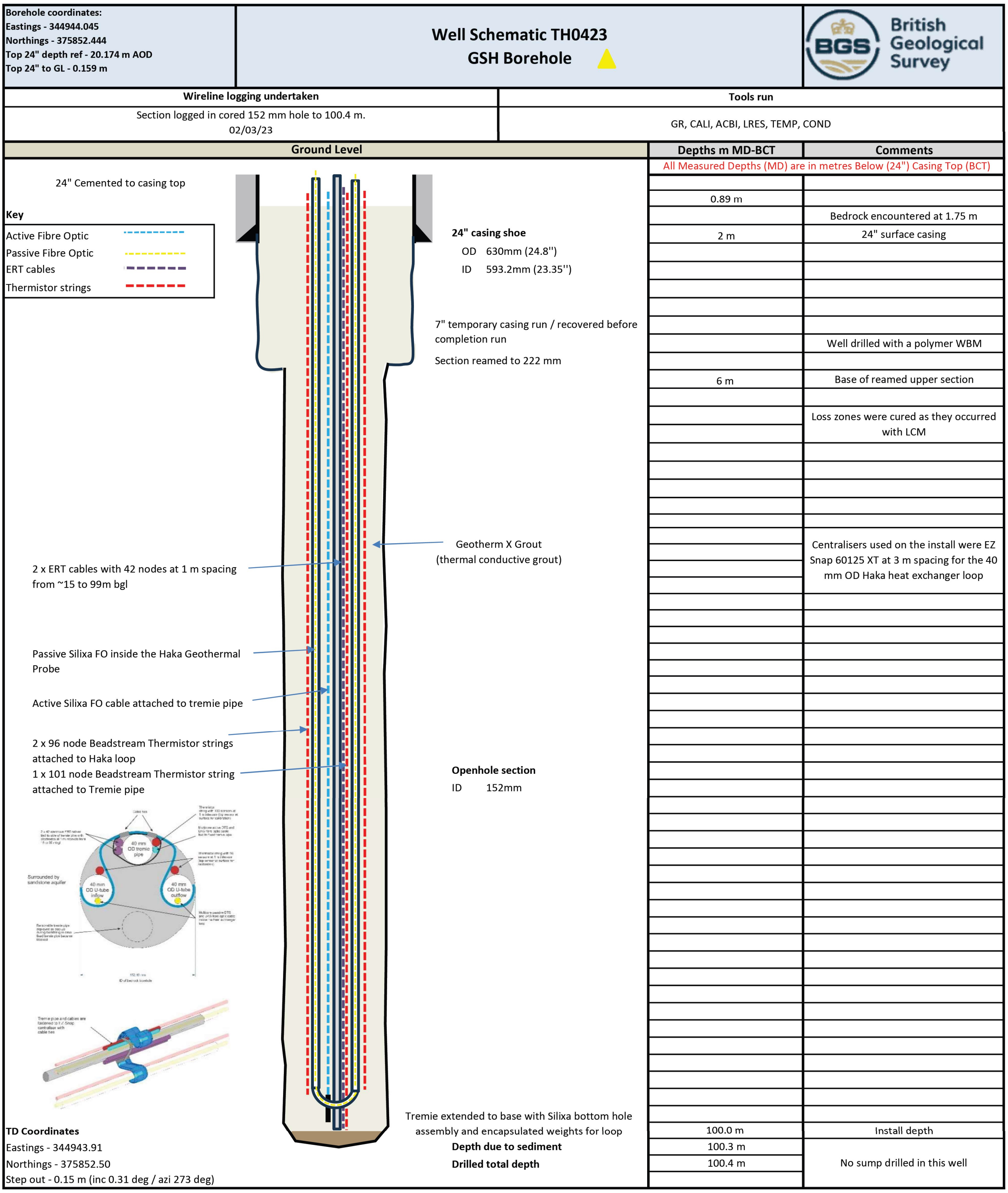


Figure 63 TH0423 Well Schematic

4.10.8 Wellhead / Well Chamber Status

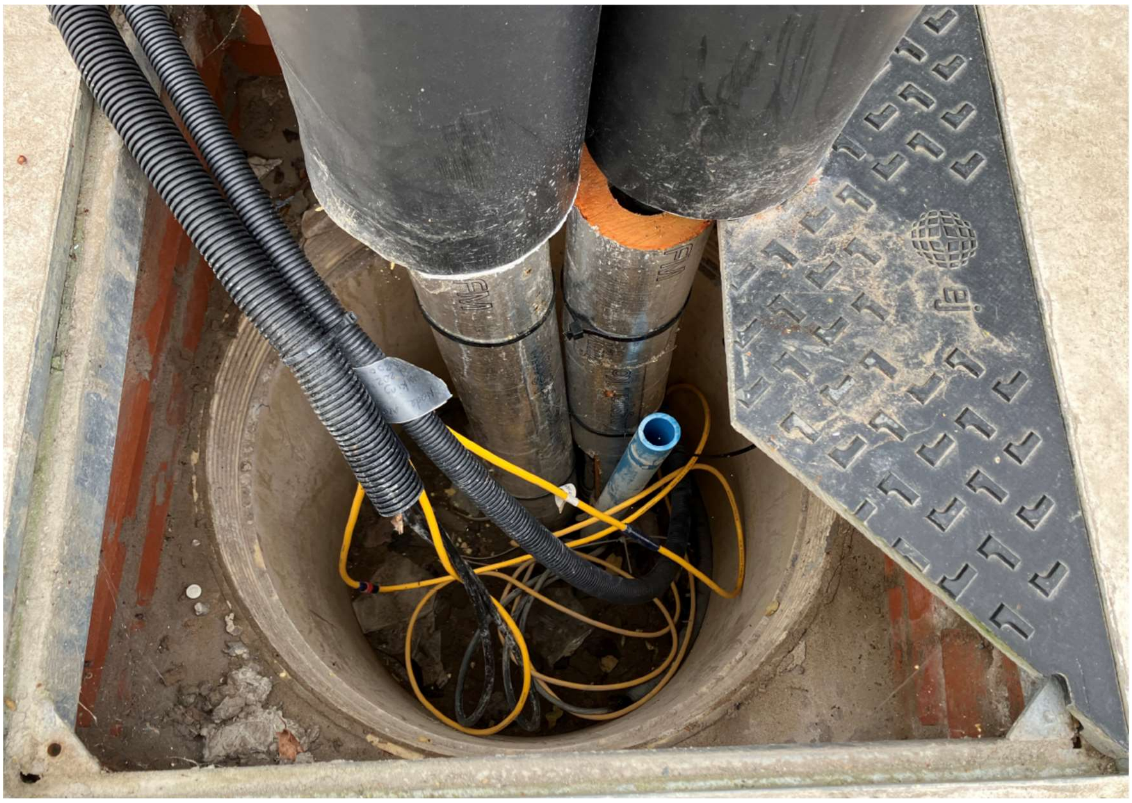


Figure 64 Wellhead chamber image TH0423

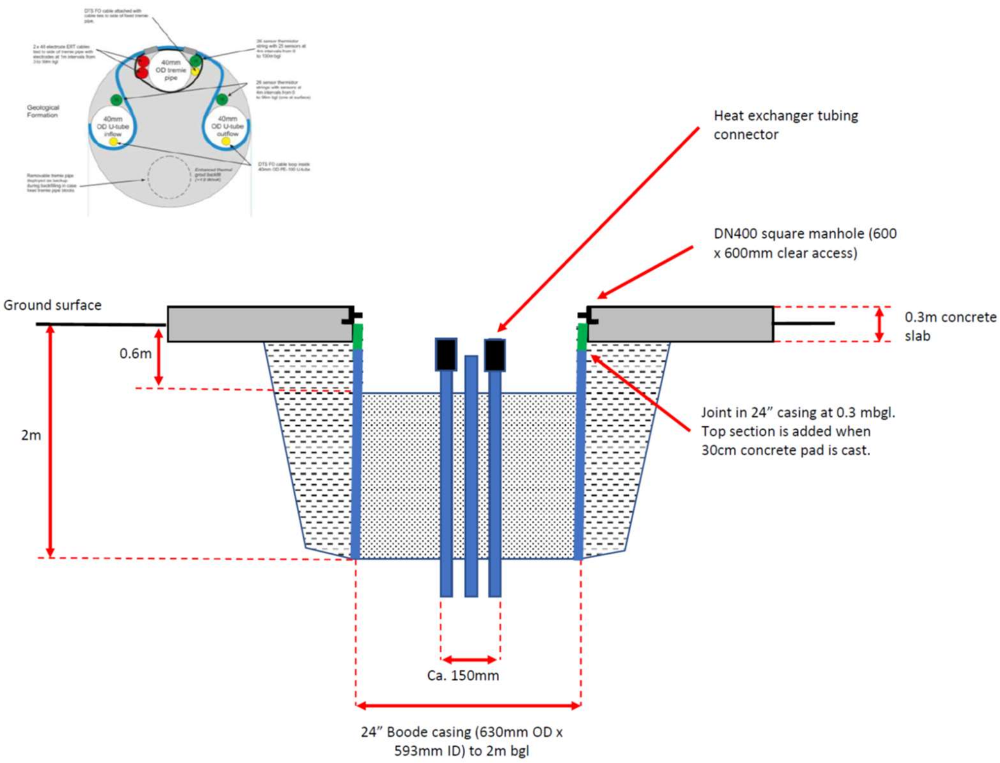


Figure 65 Wellhead chamber schematic TH0423

4.10.9 Daily Activity Summary

Table 59 Daily activity summary TH0423

Date	Depth M BGL	Operation	Parameters	Issues
10/02/23	2.0 m	Moved the Comacchio 405 rig from TH0422 and setup over TH0423. Ran temporary 7" casing and centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations.		
13/02/23	16.4 m	Made up 152 mm coring assembly and commenced coring from 2.0 m to 7.4 m before circulating the hole clean and POOH. Recovered the coring assembly and the 7" temporary casing. Picked up and set 10 ¾'' temporary casing at 2.0 m. Sealed the casing with Bentonite at the base. Made up and RIH the 222 mm reaming assembly and opened out the section down to 6.0 m with full returns. POOH and laid out assembly. Recovered the 10 ¾" casing and reran the 7" temporary casing down to 6.0 m and sealed annulus with Bentonite pellets. Made up and RIH the 152 mm coring assembly and cored ahead to 16.4 m with partial returns.	Cores being collected and curated into 1.0 m and 0.5 m lengths, boxed and labelled by Marriott. Fluid samples every 6.0 m and verticality checked every 3.0 m. Verticality checks: 0.29 deg @ 4.0 m. 0.17 deg @ 7.0 m. 0.23 deg @ 10.4 m.	Some adjustments to shaker system were necessary as the screens were blinding leading to mud losses, changed screens and monitored.
14/02/23	25.4 m	Continued to core ahead treating fractures with LCM pills down 25.4 m. Losses started at 20.9 m.	Verticality checks: 0.18 deg @ 17.9 m. 1 x 100 L (40 ppb) LCM pills pumped at 20.9 m. 40 ppb pill consisting of: Pure-Bore Powder Mica M10 Nut Plug Med Clear-Stab ULI	Night shift only for operations on TH0423.
15/02/23	35.9 m	Continued to core ahead treating fractures with LCM pills down to 35.9 m.	Verticality checks: 0.29 deg @ 29.0 m. 0.22 deg @ 35.0 m. 1 x 100 L (40 ppb) LCM pills pumped at 34.4 m.	Night shift only for operations on TH0423.
16/02/23	46.4 m	Continued to core ahead treating fractures with LCM pills down to 46.4 m.	3 x 100 L (40 ppb) LCM pills pumped at 46.4 m unable to control losses.	Night shift only for operations on TH0423. Fractures difficult to seal and each time LCM pill is pumped time is lost running tremie pipe in and allow pill to soak.
17/02/23	40.0 m	Checked level drop in TH0423. Observed 5.0 m drop in 10 minutes. Decided to core one additional run.		Fractures unable to be sealed with LCM so grout used.

Date	Depth M BGL	Operation	Parameters	Issues
		Cored from 46.4 m to 47.9 m. Slight returns at start of run, but then no returns. Recovered full core barrel showing possible fracture at 46.6 m. POOH 10 lengths of drill rod. RIH 40 mm tremie pipe to TD in preparation for grouting. Mixed 50 L of Geotherm X grout in drum, connected pump, hose and pumped down the tremie pipe. Fluid level before pumping: 13.86 m. Fluid level after pumping: 7.95 m. Fluid level after 1 min: 8.7 m. Mixed and pumped additional grout, fluid level rose to 7.0 m. After 5 minutes, level dropped to 10.0 m (3.8 m drop). After 10 minutes, level at 11.2 m. Loss rate appears to be slowing. POOH remaining tremie pipe. Connected rig drive head onto drill rod. Shut down rig and allowed grout to set. Dipped well at 46.2 m. Additional grout pill was pumped – 50 L water, 4.75 bags of Geotherm at 1.70 sg. WOC. Borehole dipped at 40.0 m.		
20/02/23	59.9 m	Dipped the well and found water level at 4.2 m and top of grout at 35.6 m. Commenced RIH with 152 mm Geobore. Washed through the grout from 35.6 m with no resistance until 3.0 m from the previous TD at 47.9 m. Recovered 2 core barrels of soft/medium soft crumbly grout. Continued to core ahead treating fractures with LCM pills down to 59.9 m.	Verticality checks: 0.32 deg @ 47.0 m. 0.26 deg @ 53.9 m. 0.30 deg @ 59.9 m. Note: Although the dip was at 35.6 m in the morning, it appears that most of the grout had been washed away during coring and it was only the 3.0 m at the bottom that was firm enough to be collected in the core barrels. 2 x 100 L (40 ppb) LCM pills pumped from 52.4 m to 59.9 m.	Mono pump broke down. Rig crew unable to repair so switched to Comacchio rig pump. The Comacchio rig pump also had an oil leak which the crew managed to reduce to allow the pump to be used. The mono pump is used for pumping flush and LCM and is more powerful than the triplex rig pump. NPT 2.25 hrs.
21/02/23	62.9 m	Continued to core ahead treating fractures with LCM pills down to 62.6 m. Unable to control losses with LCM so decision taken to cement. Pulled back Geobore assembly and RIH the 40 mm tremie pipe. Mixed and pumped 4 grout batches: Mix 1: SG 1.72, pumped at 20:15 hrs. Mix 2: SG 1.74, pumped at 20:25 hrs. Mix 3: SG 1.74, pumped at 20:40 hrs. Mix 4: SG 1.76, pumped at 20:51 hrs. POOH tremie pipe and left grout to set.	2 x 100 L (40 ppb) LCM pills pumped from 59.9 m to 62.6 m. 1 x 100 L (80 ppb) LCM pills pumped at 62.6 m. Grout used was OPC grout, not Geotherm X.	Mixing mud online. One tank is used for the shaker system so there is a tank less for mixing new mud volume. On previous well without the shaker, there was an extra tank available for mud volume. Sourcing an additional tank could therefore help to avoid having to mix mud with the rig stood.

Date	Depth M BGL	Operation	Parameters	Issues
22/02/23	43.4 m	Wait on cement. Mixed 3 x LCM pills in preparation. RIH Geobore and commenced coring through the grout. Top of grout from dip measurement expected at 37.15 m. The recovered grout in the core barrels was not fully set, easily broken up by hand and friable. Top of grout re-measured at 43.4 m. Topped up the well and monitored level drop 4.0 m in 1 hour. Losses assumed to be seepage losses from the interval from surface to 43.4 m. Completed one core run through the grout at 17:00 hrs. Observed grout hardening but still not considered hard enough to guarantee success. Continue to wait on cement.		
23/02/23	67.4 m	Cored through the grout to reach previous TD. Grout recovered in core barrels was hard. Circulated grout contaminated fluid out of the well and displaced with new polymer mud. Continued to core ahead treating fractures with LCM pills down to 67.4 m.	1 x 100 L (40 ppb) LCM pills pumped.	It was planned to trial aeration of the drilling fluid to improve performance, but this was postponed. No night shift due to crew shortage.
24/02/23	68.9 m	RIH and circulated out LCM material. Resumed coring from 67.4 m to 68.9 m (1 core run achieved). Observed 1,600 L mud loss by the end of the run (equivalent to 10 bbl.). Stopped coring and RIH tremie pipe. Pumped LCM and allowed to soak, keeping well topped up. Mixed new polymer mud. RIH with Geobore and circulated pill out. Pulled back Geobore string. Well static. Flow check completed with 80 cm draw down in 15 minutes. (BGS informed via call) continue pulling Geobore to check bit. Tight spots encountered at 55.0 m, 53.5 m, 52.0 m, 49.0 m, 46.0 m, 44.0 m, 41.0 m, 39.5 m (string had to be worked through these areas). Bit checked when on surface and nozzles blocked with LCM product – see issues column. Cleaned and ran back in hole to 33.9 m (above tight section).	LCM pill standard recipe apart from double quantity of mica, at Marriotts discretion. Pure-Bore Powder Mica M10 Nut Plug Med Clear-Stab ULI Note – all tight sections within cemented zones.	NPT – all indications suggest the first LCM pill of the day was not circulated out of the hole correctly resulting in the bit nozzles becoming blocked. This would have been apparent by the pump pressure. Drilling continued with excessive losses greater than anything seen to date which can be associated with the jetting force of the blocked bit (only 3 open, 7 nozzles blocked).
27/02/23	83.9 m	Run in hole Geobore string from 33.9 m to bottom. Continued to core ahead treating fractures with LCM pills down to 83.9 m. Inner barrel stuck inside outer resulting in string having to be POOH. Unable to treat well with LCM as a result – no path for tremie pipe to be run. Retrieved inner barrel on surface and ran back in hole to 33.0 m.	Verticality checks: 0.27 deg @ 71.9 m. 0.20 deg @ 77.0 m. 1 x 100 L (40 ppb) LCM pills pumped at 70.4 m.	Issue with mono pump, lost time trying to resolve and had to revert to using the cement unit to pump LCM pill. Latches on inner barrel stuck inside outer string. Attempts to recover unsuccessful. Unable to run tremie through pipe to

Date	Depth M BGL	Operation	Parameters	Issues
				administer LCM pill at 83.9 m.
28/02/23	100.4 m	Continued to RIH Geobore assembly to 7 joints off bottom. Ran tremie pipe and pumped LCM pill and allowed to soak. Flow checked – static. Continued to core ahead to 100.4 m and well TD treated losses as required. 40 ppb LCM spotted on bottom before POOH coring assembly.	LCM pill consisted of: 2.75 kg mica 12 kg nut plug 6 kg of clear stab Circa 60 ppb Verticality checks: 0.07 deg @ 89.0 m. 0.27 deg @ 95.0 m. 1 x 100 L (60 ppb) LCM pills pumped at 70.4 m. 2 x 100 L (40 ppb) LCM pills pumped at 97.4 m and at TD as instructed by BGS.	Continuing issue with core being dropped and having to be recovered. Unclear the cause or if catchers are being affected by sand in the recirculated mud.
01/03/23	100.4 m	Start to run in hole tremie pipe. With 68.0 m of tremie run the winch cable became caught resulting in tremie being dropped down hole. Fishing operations – see issues column. Marriotts arrived onsite at 15:30 hrs with a delivery including a catcher box for recovering the tremie pipe. Made up and ran in hole and successful latched. Tremie pipe recovered. Ran back in hole tremie after checking bottom joint wasn't plugged. Pumped LCM pill and allowed to soak for 45 minutes whilst constantly topping up. Pulled out of hole the Geobore string with the LCM pill still on bottom. Recovered the 7" temporary casing and cleaned the ledge with the reamer assembly removing any remaining Bentonite. RIH the Geobore string and circulated out any remains of the LCM pill. Flow checked the well – 30 cm drop in 15 minutes. POOH. On coming out of the hole 2,000 L of fluid was reported to be lost. Unclear if this volume was to a shallow formation with the surface casing recovered. Well still standing full.	LCM pill consisted double quantities of all products for a 40-ppb pill apart from PureBore which remained unchanged to give a circa 80 ppb pill: 2.75 kg mica 16 kg nut plug 8 kg of clear stab	6.75 hrs NPT - Ran tremie pipe to 68.0 m where the winch cable became caught resulting in tremie being dropped. Managed to engage and attempted to pull out of hole. After recovered 14 joints back to the parted joint and checking the tremie wasn't plugged started to run back in hole. Ran an additional 3 x length when the lifting head stripped out resulting in the tremie pipe being dropped again. Total length in hole 77.0 m. Attempted to engage with the same pipe this time was unsuccessful. Pulled out and ran in hole Geobore string and tried to engage with a basket spring. Unsuccessful. Larger 60 mm yellow pipe ran to work as an overshot. Managed to tag the top of the tremie at circa 33.0 m but unsuccessful in trying to rethread onto the pipe. An alternative catcher springs was then tried on the Geobore pipe. Again unsuccessful.

Date	Depth M BGL	Operation	Parameters	Issues
02/03/23	100.3 m	EGS arrived and setup over the well. Logged the borehole as per Scope down to 100.3 m before rigging down and leaving site.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged to TD.	LOLER inspections.
TH0423 GSH Install				
06/03/23	100.3 m	Prepared for running the installation. Spotted cable spoolers and associated equipment for running the GSH installation including the Loop Master. Commenced RIH with GSH installation. Picked up centraliser joint, secured base weight, braced with tremie pipe and RIH. Installation run in hole to 21.0 m. Lowered Loop Master to the ground and made cables safe and secure for leaving overnight. End of dayshift operation.	Standing water level prior to commencing installation was 13.3 m.	Tie wrapped the centraliser tremie, base weight and strengthening tremie together. This was needed to straighten the residual bend of the GSH loop to allow it to be RIH without snagging. At 17:15hrs as the BHE loop was spooled off the Loop Master, one arm of the loop became snagged on a protruding clamp on the Loop Master, causing a slight bend in the loop. The operation was stopped and the loop adjusted. There was no visual damage to the tube. Aecom inspected the section of tube, noted the depth (82.5 m depth in hole). The loop was filled with water before commencing to RIH and no leakage was observed. Aecom site management did not think it necessary to pressure test the loop. Silixa tested the FO cable inside the loop with no issues.
07/03/23	100.3 m	Lifted Loop Master and re-positioned equipment to continue with the install. Filled BHE loop with water and visually inspected the area where the loop became bent on 06/03/23. No leaks and Aecom management did not consider it necessary to pressure test the BHE loop. Continued RIH with GSH installation from 21.0 m to 72.0 m. Lowered Loop Master to ground, drained loop of water to mitigate against predicted frost and secured rig/cables.	BGS staff checked the integrity of the RST DTC thermistor cables when the BHE loop was about 21.0 m into the hole. All sensors working fine. The integrity will be checked again when BHE loop assembly is installed to TD.	Having some issues getting the BHE loop to feed into the well. Topped up loop with water and experimented with Loop Master position and strops to try to improve the angle of the tubes into the well.
08/03/23	100.4 m	Filled BHE loop with water. Continued to RIH with GSH installation from 72.0 m to 100.0 m as per design sheet. Lowered Loop Master to ground and prepared to test cables. Tested thermistor, ERT and FO cables. No issues apart from one node reading incorrect temp (99 deg C).	Well dipped at 100.4 m.	Thermistor node 15 is the anomalous node (above water table).

Date	Depth M BGL	Operation	Parameters	Issues
		Rigged up to pressure test BHE loop. Performed pressure test to 7.5 bar following testing schedule in accordance with SN EN 80. Good test. Positioned grout mixing equipment in preparation for grouting.		
09/03/23	1.0 m	Prepared for grouting and set up 2 laptops to monitor the job – one monitoring the ERT sensors (GTOM) and the other monitoring the RST thermistor 101.0 m cable. Both grout mixers were setup and tested, permanent and temporary tremie pipes circulated to confirm free and no blockages caused by running in hole and Geotherm X grout moved into location. Grout bags all pre weighted due to bag discrepancies and stacked on dedicated pallets. Commenced mixing Geotherm X grout. Proceeded to check slurry weight (1.68 sg) then pumped continuously, transferring mixed slurry from the grout mixer to a separate screed mixer tank for pumping to the well at a steady rate of 15L/min. Pulled back temporary tremie pipe at a rate of 1 joint every 3 minutes and observed fluid returns at surface at 10:56 hrs. Continued mixing and pumping the grout until grout returns were observed after pumping approx. 13 x 100 L mixes. The grouting operation finished at 12:00 hrs. Washed down the rig and grout mixing equipment, cleared work areas around TH0423. Removed unused materials from site. Lowered mast of Comacchio rig and prepared to move to next location.	Sorting grout bags according to bag weight – there is up to 2 kg range in bag weights. This will speed up the grouting procedure as weight checks will be less frequent. Grout mix 7.5 bags of Geotherm X to 100 L of water.	
TH0423 complete				

4.11 ISSUES ENCOUNTERED AND LESSONS LEARNT – GSH WELLS

Table 60 Summary table of issues encountered – GSH wells

Well number	Issue	Solution / lessons learned
TH0422 and TH0423	Difficulties regarding use of mud to drill GSH wells: significant mud loss to aquifer, significant use of LCM materials, programme implications.	Progression of TH0416 and TH0417 were progressed using water flush and LCM. ERT was used to monitor grout migration up the well during cementing to avoid sealing fractures across the array.
TH0422 and TH0423	Drilling mud.	Contract didn't allow for flexibility. Surface tanks and monitoring capabilities not available to keep the mud in specification. Restrictions on products that could be deployed limited what could be achieved due to concerns of altering the groundwater chemistry. Large fractures were difficult and time consuming to seal with the available and approved products. Contingency LCM products should have been considered.
TH0422 and TH0423	Drilling mud.	Use of drilling mud was attempted but the surface tank arrangement, fluid management and experience with these products did not allow the system to be operated efficiently. No mud checks were performed to confirm if the mud was still in spec or if a filter cake was being generated. System wasn't constantly dosed to maintain the correct concentrations. No mud weight checked were taken with the mud becoming heavy with suspended solids.
All GSH wells	LCM deployment.	Contract management didn't allow for flexibility; everything had to be instructed. Flexibility is needed to allow the drill crew and supervisors to make a call onsite. LCM deployment cannot be based on an exact fluid loss threshold or flow check values. This should be reviewed and flexibility given to the supervisors onsite to avoid significant delays.
All GSH wells	The high thermal conductivity sand- Bentonite grout (>1.3W/m/K) that was proposed for the GSH boreholes is a liquid thermal grout that doesn't set hard. BGS flagged this as a concern once extent of fractures was understood that this could be washed out through fracture zones.	Use of Geotherm-X GR for all the GSH boreholes, with LCM to avoid migration of grout into fractures during the install.

Well number	Issue	Solution / lessons learned
All GSH wells	Single stage grouting.	Main reason was to achieve the grouting in a single lift to achieve the best possible cement job for the GSH wells and thermal conductivity - uniform grout across the borehole. If performed in stages, then this would impact the quality of the install. This was achieved as detailed above by sealing fractures with LCM and monitoring returns with the ERT to ensure the grout wasn't being lost into fractures.
All GSH wells	Sealing known problematic fractures.	Problematic large zones once identified could have been grouted / sealed before advancing. Two or three main loss zones were understood across the array and could have been targeted with different approaches to seal. Several LCM pills were deployed at each of these fractures which was time consuming. Grouting and drilling out may have been a better solution and drill with water only removing the need for a mud system. Only a viable option once the ground conditions are fully understood and relevant for arrays where multiple wells are in close proximity.
All GSH wells	Grout mix consistency.	Geotherm X grout not supplied in exact 24 kg bags so obtaining a consistent mix weight was difficult. The solution was to weight bags of grout and produce piles of matching weights, so each mix was consistent and reduced the time taken to mix and check viscosity for suitability to pump down tremie pipes.
All GSH wells	Blocked tremie pipe during grout deployment.	On two occasion the backup tremie had to be used, one was a blockage downhole, the second was at surface but this unknown at the time and only located at a later stage once grouting had been completed. The learning is to continue to deploy a backup tremie pipe to achieve the best possible cement job and avoid dropping grout from above through a column of water which would not provide a consistent thermal grout signature.
TH0416 and TH0417	Monitoring grout without returns at surface.	Two of the GSH wells were drilled with mud and LCM to provide a full static well at the time of the installation to allow the grouting operations to be accurately monitored from the returning fluid (standard practice). However, this was time consuming and difficult to implement with the available equipment and experience levels of mud systems. As an alternative the remaining wells were drilled with a water and LCM if needed approach. At total depth the wells were on losses. The ERT system

Well number	Issue	Solution / lessons learned
		was proposed and used to monitor the grout as it advanced up the well to ensure grout wasn't being lost sideways. The interface between the two fluids (water and grout) is what the ERT system detected in real time. The system worked well. The protocol was to stop pumping grout if the grout level didn't continuously rise in the borehole, but this scenario never transpired. A first for using this technology in this way.
All GSH wells	The EZ Snap centralisers suggested in the original scope were proven not to provide the gripping force needed following discussions with the manufacturer and are not suitable for 40 mm pipe planned for the heat exchanger loop.	The issue was measurements stated on the spec sheet being wrong and a result of an incorrect conversion from imperial to metric units. Modified centralisers (OMEGA EZ-Snaps Geothermal Spacers, model 60-125-XT) which have the cork gromet installed to give the correct fit / gripping force for the heat exchanger loop were required.
TH0417	Extra thermistor nodes included on the cable that had to be blanked off.	On a few occasions an additional node was present in the middle of the required 1 m spacing, manufacturing issue / not quality checked before being sent. The cables had to be sent back for repair and re spliced which could have also impacted the spacing. This occurred on 3 or more occasions which caused issues with spacing out the sensors along the entire install. Check node spacing before running, if possible, but this would require unspooling the entire reel and re spooling so time consuming.
All GSH wells	RST / beaded stream interfaces.	Technical issues were encountered with the RST supplied data loggers and thermistor cables which included some faulty data loggers, some faulty sensor nodes and varying spacing between nodes. There were also several interface issues between the technologies which had to be resolved. The wireless system and individual logger boxes in at the wellheads were powered by batteries and if the voltage dropped below a certain threshold the strings became corrupt, and a factor reset was required that could only be performed by an RST engineer. This occurred several times and eventually the wireless system was removed and replaced with a wired solution with all connections being made directly into the RSTAR and removing the need for the individual logger boxes.

Well number	Issue	Solution / lessons learned
TH0416	Damage identified on the HAKA probe during install.	The damaged section was isolated to one small area of the loop; the depth of damage was ~1 mm. The Contractor explored various avenues to find a solution and fix the damaged section; however, none have been identified as suitable or available in the timeframe required. The loop was pressure test, passed and therefore accepted before being run in hole. Contingency planning for this scenario should be made in advance of mobilising to site and have options to repair if damage to the loop is more significant.

4.12 ABSTRACTION / REINJECTION WELL – TH0406 SUMMARY OF OPERATIONS

4.12.1 Key Well Data

Table 61 TH0406 Key well data

<table>
<tr><td>Well name</td><td colspan="3">TH0406</td></tr>
<tr><td>Well classification</td><td colspan="3">Open Loop – abstraction/reinjection well</td></tr>
<tr><td>Depth measurement units</td><td colspan="3">Metres</td></tr>
<tr><td>Depth reference point</td><td colspan="3">Top of 24” casing</td></tr>
<tr><td>Depth reference details</td><td colspan="3">Top 24" depth ref - 20.031 m AOD
Top 24" to GL - 0.055 m</td></tr>
<tr><td>Start date</td><td colspan="3">Intermediate section started on 22/02/23 and was completed on 03/03/23.
Lower section started on the 25/04/23.</td></tr>
<tr><td>End of drilling date</td><td colspan="3">09/05/23.</td></tr>
<tr><td>Install dates</td><td colspan="3">Well airlifted on 17/05/23.
Installed on 23/11/23.</td></tr>
<tr><td colspan="4">Casing & Drilled Hole Depths</td></tr>
<tr><td>Hole section and size</td><td>Drilled depth (m BGL)</td><td>Casing size</td><td>Casing shoe depth (m BGL)</td></tr>
<tr><td>Top hole
n/a</td><td>n/a</td><td>24” Boode PVC casing
630 mm OD
593.2 mm ID</td><td>2.0 m</td></tr>
<tr><td>Intermediate section
Cored in 152 mm then opened out to 444 mm</td><td>Cored to 16.2 m
Reamed to 15.5 m</td><td>11.5” Boode PVC casing
330 mm OD
292 mm ID</td><td>Run to 15.0 m (14.70 m without shoe after failure)</td></tr>
<tr><td>Sleeve casing</td><td>n/a</td><td>Sleeve Casing
OD 280 mm
ID 255 mm
Boode C type (flush joint) PVC casing.</td><td>15.58 m</td></tr>
<tr><td>Final section to TD
Cored in 146 mm then opened out to 222 mm</td><td>Cored to 100.5 m
Reamed to 100.0 m</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Installation</td><td>n/a</td><td>Geopro packer, valve and Grundfos SP46-5 pump</td><td>Packer set at 35.04 m mid element</td></tr>
<tr><td colspan="2">Surface Location Coordinates:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Easting / Northing (OS GRID)</td><td colspan="2">Easting X: 344938.177
Northing Y: 375835.398</td></tr>
<tr><td colspan="2">Ordnance Survey Grid Reference</td><td colspan="2">Latitude N: 53°16′36″
Longitude W: 002°49′38″</td></tr>
<tr><td colspan="2">12 Character National Grid Reference</td><td colspan="2">SJ 44938 75835</td></tr>
<tr><td colspan="4">Well TD Coordinates:</td></tr>
</table>

Easting / Northing (OS GRID)	Easting X: 344937.75, Northing Y: 375834.78 Step out - 0.75 m (inclination 0.79 deg / azimuth 223 deg)

4.12.2 Summary of Drilling Operations

The Soilmec rig was mobilised and rigged up over TH0406. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 16.2 m with 95% returns reported throughout the section. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered before making up and running in hole a 444 mm reamer assembly. A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

The 444 mm reamer and pilot bit opened out the hole down to 15.5 m and the well circulated with full returns before displacing to clean mud. The assembly was POOH and laid out before setting up to run the intermediate casing. A temporary shoe was made up to the first joint of 330 mm OD casing with ERT and fibre optic cables secured to the outside and RIH. The shoe joint comprised of a short section of casing that had a precast concrete plug in the base. This had been predrilled and raw plugs inserted thought the side to help grip the cement plug and avoid it falling out when run (this occurred on TH0424 with no additional securing method). The remaining joints of casing were run, securing the ERT and fibre optic cable to the outside with cable ties and positioning the shoe at 15.0 m. The grout unit was rigged up before grouting the 330 mm annulus with 6 x 100 L batches of grout.

A thermally conductive grout was used which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water. This produced a grout with a minimum weight of 1.67 sg.

Grout was delivered from the bottom up, via a retractable 40 mm tremie pipe. Grout levels were tagged within the Boode casing and were topped up during completion of the headworks. Dry and wet samples of grout were taken as per specification.

The rig was moved off location (03rd March 2023) once the grout had set as it was needed to avoid the casing rising due to buoyancy.

The rig was mobilised back on the 25th April 2023 and setup. The 7” temporary casing was run to 15.0 m, sat on top of the intermediate casing shoe and sealed at in the annulus with Bentonite.

Made up and RIH the 146 mm Geobore assembly and cored through the cement plug and observed the 7” temporary casing drop. An additional section of 7” casing was added and the casing reset. Commenced coring from 16.2 m to 40.3 m with losses increasing with depth with approx. 50% returns by 40.3 m.

The decision was taken to recover the 7” temporary casing before coring deeper as it wasn’t set correctly in the well and was unstable. The Geobore was pulled before recovering the casing. The casing was checked before rerunning and landing out on the 444 mm x 146 mm shoulder beneath the base of the 333 mm casing shoe. Bentonite pellets were introduced into the annulus to seal.

Figure 66 Temporary 7” casing reset onto the 444 mm x 146 mm shoulder

The Geobore assembly was RIH and continued to core ahead to 53.8 m where operations were stopped due to the last 4 x E-Totco inclination surveys being above the permitted tolerance. The string was pulled back 7 joints (approx. 11.0 m) before washing, working the string through the section with high RPM and slow running speed to try and smooth the well profile. Cored ahead to 80.8 m where the coring assembly became blocked with a dropped core section. During the core recovery operation, the cable for the overshot used to recover the inner barrel parted at the shackle leaving the inner barrel inside the assembly. Whilst the string was stationary during this operation it became stuck.

The string was worked until movement and rotation could be re-established. The string was worked for several hours before it was recovered. All joints had become over torqued and were difficult to breakout and as a result were quarantined and sent away for inspection.

There was no evidence of what cause the pipe to become stuck. No marks, gouges on the drill pipe. No core was recovered in the last run so 4.5 m of core was lost and the well dipped at 80.0 m.

The decision was taken to move the rig off location on the 27th April 2023 until a forward plan could be made.

Mobilised the Soilmec rig back over TH0406 on the 03rd May 2023. RIH the Geobore assembly and cored from 80.8 m to 100.5 m with good core recovery and no issues. Recovered the coring assembly and the temporary 7" casing.

EGS were mobilised and the well was wireline logged from 2.0 m to 100.0 m. Full details of wireline logging programme undertaken can be found in **Section 4.12.5**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

Made up and RIH the 222 mm reamer assembly down to 15.0 m and opened out the hole from 146 mm down to TD at 100.0 m before circulating the hole clean and pumping a high viscosity polymer sweep. Continued to circulate until the shaker were clean with good returns throughout (90%). Displaced the well with 5,000 L of clean water before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Hole dipped at 100.1 m.

The decision was taken to clean up the fractures further and remove any remaining cuttings. The borehole was dipped at 99.15 m before commencing the air lifting operation. A 2" air lifting assembly was RIH and a three-stage air lift was completed. The depths of each stage were 80.0 m, 95.0 m and 98.0 m. The assembly was recovered and the well dipped at 99.4 m. Total volume of cuttings recovered was estimated at 0.15 m^3 or 3.84 m borehole length.

4.12.3 Sleeve casing installation

On the 18th May 2023 BGS ran their downhole inspection camera to check the condition of the intermediate casing for damage and noticed a poor cement job around the casing shoe at 15.0 m. The shoe was still attached, see images in **Section 4.16**.

The Soilmec rig was moved back over TH0406 on the 14th June 2023 and prepared to run a sleeve casing string. The sleeve casing is used and run inside the existing intermediate casing to protect the poorly cement shoe during future operations and packer / pump deployments.

RIH with 3 x full lengths of sleeve casing plus a short 1.0 m length to give a 0.43 cm stickup. The sleeve casing run was Boode PVC 280 mm OD x 255 mm ID, C Type flush joint casing. The casing was checked with the Marriotts downhole camera which showed the casing not to be 100% central over the open hole section beneath.

The decision was taken to run a stepped drag bit to form a socket to accept the sleeve casing. The bit was RIH to 15.5 m where it was advanced 6 cm putting the shoulder at 15.56 m. The stepped bit assembly was pulled before rerunning the sleeve casing. All indications / measurement suggested the sleeve was at the required depth but following an additional camera run it was confirmed not to be in the socket. The sleeve casing was recovered before attempting without the bottom thread and a chamfered end. Still unsuccessful. EGS were mobilised to site and completed an acoustic image log around the shoe to better understand the well geometry.

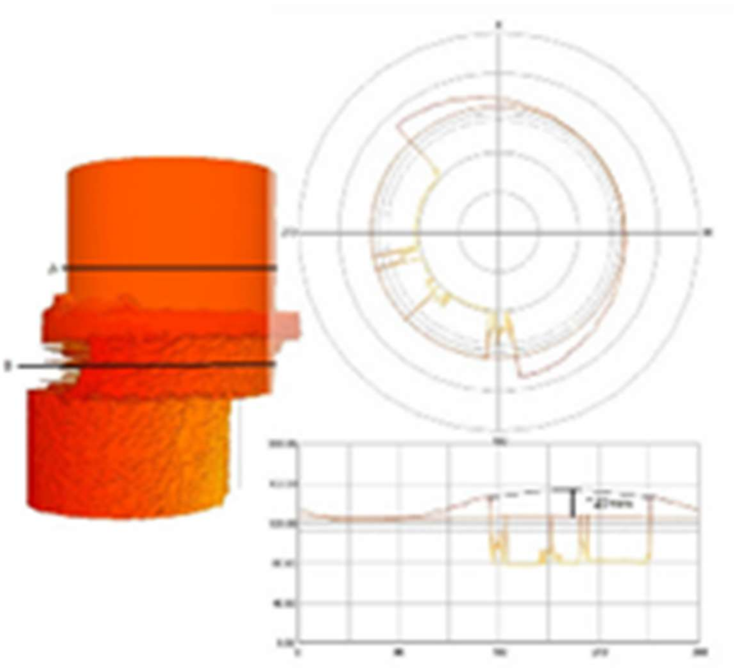


Figure 67 Acoustic image results of intermediate casing shoe depth for sleeve casing setting

The acoustic image shows the sleeve casing (upper orange cylinder) was offset from the open hole (rough surfaced cylinder below).

RIH an assembly consisting of 222 mm reamer, 2.5 m sub and 15.0 m of rods to 17.5 m on the rig winch to check through bore. Ran in with no resistance. Pulled up but observed assembly jump slightly at around 15.5 m. Ran back down and the same thing happened. Ran down and back up 4 more times with no more indication. The sleeve casing did not move at surface at any time during the test. POOH and laid down assembly. Downhole camera rerun but the casing hadn't moved, still above the socket. Marriotts worked and rotated the sleeve casing and managed to work it into the socket. A camera run was completed which confirmed the sleeve casing was fully engaged in the socket and central over the open hole below.

4.12.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0406 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 62 Drilling fluid summary table – TH0406

	TH0406
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	786
Ultrabore additive lost (kg)	11.2
Purebore additive lost (kg)	5.6

Once the intermediate section was drilled the well was cased with 330 mm OD Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section apart from a high viscosity sweep and water used throughout.

No LCM pills were deployed in this well.

4.12.5 Geophysical Logging Undertaken

Table 63 Geophysical logging summary TH0406

Wireline logging undertaken	Tools run
Section logged from 2.0 m to 100.0 m. Top section from 2.0 m to 15.0 m through casing, lower section to TD in cored 146 mm hole. (04/05/23)	GR, CALI, ACBI, LRES, TEMP, COND
Intermediate casing shoe investigation (18/07/23)	Acoustic imager run to confirm well geometry at the shoe depth and better understand how the sleeve casing was seated.

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.75 m and within the 1/100 tolerance.

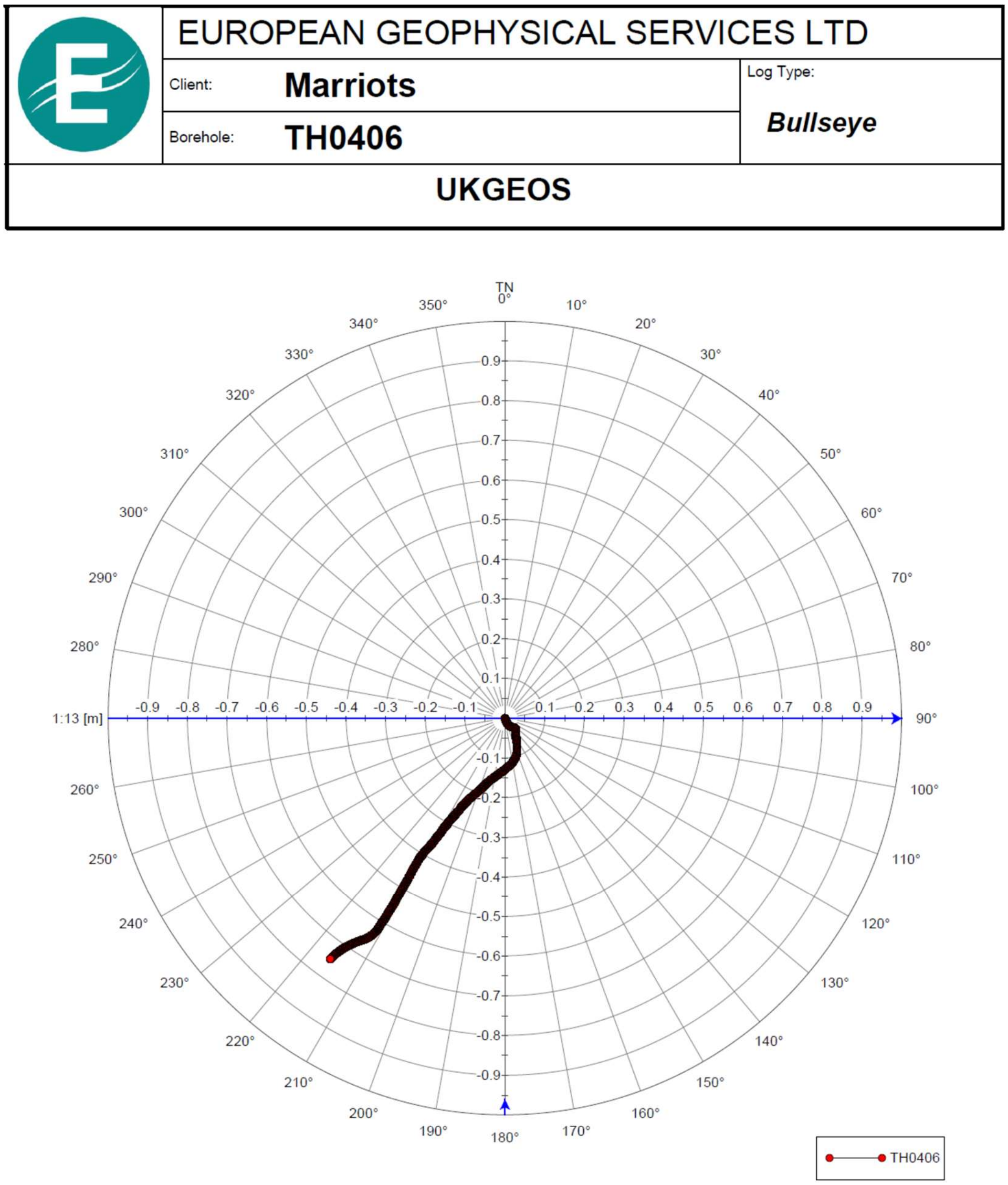


Figure 68 Verticality bullseye plot for TH0406, © European Geophysical Services Ltd

4.12.6 Summary of Installation Operations

Installation criteria for TH0406:

- Produce a detailed install protocol showing the packer setting depth and location of each completion component.
- Review available wireline logs, in particular the calliper log and select suitable packer setting location in a section of gauge hole.
- Accurately monitor the deployment and generate a tubing tally for the rising main before commencement.
- Suspend the packer and pump assembly securely at surface with C plate and speed clamp before inflation.
- Ensure the packer remains inflated with 10 bars of pressure to achieve a good seal and isolate the upper confined aquifer.

Summary of operations:

The packer, downhole valve and pump assembly was made up in a single assembly on the ground. The pump power cable was terminated in a resin filled connector and all hydraulic lines were made up to the packer mandrel. The completed assembly was picked up and RIH utilising a telehandler with a hydraulic winch attachment.

Figure 69 TH0406 pump and packer assembly being RIH

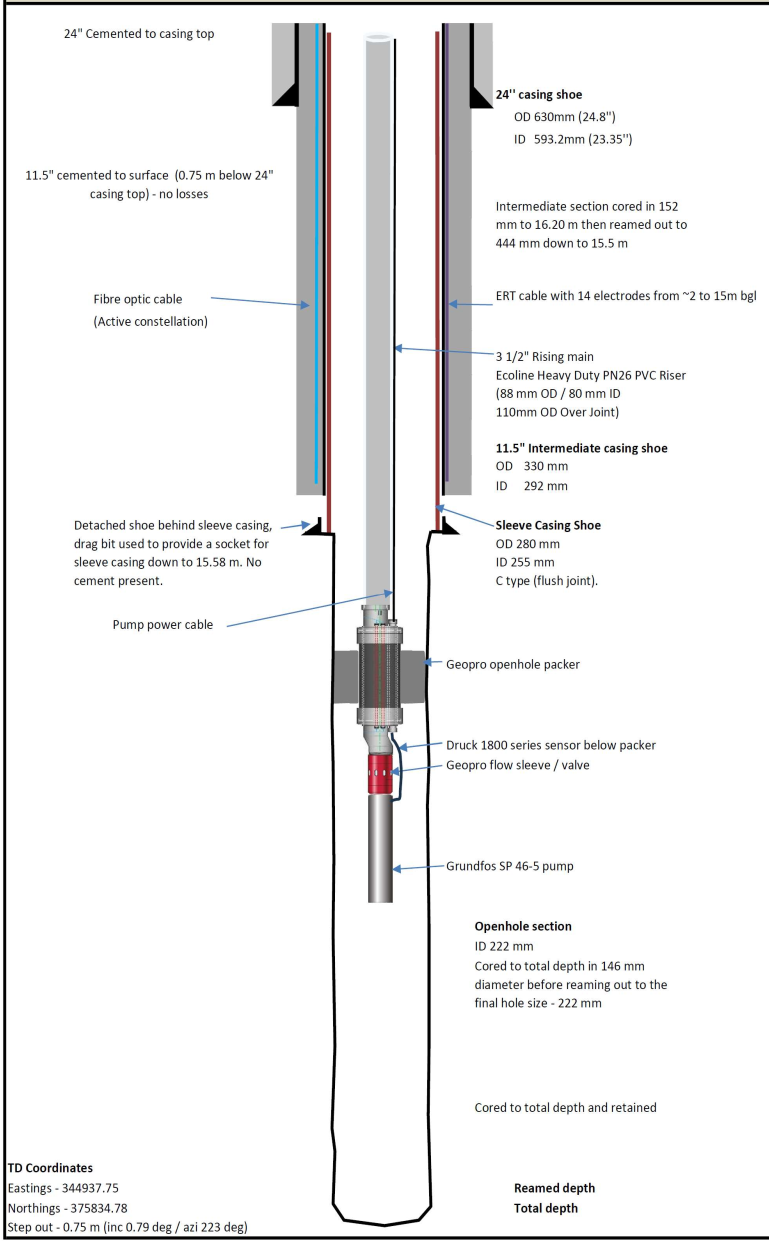
The assembly was RIH on sections of 3 ½” Ecoline Heavy Duty PN26 rising main as per the installation sheet placing the mid element of the packer at 35.04 m. The rising main was secured at surface on a C plate with the Speedclamp still attached. The packer was inflated with 15 bars before rigging down. The pump wasn’t run at this stage as the inverter drives in the well enclosures hadn’t been wired in to the surface connection and infrastructure.

4.12.7 TH0406 Borehole Well Schematic

Borehole coordinates: Eastings - 344938.177 Northings - 375835.398 Top 24" depth ref - 20.031 m AOD Top 24" to GL - 0.055 m	Well Schematic TH0406 Abstraction / Reinjection Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Section logged from 2 to 100 m. Top section from 2 to 15 m through casing, lower section to TD in cored 146 mm hole. 04/05/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments
	Bedrock encountered at 1.75 m
2 m	24" surface casing shoe
14.70 m	End of intermediate casing without shoe
15.58 m	Sleeve casing run with 6.0 mm clearence either side inside the intermediate casing and landed on shoulder
35.04 m	Geopro packer (mid element)
36.39 m (base)	Druck 1800 series pressure sensor
36.92 m	Geopro valve / sleeve
38.53 m	Grundfos SP 46-5 pump
100.0 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

Figure 70 TH0406 Well Schematic

4.12.8 Wellhead / Well Chamber Status

Figure 71 Wellhead status TH0406

Note: lines shown are for the hydraulically operated valve above the pump

Figure 72 Speed clamp and C plate supporting rising main TH0406

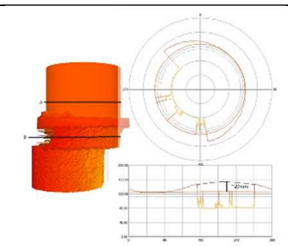
4.12.9 Daily Activity Summary

Table 64 Daily activity summary TH0406

Date	Depth M BGL	Operation	Parameters	Issues
22/02/23	16.2 m	Moved the Soilmec rig from TH0415 and setup over TH0406. RIH temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Made up 152 mm coring assembly and commenced coring from 2.0 m to 16.2 m before circulating the hole clean.	Verticality checks: 0.35 deg @ 5.0 m. 0.12 deg @ 8.0 m. 0.49 deg @ 11.0 m. 0.31 deg @ 14.0 m. Average returns 95% through the interval.	
28/02/23	16.2 m	POOH the coring assembly and the 7" temporary casing.		
02/03/23	16.2 m	Made up the 444 mm reamer assembly and ran in hole. Commenced reaming using a polymer mud system. Hole opened out down to 15.5 m. Circulate the hole and displaced the well to clean mud. Pulled out of hole the reamer assembly leaving the bottom hole assembly in the mast. Grout unit and Geotherm X moved in preparation for install.	Mud system helped to clear cuttings and allowed reamer to advance without packing off.	
03/03/23	15.0 m	Commenced setup for installation, recovered the 444 mm reamer assembly from the mast and laid down. Setup spooling frame and cables and laid out the 330 mm OD casing. RIH with 330 mm OD permanent Boode PVC casing complete with Fibre Optic and ERT cables to 15.0 m (0.5 m above reamed shoulder) and grouted in place. Rig moved off location once grout has set.	Grouted back to surface with 6 x 100 L batches of Geotherm X.	
25/04/23	40.3 m	Rig moved back over the location and setup. Ran and set 7'' temporary casing at 15.0 m into a layer of Bentonite pellets on top of the 330 mm casing cement shoe. Cored through the cement plug with 146 mm Geobore and observed the 7'' temporary casing drop. Reset the 7'' casing with one additional section. Commenced coring from 16.2 m to 40.3 m.	Verticality checks: 0.51 deg @ 17.8 m. 0.32 deg @ 19.3 m. 0.62 deg @ 22.3 m. 0.38 deg @ 28.3 m. 0.79 deg @ 34.3 m. 0.59 deg @ 40.3 m. Returns approx. 50% at 40.3 m.	7" temporary casing dropped resulting in an additional section of casing being installed and re set. Later confirmed as the casing shoe backing off and dropping.
26/04/23	80.8 m	POOH with Geobore string to surface before POOH the 7" temporary casing. Re-ran the 7" casing and bottomed out on the 444 mm x 146 mm shoulder beneath the base of the 330 mm Boode casing at 15.4 m. Introduced Bentonite pellets into the 330 mm x 7'' casing annulus to provide a seal.	Verticality checks: 0.62 deg @ 46.3 m. 0.70 deg @ 52.3 m. 0.74 deg @ 58.3 m. 0.70 deg @ 70.3 m. 0.70 deg @ 76.3 m.	The 7'' casing was still unstable and had dropped approx. 20 cm. It was decided to POOH the Geobore and pull/re-run the 7'' before coring deeper.

		Continued coring from 40.3 m to 53.8 m. Stopped coring due to previous 4 x E-Totco readings being out of tolerance (above 0.57 deg). Pulled back 7 lengths of Geobore pipe, approx. 11.0 m before washing / working the string through the section with high RPM and slow running speed to try and smooth well profile. Cored ahead from 53.8 m to 80.8 m where the Geobore string became blocked by dropped core. Managed to recover dropped core however string became stuck. Attempted to free were unsuccessful.		E-Totco inclination surveys above allowed tolerance. String worked to try and reduce before coring ahead. Blocked Geobore string due to dropped core. Stuck coring assembly. During the operations to recover the dropped core, the cable of the overshot used to recover the inner barrel parted at the shackle. Geobore string to be POOH to resolve once free.
27/04/23	80.0 m	Continued efforts to free stuck Geobore. Rotated 90 deg – worked down 10'' then worked Geobore assembly upwards. After working for several hours full rotation was re-established. String worked and managed to pull a single joint with good upward movement. Connected back to string and manged to pull a further 50 cm but full rotation was lost (partial rotation / string stalling as it was pulled). Unable to move up any further. Continue to work string as locked tight. Very slow progress. Continued to work string, stripped threads on circulation head which had to be replaced. Worked until the string began to move whilst rotating and circulating (pulled 7 joints). Continued to pull out of hole the Geobore string conventionally (difficulty breaking joints as over torqued) to surface and recovered the inner stuck barrel and recovered the sub that had been dropped. Rig moved off location to TH0408 until a forward plan could be developed to resolve the hole conditions.	Removed core from barrel – 76.3 m to 77.8 m calipered at 101.7 mm (Geobore generates 102 mm cores) 77.8 m - 79.3 m core section is heavily 'worked' and washed maybe due to being dropped and then recovered. Core recovery in these 2 runs was poor only 40% recovered. Last core depth recovered is 79.3 m, but the hole depth is 80.8 m.	Stuck pipe recovery hampered due to core barrel still inside the Geobore. Recovery tool dropped on night shift so unable to recover due to D shackle not being made up correctly. Pump rate had to be reduced significantly due to this flow restriction. Over torqued joints slowing recovery of string. 146 mm Geobore assembly quarantined and pipe for inspection and drifting after having to break out with pipe tongs. No evidence of what caused the pipe to become stuck. No marks / gouges on the pipe. No core was recovered in the barrel from the last run so 4.5 m of core lost. Well dipped at 80.0 m.
03/05/23	100.5 m	Set up and levelled the Soilmec rig over TH0406. RIH with the Geobore assembly. Cored from 80.8 m to 100.5 m. Good core recovery reported and no issues at the depth (80.8 m) where the assembly previously became stuck. Pulled back Geobore off bottom.	Verticality checks: 0.86 deg @ 83.2 m. 0.28 deg @ 87.2 m. 0.77 deg @ 93.7 m. Had returns initially while establishing circulation but then lost.	
04/05/23	100.5 m	POOH the 146 mm Geobore assembly and the temporary 7" casing installed to 15.0 m. Waiting on EGS to arrive.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged to TD.	

		EGS arrived and setup over the well. Logged the borehole as per Scope down to 100.0 m before rigging down and leaving site.		
05/05/23	100.5 m	No works undertaken on TH0406.		
09/05/23	100.1 m	Made up and RIH a 222 mm reamer assembly. Opened out the hole (146 mm to 222 m) from 15.0 m to 100.0 m. Circulated the hole clean. Pumped high viscosity polymer sweep and continued to circulate until shaker clean. Displaced the well with 5,000 L of clean water before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Rigged down from TH0406. Hole dipped at 100.1 m.	90% returns.	Approximate expected volume of returns from the well was 1.87 m^3. Skip below shaker holds roughly 1 m^3. The skip has been filled twice during the reaming and there is also sediment in the returns tank downstream of the shaker.
17/05/23	99.4 m	Made up and ran in hole the air lifting string to 80.0 m. Completed air lift at 80.0 m. Advanced the 2" string to 95.0 m, reconnected surface lines and completed the second stage before RIH to 98.0 m and air lifting for a final time. POOH assembly and laid down. Prepared and move the rig off location and store onsite as the Comacchio is no longer required for critical path operations.	Water level drawdown was stable across the various airlift depths, Airlift 1 was stable at ~25.5 m, Airlift 2 at 95.0m stable at ~26.0 m and Airlift 3 at 98.0 m stable at ~26.0 m. Borehole was dipped at 99.15 m before the airlifting started. Dipped at 99.4 m an hour after the final lift. 12,985 L of groundwater extracted. From this an estimated 0.15 m^3 volume of sediment was removed or 3.84 m coverage of borehole length.	Air lifting undertaken to remove cuttings from open fractures.
TH0406 casing shoe issue / sleeve casing				
18/05/23	99.4 m	Ran BGS owned inspection camera into TH0406 – noticed the intermediate casing shoe was still attached but poor cement job at the base.		Poor cement job around intermediate casing shoe.
14/06/23	99.4 m	Rigged down Soilmec rig from TH0418 and moved into position over TH0406 in preparation for sleeving of the intermediate casing.	This operation will be to run a smaller OD casing inside the existing casing to 15.0 m to sleeve across the shoe area where problems have occurred.	
15/06/23	99.4 m	RIH with 3 joints of sleeve casing plus a 1.0 m length. Final stick up 0.43 cm above the existing Boode casing.	Sleeve casing: OD 280 mm ID 255 mm C type (flush joint).	
16/06/23	99.4 m	No works undertaken on TH0406.		
19/06/23	99.4 m	No works undertaken on TH0406.		
20/06/23	99.4 m	Ran Marriott downhole camera in TH0406 to base of the sleeve casing. Captured video. In this well the sleeved casing appears to be offset and not 100% over the open hole.		

29/06/23	99.4 m	Stepped bit RIH on rods to 15.5 m with 1.2 m stickup. Advanced 6 cm to 1.14 cm stickup (i.e. top of shoulder prior to stepping to 200 mm, now at 15.56 m). Sleeve casing rerun until it held up (0.38m stickup). Lengths ran totalled 15.93 m and 0.38m stickup put base at 15.55 m. Sleeving thought to be successful but camera run needed to confirm. Attempted camera run but too murky. Rig off location.	Camera RIH offline and confirmed sleeve casing not sitting in the socket.	
17/07/23	99.4 m	Moved rig from TH0412 to TH0406 and set up over well. Recovered sleeve casing. Cut off threads from bottom joint. Chamfered end of bottom joint washed out plastic remnants from inside pipe and re-ran the joints. Landed off the casing and moved rig off location. Ran camera which revealed that the casing is now sitting slightly higher above the shoulder that was cut with the stepped bit.		
18/07/23	99.4 m	EGS mobilised to site and performed acoustic image log of the interval where the sleeve casing is seated. Wait on results / data to be processed.		
19/07/23	99.4 m	Log output from acoustic imager shows the sleeve casing (upper orange cylinder) is offset from the open hole (the rough surfaced cylinder at the bottom). Wait on decision for forward plan.		
20/07/23	99.4 m	Moved Comacchio rig from BGS compound to TH0406 and set up over well.		
21/07/23	99.4 m	Ran assembly consisting of 222 mm hole opener, 2.5 m of subs plus 15.0 m of rods to 17.5 m on the rig winch to check through bore. Ran in with no resistance. Pulled up and observed assembly jump slightly (the depth of this was estimated to be about 15.5 m). Ran back down and the same thing happened. Ran down and back up 4 more times with no more indication. The sleeve casing did not move at surface at any time during the test. POOH and laid down assembly.		
24/07/23	99.4 m	Ran camera in hole to confirm if the sleeve had moved during the 222 mm reamer run. Results showed slight damage on one edge but sleeve casing in the same position. Camera also ran upside down to get a clear image of the exposed lip. Decision taken to pull sleeve casing out and open out the stepped section and attempt to re-run.		

		Whilst waiting on approval Marriotts managed to work the string back into the socket and landed it off at the same depth as before on the lower shoulder. Casing was rotated and worked with the winch with the camera run on the other winch to help with the installation. Ran the 222 mm reamer assembly as before on the winch with no restrictions observed into and out of the open hole section. Bit run a total of 8 times and observed by Aecom. POOH the reamer assembly and laid out and secured the well.		
25/07/23	99.4 m	Sleeve casing confirmed good by downhole camera. Rig removed off TH0406 before cutting down the intermediate and sleeve casings to the required heights (700 mm and 350 mm BGL).		
TH0406 packer and pump Install				
23/11/23	99.4 m	Made up the packer and pump assembly as per the install sheet taking measurements of all components. RIH and positioned packer mid element at 35.04 m and inflated. Rising main secured at surface on a C plate and with the Speedclamp still attached.	3 ½" Rising main Ecoline Heavy Duty PN26 PVC Riser (88 mm OD / 80 mm ID 110 mm OD Over Joint) Note: pump tested at a later stage once inverter drives and wiring on surface had been completed.	
TH0406 complete				

4.13 ABSTRACTION / REINJECTION WELL – TH0408 SUMMARY OF OPERATIONS

4.13.1 Key Well Data

Table 65 TH0408 Key well data

Well name	TH0408		
Well classification	Open Loop – abstraction/reinjection well		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.086 m AOD Top 24" to GL - 0.085 m		
Start date	Intermediate section started on the 17/03/23 and completed on 22/03/23. Lower section started on the 28/04/23.		
End of drilling date	12/05/23. Sleeve casing run from 04/07/23 to 05/07/23.		
Install dates	Air lifted on 17/05/23, installed on 17/11/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 444 mm	Cored to 16.1 m Reamed to 15.5 m	11.5" Boode PVC casing 330 mm OD 292 mm ID	Run to 15.0 m (14.69 m without shoe after failure)
Sleeve casing	n/a	Sleeve Casing OD 280 mm ID 255 mm Boode C type (flush joint) PVC casing.	15.6 m
Final section to TD Cored in 146 mm then opened out to 222 mm	Cored to 100.5 m Reamed to 100.0 m	n/a	n/a
Installation	n/a	Geopro packer, valve and Grundfos SP46-5 pump	Packer set at 33.11 m mid element
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344930.719 Northing Y: 375850.685	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′38″	
12 Character National Grid Reference		SJ 44931 75851	
Well TD Coordinates:			

Easting / Northing (OS GRID)	Easting X: 344930.97 Northing Y: 375850.44 Step out - 0.35 m (inclination 0.46 deg / azimuth 82 deg)

4.13.2 Summary of Drilling Operations

The Soilmec rig was mobilised and rigged up over TH0408. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 16.1 m with full returns throughout. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered before making up and running in hole a 444 mm reamer assembly. A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

The 444 mm reamer and pilot bit opened out the hole down to 15.5 m and the well circulated with full returns before displacing to clean mud. The assembly was POOH and laid out before setting up to run the intermediate casing. A temporary shoe was made up to the first joint of 330 mm OD casing with ERT and fibre optic cables secured to the outside and RIH. The shoe joint comprised of a short section of casing that had a precast concrete plug in the base. This had been predrilled and raw plugs inserted thought the side to help grip the cement plug and avoid it falling out when run (this occurred on TH0424 with no additional securing method). The remaining joints of casing were run, securing the ERT and fibre optic cable to the outside with cable ties with the shoe at 15.0 m (0.5 m above reamed shoulder). The grout unit was rigged up before grouting the 330 mm annulus with 6 x 100 L batches of grout with a weight between 1.70 and 1.72 sg.

Figure 73 Intermediate 330 mm OD casing installed with ERT and FO, grout level below GL

A thermally conductive grout was used which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100L of water.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe. Grout levels were tagged within the Boode casing and were topped up during completion of the headworks. Dry and wet samples of grout were taken as per specification.

The rig was moved off location (22nd March 2023) once the grout had set as the rig was needed to avoid the casing rising due to buoyancy.

The rig was mobilised back on the 28th April 2023 and setup. The 7” temporary casing was run to 15.0 m, sat on top of the intermediate casing shoe and sealed in the annulus with Bentonite.

Made up and RIH the 146 mm Geobore assembly and cored through the cement plug and commenced coring from 16.1 m to 42.9 m where returns were lost. Continued to core ahead to 100.5 m with good core recovery and no issues encountered. Partial returns were noted towards the base of the well. Recovered the coring assembly and the temporary 7” casing.

EGS were mobilised and the well was wireline logged from 2.0 m to 98.2 m. The bottom of the hole was confirmed to be approx. 30 cm from centre. The wireline tools were unable to reach total depth and hung up short due to debris in the well. Full details of wireline logging programme undertaken can be found in **Section 4.13.5**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

Made up and RIH the 222 mm reamer assembly down to 15.0 m and opened out the hole from 146 mm down to TD at 100.5 m with full returns before circulating the hole clean and pumping a high viscosity polymer sweep. Continued to circulate until the shaker were clean with good returns throughout. Displaced the well with 2,000 L of clean water before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Hole dipped at 100.5 m.

When the assembly was 4.0 m off bottom the string was dropped and a rod spanner became wedged at an angle inside the 330 mm OD intermediate casing. The spanner was retrieved but in doing so scoring occurred in the top 4.0 m of the PVC casing. This was checked with a camera, but the scoring was only a few mm deep.

Figure 74 Scoring on the intermediate casing from dropped spanner

The well was re dipped at 98.9 m once the hole had time to settle. The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. A 2” air lifting assembly was RIH, and a two-stage air lift was completed. The depths of each stage were 83.0 m and 97.0 m. The assembly was recovered and the well dipped at 97.9 m. The rig was moved off TH0408 on the 12th May 2023.

4.13.3 Sleeve casing installation

On the 22nd June 2023 a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the shoe had become fully detached, see images in **Section 4.16**.

The Comacchio rig was moved back over TH0408 on the 29th June 2023 and prepared for the sleeving operations. A 273 mm reamer assembly was lowered into the well on the winch and sat down on the top of the detached shoe at 15.15 m. The string was turned with a pipe wrench and worked down to 15.51 m where it became tight. Changed over to the rig and turned mechanically progressing an additional 10 cm. Worked the string at 15.5 m removing any residual cement that remain on the shoe and or shoulder before POOH.

RIH the sleeve casing. The sleeve casing run was Boode PVC 280 mm OD x 255 mm ID, C Type flush joint casing. Total length RIH was 15.945 m (15.55 m shoulder depth / 0.395 m stickup). Annulus clearance between intermediate and new casing is 6 mm.

The camera was run to confirm the correct seating of the sleeve casing, but a centraliser arm was across the borehole restricting access. A magnet was run on a rope and the centraliser latched and recovered. A further camera run was confirmed and the sleeve casing accepted.

4.13.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0408 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 66 Drilling fluid summary table – TH0408

	TH0408
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	246
Ultrabore additive lost (kg)	3.42
Purebore additive lost (kg)	1.7

Once the intermediate section was drilled the well was cased with 330 mm OD Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section apart from a high viscosity sweep and water used throughout. No LCM pills were deployed in this well.

4.13.5 Geophysical Logging Undertaken

Table 67 Geophysical logging summary TH0408

Wireline logging undertaken	Tools run
Section logged from 2.0 m to 98.2 m. Top section from 2.0 m to 15.0 m through casing, lower section to TD in cored 146 mm hole. (05/05/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.35 m and within the 1/100 tolerance.

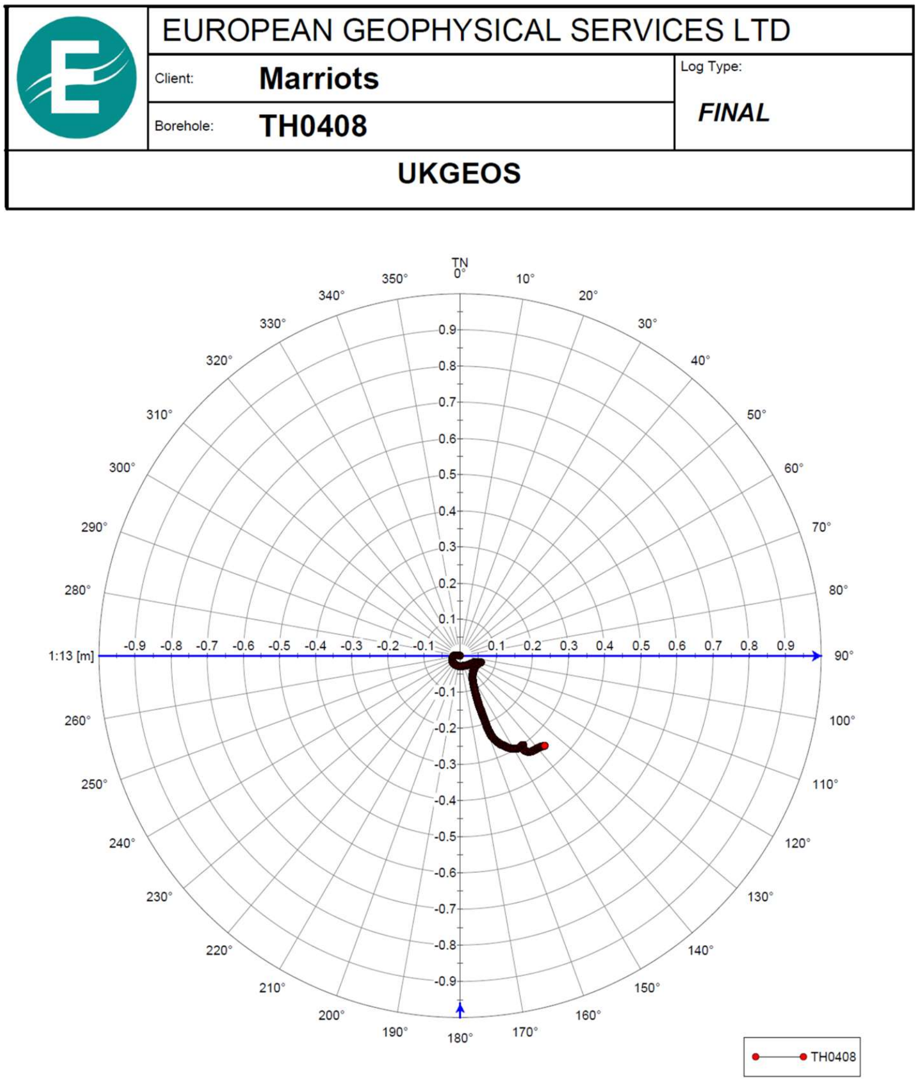


Figure 75 Verticality bullseye plot for TH0408, © European Geophysical Services Ltd

4.13.6 Summary of Installation Operations

Installation criteria for TH0408:

- Produce a detailed install protocol showing the packer setting depth and location of each completion component.
- Review available wireline logs, in particular the calliper log and select suitable packer setting location in a section of gauge hole.
- Accurately monitor the deployment and generate a tubing tally for the rising main before commencement.
- Suspend the packer and pump assembly securely at surface with C plate and speed clamp before inflation.
- Ensure the packer remains inflated with 10 bars of pressure to achieve a good seal and isolate the upper confined aquifer.

Summary of operations:

The packer, downhole valve and pump assembly was made up in a single assembly on the ground. The pump power cable was terminated in a resin filled connector and all hydraulic lines were made up to the packer mandrel. The completed assembly was picked up and RIH utilising a telehandler with a hydraulic winch attachment. The packer was inflated when just below ground level and checked for leaks before bleeding off, deflating and continuing in hole.

Figure 76 TH0408 pump and packer successfully RIH.

The assembly was RIH on a 3 ½” Ecoline Heavy Duty PN26 rising main as per the installation sheet placing the mid element of the packer at 33.11 m. The rising main was secured at surface on a C plate and with the Speedclamp still attached. The packer was inflated with water to 15 bars before rigging down. The downhole pump wasn’t tested at this stage as the inverter drives in the well enclosures hadn’t yet been wired in to the surface connections.

4.13.7 TH0408 Borehole Well Schematic

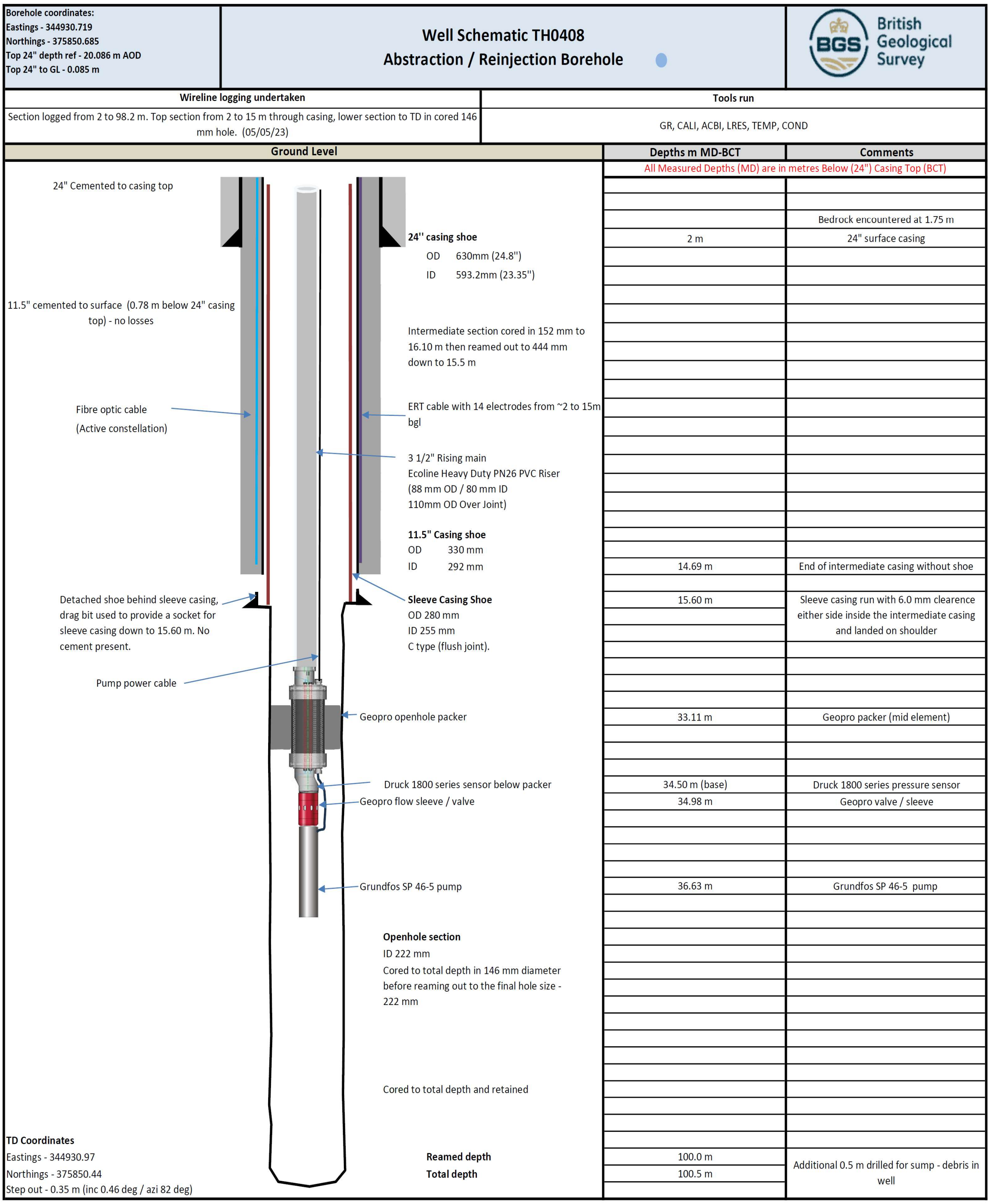


Figure 77 TH0408 Well Schematic

4.13.8 Wellhead / Well Chamber Status

Figure 78 Wellhead status TH0408

Note: lines shown are for the hydraulically operated valve above the pump

Figure 79 Speed clamp and C plate supporting rising main TH0408

4.13.9 Daily Activity Summary

Table 68 Daily activity summary TH0408

Date	Depth M BGL	Operation	Parameters	Issues
17/03/23	2.0 m	Moved the Soilmec rig and setup over TH0408. Ran temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations.		
20/03/23	16.1 m	Prepared polymer mud volume. Made up 152 mm coring assembly and commenced coring from 2.0 m to 16.1 m before circulating the hole clean. POOH the coring assembly and the 7" temp casing. Core from TH0408 being retained on site in 1.5 m sections, marked with depths and boxed for possible future analysis. Made up the reamer assembly and ran in hole. Commenced reaming TH0408 in 17 ½" (444 mm) using a polymer mud system. Hole opened out to 9.2 m.	Verticality checks: 0.35 deg @ 11.6 m. 0.28 deg @ 14.6 m. No flush loss reported.	
21/03/23	16.1 m	Continued to open out the hole to 444 mm down to 15.5 m. Circulate the hole and displaced the well to clean mud. Pulled out of hole the reamer assembly. Setup spooling frame and cables and laid out the 330 mm OD casing. RIH with 330 mm permanent Boode PVC casing complete with Fibre Optic and ERT cables to 15.0 m (0.5 m above reamed shoulder).	Mud system helped to clear cuttings and allowed reamer to advance without packing off. Mud used to allow top holes to be drilled whilst other boreholes were being drilled onsite to reduce the risk of cross borehole flow. 3 x joints of 330 mm casing RIH.	
22/03/23	15.0 m	Positioned materials and equipment for grouting. Commenced mixing Geotherm X grout. Mixed and pumped 6 batches of grout with 100 L of water, 7.5 bags of grout with a weight range of 1.70 - 1.72 sg Pulled back tremie pipe after each batch pumped. Washed down all equipment and cleared site. Moved Soilmec rig off TH0408 and relocated to TH0414.	Grouted back to surface with 6 x 100 L batches of Geotherm X. Mud displaced out of annulus with the grout and intermediate casing filled with clean water before drilling out.	
28/04/23	63.9 m	Rig moved back over the well and setup. Ran and set 7'' temporary casing to 15.0 m into a layer of Bentonite pellets introduced on top of the 330 mm casing cement shoe.	Verticality checks: 0.15 deg @ 18.9 m. 0.23 deg @ 21.9 m. 0.41 deg @ 27.9 m. 0.22 deg @ 33.9 m.	

Date	Depth M BGL	Operation	Parameters	Issues
		Cored through the cement plug and cored ahead from 15.0 m to 63.9 m with water only. Returns lost at 42.9 m.	0.36 deg @ 39.9 m. 0.01 deg @ 45.9 m. 0.42 deg @ 51.9 m. 0.07 deg @ 57.9 m. 0.20 deg @ 63.9 m. Returns lost at 42.9 m.	
02/05/23	100.5 m	Resumed coring in 146 mm hole from 63.9 m to 100.5 m. POOH with Geobore string to surface before POOH the 7” temporary casing.	Verticality checks: 0.37 deg @ 75.9m. 0.19 deg @ 81.9 m. 0.23 deg @ 93.9 m. Partial returns noted toward the base of the well.	
05/05/23	98.2 m	EGS arrived and setup over the well. Logged the borehole as per Scope down to 98.2 m before rigging down and leaving site.	Wireline tools ran - GR, CALI, ACBI, LRES, TEMP, COND. Logged to 98.2 m.	Bottom of hole approx. 30 cm from centre. Unable to reach bottom with wireline tools, HUD 98.2 m and bottom of hole very dirty.
10/05/23	98.2 m	Moved the Soilmec rig over the well and set up. Made and RIH the 222 mm reamer. Opened out the hole (146 mm to 222 m) from 15.0 m to 85.0 m.		
11/05/23	98.9 m	Continued to open out the hole (146 mm to 222 m) from 85.0 m to 100.5 m with full returns. Circulated the hole clean until the shaker was clean. Displaced the well with 2,000 L of clean water before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Well dipped at 98.6 m RIH Geobore string to 85.0 m. Washed down to TD at 100.5 m and circulated the hole. Pumped around a high viscosity sweep and chased with 5,000 L of clean water. Dipped hole through Geobore at 100.5 m before POOH. Re-dipped the well at 98.9 m. Prepared equipment for airlifting.	Full returns whilst reaming.	With the string 4.0 m off bottom, the string was dropped to the bottom of the hole with a rod spanner wedged on an angle inside the 330 OD x 290 mm ID Boode PVC casing. The assembly was successfully retrieved but caused some scoring around the circumference of the top ~4.0 m of the PVC casing. This incident resulted in approx. 0.5hrs NPT.
12/05/23	97.9 m	Made up and ran in hole the 4” air lifting string to 83.0 m. Completed air lift at 83.0 m. Advanced the string to 97.0 m, reconnected surface lines and completed the second stage air lift. POOH assembly and laid down. Well dipped at 97.9 m. Rigged down surface pipework and airlifting equipment. Rig moved off location.		Air lifting undertaken to remove cuttings from open fractures.
TH0408 casing shoe issue / sleeve casing				
22/06/23	97.9 m	Ran downhole camera into TH0408 and noticed the 330 mm casing shoe had fully turned off and become detached.		See **Section 4.16** issues encountered and solutions for full

Date	Depth M BGL	Operation	Parameters	Issues
				details on detached shoe.
27/06/23	97.9 m	Attempted to knock cement out of casing shoe but the rods were holding up 30 cm too high – unable to break through.		
28/06/23	97.9 m	Ran camera in TH0408. Observed that the detached shoe has been damaged by running the CP assembly during efforts to knock out the cement from inside.		
29/06/23	97.9 m	Comacchio 405 setup over the well. Reamed shoulder understood to be at 15.45 m. Ran in 273 mm hole opener to 15.15 m on winch, (sat on detached casing shoe). Turned string with pipe wrench with slight slack on winch until the hole opener lowered to 15.51 m. Continued to turn as far as possible by hand (circa 180 degrees) then became tight. Switched to the rig and turned mechanically and progressed to 10 cm below the original reamed shoulder. Advanced hole opener to 15.55 m. Pulled back 2 cm and rotated string 5 times to clear any residual concrete/material before POOH. Ran in sleeve casing and achieved a 0.40 m stickup so within 5 mm of expected.	This operation will be to run a smaller OD casing inside the existing casing to 15.0 m to sleeve across the shoe area where problems have occurred. Total sleeve casing length 15.945 m. 15.55 m shoulder depth = 0.395 m stickup. Sleeve casing: OD 280 mm ID 255 mm C type (flush joint).	
30/06/23	97.9 m	Investigated sleeve casing with camera. Observed 2 arms of centraliser across the borehole, but the sleeve casing looks central.		
03/07/23	97.9 m	Rigged up Comacchio 405 rig over TH0408. Ran a magnet on rope down to the centraliser depth at ~ 15.0 m and managed to snag the centraliser and pull it free. It appears that all parts that were across the wellbore were recovered but this needs to be confirmed with a camera run.		
04/07/23	97.9 m	Ran camera and confirmed sleeve casing acceptable and well clear of obstructions.		
TH0408 packer and pump Install				
17/11/23	97.9 m	Made up the packer and pump assembly as per the install sheet taking measurements of all components. RIH to just below GL. Packer inflated and visually inspected for any leaks before bleeding off and deflating the packer through the manifold. RIH and positioned packer mid element at 33.11 m and inflated with 15 bars. Packer to remain inflated Rising main secured at surface on a C plate and with the Speedclamp still attached.	3 ½" Rising main Ecoline Heavy Duty PN26 PVC Riser (88 mm OD / 80 mm ID 110 mm OD Over Joint) Note: pump tested at a later stage once inverter drives and wiring on surface had been completed.	
TH0408 complete				

4.14 ABSTRACTION / REINJECTION WELL – TH0412 SUMMARY OF OPERATIONS

4.14.1 Key Well Data

Table 69 TH0412 Key well data

<table>
<tr><td>Well name</td><td colspan="3">TH0412</td></tr>
<tr><td>Well classification</td><td colspan="3">Open Loop – abstraction/reinjection well</td></tr>
<tr><td>Depth measurement units</td><td colspan="3">Metres</td></tr>
<tr><td>Depth reference point</td><td colspan="3">Top of 24” casing</td></tr>
<tr><td>Depth reference details</td><td colspan="3">Top 24" depth ref - 20.288 m AOD
Top 24" to GL - 0.070 m</td></tr>
<tr><td>Start date</td><td colspan="3">Intermediate section started on the 05/04/23 and completed on 12/04/23.
Lower section started on the 17/04/23.</td></tr>
<tr><td>End of drilling date</td><td colspan="3">03/05/23.
Remedial cement job on casing shoe completed between 11/07/23 and 13/07/23.</td></tr>
<tr><td>Install dates</td><td colspan="3">Air lifting 16/05/23, after remedial cementing operation of shoe due to debris from this operation.
Installed from 22/11/23 to 23/11/23.</td></tr>
<tr><td colspan="4">Casing & Drilled Hole Depths</td></tr>
<tr><td>Hole section and size</td><td>Drilled depth (m BGL)</td><td>Casing size</td><td>Casing shoe depth (m BGL)</td></tr>
<tr><td>Top hole
n/a</td><td>n/a</td><td>24” Boode PVC casing
630 mm OD
593.2 mm ID</td><td>2.0 m</td></tr>
<tr><td>Intermediate section
Cored in 146 mm then opened out to 444 mm</td><td>Cored to 16.2 m
Reamed to 15.5 m</td><td>11.5” Boode PVC casing
330 mm OD
292 mm ID</td><td>Run to 15.0 m

(14.69 m without shoe after failure)

(Detached shoe at 15.3 m, cemented in place and drilled back through)</td></tr>
<tr><td>Final section to TD
Cored in 146 mm then opened out to 222 mm</td><td>Cored to 100.5 m
Reamed to 100.0 m</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Installation</td><td>n/a</td><td>Geopro packer, valve and Grundfos SP40 pump</td><td>Packer set at 34.12 m mid element</td></tr>
<tr><td colspan="2">Surface Location Coordinates:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Easting / Northing (OS GRID)</td><td colspan="2">Easting X: 344953.443
Northing Y: 375842.839</td></tr>
<tr><td colspan="2">Ordnance Survey Grid Reference</td><td colspan="2">Latitude N: 53°16′36″
Longitude W: 002°49′37″</td></tr>
<tr><td colspan="2">12 Character National Grid Reference</td><td colspan="2">SJ 44953 75843</td></tr>
</table>

Well TD Coordinates:	
Easting / Northing (OS GRID)	Easting X: 344953.19 Northing Y: 375842.84 Step out - 0.25 m (inclination 0.8 deg / azimuth 258 deg)

4.14.2 Summary of Drilling Operations

The Soilmec rig was mobilised and rigged up over TH0412. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 16.2 m with full returns throughout utilising a polymer mud system. The hole was circulated clean before POOH the assembly.

Figure 80 Image of the 146 mm Geobore coring assembly and rods

A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

The 7” temporary casing was recovered before making up and running in hole a 444 mm reamer assembly.

The 444 mm reamer and pilot bit opened out the hole down to 15.5 m and the well circulated before displacing to clean mud. The assembly was POOH and laid out before setting up to run the intermediate casing. A temporary shoe was made up to the first joint of 330 mm OD casing with ERT and fibre optic cables secured to the outside and RIH. The shoe joint comprised of a short section of casing that had a precast concrete plug in the base. This had been predrilled and raw plugs inserted thought the side to help grip the cement plug and avoid it falling out when run (this occurred on TH0424 with no additional securing method). The remaining joints of casing were run, securing the ERT and fibre optic cable to the outside with cable ties with the shoe at 15.0 m (0.5 m above reamed shoulder). The grout unit was rigged up before grouting the 330 mm annulus with 5 x 100 L batches of grout with a weight between 1.68 sg and 1.72 sg. Only 5 batches were pumped due to a limited quantity of Geotherm X being available on site. This was to ensure sufficient grout was available for the grouting of TH0416. TH0412 was topped up at a later stage to just below GL.

A thermally conductive grout was used which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe. Dry and wet samples of grout were taken as per specification. The grout level was tagged within the Boode casing and topped up during completion of the headworks.

The 7” temporary casing was run to 15.0 m, sat on top of the intermediate casing shoe and sealed at the base with Bentonite. Excessive movement was noted in the casing, so it was recovered and plastic centralisers installed before rerunning and sealing.

Made up and RIH the 146 mm Geobore assembly and cored through the cement plug and commenced coring from 16.2 m to 26.7 m where returns were lost. Continued to core ahead to 100.5 m with good core recovery and no issues encountered. Partial returns were noted between 41.7 m and 49.0 m (30 %) but were lost again. Once TD had been reached the coring assembly was POOH and the temporary 7” casing recovered.

Made up and RIH the 222 mm reamer assembly down to 15.0 m and opened out the hole from 146 mm down to 70.0 m when the rig had a mechanical breakdown (bearing failure in drive head). The issue was troubleshot onsite, but the decision was taken to remove from site and repair the rig back in Marriotts base in Chesterfield. The rig was moved off the well on the 21st April 2023.

EGS were mobilised and an acoustic imager tool was run in hole to confirm the condition of the borehole. Vertical scoring was noted on the acoustic image log which impacted the quality significantly. An optical imager was run FOC to check the condition of the borehole walls and whether the vertical scoring could be attributed to the reaming operation. The results were inconclusive.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The Soilmec rig was mobilised over the well on 02nd May 2023 and the 222 mm reamer made up and run back in hole. The hole was opened out down to TD at 100.0 m with returns throughout. The well was circulated clean before back reaming out of hole. Back reaming was undertaken not because of tight hole conditioned but to see if it would eliminate the vertical scoring on the borehole wall.

The well was dipped 98.4 m.

Made-up and RIH the Geobore assembly and washed down to 100.5 m before circulating the hole and pumping a high viscosity polymer sweep. Continued to circulate until the shaker were clean with good returns throughout. Displaced the well with 4,500 L of clean water before POOH. The rig was moved off location on the 03rd May 2023.

EGS were mobilised back to site, and the well was wireline logged from 15.0 m to 100.5 m with a full logging suite of tools. The bottom of the hole was confirmed to be well within deviation tolerance. Vertical scoring was still present on the acoustic image log. Back reaming out of hole hadn't improved the log quality.

Full details of wireline logging programme undertaken can be found in **Section 4.14.5**.

The Comacchio rig was moved back over the well on the 16th May 2023 and setup. The well was re dipped at 99.15 m once the hole had time to settle so the decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. A 4" air lifting assembly was RIH and a three-stage air lift was completed. The depths of each stage were 80.0 m, 95.0 m and 98.0 m. The assembly was recovered, and the rig was moved off TH0412 on the 16th May 2023.

4.14.3 Sleeve casing installation

On the 18th May 2023 a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the shoe had become fully detached and dropped, no grout present and an exposed centraliser was across the well and causing a snagging risk. Damage to the bottom 3 x ERT electrodes also identified, see images in **Section 4.16**.

The Comacchio rig was moved back over TH0412 on the 19th June 2023 and prepared for sleeving operations. RIH 3 x lengths of sleeve casing. The sleeve casing run was Boode PVC 280 mm OD x 255 mm ID, C Type flush joint casing. The camera was run to confirm the correct seating of the sleeve casing, but it was noted to be resting partially on the ledge and not central in the well restricting access into the lower section. The sleeve casing was recovered.

Made up and RIH a stepped drag bit on drill rods to the existing open hole shoulder. Advanced the assembly with rotation to create a new socket to accept the sleeve casing. The hole was flushed before POOH. The sleeve casing was picked backup and rerun in hole and landed out on the shoulder. Rigged up and ran the Marriotts downhole camera. Observed that there was a cable tie in the wellbore which was fished out using an improvised hook. Camera footage revealed the sleeve was still not centralised over the open hole. Attempted to alter position of sleeve casing but unable to achieve much movement due to close tolerance between the inner and outer casings.

Topped up grout level in intermediate casing annulus to the correct height whilst formulating a forward plan.

The decision was taken to perform a remedial cement job around the detached shoe to secure and fix it in place. A bung was prepared and run in hole to 16.0 m to form a base for the grout. The well status before this operation commenced is detailed below:

- Bottom of intermediate casing: 14.69 m.
- Top of detached shoe: 15.0 m.
- Bottom of detached shoe: 15.3 m.
- Transition from 444 mm to 222 mm open hole: 15.3 m.
- Open hole 'bung' to support grout: 16.0 m.

RIH a 60 mm tremie pipe to 15.0 m before introducing 2 ¼ bags of cement/Bentonite pellets to bring the level to 15.4 m and then 2 bags of sharp sand to 15.12 m. Rigged up the grout mixing equipment and introduced 3 x mixes of grout as follow:

- First mix – 100 L - 3 bags cement - 1 tub Bentonite at 1.55 sg.
- Second mix – 100 L - 3 bags cement - 1 tub Bentonite 1.62 sg.
- Third mix – 50 L - 1.5 bags cement - ½ tub Bentonite 1.57 sg.

Waited on cement for 24 hours. Grout level dipped at 14.3 m (40 cm inside the intermediate casing) and prepared the assemblies for cleanout. Three assemblies were run to complete the drill out of the cement plug, and they were as follows:

Assembly #1 - consisted of a 286 mm stepped bit run on drill rod, once on depth the tether used to deploy the cement bung was parted. The grout was drilled out to 14.8 m before POOH.

Assembly #2 – consisted of a 127 mm pilot bit crossed over to a 273 mm hole opener. RIH and continued to drill out the grout with minimum WOB to 15.14 m before POOH.

Assembly #3 – consisted of a pilot bit, 222 mm hole opener immediately behind it and 216 mm reamer. RIH and washed through the remaining grout and worked down to 17.3 m before POOH.

The well was dipped at 93.4 m due to the sand, Bentonite and grout bung dropping in the hole but not fully to TD. The downhole camera was rerun which confirmed good grout coverage across the detached shoe with clear entry into the open hole section. RIH with pilot bit and 222 mm hole opener to 94.0 m and worked the string down to 96.0 m before circulating the hole. POOH the assembly and laid down the reamer. The hole was dipped at 94.7 m which was accepted by BGS.

4.14.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0412 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 70 Drilling fluid summary table – TH0412

	TH0412
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	246
Ultrabore additive lost (kg)	3.5
Purebore additive lost (kg)	1.8

Once the intermediate section was drilled the well was cased with 330 mm OD Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section apart from a high viscosity sweep and water used throughout.

No LCM pills were deployed in this well.

4.14.5 Geophysical Logging Undertaken

Table 71 Geophysical logging summary TH0412

Wireline logging undertaken	Tools run
Section logged from 15.0 m to 65.0 m in reamed 222 mm hole. (27/04/23)	ACBI, Optical imager
Section logged from 1.5 m to 100.2 m. Top section from 2.0 m to 15.0 m through the intermediate casing then lower section below shoe to TD in reamed 222 mm hole. (04/05/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.25 m and within the 1/100 tolerance.

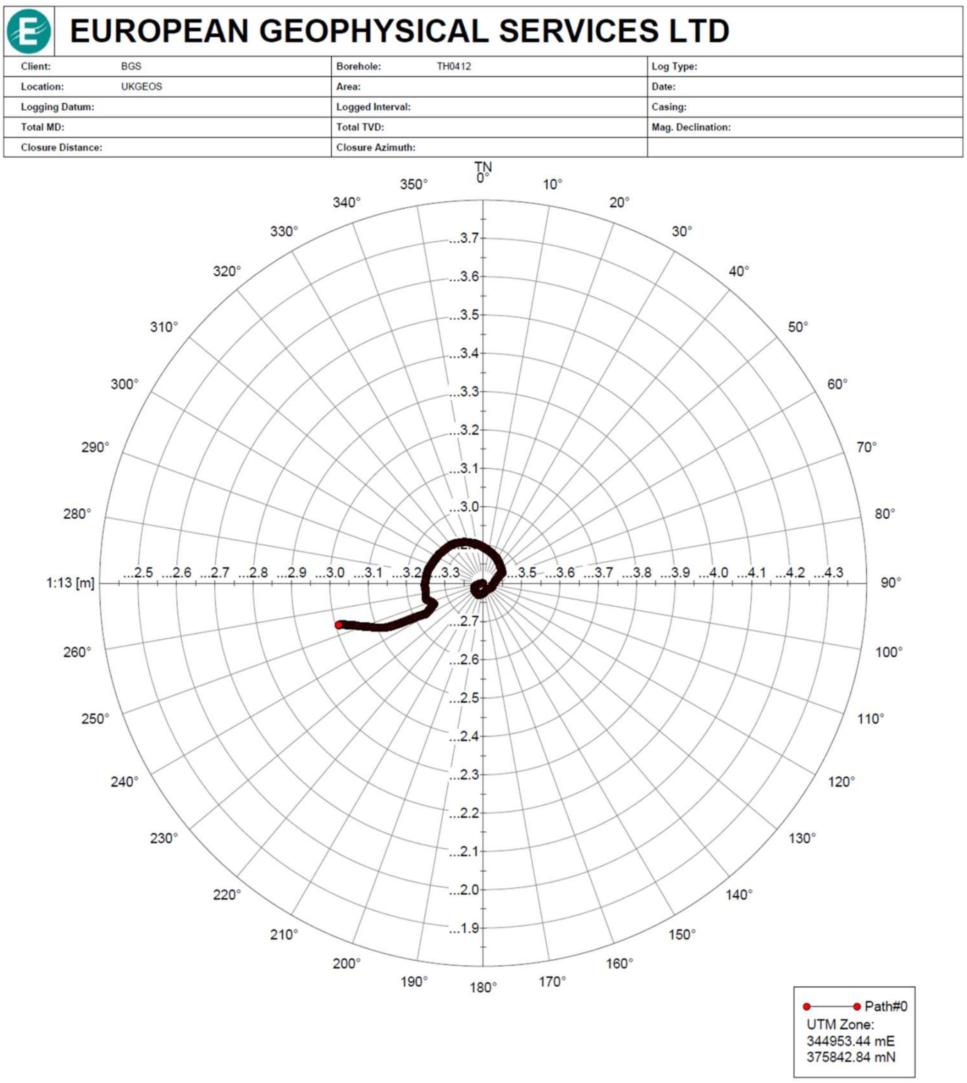


Figure 81 Verticality bullseye plot for TH0412, © European Geophysical Services Ltd

4.14.6 Summary of Installation Operations

Installation criteria for TH0412:

- Produce a detailed install protocol showing the packer setting depth and location of each completion component.
- Review available wireline logs, in particular the calliper log and select suitable packer setting location in a section of gauge hole.
- Accurately monitor the deployment and generate a tubing tally for the rising main before commencement.
- Suspend the packer and pump assembly securely at surface with C plate and speed clamp before inflation.
- Ensure the packer remains inflated with 10 bars of pressure to achieve a good seal and isolate the upper confined aquifer.

Summary of operations:

The packer, downhole valve and pump assembly was made up in a single assembly on the ground. The pump power cable was terminated in a resin filled connector and all hydraulic lines were made up to the packer mandrel. The completed assembly was picked up and RIH utilising a telehandler with a hydraulic winch attachment. The Packer was inflated when just below ground level and checked for leaks before bleeding off, deflating and continuing in hole.

Figure 82 Setting up in readiness for running the packer and pump assembly into TH0412

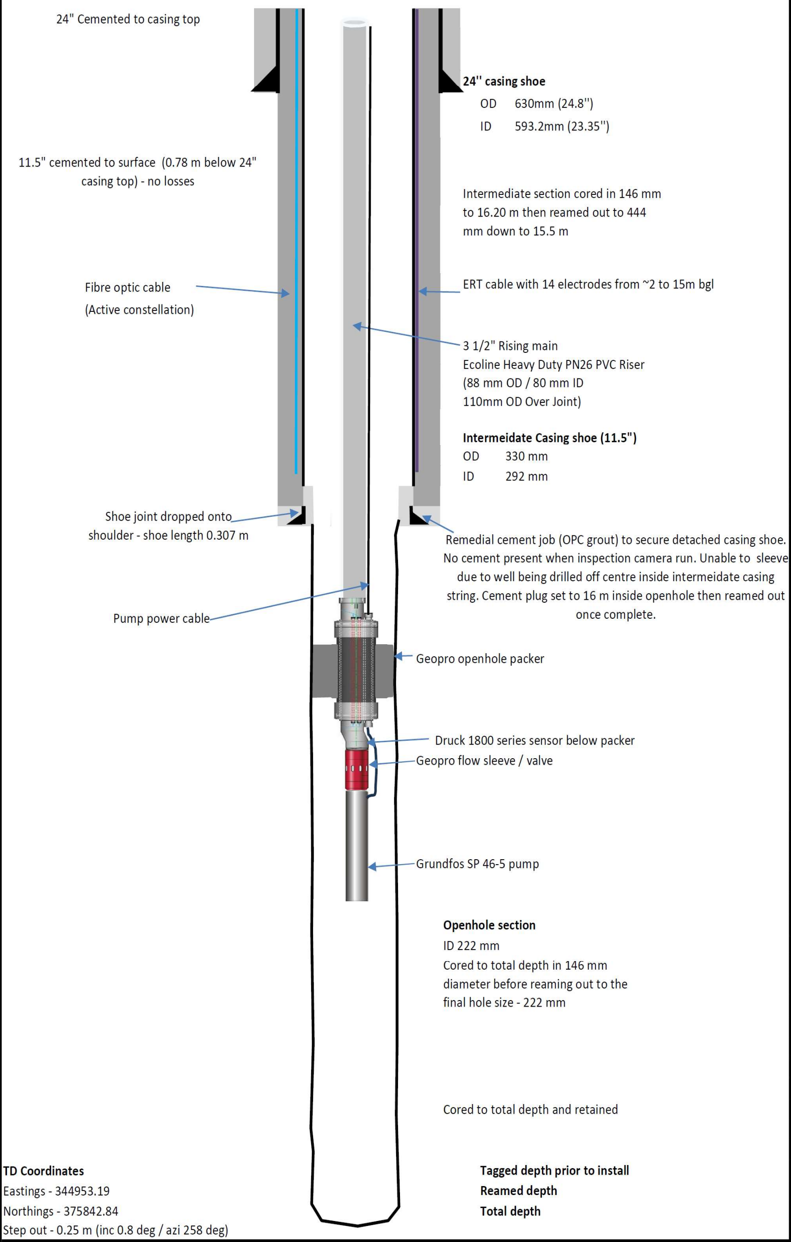
The assembly was RIH on a 3 ½" Ecoline Heavy Duty PN26 rising main as per the installation sheet placing the mid element of the packer at 34.12 m. The rising main was secured at surface on a C plate and with the Speedclamp still attached. The packer was inflated with 13.5 bar before rigging down. The downhole pump wasn't tested at this stage as the inverter drives in the well enclosures hadn't yet been wired in to the surface connections.

4.14.7 TH0412 Borehole Well Schematic

Borehole coordinates: Eastings - 344953.443, Northings - 375842.839, Top 24" depth ref - 20.288 m AOD, Top 24" to GL - 0.070 m	Well Schematic TH0412 Abstraction / Reinjection Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Section logged from 1.5 to 100.2 m. Top section from 2 to 15 m through the intermidiate casing then lower section below shoe to TD in reamed 222 mm hole. (04/05/23)	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
14.69 m	End of intermediate casing without shoe
15.30 m	Detached 330 mm intermediate PVC casing shoe
34.12 m	Geopro packer (mid element)
35.48 m (base)	Druck 1800 series pressure sensor
35.99 m	Geopro valve / sleeve
37.60 m	Grundfos SP 46-5 pump
93.4 m	
100.0 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

Figure 83 TH0412 Well Schematic

4.14.8 Wellhead / Well Chamber Status

Figure 84 Wellhead status TH0412

Note: lines shown are for the hydraulically operated valve above the pump

Figure 85 Speed clamp and C plate supporting rising main TH0412

4.14.9 Daily Activity Summary

Table 72 Daily activity summary TH0412

Date	Depth M BGL	Operation	Parameters	Issues
05/04/23	16.2 m	Moved the Soilmec rig and setup over TH0412. Ran temporary 7” casing centralised inside the 24” surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Cored through the hardcore with 146 mm Geobore assembly and then advanced from 2.0 m to 16.2 m. Cored with a polymer-based mud system. POOH coring assembly.	No flush losses. Verticality checks: 0.17 deg @ 3.6 m. 0.50 deg @ 5.7 m. 0.41 deg @ 8.7 m. 0.15 deg @ 11.7 m. 0.29 deg @ 14.7 m.	Hardcore present in the hole which cannot be drilled through with the fine toothed 152 mm special order core head. Instead, a 146 mm larger toothed standard core head was used.
06/04/23	16.2 m	Made up the reamer assembly and ran in hole. Commenced reaming TH0412 in 17 ½” (444 mm) to 15.5 m.	Mud system helped to clear cuttings and allowed reamer to advance without packing off.	
11/04/23	16.2 m	RIH with reamer and circulated the hole clean with fresh polymer mud. POOH the 444 mm reamer assembly and laid down. Setup spooling frame and cables and laid out the 330 mm OD casing. RIH with 330 mm permanent Boode PVC casing complete with Fibre Optic and ERT cables to 15.0 m (0.5 m above reamed shoulder).	Mud used to allow top holes to be drilled whilst other boreholes were being drilled onsite to reduce the risk of cross borehole flow. 3 x joints of 330 mm casing RIH.	
12/04/23	15.0 m	Positioned materials and equipment for grouting. RIH tremie pipe and connected hoses. Commenced mixing Geotherm X grout. Mixed and pumped 5 batches of grout with 100L of water, 7.5 bags of grout with a weight range of 1.68-1.72 sg. Pulled back tremie pipe after each batch pumped. Pulled out remaining tremie pipe and washed down all equipment and cleared site. Wait on cement.	Grouted back with 5 x 100L batches of Geotherm X. Mud used in top hole section only. Mud displaced out of annulus with the grout and intermediate casing filled with clean water before drilling out.	Only 5 batches were pumped due to a limited quantity of Geotherm X being available on site. This was to ensure sufficient Geotherm was available for the grouting of TH0416. TH0412 was topped up later.
17/04/23	41.7 m	Moved shaker package to TH0412 and connected pipe work. Ran and set 7’’ casing at 15.0 m into a layer of Bentonite pellets on top of the cement shoe run on the 330 mm casing. Excessive movement of 7” casing noted so recovered and fitted with plastic centralisers and rerun and seated into the Bentonite providing the seal. RIH with 146 mm Geobore coring assembly. Cored through the cement plug and worked string down through rat hole to 16.2 m. Cored ahead to 41.7 m with water only.	Verticality checks: 1.01 deg @ 17.7 m. 0.37 deg @ 20.7 m. 0.30 deg @ 26.7 m. 0.12 deg @ 32.7 m. 0.09 deg @ 38.7 m. Returns lost at 26.7 m.	Plan to core TH0412 to depth, install ‘diver’ logger to monitor fluid level then move to TH0404 and core to depth, monitoring the logger for any evidence of fluid communication between the 2 wells.

Date	Depth M BGL	Operation	Parameters	Issues
		Returns lost at 26.7 m.		
18/04/23	100.5 m	Continued coring in 146 mm hole from 41.7 m to 100.5 m. POOH with Geobore string to surface before POOH the 7” temporary casing.	Had returns when coring resumed at 41.7 m at 30-40%. Then returns were lost again by 49.0 m. Verticality checks: 0.20 deg @ 44.7 m. 0.42 deg @ 50.7 m. 0.09 deg @ 56.7 m. 0.35 deg @ 68.7 m. 0.56 deg @ 80.7 m. 0.53 deg @ 86.7 m. 0.53 deg @ 92.7 m. 0.52 deg @ 98.7 m.	
20/04/23	100.5 m	Made and RIH the 222 mm reamer. Opened out the hole (146 mm to 222 m) from 15.0 m to 38.5 m with no returns. At 38.5 m partial returns were regained. Continued to ream down to 56.6 m (40% returns). Reamed to 70.0 m where a rig breakdown occurred – operation suspended.		
21/04/23	100.5 m	Troubleshoot breakdown on Soilmec rig. Lowered mast and moved off well ready for transport.		Problem is bearing failure in drive head. Onsite repair not possible and the rig had to be demobilised back to Chesterfield.
24/04/23	65.8 m	No activity but hole has been dipped at approx. 65.8 m.		The reaming operation leads to cuttings falling and filling up the open hole below the reaming assembly. At the point when the open hole is full of cuttings, continued reaming forces cuttings back up the hole above the reamer and these cuttings fill fractures which in turn means that at a certain point, fluid returns are established.
27/04/23	65.8 m	EGS wireline mobilised to site and rigged up over TH0412. Made up the Acoustic Imager tool, calibrated and RIH to take log. Optical tool also ran in assembly FOC to confirm condition of borehole after reaming.		Vertical scoring visible on both the acoustic and optical Imager logs on the borehole wall.
02/05/23	98.4 m	Moved Soilmec rig into position and levelled the rig. Made up the 222 mm reaming assembly and RIH. Washed down and continued to open out the hole (146 mm to 222 m) from 70.0 m to 100.0 m with returns throughout.		Back reamed out of hole to assess effect on hole quality compared to straight POOH. The hole will be re-logged, and the results compared to the

Date	Depth M BGL	Operation	Parameters	Issues
		Circulated the hole clean until the shakers were clean before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Well dipped at 98.4 m.		previous log to check if vertical scoring is eliminated by back reaming.
03/05/23	100.5 m	Laid out the reamer assembly. Made up and RIH Geobore string and washed down to TD at 100.5 m and circulated the hole. Pumped around a high viscosity sweep and chased with 4,500 L of clean water before POOH. Rig moved off location.		
04/05/23	100.5 m	EGS arrived, set up over TH0412 and ran full suite of logs including Acoustic Imager tool from TD to surface.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND Logged to 100.2 m.	Vertical scoring was still visible on the log for the lower reamed section even though the assembly was back reamed out of hole.
16/05/23	100.5 m	Moved the Comacchio rig over the well and set up. Well dipped at 99.15 m. Prepared equipment for airlifting. Made up and ran in hole the 4" air lifting string to 80.0 m. Completed air lifts at 80.0 m, 95.0 m and 98.0 m before POOH assembly. Rigged down surface pipework and airlifting equipment. Rig moved off location.	Each air lift stage circa 30 minutes to complete.	Air lifting undertaken to remove cuttings from open fractures.
TH0412 casing shoe issue / sleeve casing				
18/05/23	100.5 m	Ran downhole camera into TH0412 – casing shoe fully detached and dropped; no grout present and a centraliser was seen across the well causing a snagging risk. Damage to the bottom 3 x ERT electrodes possible as exposed, shoe fully turned off and detached.		See **Section 4.16** issues encountered and solutions, for full details on the detached shoe.
19/06/23	100.5 m	Setup the rig over TH0412. RIH with 3 joints of sleeve casing plus a 1 m length. Landed out the casing with 0.5m stickup. Camera run required to confirm status.	Sleeve casing: OD 280 mm ID 255 mm C type (flush joint).	
21/06/23	100.5 m	Ran the Marriott downhole camera to base of the sleeve casing. Water quality too murky to get a clear image of the sleeve casing. Run aborted.		
22/06/23	100.5 m	Reran the Marriott downhole camera to base of the sleeve casing. Obtained images showing that the sleeve casing is resting partially on the ledge but not fully centralised in the borehole.		Additional work required to resolve.
29/06/23	100.5 m	POOH with sleeve casing joints. Made up and RIH a stepped drag bit on drill rods to the existing open hole shoulder. Advanced assembly carefully to create a new socket to accept the sleeve casing. Flushed hole and	Centralisation to be checked with a camera run.	

Date	Depth M BGL	Operation	Parameters	Issues
		POOH with stepped bit assembly. Re-ran and landed out the sleeve casing.		
30/06/23	100.5 m	Rigged up and ran Marriotts downhole camera. Observed that there was a cable tie in the wellbore which was fished out using an improvised hook. Camera footage revealed that sleeve casing was not quite centralised over the open hole.		Sleeve casing not sitting central in the well causing an obstruction to the lower section. Not accepted.
04/07/23	100.5 m	Attempted to alter position of casing sleeve. Unable to achieve much movement due to close tolerance between the inner and outer casings. Ran camera which shows the sleeve casing is still off centre and not fully over the borehole.		
06/07/23	100.5 m	Topped up grout level in intermediate casing annulus to the correct height. Moved rig from TH0408 to TH0412 and set up Comacchio over the well. Ran camera to determine the orientation of the shoulder offset. Marked the casing to show which side has the shoulder visible. POOH and laid down the 3 joints of sleeve casing. Re-ran camera in the well to obtain video of the open hole shoulder. Detached shoe is clearly visible offset from the centre of the open hole.	Shoulder appears to be on the SW side of the borehole.	
11/07/23	100.5 m	Prepared ‘bung’ to run in open hole as a base for grouting. Lowered grouting ‘bung’ down to 16.0 m. Ran lengths of 60 mm tremie pipe to 15.0 m before introducing 2 ¼ bags of cement/Bentonite pellets to bring level to 15.4 m. Introduced 2 bags of sharp sand to bring level to 15.12 m.	Bottom of intermediate casing: 14.7 m. Top of detached shoe: 15.0 m. Bottom of detached shoe: 15.3 m. Transition from 444 mm to 222 mm open hole: 15.3 m. Open hole ‘bung’ to support grout: 16.0 m.	
12/07/23	14.3 m	Dipped well at 15.12 m. Water table level at 14.5 m, water level in the well 13.2 m. Retrieved 60 mm tremie pipe. Attempted to remove water from the well with hose and pump but this was not successful. Commenced mixing grout. First mix – 100 L of water, 3 bags cement, 1 tub Bentonite. Grout weight - 1.55 sg. Second mix – 100 L of water, 3 bags cement, 1 tub Bentonite. Grout weight - 1.62 sg. Third mix – 50 L of water, 1.5 bags cement, ½ tub Bentonite. Grout weight - 1.57 sg. The fluid level rose 2.0 m during the grout job. Wait on grout. Water level dipped at 12.0 m, grout level at 14.3 m.	The reason for attempting to remove water was to remove weight from above the ‘bung’ as there was concern about the strength of the tether. Grout is 40 cm inside the intermediate casing.	

Date	Depth M BGL	Operation	Parameters	Issues
13/07/23	93.4 m	Continued to WOC for full 24 hours. Made up stepped bit assembly and RIH. Pulled and parted the tether used to deploy cement bung. Commenced drilling out 0.5 m of grout to 14.8 m. Returns to surface with remains of cord. POOH. Made up assembly #2 and RIH to 14.8 m and continued drilling out cement carefully with minimum WOB to 15.14 m. Made up assembly #3 with pilot bit, 222 mm hole opener immediately behind it and 216 mm reamer. RIH and washed through to 17.3 m. POOH. Dipped well at 93.4 m. The sand, Bentonite and the grouting bung have dropped into the hole but not quite reached TD.	Assembly #1 consisted of a 286 mm stepped bit on drill rods. Assembly #2 consisted of 127 mm pilot bit, crossed over to 273 mm hole opener. Dimension from end of bit to shoulder of hole opener – 44 cm. 15.14 m is the depth the shoulder of the hole opener reached. With the shoulder at this depth, the bit was 44 cm deeper at 15.58 m. The 222 mm open hole starts at ~15.3 m so the pilot bit has penetrated approx. 28 cm into the open hole.	
14/07/23	94.7 m	Set up camera and ran in hole. Observed good grout coverage across the detached shoe area and the top of the open hole is elongated following the drill out operation. There is good entry from the casing shoe into the open hole. RIH with pilot bit and 222 mm hole opener on drill rods. RIH to 94.0 m dipped depth and continued to 96.0 m. Flushed hole. POOH drill rods. Hole dipped to 94.7 m.		
TH0412 packer and pump Install				
22/11/23	93.4 m	Dipped well at 93.4 m before commencing install. Made up the packer and pump assembly as per the install sheet taking measurements of all components. RIH to just below GL. Packer inflated and visually inspected for any leaks before bleeding off and deflating the packer through the manifold. RIH and positioned packer mid element at 34.12 m. Rising main secured at surface on a C plate and with the Speedclamp still attached.	3 ½” Rising main Ecoline Heavy Duty PN26 PVC Riser (88 mm OD / 80 mm ID 110mm OD Over Joint).	
23/11/23	93.4 m	Inflated packer with 13.5 bar and monitored. Packer to remain inflated.	Note: pump tested at a later stage once inverter drives and wiring on surface was complete.	
TH0412 complete				

4.15 ABSTRACTION / REINJECTION WELL – TH0414 SUMMARY OF OPERATIONS

4.15.1 Key Well Data

Table 73 TH0414 Key well data

Well name	TH0414		
Well classification	Open Loop – abstraction/reinjection well		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.404 m AOD Top 24" to GL - 0.070 m		
Start date	Intermediate section started on the 27/03/23 and completed on 04/04/23. Lower section started on the 24/04/23.		
End of drilling date	16/05/23.		
Install dates	Air lifted 15/05/23. Installed from 16/11/23 to 17/11/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 444 mm	Cored to 16.1 m Reamed to 15.5 m	11.5" Boode PVC casing 330 mm OD 292 mm ID	Run to 15.0 m (without shoe after failure 14.7 m)
Sleeve casing	n/a	Sleeve Casing OD 280 mm ID 255 mm Boode C type (flush joint) PVC casing.	15.44 m
Final section to TD Cored in 146 mm then opened out to 222 mm	Cored to 100.5 m Reamed to 100.0 m	n/a	n/a
Installation	n/a	Geopro packer, valve and Grundfos SP46-5 pump	Packer set at 34.98 m mid element
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344945.995 Northing Y: 375858.124		
Ordnance Survey Grid Reference	Latitude N: 53°16′37″ Longitude W: 002°49′38″		
12 Character National Grid Reference	SJ 44946 75858		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344945.72 Northing Y: 375858.69 Step out - 0.63 m (inclination 0.53 deg / azimuth 328 deg)		

4.15.2 Summary of Drilling Operations

The Soilmec rig was mobilised and rigged up over TH0414. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 16.1 m with full returns throughout. The hole was circulated clean before POOH the assembly.

The 7” temporary casing was recovered before making up and running in hole a 444 mm reamer assembly. The 444 mm reamer and pilot bit opened out the hole down to 15.5 m and the well circulated with full returns before displacing to clean mud. The assembly was POOH and laid out before setting up to run the intermediate casing. A temporary shoe was made up to the first joint of 330 mm OD casing with ERT and fibre optic cables secured to the outside and RIH. The shoe joint comprised of a short section of casing that had a precast concrete plug in the base. This had been predrilled and raw plugs inserted thought the side to help grip the cement plug and avoid it falling out when run (this occurred on TH0424 with no additional securing method). The remaining joints of casing were run, securing the ERT and fibre optic cable to the outside with cable ties with the shoe at 15.0 m (0.5 m above reamed shoulder). The grout unit was rigged up before grouting the 330 mm annulus with 6 x 100 L batches of grout.

Figure 86 Intermediate 330 mm OD casing being RIH with ERT and FO cables secured to the outside

A thermally conductive grout was used which satisfied the Specification for the intermediate casing string. The grout product used was "Geotherm-X GR," which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe. Dry and wet samples of grout were taken as per specification. Grout levels were tagged within the Boode casing and were topped up during completion of the headworks.

The rig was moved off location (04th April 2023) once the grout had set as it was needed to avoid the casing rising due to buoyancy.

The Comacchio rig was mobilised back on the 24th April 2023 and setup. The 7" temporary casing was run to 15.0 m with plastic centralisers installed, sat on top of the intermediate casing shoe and sealed at in the annulus with Bentonite.

Made up and RIH the 146 mm Geobore assembly and cored through the cement plug and commenced coring from 16.1 m to 19.2 m where the assembly became temporarily stuck. The string was worked and freed successfully. It was noted that the returned were grey and not the normal red indicating possible cement collapse behind the bit causing a pack off to occur. The coring assembly was advanced down to 100.5 m with good core recovery but with fluid returns being lost from 28.2 m and not regained. The well was circulated and the coring assembly recovered along with the temporary 7” casing.

The rig was moved off location on the 25th April 2023.

EGS were mobilised and the well was wireline logged in the cored hole from 2.0 m to 99.5 m with no issues. Full details of wireline logging programme undertaken can be found in **Section 4.15.5**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The Soilmec rig was moved back over the well on the 09th May 2023. A 222 mm reamer assembly was made up and RIH down to 15.0 m and opened out the hole from 146 mm down to TD at 100.0 m with partial returns initially, increasing to full returns by TD. The well was circulated clean before pumping a high viscosity polymer sweep. Continued to circulate until the shakers were clean with good returns throughout. Displaced the well with 5,000 L of clean water before back reaming out of hole (trying to avoid vertical score marks on borehole wall). Hole dipped at 100.0 m.

The Soilmec rig was moved off location on the 10th May 2023.

The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. The Comacchio rig was mobilised and setup and a 4” air lifting assembly was RIH. A three-stage air lift was completed. The depths of each stage were 50.0 m, 75.0 m and 98.0 m. During the final stage the compressor failed so the decision was taken to pull back until a replacement compressor was mobilised to site. The well dipped at 98.0 m. The air lifting string was run back to 98.0 m and the final air lift stage completed successfully before POOH. The well dipped at 98.5 m. The rig was moved off TH0414 on the 16th May 2023.

4.15.3 Sleeve casing installation

On the 30th May 2023 EGS were mobilised to site and a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the casing shoe had become fully detached and dropped, no grout present at the base of the shoe, there was an exposed centraliser presenting a snagging risk and a collar of grout inside the shoe, see images in **Section 4.16**.

The Comacchio rig was moved back over TH0414 on the 21st June 2023 and prepared for sleeving operations. A CP internally chamfered shoe was RIH on 10 ¾” casing to remove the cement collar inside the detached shoe. The assembly was RIH and tagged TOC inside the shoe at 15.36 m. The assembly was worked knocking down several times until the string dropped 24 cm to 15.6 m. This drop confirmed the cement had been removed and the assembly was now resting on the shoulder in the well. The assembly was POOH.

RIH the sleeve casing landing off on the well shoulder at 15.60 m. The sleeve casing run was Boode PVC 280 mm OD x 255 mm ID, C Type flush joint casing. Annulus clearance between intermediate and new casing is 6 mm.

The camera was run and confirmed the sleeve casing was sitting central in the well. Sleeve casing accepted by BGS.

4.15.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0414 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 74 Drilling fluid summary table – TH0414

	TH0414
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	828
Ultrabore additive lost (kg)	11.8
Purebore additive lost (kg)	5.9

Once the intermediate section was drilled the well was cased with 330 mm OD Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section apart from a high viscosity sweep and water used throughout.

No LCM pills were deployed in this well.

4.15.5 Geophysical Logging Undertaken

Table 75 Geophysical logging summary TH0414

Wireline logging undertaken	Tools run
Section logged from 2.0 m to 99.5 m. Top section from 2.0 m to 15.0 m through casing, lower section to TD in cored 146 mm hole. (27/04/23)	GR, CALI, ACBI, LRES, TEMP, COND

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.63 m and within the 1/100 tolerance.

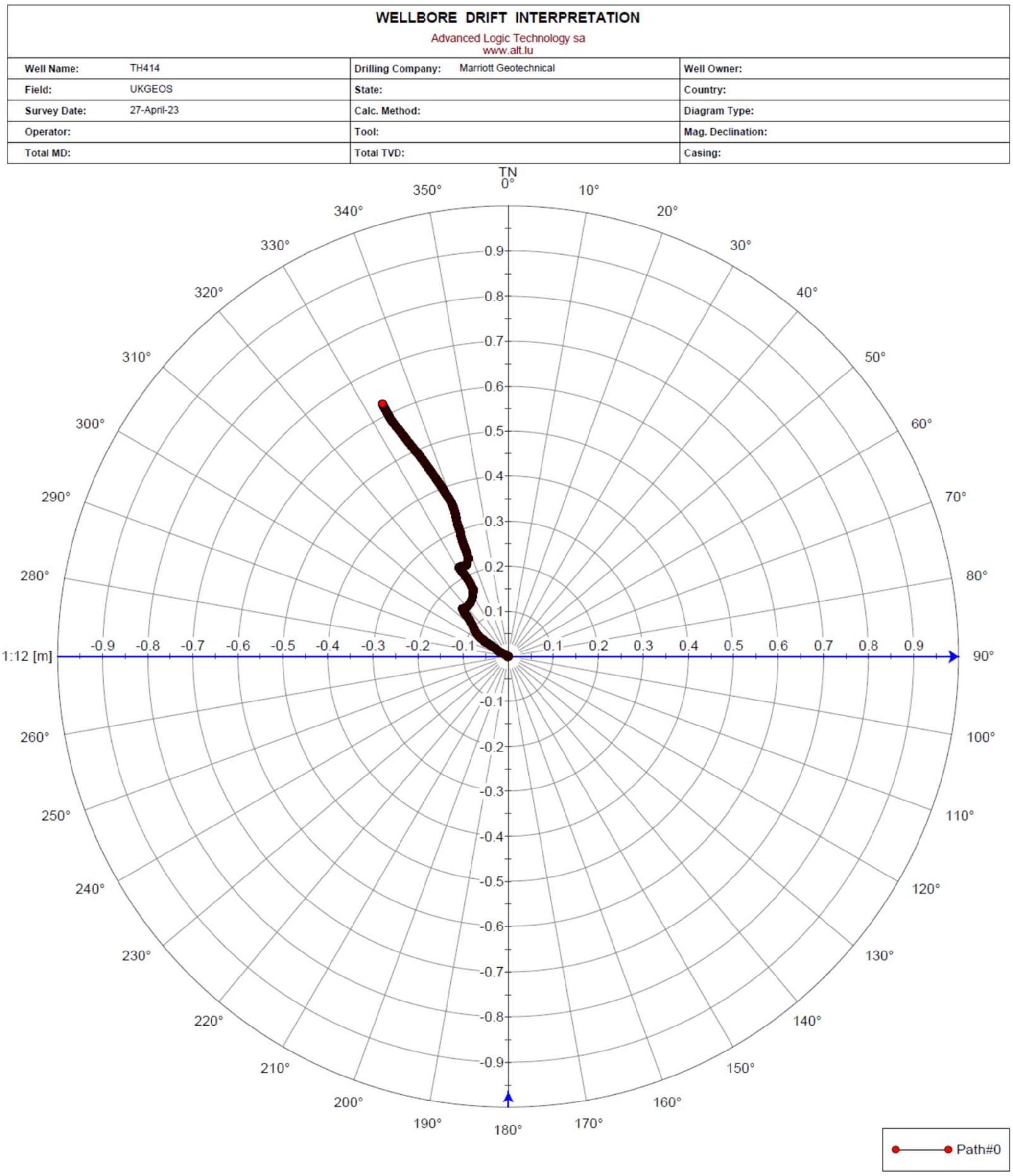


Figure 87 Verticality bullseye plot for TH0414, © European Geophysical Services Ltd

4.15.6 Summary of Installation Operations

Installation criteria for TH0414:

- Produce a detailed install protocol showing the packer setting depth and location of each completion component.
- Review available wireline logs, in particular the calliper log and select suitable packer setting location in a section of gauge hole.
- Accurately monitor the deployment and generate a tubing tally for the rising main before commencement.
- Suspend the packer and pump assembly securely at surface with C plate and speed clamp before inflation.
- Ensure the packer remains inflated with 10 bars of pressure to achieve a good seal and isolate the upper confined aquifer.

Summary of operations:

The packer, downhole valve and pump assembly was made up in a single assembly on the ground. The pump power cable was terminated in a resin filled connector and all hydraulic lines were made up to the packer mandrel. The completed assembly was picked up and RIH utilising a telehandler with a hydraulic winch attachment. The packer was inflated when just below ground level with 2 bar and checked for leaks. The pressure dropped to 0.5 bar. The test was repeated overnight with the same result. The decision was taken to recover and tighten the inflation / deflation lines into the packer mandrel. Once complete the packer and pump assembly was run back in hole to circa 36.0 m.

The assembly was RIH on a 3 ½” Ecoline Heavy Duty PN26 rising main.

The assembly was RIH 1.0 m deeper than the final setting depth and the packer inflated and pressure tested, this time holding pressure. The pressure was bled off and the fluid in the packer element removed with compressed air to allow it to be fully deflated and moved. The string was pulled back 1.0 m as per the installation sheet placing the mid element of the packer at 34.98 m. The rising main was secure at surface on a C plate and with the Speedclamp still attached. The packer was inflated with 15.0 bar before rigging down. The pump wasn’t tested at this stage as the inverter drives in the well enclosures hadn’t been wired in to the surface connections.

4.15.7 TH0414 Borehole Well Schematic

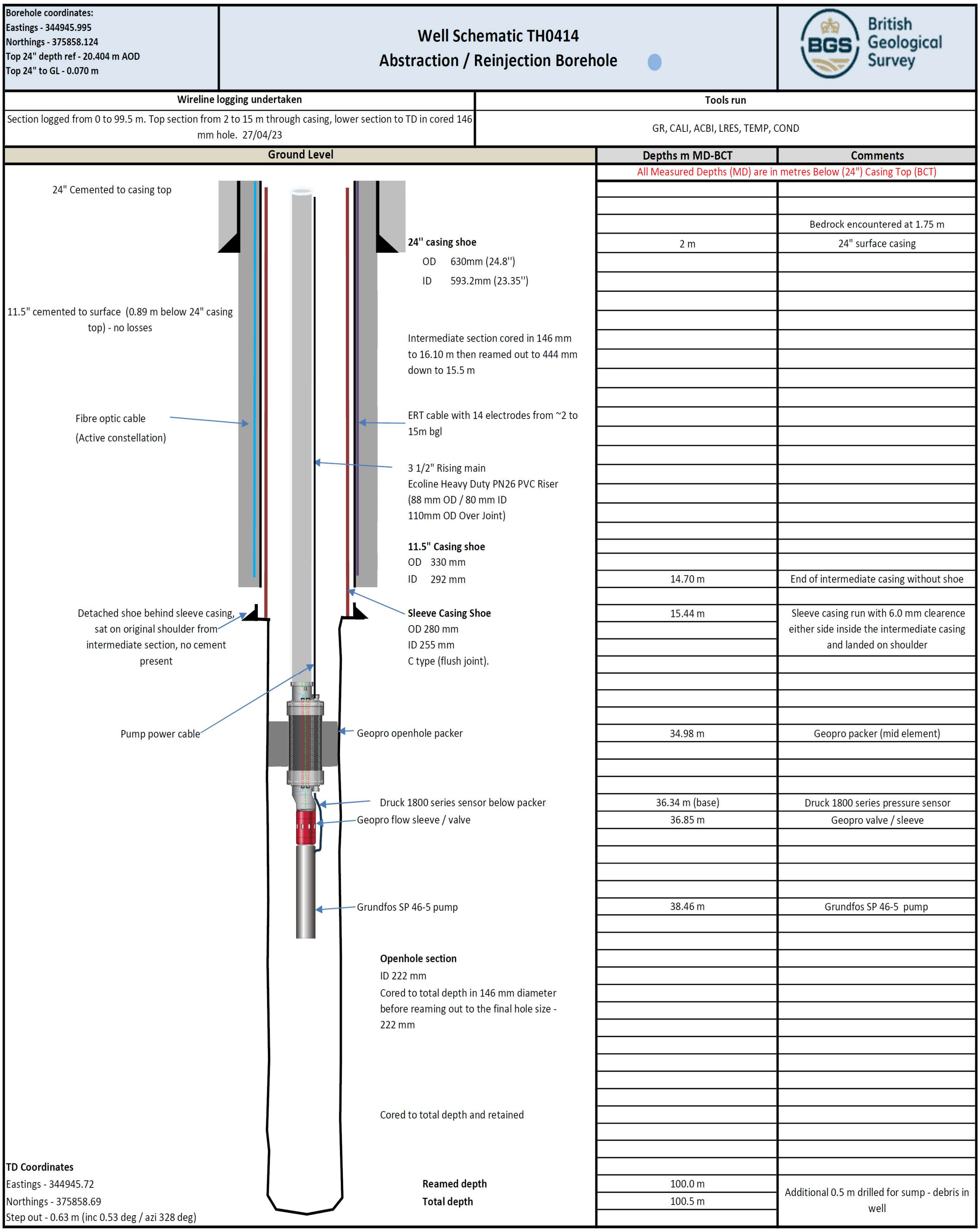


Figure 88 TH0414 Well Schematic

4.15.8 Wellhead / Well Chamber Status

Figure 89 Wellhead status TH0414

Note: lines shown are for the hydraulically operated valve above the pump

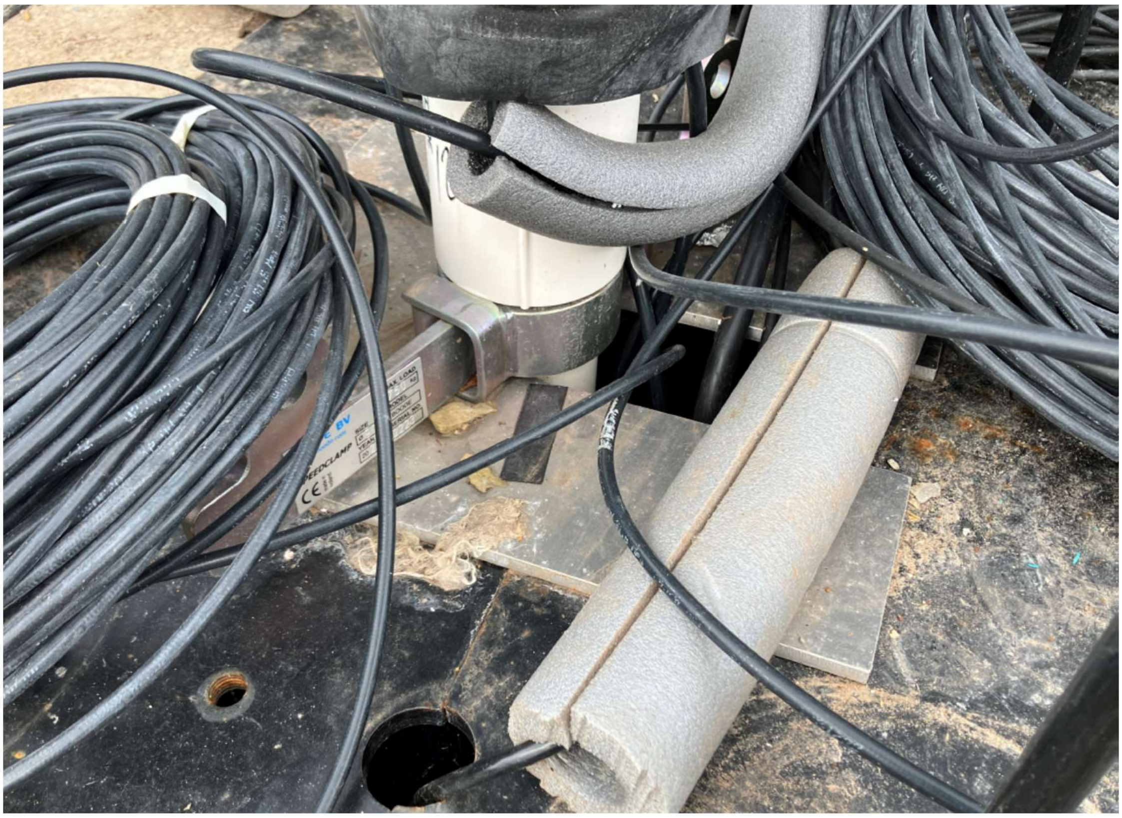


Figure 90 Speed clamp and C plate supporting rising main TH0414

4.15.9 Daily Activity Summary

Table 76 Daily activity summary TH0414

Date	Depth M BGL	Operation	Parameters	Issues
27/03/23	16.1 m	Moved the Soilmec rig and setup over TH0414. Ran temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Mixed a volume of mud. Made up 146 mm Geobore assembly. Cored well from 2.0 m to 16.1 m. Cored with a polymer-based mud system. POOH coring assembly and recovered 7" temporary casing. Made up the reamer assembly and ran in hole. Commenced reaming TH0414 in 444 mm down to 12.5 m.	Good returns throughout. Verticality checks: 0.45 deg @ 5.6 m. 0.45 deg @ 8.6 m. 0.48 deg @ 11.6 m. 0.14 deg @ 14.6 m. Mud used to allow top holes to be drilled whilst other boreholes were being drilled onsite to reduce the risk of cross borehole flow.	
28/03/23	16.1 m	Continued reaming hole from 12.5 m to 15.5 m (section TD) with 444 mm reaming assembly. Circulated the hole to clean drilling fluid and dumped old fluid. POOH reamer assembly.	Mud system helped to clear cuttings and allowed reamer to advance without packing off.	
04/04/23	15.0 m	Dipped well at 14.2 m. RIH with reamer and circulated the hole clean with polymer mud. POOH the 444 mm reamer assembly and laid down. Dipped well to 15.5 m. Setup spooling frame and cables and laid out the 330 mm OD casing. RIH 330 mm permanent Boode PVC casing complete with Fibre Optic and ERT cables to 15.0 m (0.5 m above reamed shoulder). RIH tremie pipe and connected hoses. Commenced mixing Geotherm X grout. Mixed and pumped 6 batches of grout with 100 L of water, 7.5 bags of grout. Pulled out remaining tremie pipe and washed down all equipment and cleared site. Wait on cement.	3 x joints of 330 mm casing RIH. Mud used in top hole section only. Displaced to clean water following intermediate casing being run and grouted. Crosswire check completed on casing before grouting. Grouted back with 6 x mixes of Geotherm X (100 L of water and 7.5 bags of grout).	
24/04/23	62.7 m	Moved Comacchio 405 from TH0415 to TH0414. Set up and levelled rig over well. Ran 15.0 m of 7'' centralised temporary casing, sealing the annulus with Bentonite. RIH with 146 mm Geobore coring assembly. Cored through the cement plug and worked string down through rat hole to 16.1 m. Cored ahead to 62.7 m with water only. Temporarily stuck with loss of returns at end of core run 17.7 m to 19.2 m. Worked free and regained returns. See issues column. Returns lost at 28.2 m.	Verticality checks: 0.57 deg @ 17.7 m. 0.65 deg @ 19.2 m. 0.27 deg @ 26.7 m. 0.14 deg @ 32.7 m. 0.20 deg @ 38.7 m. 0.24 deg @ 44.7 m. 0.32 deg @ 50.7 m. 0.36 deg @ 56.7 m. 0.41 deg @ 62.7 m.	From circa 20.0 m tight hole conditions were experienced, possibly due to pieces of the 330 mm cement shoe becoming detached. The returns turned grey rather than red, indicating that cement was being drilled not formation. Pumped a 100 L pill of Purebore polymer and worked the string. No reports of significant returns but

Date	Depth M BGL	Operation	Parameters	Issues
				the problem ceased after this.
25/04/23	100.5 m	Continued to core ahead (146 mm hole) with no returns from 62.7 m to 100.5 m and well TD. Circulated the hole clean. POOH with Geobore string to surface before POOH the 7” temporary casing. Moved rig off location.	Verticality checks: 0.51 deg @ 68.7 m. 0.26 deg @ 74.7 m. 0.40 deg @ 86.7 m. 0.54 deg @ 92.7 m. 0.52 deg @ 98.7 m.	
27/04/23	100.5 m	EGS arrived, set up over TH0414 and ran full suite of logs including Acoustic Imager tool from TD to surface.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND Logged to 99.5 m.	Logged in cored hole due to previous issues with scoring in the reamed hole.
09/05/23	100.5 m	Moved Soilmec rig back to TH0414 and set up rig over the borehole. Made and RIH the 222 mm reamer. Opened out the hole (146 mm to 222 m) from 15.0 m to 31.0 m. Pulled back reaming assembly off bottom.		
10/05/23	100.0 m	Continued to open out the hole (146 mm to 222 m) from 31.0 m to 100.0 m with returns. Circulated the hole. Pumped around a high viscosity sweep and circulated until shakers were clean. Chased with 5,000 L of clean water before POOH. Assembly back reamed out. Hole dipped at 100.0 m.	Initial returns in the region of 40%, gradually increased to 100%.	Problem with shale shaker not separating solids from liquid – solids being deposited into suction tank and therefore returned to well. Pulled back 6.0 m off bottom with reaming assembly to troubleshoot equipment. Cleared sediment from tank system and adjusted shaker system.
15/05/23	100.0 m	Moved the Comacchio rig over the well and set up. Prepared equipment for airlifting. Made up and ran in hole the 4” air lifting string to 50.0 m. Completed air lifts at 50.0 m and 75.0 m before advancing to 98.0 m. Commenced final air lift stage but compressor failed resulting in operation being abandoned. POOH assembly.	Each air lift stage circa 30 minutes to complete.	Air lifting undertaken to remove cuttings from open fractures.
16/05/23	98.5 m	Borehole dipped at 98.0 m. RIH the 4” air lifting string to 98.0 m. Completed the third and final stage of the air lift programme. POOH the air lifting assembly and laid out. Rigged down surface pipework and airlifting equipment. Rig moved off location.		

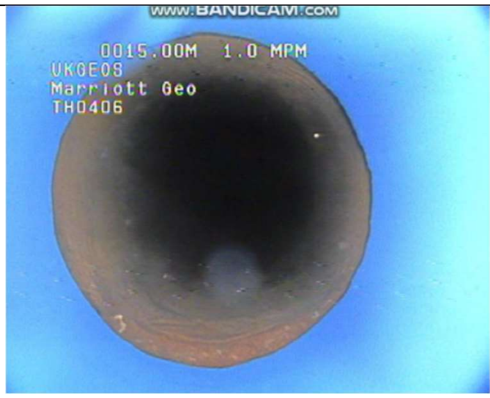
Date	Depth M BGL	Operation	Parameters	Issues
		Borehole dipped at 98.5 m.		
TH0414 casing shoe issue / sleeve casing				
30/05/23	98.5 m	EGS mobilised to site and rigged up over the well. Downhole camera deployed to get a clear image of the status of the shoe. Casing shoe fully detached and dropped, no grout present at base, exposed centraliser presents creating a snagging risk and collar of grout inside shoe. EGS rigged down.		See **Section 4.16** issues encountered and solutions, for full details on detached shoe.
21/06/23	98.5 m	Moved rig over and setup. Commence running in CP internally chamfered shoe on the 10 ¾'' casing to remove cement collar from inside the detached shoe. Tagged top of cement inside shoe at ~15.36 m. After several knocks downwards, observed string drop 24 cm to ~15.6 m. Confirmed no further progress and assembly sitting on ledge and fully through the detached shoe. POOH. RIH with sleeve casing to seat on shoulder of hole below casing shoe.	Location of end of casing to be confirmed by camera.	
22/06/23	98.5 m	Ran the Marriotts downhole camera into the well to confirm status of sleeve casing. Ran down to the base of the casing sleeve. Video shows that the casing is fully centralised over the borehole. Sleeve casing accepted by BGS.		
TH0414 packer and pump Install				
16/11/23	98.5 m	Made up the packer and pump assembly as per the install sheet taking measurements of all components. Performed low pressure test to 2 bar but the pressure dropped by 0.5 bar. Decision taken to recover and inspect. Retightened fittings, no signed of leaks and ran in hole to target depth (packer mid element 35.0 m). Repeated pressure test at 35.0 m, inflated and held ok. On attempt to deflate and pull back 1.0 m, (released quick valve on de pressurisation line) packer found to be still inflated and engaged with BH wall. Following a call with the supplier air was pumped down the de pressurisation line to fully deflate the packer. The packer was moved and 1.0 m higher.	3 ½" Rising main Ecoline Heavy Duty PN26 PVC Riser (88 mm OD / 80 mm ID 110mm OD Over Joint).	Pressure test attempted – 1.5 bar dropped 0.5 over 30 minutes. Applied 2 bar and left overnight. Again dropped 0.5 bar. Packer recovered, inspected and fittings tightened before running to depth without repeating test.
17/11/23	98.5 m	Positioned packer at final depth of 34.98 m (mid packer element) and inflated. Pressure applied 15 bar on surface gauge and monitored. Packer to remain inflated. Rising main secured at surface on a C plate and with the Speedclamp still attached.	Note: pump tested at a later stage once inverter drives and wiring on surface was complete.	
TH0414 complete				

4.16 ISSUES ENCOUNTERED AND SOLUTIONS – ABSTRACTION / REINJECTION WELLS

Table 77 Summary table of issues encountered – Abstraction / reinjection wells

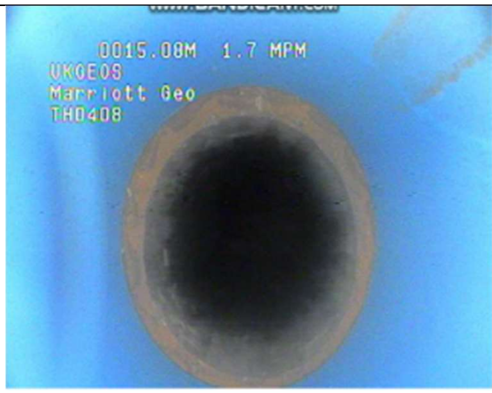
Well number	Issue	Solution
All Abstraction / Reinjection wells	Total depth (TD) shallower than 100.0 m due to poor hole cleaning.	A shallower TD was seen to be preferable than further airlifting, that was costly due to programme extensions. This approach was taken to retain fracture flow paths within the aquifer and remove as many of the drill cuttings / fines from the fractures as possible to achieve as close to the original state as possible. If this isn't critical then a mud and LCM approach could be adopted to drill.
Wireline / geophysical logging	Vertical scoring on wireline logs undertaken in reamed holes.	Although the exact cause is unknown (measurement taken of reamer and pulling techniques changed), undertaking acoustic image logging within reamed boreholes has resulted in visual "scoring" of the acoustic image log and a poorer quality log overall. Geophysical logging was undertaken in the cored borehole prior to reaming where possible.
All Abstraction / Reinjection wells	Reamer striations on borehole wall impacting sealing capabilities of packer assembly.	Following an inspection of the depths of the groves and discussing with the packer manufacturer this is not a concern, and the packer element will and are successfully sealing against the wall. Different recovery techniques when pulling out the reamer were adopted but similar results.
All Abstraction / Reinjection wells	Failed casing shoes See below for full details of each well and measures taken to resolve.	Shoes failed both when coring through and reaming, not linked to reaming alone. It was noted that the temporary casing dropped when coring on at least one well which suggested the shoe had failed. Review methods of setting and grouting the casing for future operations. Review alternative casing shoe options to see if a better option is available. Avoid a precast cement shoe if possible. Look to thread lock and or look to get a left-handed male threaded shoe track.

<table>
<tr><th>Well number</th><th>Issue</th><th>Solution</th></tr>
<tr><td></td><td></td><td>Set casing in tension just off bottom, ensure tremie pipe is level with shoe. Do not advance pilot hole deeper than instructed (0.5 m max).</td></tr>
<tr><td>TH0406</td><td>

Poor cement job beneath original casing, shoe however still attached.</td><td>

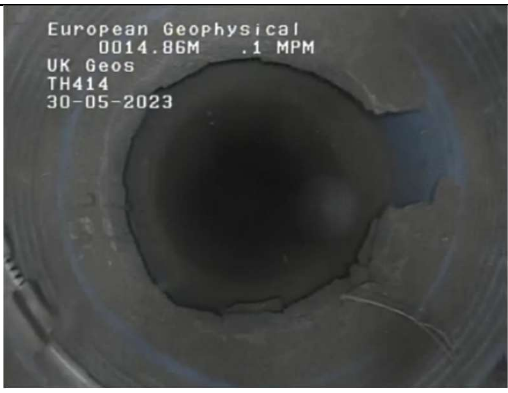
Step and drag bit used to create rebate. Casing seated but camera run showed approximately 13 mm overhang to the open hole below (snagging risk). Sleeve removed. Rebate worked and string rerun and worked by hand into socket.

Sleeve casing - 280 mm OD x 255 mm ID and set at 15.58 m.</td></tr>
<tr><td>TH0408</td><td>

Failed casing shoe: shoe fully turned off and detached.</td><td>

Residual cement was removed, and a step bit ran to create a rebate. Sleeve casing was run but centraliser became trapped underneath. Sleeve casing was lifted and worked into the socket.

Sleeve casing - 280 mm OD x 255 mm ID and set at 15.60 m.</td></tr>
</table>

Well number	Issue	Solution
TH0412	 Casing shoe fully detached and dropped, no grout present and centraliser across well creating a snagging risk. Damage to the bottom 3 x ERT electrodes, shoe fully turned off and detached.	 Not sleeved, attempted but misalignment between permanent casing and lower hole reduced the access to the lower section. Well not drilled in centre of previous casing. Solution was to perform a secondary cement job around the shoe and drill out. A temporary plug was used as a base for cement. This was subsequently drilled out and the debris pushed to bottom - well dipped at 96.0 m.
TH0414	 Casing shoe fully detached and dropped, no grout present around shoe, exposed centraliser presents creating a snagging risk and collar of grout inside shoe.	 Grout knocked out of shoe and sleeve casing run and landed on original shoulder. Sleeve casing - 280 mm OD x 255 mm ID and set at 15.44 m.

4.17 ERT AND DTS MONITORING WELL – TH0407 SUMMARY OF OPERATIONS

4.17.1 Key Well Data

Table 78 TH0407 Key well data

Well name	TH0407		
Well classification	Electrical resistance Tomography (ERT) and Distributed Temperature Sensing (DTS) monitoring wells with deep sampling port		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 19.962 m AOD Top 24" to GL - 0.115 m		
Start date	Intermediate section started on the 29/11/22 and completed on 07/12/22. Lower section started on the 08/12/22.		
End of drilling date	22/12/22.		
Install dates	Air lifted 04/01/23. Installed on the 06/01/23. Staged grouted between 13/01/23 and 23/01/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 311 mm	Cored to 10.8 m Reamed to 6.1 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.1 m
Final section to TD Cored in 152 mm then opened out to 200 mm	Cored to 106.4 m Reamed to 105.0 m	n/a	n/a
Installation	n/a	3" Boode PVC tubing 75 mm OD 67.8 mm ID Screen section between 97.36 and 98.36 m	99.44 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344925.069 Northing Y: 375852.636	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′39″	
12 Character National Grid Reference		SJ 44925 75853	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344924.13 Northing Y: 375852.94 Step out - 0.99 m (inclination 0.66 deg / azimuth 314 deg)	

4.17.2 Summary of Drilling Operations

The Soilmec rig was moved over TH0407 on the 29th November 2022 and setup. A string of 7” temporary casing was RIH and centralised inside the 24” surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 10.8 m with no returns where the operation was stopped due to out of tolerance inclination readings (0.98 deg and 0.86 deg both at 9.0 m). The rig was moved off the well whilst a forward plan could be agreed.

The Soilmec rig was mobilised back on the 07th December 2022 and a 311 mm reamer assembly was made up and RIH. The hole was opened out down to 6.1 m before circulating the hole clean and POOH. A 10 ¾” (273 mm) temporary string of casing was RIH to 6.1 m and centralised within the 24” casing. The base was sealed with Bentonite. The rig was swapped for the smaller Comacchio 405 before performing a crosswire check on the casing to confirm it had been set verticality. The 152 mm coring assembly was picked backup and coring resumed down to 15.3 m with circa 40% returns. At this depth sand was seen flowing into the well. The assembly was pulled back and the operation suspended.

The BGS inspection camera was run but no clear evidence was seen of any hole collapse, but three large fractures were noted from around 11.0 m. The decision was taken to grout the problematic zone before advancing deeper. A tremie pipe was RIH to HUD at 14.0 m (top of sand accumulation). The following grout mix was pumped:

- 20 L of water.
- 25 kg of cement (standard OPC grout).
- 2.5 kg of Bentonite.

After waiting on cement, the well was dipped at 10.4 m. The downhole camera was re deployed and showed all major fractures had been sealed with grout.

The coring assembly was re-run, and TOC was tagged at 10.4 m. The grout was drilled out and the hole cored to 15.8 m. At 14.8 m the string pulled tight but was successfully freed. All indications suggest this was due to the grout setting not being uniform, confirmed by sections of grout recovered in the core barrel not being fully set.

An inclination reading taken at 15.0 m (0.53 deg) was high and suggested the well maybe out of tolerance if it was allowed to advance deeper. The decision was taken to try and work the coring assembly between 6.1 m and 15.8 m with high RPM and slow running speed to open out the hole and improve the well inclination. Coring continued to 19.4 m taking numerous E-Totco surveys. Borehole remained out of tolerance.

EGS were mobilised to site and logged the upper section of the hole with a full logging suite including a full gyro survey to confirm both inclination and azimuth. Full details of the tools run are in **Section 4.17.4**. the results of the survey were acceptable and indicated the well trajectory was improving so coring was allowed to continue.

The well was cored to 31.4 m with the inclination reading slowly decreasing back to 0.44 deg at 30.0 m however remained high.

EGS were mobilised back to site on the 19th December 2022 to perform a second gyro survey. The results confirmed the well remained out of tolerance at 0.60 deg due west. BGS agreed for drilling to proceed based on the projected TD location having a step out of circa 1.5 m by 101.0 m.

The hole was cored in 152 mm from 31.4 m to 106.4 m with no returns and taking inclination surveys every 6.0 m drilled. High verticality reading remained (0.78 deg at 97.0 m). The hole was circulated clean before POOH the assembly.

Figure 91 Recovered core and fluid samples from TH0407 in the cold store onsite

EGS were mobilised back to site on 21st December 2022 to complete the logging of the lower section from 19.1 m to 106.0 m. The verticality log showed the well had deviated 0.80 deg due west of the array with a lateral deviation of 0.98 m (just within the tolerance stated within the Scope). Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

A 200 mm reamer assembly was made up and RIH and opened out the hole from 152 mm down to TD at 105.0 m. No returns were seen until the assembly reached 60.0 m, increasing to 60% by 98.0 m where returns were lost again and not regained indicating a large fracture at the base of the well. The well was circulated clean before POOH and recovering the string of temporary 10 ¾" (273 mm) casing.

The operations were suspended on the 23rd December 2022 and the site shut down for Christmas.

Operations recommenced on the 03rd January 2023 and the well dipped at 91.4 m. The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. A 4" air lifting assembly was RIH, and a two-stage air lift was completed. The depths of each stage were 64.0 m and 89.6 m. The assembly was POOH and the well dipped the next morning to 102.3 m.

4.17.3 Materials, Flush and Drilling Additive Used

TH0407 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

Due to running sands and large fractures being encountered between 11.0 m and 15.2 m the decision was taken to emplace a cement plug at the base of the well as detailed below in **Table 79**.

Table 79 Summary table of grouting operations to stabilise the hole conditions – TH0407

	TH0407
Grout pills pumped to stem losses	1 x OPC grout plug (1 bags grout, 2.5 kg Bentonite and 20 L of water at 14.0 m (top of sand infill).
Water volume (L)	20
OPS grout (kg)	25
Bentonite (kg)	2.5

4.17.4 Geophysical Logging Undertaken

Table 80 Geophysical logging summary TH0407

Wireline logging undertaken	Tools run
Upper section logged to 19.0 m due to inclination concern. (16/12/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Gyro survey at 31.4 m due to inclination concern. (19/12/22)	Gyro only to give inclination and azimuth readings.
Lower section logged in cored 152 mm hole from 19.1 to 106.0 m. (21/12/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.99 m and just within the 1/100 tolerance.

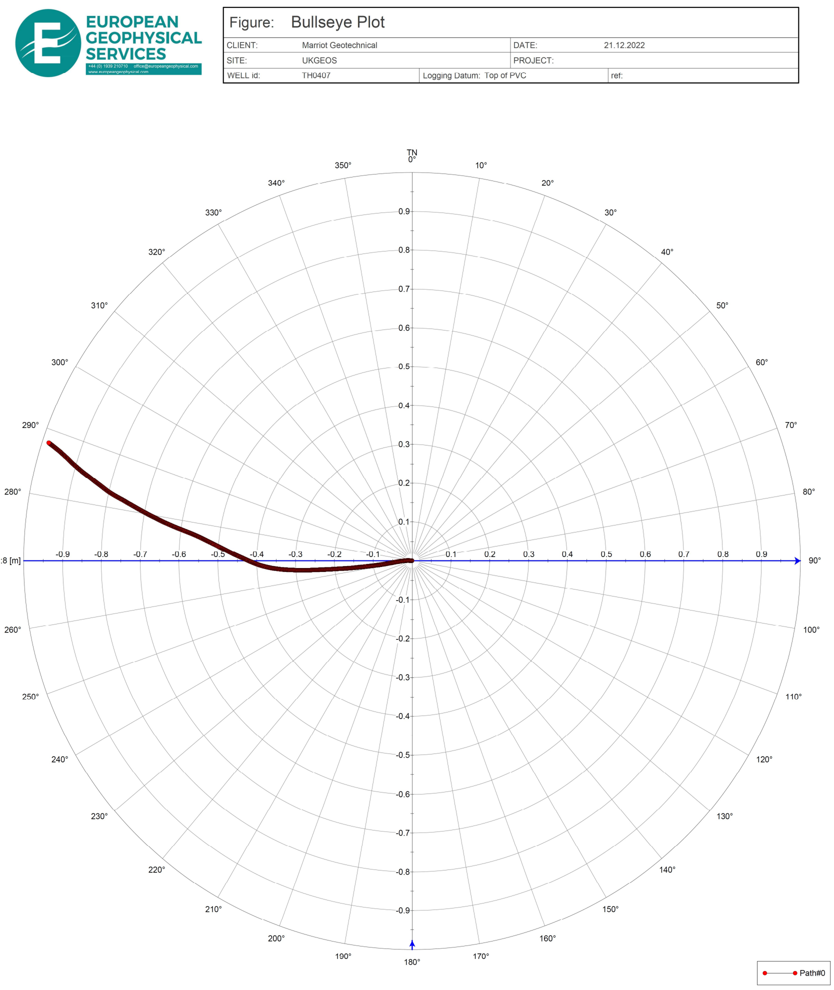


Figure 92 Verticality bullseye plot for TH0407, © European Geophysical Services Ltd

4.17.5 Summary of Installation Operations

Installation criteria for TH0407:

- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography and fibre optic cables on the outside of the tubing ensuring that ERT electrodes are at correct depths.
- Ensure the tubing run is large enough to allow a pump to be deployed in future to sample a screen section at the base of the well.
- Accurately monitor the deployment maintaining accurate records throughout.
- Backfill with grout, with uniform density to ensure consistent thermal properties as per supplier’s specifications.
- Ensure the install is centralised in the borehole and maintained in tension during grouting operations.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared the installation BHA and setup the cable reel stands and equipment in preparation for running. A 60 mm retrievable tremie pipe was RIH 91.0 m before dipping the well to 99.55 m. This was less than Scope however it was accepted by BGS and the installation plan modified to account for this slightly shallower depth.

Held a pre-installation meeting with all parties before Commencing the installation. The base (79 mm length) section was screwed into the plain sump and screen casing and lowered into the well with both the ERT and fibre optic cables attached to the outside. The assembly was RIH as per the installation sheet putting the base of the installation at 99.44 m. This was 5.7 cm higher than planned due to sediment accumulation as the install was run to the base of well.

The ERT cables were functions tested with a pause halfway to test the deep ERT string and again once at total depth. All electrodes tested ok.

Back filling operations then commenced. See **Section 4.17.6** for the backfill materials and grout lifts undertaken. Stage grouting was undertaken to avoid high volumes of grout being lost to fractures. Each grout lift volume was calculated based on wireline logs to identify large fractures, assumed gauged hole and grout mix yields based on cement concentration. In each case the TOC was planned to be a few metres above known large fractures. By taking this approach, it avoided having a large hydrostatic pressure generated by the grout column acting on open fractures. The risk of permanently sealing fractures across the site was very high if this approach hadn't been taken due to the know connectivity of fractures and communication between boreholes seen during the drilling phase.

After each grout lift was completed the 60 mm tremie pipe was pulled back above the TOC and flushed cleaned. All four ERT/DTS wells had been drilled and the installation run in advance of the grouting operations to allow all four wells to be grouted in sequence. The grout unit was positioned in the centre and lines were rigged up to each well.

All wells were topped up with grout to 1.0 m below ground level.

Figure 93 TH0407 installation being run and backfilled with grout

4.17.6 Backfill and grouting operations

The ERT/DTS wells were grouted in stages to avoid overloading fractures with grout. Each stage is detailed in the table below. Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a temporary tremie pipe that was retracted as the grout was pumped. The tremie pipe was kept toward the top of the grout and pulled above after each stage was completed. The distances to pull back were based on hole volume calculations.

Table 81 Stage grouting summary table TH0407

Grout lift	Base (m)	Top (m)	Comments	Number of batches pumped	Grout weights (SG)	Recipe	Lift height per 100 L mix (m)	Dip inside install to top of 24" casing
	99.513	97.07	1-2mm MGS filter sand					
	97.07	94.17	Bentonite pellets					
	94.17	89.85	Bentonite/ cement pellets					
1	89.85	76.4		2	1.70 / 1.675	First mix 7.5 bags Second mix 8 bags as still reading light after 7.5 bags more water added	6.725	
2	76.4	56.8		4	1.68 / 1.69 / 1.74 / 1.66	7.5 bags	4.9	99.5
3	56.8	50.05		1	1.68	7.5 bags	6.75	99.57
4	50.05	25.1		5	1.67 / 1.68 / 1.71 / 1.71 / 1.71	7.5 bags	4.99	
5	25.1	15.55		2	1.68/1.68	7.5 bags / 100 L 7.5 bags / 100 L	4.775	99.62
6	15.55	4.8		2.6	1.69/1.69/1.69	7.5 bags / 106 L 7.5 bags / 104 L 3.75 bags / 52 L	4.135	
7	4.8	2.1				7.5 bags		99.62
8	2.1				Topped up with bucket mix			

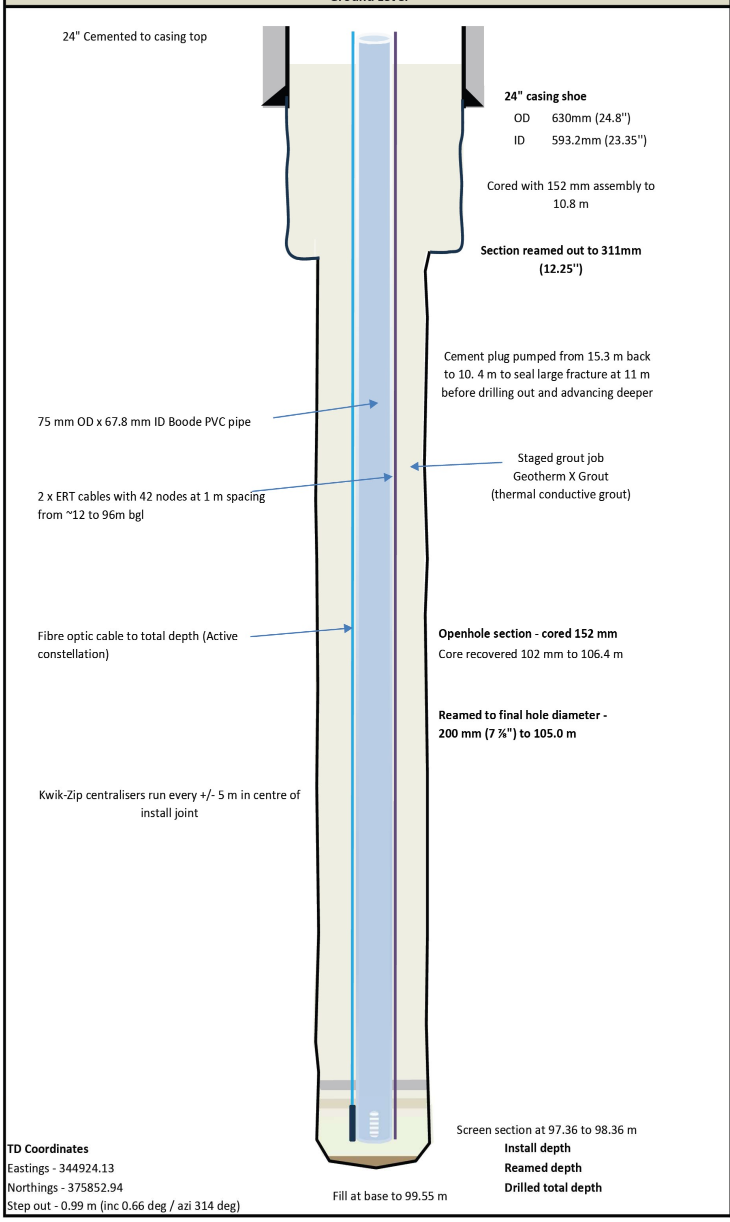
The final grout levels within the 24” surface casing were dipped and topped up to final levels during completion of the headworks.

4.17.7 TH0407 Borehole Well Schematic

Borehole coordinates:	Well Schematic TH0407	
Eastings - 344925.069 Northings - 375852.636 Top 24" depth ref - 19.962 m AOD Top 24" to GL - 0.115 m	ERT/DTS Monitoring Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Upper section logged to 19 m due to inclination concern. 16/12/22	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Lower section logged in cored 152 mm hole from 19.1 to 106.0 m. 21/12/22	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

Ground Level



All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
0.98m	Grout stage #7	0.98 to 4.80 m
	Bedrock encountered at 1.75 m	
2 m	24" surface casing	
	Grout stage #6	4.80 to 15.55 m
6.1	Open hole size remaining after 10 3/4" temp casing recovered	
	Grout stage #5	15.55 to 25.10 m
	Grout stage #4	25.10 to 50.05 m
	Grout stage #3	50.05 to 56.80 m
	Grout stage #2	56.80 to 76.40 m
	Grout stage #1	76.40 to 89.85 m
	Bentonite Cement Pellets	89.95 to 94.17 m
	Bentonite Pellets (Mikolit 300)	94.17 to 97.07 m
	1 - 2 mm MGS filter sand	97.07 to 99.51 m
99.44 m		
105.0 m	Additional metres drilled for sump - debris in well and for logging tools	
106.4 m		

Figure 94 TH0407 Well Schematic

4.17.8 Wellhead / Well Chamber Status

Figure 95 Wellhead chamber image TH0407

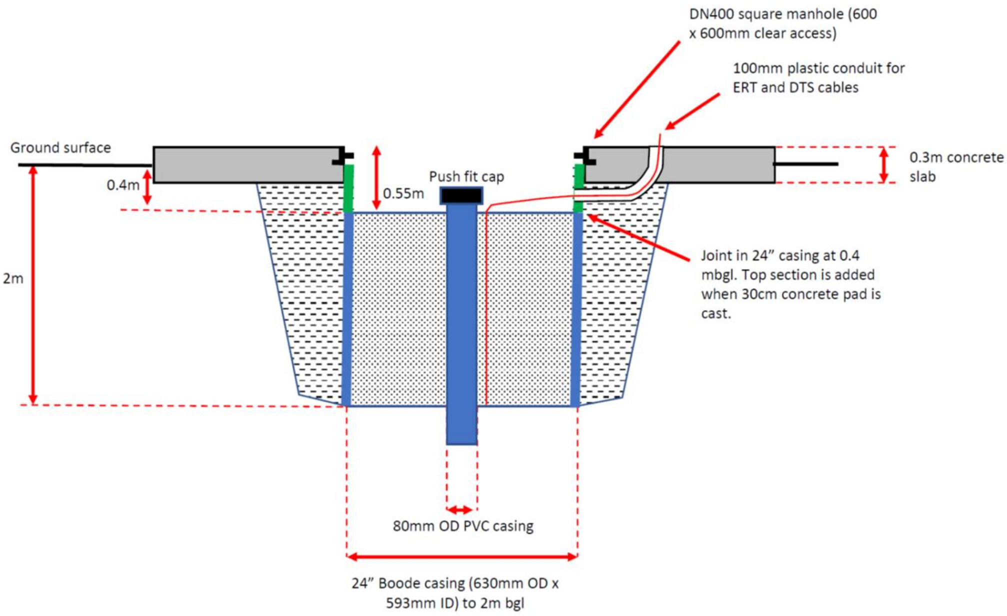


Figure 96 Wellhead chamber schematic TH0407

4.17.9 Daily Activity Summary

Table 82 Daily activity summary TH0407

Date	Depth M BGL	Operation	Parameters	Issues
29/11/22	7.0 m	Moved the Soilmec rig and setup over TH0407. Ran temporary 7” casing centralised inside the 24” surface casing to 2.1 m and sealed with Bentonite to the base. Prepared for coring operations. Made up 152 mm Geobore assembly. Cored well from 2.0 m to 7.0 m.	Verticality checks: 0.27 deg @ 4.0 m. 0.45 deg @ 7.0 m.	
02/12/22	10.8 m	Resumed coring from 7.0 m to 10.8 m. No returns. One Inclination result out of tolerance. Inclination reading: 0.98 deg at 9.0 m. The survey was repeated at 9.0 m and 0.86 deg was obtained. One more run was made and a further survey taken: 0.30 deg at 10.5 m. Rig moved off location whilst a forward plan could be made.	No returns. Verticality checks: 0.98 deg @ 9.0 m. 0.86 deg @ 9.0 m. 0.30 deg @ 10.5 m.	Well inclination out of tolerance. It is planned to resume coring and take one more run and then checking the survey again.
07/12/22	10.8 m	Relocated Soilmec rig and set up over TH0407. Made up and RIH 311 mm reaming assembly and reamed hole from 152 mm to 311 mm down to 6.1 m. Circulated the hole clean before POOH. Ran temporary 273 mm (10 ¾’’) casing to 6.1 m and centralised within the 24” surface casing. Sealed annulus at the base with Bentonite pellets. Lowered mast and moved rig off TH0407.		
08/12/22	10.8 m	Moved the Comacchio 405 into position and setup. Flushed borehole down to 10.8 m before performing a crosswire survey to ensure the temporary casing was sitting vertically before progressing / coring ahead. Made up and RIH the 152 mm Geobore assembly to TD. Operation suspended whilst surface tanks cleaned.		
09/12/22	15.3 m	Resumed coring with 152 Geobore assembly, cored to 15.3 m with 40% flush return. Experienced back flush of sand cuttings into wellbore. Stopped drilling, pulled back assembly and awaited instruction.	Verticality checks: 0.38 deg @ 13.0 m. 40% returns.	Sand entering the borehole as coring advanced. Operation stopped to try and ascertain the cause.
12/12/22	15.3 m	Ran BGS downhole camera into TH0407 to investigate sand ingress into borehole during coring. First run would not pass deeper than ~9.0 m. Attached camera to AECOM dip line to		

Date	Depth M BGL	Operation	Parameters	Issues
		add weight and top of sand layer was observed at ~14.0 m. There was no evidence of hole collapse, and the hole was in good condition. Several possible fractures were observed but it was not possible to confirm that these were the source of the sand ingress.		
13/12/22	15.3 m	On further review of the downhole camera video three main large fractures (voids) from around ~ 11.0 m with several minor fractures were identified. Rigged up grout unit and lines. RIH tremie pipe and grouted from 14.0 m from top of sand accumulation to 8.9 m (dipped depth). Wait on cement.	Summary of grout mix: 20 L of water, 25 kg of cement and 2.5 kg Bentonite. Borehole drilled to 15.3 m; sand accumulated 1.3 m thick from 15.3 m - 14.0 m.	Given the sizes of these major fractures the decision was taken to grout the base of the borehole.
14/12/22	15.8 m	Well dipped at 10.4 m. Reran the downhole camera and confirmed the major voids had been sealed with grout, although there were still minor fractures remaining at circa 9.0 m that appeared to have water flow imprints. Made up and RIH 152 mm Geobore assembly and tagged TOC at 10.4 m, drilled through to 14.8 m (sand accumulation from 14.0 m), where the drill string pulled tight. Worked string and recovered to surface. Ran BGS camera to find the cause, inconclusive. Decision taken to drill an additional core run. Ran back in hole and cored from 14.8 m to 15.8 m.	The top of the last major fracture was ~ 11.0 m and has been grouted with top grout dipping @ 10.4 m. Verticality checks: 0.53 deg @ 15.0 m.	High inclination readings indicating borehole trajectory maybe deviating from tolerance with depth. A possible cause of this deviation can be attributed to not using centralisers during the reaming of the 311 mm section. The grout cores were observed. Grout had variable setting, with some soft sections. This suggested the grout settling was not uniform before drilling. Possible cause of the stuck drill string.
15/12/22	19.4 m	Awaiting Marriott to issue BGS the drilling plan for TH0407. Marriott proposed to work the assembly, hoping to correct the verticality issues. Made up and ran back in the 152 mm assembly and worked the string between 6.1 m to 15.8 m. String worked with high RPM and slow running speed to try and rectify the inclination issue. Continued to advance the borehole from 15.8 m to 19.4 m taking numerous inclination surveys.	Verticality checks: 0.62 deg @ 17.0 m. 0.61 deg @ 17.0 m. 0.57 deg @ 17.0 m. 0.55 deg @ 17.0 m. 0.75 deg @ 18.0 m.	Borehole inclination out of tolerance.
16/12/22	31.4 m	EGS mobilised to site and commence running geophysics in the BH. Run required to confirm borehole inclination and azimuth to confirm if drilling could continue. Results from the wireline survey were acceptable so the coring assembly was picked backup and RIH. Resumed coring with 152 mm Geobore from 19.4 m to 31.4 m with no flush return. E-Totco verticality survey reading was taken at an average interval of 3.0 m.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 19.0 m. No flush returns. Verticality checks: 0.71 deg @ 21.0 m. 0.55 deg @ 23.0 m. 0.54 deg @ 26.0 m. 0.44 deg @ 30.0 m.	Relatively high E-Totco verticality readings, with decreasing values returning towards tolerance.

Date	Depth M BGL	Operation	Parameters	Issues
19/12/22	65.9 m	EGS mobilised to site again and commence running geophysics in the borehole. Run required to confirm borehole inclination and azimuth to confirm if drilling can continue. See comments in issues column. Continued coring with 152 mm Geobore assembly from 31.4 m to 65.9 m with no flush return. E-Totco verticality survey readings were taken at an average interval of 6.0 m.	Verticality checks: 0.66 deg @ 37.0 m. 0.68 deg @ 43.0 m. 0.48 deg @ 49.0 m. 0.59 deg @ 56.0 m. 0.46 deg @ 61.0 m.	BH verticality readings is still out of tolerance, measuring 0.6 deg due west of the borehole arrays. BGS agreed for drilling to proceed based a trajectory calculation that the borehole inclination would be within the range of a 1.5 m step out at depth (101.0 m).
20/12/22	106.4 m	Continued to core ahead from 65.9 m to 106.40 m with no flush return. Performed E-Totco verticality reading every 6.0 m. Circulated the hole before POOH.	Verticality checks: 0.85 deg @ 67.0 m. 0.84 deg @ 73.0 m. 0.75 deg @ 79.0 m. 0.83 deg @ 85.0 m. 0.37 deg @ 91.0 m. 0.78 deg @ 97.0 m.	High verticality reading remain.
21/12/22	106.4 m	EGS arrived, set up over TH0407 and ran a full suite of logs from TD to surface. EGS rig down and de mobilised from site. Made up and RIH a 200 mm reaming assembly, commenced opening out the hole down to 34.50 m. No flush return.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 106.0 m. Verticality log shows that the borehole has deviated of 0.8 deg due west of the arrays, with a lateral deviation of 0.98 cm.	
22/12/22	106.4 m	Resumed reaming from 34.50 m to 105.0 m. Once depth had been achieved the well was circulated for 30 minutes (hole cleaned up to 98.0 m where total losses occurred). Performed crosswire survey before POOH reaming assembly. Recovered the temporary 273 mm (10 ¾”) casing and laid out.	No flush return from 34.5 m to 60.0 m. However, 10% flush return from 60.0 m to 77.0 m, increased to 60% from 77.0 m to 98.0 m and no return from 98.0 m to TD.	Large fracture encountered at base of well.
23/12/22	106.4 m	Site shutdown from Christmas break.		
03/01/23	91.40 m	Well dipped at 91.4 m after shutdown. Prepared equipment for airlifting. Made up and ran in hole the 4” air lifting string to 64.0 m. Completed air lifts at 64.0 m and 89.6 m before POOH the assembly. Airlifted for 15 minutes at each station with waste flush diverted from the active tank to skips. Well to be dipped once any remaining fines had settled.		
TH0407 ERT/DTS install				

Date	Depth M BGL	Operation	Parameters	Issues
04/01/23	102.3 m	Well dipped at 102.3 m. Prepared for running the installation. Spotted cable spoolers and associated equipment. Commenced RIH tremie pipe (60 mm) down to 91.0 m.		
05/01/23	102.3 m	Operations focused on install in TH0409.		
06/01/23	94.17 m	Well dipped at 99.55 m higher than installation plan issued and Scope requirements. Set up the installation scaffolding tower with wooden cable reel system holding the ERT/FO cables. Held a pre-installation meeting with all parties. Commenced installation with the base (79 mm length) screwed into the plain sump and screen casing and lowered with attached cables as per the installation sheet. Completed running the deep ERT string in the well. BGS tested the functionality of the bottom ERT cable electrodes, all tested ok. Continued and completed running the installation to total depth to casing joint no. 42. Repeated the functionality test of the ERT cable and fibre optic cable, all tested ok. Base of install at 99.44 m. This was 5.7 cm higher than planned due to sediment accumulation as the install was run to the base of the well. Commenced backfilling with 1-2 mm MGS filter sand and Bentonite. Summary of backfilling: 3.5 bags of 1-2 mm filter sand = 99.51 m - 97.07 m. 2 bags of Bentonite = 97.07 m - 94.17 m.	PVC centraliser was fixed on the PVC casing at intervals of 3.0 m. Pipe tally generated before commencing with all tubing lengths known.	Installation base was planned for 100.07 m. However, a new installation plan was issued by BGS due to shallower dip, resulting in a delay in operation.
09/01/23	89.95 m	Well dipped at 94.17 m. Poured Bentonite cement pellet into well, flushing down the tremie pipe with water hose. Initial level 94.17 m. After 6.5 bags, level at 89.95 m. Tremie pipe at 88.0 m.		
13/01/23	76.4 m	Set tremie at 88.8 m and prepared for grouting operations. Mixed and pumped grout lift #1 as follows: **Mix 1:** No of bags = 7.5 Weight = 1.70 sg Start pumping = 13:55 hrs End of pumping = 13:58 hrs **Mix 2:** No of bags = 8 Weight = 1.675 sg Start pumping = 14:30 hrs End of pumping = 14:35 hrs	Stage grouting undertaken to avoid loading fractures with excessive weight. Lifts calculated based on wireline logs and known fractures bringing TOC a few metres above large fractures in each case.	The grout developed lumps, which blocked the mouth of the mixer hose, making it difficult to pump through. Also, variable high-density readings above 1.74 sg were taken. Because of this, the grout was transferred to the pump tank, diluted to 1.62 sg, and topped up with a half bag to 1.675 sg. However, the amount of water used for the dilution could not be

Date	Depth M BGL	Operation	Parameters	Issues
				accounted for but suspected to be a small volume.
16/01/23	76.4 m (expected TOC 58.0 m)	Well dipped at 76.4 m (78.0 m calculated for lift 1). Continued with stage grouting operations as follows: Lift #2 – planned top 58.0 m: **Mix 1:** No of bags = 7.5 with 100 L of water Weight = 1.68 sg **Mix 2:** No of bags = 7.5 and 100 L of water Weight = 1.69 sg **Mix 3:** No of bags = 3.75 and 50 L of water Weight = 1.74 sg **Mix 4:** No of bags = not recorded Weight = 1.67 sg Pulled back tremie. Flushed grout pump and lines and WOC.		
17/01/23	56.8 m (before grouting no dip taken after)	Well dipped at 56.8 m (58.0 m calculated for lift 2). Continued with stage grouting operations as follows: Lift #3 **Mix 1:** No of bags = not recorded Weight = 1.68 sg Start Mixing = 15:25 hrs Start pumping = 15:45 hrs End of pumping = 15:45 hrs Pulled back tremie, washed cement mixer, and equipment. WOC.		
18/01/23	50.05 m (before grouting no dip taken after)	Well dipped at 50.05 m. Continued with stage grouting operations as follows: Summary of mixes for Lift #4: **Mix 1** = 1.67 sg from 10:15hrs - 10:35 hrs. **Mix 2** = 1.68 sg from 10:35hrs - 10:45 hrs. **Mix 3** = 1.71 sg from 10:45hrs - 10:56 hrs. **Mix 4** = 1.71 sg from 10:55hrs - 11:07 hrs. **Mix 5** = 1.71 sg from 11:07hrs - 11:17 hrs. Pulled back 6 joints of tremie pipe. Flushed grout pump and lines and WOC.	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
19/01/23	25.1 m (before grouting no dip taken after)	Well dipped at 25.1 m. Continued with stage grouting operations as follows: Summary of mixes for Lift #5:		

Date	Depth M BGL	Operation	Parameters	Issues
		Mix 1 = 1.68 sg from 14:40hrs - 14:55 hrs. **Mix 2** = 1.68 sg from 14:50hrs - 15:10 hrs. Pulled back 6 joints of tremie pipe. Flushed grout pump and lines. WOC.	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
20/01/23	15.55 m	Well dipped at 15.55 m. Operations suspended waiting on instruction from Marriotts / Aecom to continue. Delay due to tremie pipe snapping and being lost in several of the ERT/DTS wells.		NPT 7.5 hours
23/01/23	15.55 m (before grouting no dip taken after)	Recovered the 60 mm tremie pipe and replaced with 40 mm pipe due to numerous failures of the 60 mm pipe. Continued with stage grouting operations as follows: Summary of mixes for Lift #6: **Mix 1**: 1.69 sg, 7.5 bags and 106 L water Flushed line and pulled back 1 joint of tremie. **Mix 2**: 1.69 sg, 7.5 bags and 104 L water Flushed line and pulled back 2 joints of tremie. **Mix 3**: part mix (0.6): 1.69 sg, 3.75 bags and 52 L water. All tremie pipe out of hole. Water level visible at ~3.0 m. Flushed grout pump and lines and WOC.		
24/01/23	4.80 m (before grouting no dip taken after)	Well dipped at 4.8 m after all 6 lifts had been pumped. Topped up grout level in well (lift #7) to back inside the 24” surface casing with the following: 1.25 mixes at 1.67 sg. 7.5 bags of geotherm X GR + 100 L of water per mix.		
25/01/23	1.94 m Final tag 0.98 m	Well dipped at 1.94 m after lift #7. Well later topped up offline and TOC tagged at 0.98 m.		
TH0407 complete				

4.18 ERT AND DTS MONITORING WELL – TH0409 SUMMARY OF OPERATIONS

4.18.1 Key Well Data

Table 83 TH0409 Key well data

Well name	TH0409		
Well classification	Electrical resistance Tomography (ERT) and Distributed Temperature Sensing (DTS) monitoring wells with deep sampling port		
Depth measurement units	Metres		
Depth reference point	Top of 24” casing		
Depth reference details	Top 24" depth ref - 19.928 m AOD Top 24" to GL - 0.108 m		
Start date	Intermediate section started on the 31/08/22 and completed on 21/11/22. Lower section started on the 22/11/22.		
End of drilling date	24/11/22.		
Install dates	Air lifted 28/11/22. Installed on 05/01/23. Staged grouted between 13/01/23 and 24/01/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24” Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 17.1 m Reamed to 6.1 m	Temporary 10 ¾” casing used (273 mm OD x 250 mm ID) recovered before completion run	6.1 m
Final section to TD Cored in 146 mm then opened out to 200 mm	Cored to 105.9 m Reamed to 101.0 m	n/a	n/a
Installation	n/a	3” Boode PVC tubing 75 mm OD 67.8 mm ID Screen section between 98.04 and 98.99 m	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344936.221, Northing Y: 375829.728		
Ordnance Survey Grid Reference	Latitude N: 53°16′36″ Longitude W: 002°49′38″		
12 Character National Grid Reference	SJ 44936 75830		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344935.63, Northing Y: 375829.44 Step out - 0.66 m (inclination 0.46 deg / azimuth 216 deg)		

4.18.2 Summary of Drilling Operations

The Soilmec rig was moved over TH0409 on the 31st August 2022 and setup. A string of 7" temporary casing was RIH and centralised inside the 24" surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 5.1 m where the operation was stopped due to E-Totco tool being too large to fit inside the Geobore pipe (first well it was deployed in). The mandrel the tool is run on was machined down to the correct size at a local machine shop. Whilst this delay occurred the string remained on bottom and became stuck. The temporary casing was recovered and the 6" wash pipe run in hole and worked down over the struck assembly and successfully recovered both strings.

The 7" temporary casing was rerun and sealed before continuing to core to 17.1 m. Losses were noted at 13.0 m. The assembly was recovered along with the temporary casing.

EGS were mobilised to site on 06th September 2022 to log the upper section of the well from 2.0 m to 16.85 m. Full details of the tools run can be found in **Section 4.18.4**. The VP and VS logs were not run as per Scope due to the water level in the borehole being at 13.4 m. These were subsequently descoped from the programme.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The Soilmec rig was mobilised back on the 21st November 2022 and a 311 mm reamer assembly was made up and RIH. The hole was opened out down to 6.1 m before circulating the hole clean and POOH. A 273 mm OD (10 ¾") temporary string of casing was RIH to 6.1 m and centralised within the 24" surface casing. The annulus was sealed with Bentonite before performing a crosswire check on the casing to confirm it had been set verticality. A 146 mm coring assembly was picked backup and washed down to 17.1 m with 40% returns. Cored 10 cm to 17.2 m and recovered 20 cm of fill and pebbles with 10 cm of solid core. Continued to core ahead to 18.7 m where a verticality survey was taken. Whilst the string was stationary the pipe became stuck. Unable to move up or down or rotate. The string was worked for over an hour and eventually it was worked free. The string was recovered and inspected before running back in hole and coring ahead to total depth at 105.9 m. The Scope required a 100.0 m hole to be drilled but a sump was drilled by Marriotts to accommodate any sediment remaining in the hole. Fluid returns were lost at 35.2 m and verticality readings were close to and over tolerance (0.5729 deg) throughout the drilling. Maximum inclination recorded was 0.66 deg at 20.0 m. The hole was circulated clean before POOH the assembly.

A 200 mm reamer assembly was made up and RIH and opened out the hole from 146 mm down to 60.0 m where the hole was circulated clean and the assembly recovered. A crosswire check was completed in two-way direction at 14 stations (same depths at E-Totco readings) as it was advanced deeper to ensure verticality and to cross check the survey tool results. Assembly recovered and the 200 mm reamer was run back in hole.

Figure 97 200 mm reamer assembly

Continued to open out the hole down to TD and 101.0 m. The well was circulated clean before POOH.

The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. The well was dipped at 97.8 m. A 4” air lifting assembly was RIH, and a three-stage air lift was completed. The depths of the stages were 50.0 m, 83.0 m and 95.0 m. The assembly was POOH and the well dipped to 100.1 m.

The following day the well dipped shallow at 99.75 m so the air lifting assembly was run back to 95.0 m and the final air lift stage repeated. The string was recovered and the well dipped at 100.6 m.

EGS were mobilised back to site on 29th November 2022 to log the lower section of the well from 16.85 m to 100.3 m. Full details of the tools run can be found in **Section 4.18.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The 273 mm temporary casing was recovered and the rig moved off the well.

Prior to running the installation, the well dipped shallow (98.4 m) so the Comacchio rig was mobilised back to TH0409 and a 2” air lifting string run. Airlifting was performed at 95.5 m and 98.0 m but the well still dipped shallow at 98.40 m with no improvement. The same air lifting programme was repeated the next day and the well dipped at 101.1 m on completion. The string was POOH and preparation commenced for the installation phase.

4.18.3 Materials, Flush and Drilling Additive Used

TH0409 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.18.4 Geophysical Logging Undertaken

Table 84 Geophysical logging summary TH0409

Wireline logging undertaken	Tools run
Upper section logged in cored 146 mm hole to 16.85 m. (06/09/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Lower section logged in reamed 200 mm hole from 16.85 to 100.3 m. (29/11/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.66 m and within the 1/100 tolerance.

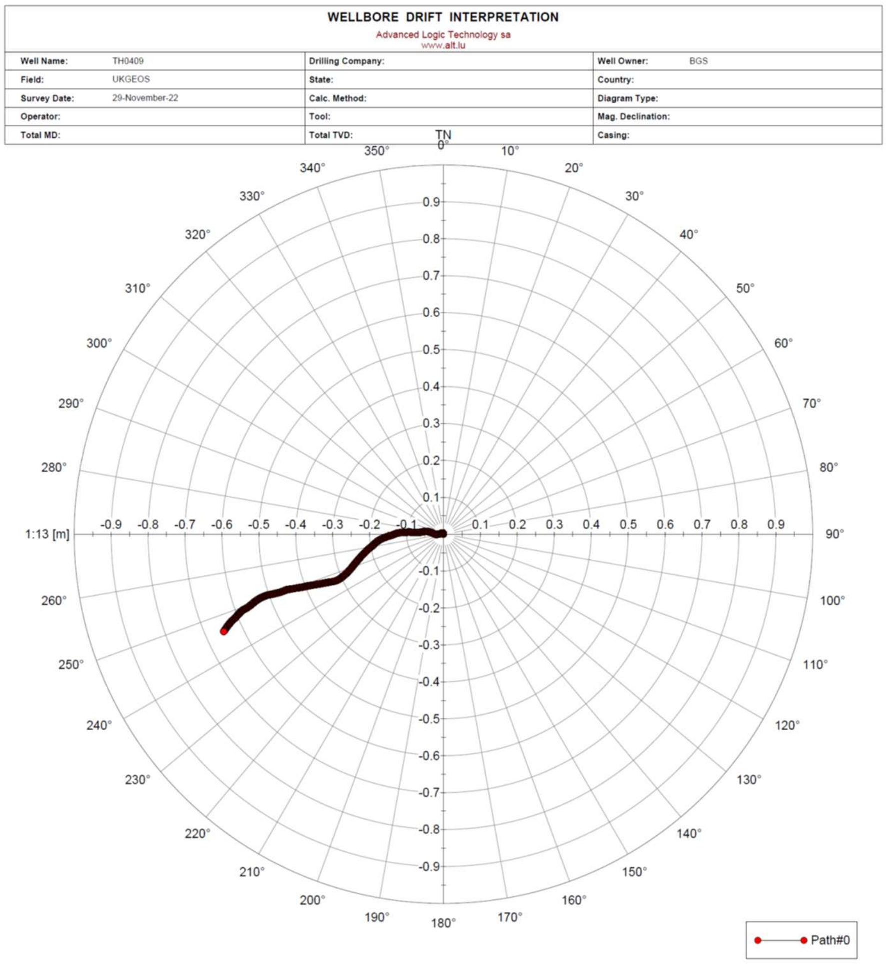


Figure 98 Verticality bullseye plot for TH0409, © European Geophysical Services Ltd

4.18.5 Summary of Installation Operations

Installation criteria for TH0409:

- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography and fibre optic cables on the outside of the tubing ensuring that ERT electrodes are at correct depths.
- Ensure the tubing run is large enough to allow a pump to be deployed in future to sample a screen section at the base of the well.
- Accurately monitor the deployment maintaining accurate records throughout.
- Backfill with grout, with uniform density to ensure consistent thermal properties as per supplier's specifications.
- Ensure the install is centralised in the borehole and maintained in tension during grouting operations.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared the installation BHA and setup the cable reel stands and equipment in preparation for running. A 60 mm retrievable tremie pipe was RIH to 100.56 m.

Held a pre-installation meeting with all parties before commencing the installation. The base (77 mm length) section was screwed into the plain sump and screen casing and lowered into the well with both the ERT and fibre optic cables attached to the outside. The assembly was RIH as per the installation sheet putting the base of the installation at 100.00 m.

The ERT cables were functions tested with a pause halfway to test the deep ERT string and again once at total depth. All electrodes tested ok.

Back filling operations then commenced. See **Section 4.18.6** for the backfill materials and grout lifts undertaken. Stage grouting was undertaken to avoid high volumes of grout being lost to fractures. Each grout lift volume was calculated based on wireline logs to identify large fractures, assumed gauged hole and grout mix yields based on cement concentration. In each case the TOC was planned to be a few metres above known large fractures. By taking this approach, it avoided having a large hydrostatic pressure generated by the grout column acting on open fractures. The risk of permanently sealing fractures across the site was very high if this approach hadn't been taken due to the know connectivity of fractures and communication between boreholes seen during the drilling phase.

After the completion of lift #3 the string pulled tight and jumped when it was pulled back. It was later confirmed that the 60 mm tremie pipe had snapped and a section from 78.0 m to 44.0 m had been lost in the well. A second 60 mm tremie was RIH between the centraliser ribs to allow the remaining grout lifts to be completed.

Following several tremie pipe failures in this and other ERT/DTS wells site operations were suspended on the 20th January 2023 to allow a forward plan to be developed. The decision was taken to remove all 60 mm pipe from the wells and quarantine and use 40 mm pipe going forward.

After each grout lift was completed the tremie pipe was pulled back above the TOC and flushed cleaned. All four ERT/DTS wells had been drilled and the installation run in advance of the grouting operations commencing to allow all four wells to be grouted in sequence. The grout unit was positioned in the centre and lines were rigged up to each well. All wells were topped up with grout to 1.0 m below ground level.

4.18.6 Backfill and grouting operations

The ERT/DTS wells were grouted in stages to avoid overloading fractures with grout. Each stage is detailed in the table below. Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a temporary tremie pipe that was retracted as the grout was pumped. The tremie pipe was kept toward the top of the grout and pulled above after each stage was completed. The distances to pull back were based on hole volume calculations. A section of 60 mm tremie pipe was lost in TH0409 and was grouted in place as it couldn't be recovered.

Table 85 Stage grouting summary table TH0409

Grout lift	Base (m)	Top (m)	Comments	Number of batches pumped	Grout weights SG	Recipe	Lift height per 100 L mix (m)	Dip inside install to top of 24" casing
	101.0	99.9	MGS filter gravel					
	99.9	96.9	1-2mm MGS filter sand					
	96.9	95.27	Bentonite pellets					
	95.27	92.36	Bentonite/ cement pellets					
1	92.36	83.4		2	1.71 / 1.71	7.5 bags	4.48	
2	83.4	79.7		1	1.67	7.5 bags	3.7	
3	79.7	56.23	Tremie parted / left in hole	5	1.68 / 1.67 / 1.73 / 1.67	7.5 bags	4.7	99.97
4	56.23	42.0	19-Jan-23	3	1.67 / 1.70 / 1.70	8.0 bags / 105 L 7.5 bags / 103 L 7.5 bags / 107 L	4.74	100.01
5	42.0	32.1	23-Jan-23	2	1.68 / 1.68	7.5 bags / 104 L 7.5 bags / 104 L	5.0	100.05
6	32.1	22.4	23-Jan-23	2	1.67 / 1.67	7.5 bags / 104 L 7.5 bags / 104 L	4.85	
7	22.4	2.35	24-Jan-23	4.5	1.67 / 1.69 / 1.68 / 1.69 / 1.69	7.5 bags / 104 L 7.5 bags / 104 L 7.5 bags / 104 L 7.5 bags / 104 L 3.75 bags / 52 L		
8	2.35				Topped up with bucket mix			100.0

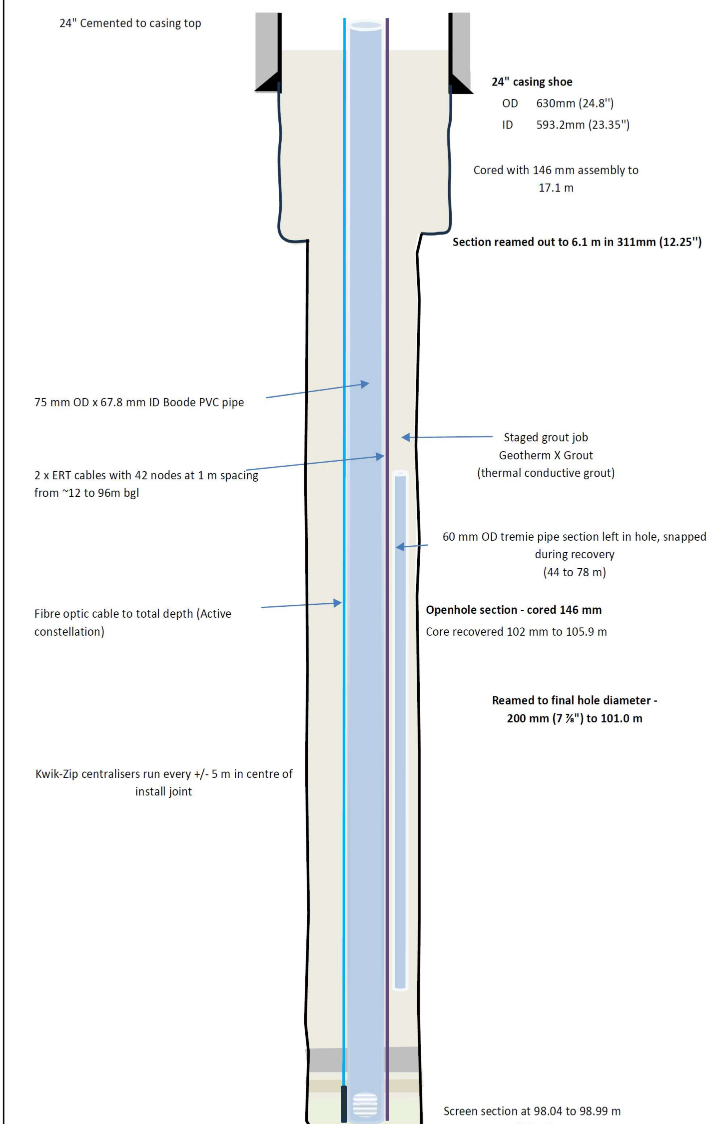
The final grout levels within the 24" surface casing were dipped and topped up to final levels during completion of the headworks.

4.18.7 TH0409 Borehole Well Schematic

Borehole coordinates	Well Schematic	
Borehole coordinates: Eastings - 344936.221 Northings - 375829.728 Top 24" depth ref - 19.928 m AOD Top 24" to GL - 0.108 m	Well Schematic TH0409 ERT/DTS Monitoring Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Upper Section logged in cored 146 mm hole to 16.85 m. 06/09/22	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Lower section logged in reamed 200 mm hole from 0 to 100.3 m. 29/11/22	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

Ground Level



TD Coordinates
Eastings - 344935.63
Northings - 375829.44
Step out - 0.66 m (inc 0.46 deg / azi 216 deg)

Depths m MD-BCT	Comments	Backfill depths
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)		
0.88m	Grout stage #8	0.88 to 2.35 m
	Bedrock encountered at 1.75 m	
2 m	24" surface casing	
	Grout stage #7	2.35 to 22.40 m
6.1 m	Open hole size remaining after 10 3/4" temp casing recovered	
	Grout stage #6	22.40 to 32.10 m
	Grout stage #5	32.10 to 42.0 m
	Grout stage #4	42.0 to 56.23 m
	Grout stage #3	56.23 to 79.70 m
	Grout stage #2	79.70 to 83.40 m
	Grout stage #1	83.40 to 92.36 m
	Bentonite Cement Pellets	92.36 to 95.27 m
	Bentonite Pellets (Mikolit 300)	95.27 to 96.90 m
	1 - 2 mm MGS filter sand	96.90 to 99.90 m
	4 - 10 mm MGS filter gravel	99.90 to 101.0 m
100.0 m		
101.0 m	Additional metres drilled for sump - debris in well and for logging tools	
105.9 m		

Figure 99 TH0409 Well Schematic

4.18.8 Wellhead / Well Chamber Status

Figure 100 Wellhead chamber image TH0409

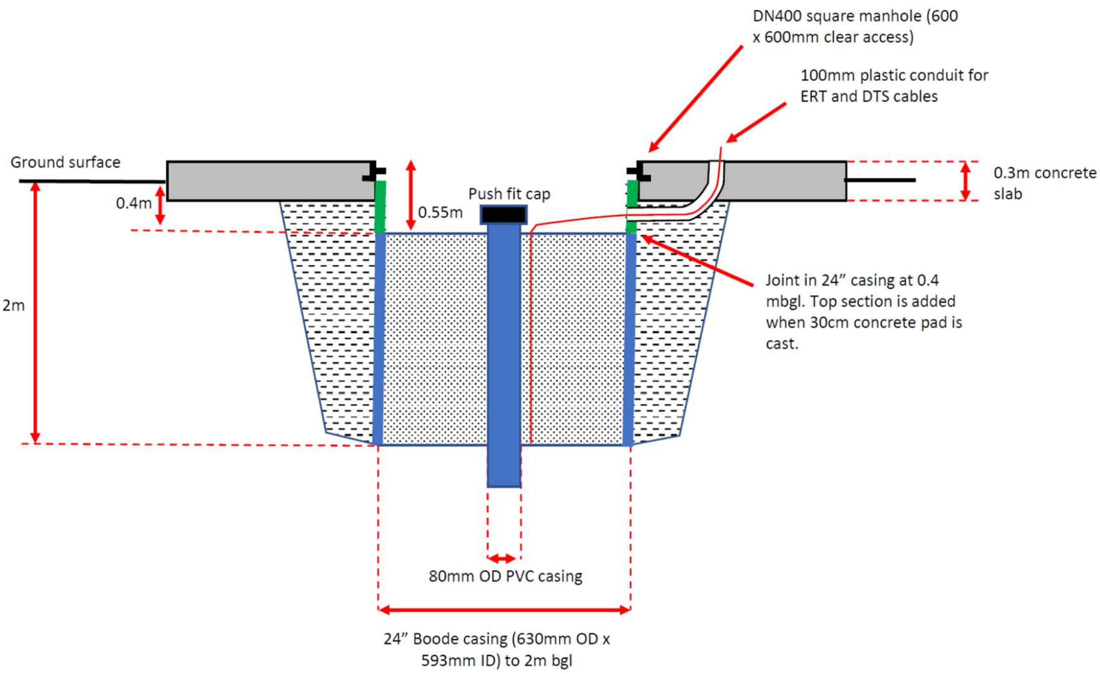


Figure 101 Wellhead chamber schematic TH0409

4.18.9 Daily Activity Summary

Table 86 Daily activity summary TH0409

Date	Depth M BGL	Operation	Parameters	Issues
31/08/22	5.1 m	Moved the rig over TH0409, levelled the ground and setup. Ran temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Made up Geobore coring assembly. Cored well from 2.0 m to 5.1 m.		
01/09/22	5.1 m	No coring undertaken due to issue with verticality tool being too large to fit inside the Geobore pipe. Tool sent off site to be machined.		Issues with E-Totco tool not fitting inside the Geobore string. Tool had to be sent offsite and machined down. Should have been checked before mobilising to site.
02/09/22	5.1 m	Geobore string stuck in hole due to it remaining in the hole and stationery whilst the E-Totco tool was machined. Recovered 7'' temporary casing from borehole. RIH with 6''washover pipe and commenced washing over the stuck Geobore string. Worked down the outside until free. Recovered both strings from the hole. Reran and sealed the temporary 7" casing. No coring undertaken.		Geobore string stuck in hole. Marriotts experienced problems with rig control unit.
05/09/22	17.1 m	RIH with Geobore coring assembly and resumed coring from 5.1 m to 17.1 m. Losses noted at 13.0 m but no further information provided – see issues column.	Verticality survey taken at 3.75 m, 6.7 m, 9.75 m and 12.75 m. Full details not provided in daily reports.	Marriott still working to fix rig's control unit. Issue resolved by 10:00 am. Losses noticed at 13.0 m, but Marriotts drilled ahead to 17.0 m without notifying all parties. This resulted in not knowing where the loss zone was and whether it will impact the intermediate shoe location.
06/09/22	17.1 m	POOH the Geobore string and the 7" temporary casing. Marriotts moved the rig off location and onto TH0413. EGS arrived, set up over TH0409 and ran full suite of logs from TD to surface. EGS rig down and de mobilised from site.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. VP and VS, as per scope, were not run due to the low water level (water level at 13.4 m and borehole depth is 17.1 m). Logged to 16.85 m.	

21/11/22	17.1 m	Relocated the Soilmec rig and set up over TH0409. Made up and RIH the 311 mm reaming assembly and opened out the hole down to 6.1 m. Circulated the hole clean before POOH. Ran temporary 273 mm OD (10 ¾'') casing to 6.1 m and centralised within the 24" surface casing using crosswire check. Sealed annulus at the base with Bentonite pellets. Made up and RIH the Geobore assembly to 8.1 m.		When reaming at 4.5 m the transfer pump failed resulting in a fitter needing to be mobilised to site. 2 hours NPT.
22/11/22	35.2 m	Resumed RIH with Geobore assembly (146 mm) and washed back down to 17.1 m with 40% flush return. Cored 10 cm to 17.2 m. POOH with core barrel and recovered approximately 20cm of soft fill and pebbles with 10 cm of solid core. Continued to core from 17.2 m to 18.7 m and recovered core before taking E-Totco survey. String stuck. Unable to move up/down or rotate assembly. Attempted to work pipe free and after approximately 1 hour the pipe came free. POOH to surface and inspected the assembly. Ran back in hole and resumed coring from 18.7 m to 35.2 m with 10% returns.	Verticality checks: 0.38 deg @ 13.0 m. 40% returns. After freeing pipe, the hole was dipped at 18.55 m (15 cm of fill). 10% returns. Verticality checks: 0.66 deg @ 20.0 m. 0.46 deg @ 23.0 m. 0.33 deg @ 26.0 m. 0.26 deg @ 32.0 m.	String stuck at 18.7 m. String worked and freed after 1 hour 10 minutes.
23/11/22	71.2 m	Continued coring with 146 mm Geobore assembly from 35.2 m to 71.2 m with no flush return. Performed E-Totco survey every core run instead of every 6.0 m due to the higher values. Cores were curated into 1.0 m and 0.5 m sections by Marriott with fluid samples collected every 6.0 m as defined in scope.	Verticality checks: 0.64 deg @ 38.0 m. 0.38 deg @ 39.0 m. 0.58 deg @ 41.0 m. 0.53 deg @ 42.0 m. 0.58 deg @ 44.0 m. 0.61 deg @ 47.0 m. 0.26 deg @ 53.0 m. 0.51 deg @ 56.0 m. 0.57 deg @ 59.0 m. 0.54 deg @ 65.0 m.	E-Totco survey values are quite high, exceeding tolerance (0.5729 deg) in most instances.
24/11/22	105.9 m	Continued to core ahead from 71.2 m to 105.9 m with no flush return. Circulated the hole before POOH. Made up and RIH a 200 mm reaming assembly, commenced opening out the hole from 146 mm down to 18.5 m. No flush return.	ROP – 5 minutes per 1.5 m core run. No returns. Verticality checks: 0.58 deg @ 71.0 m. 0.31 deg @ 74.0 m. 0.38 deg @ 77.0 m. 0.26 deg @ 83.0 m. 0.22 deg @ 89.0 m. 0.56 deg @ 95.0 m. 0.66 deg @ 101.0 m. The additional ~ 4.0 m drilled was for the sump to accommodate any cuttings that remained in the well.	Verticality reading towards the base of the well above tolerance.

25/11/22	105.9 m	Resumed reaming operations from 18.5 m to 60.0 m before circulating the hole and POOH. Commenced crosswire measurement in two-way direction from 7.0 m to reamed depth of 60.0 m and back to surface. 14 stations taken. Ran back in hole 200 mm reamer and opened out the hole from 60.0 m to TD at 101.0 m. The well was circulated before POOH reaming assembly.	Crosswire measurements were taken at the same depth as E-Totco survey tool to compare results.	
28/11/22	100.1 m	Rig up tanks, hoses and rack airlift pipes in preparation for RIH with airlift assembly. Dipped well at 97.8 m. RIH with airlift pipe on winch to 50.0 m. Attached airline to the elbow fitting. Taped airline to the airlift pipe and continue RIH. RIH by hand the data logger to 45.0 m and secured. Completed air lifts at 50.0 m. RIH to 83.0 m At 83.0 m after connecting another length of airlift pipe, the lifting sub pulled out of the box connection, causing the airlift string to fall approximately 17.0 m to the bottom of the hole. The string stuck in the sediment at the bottom of the hole. Additional lengths of airlift pipe were run and successfully re-engage the dropped pipe which was then worked free using the winch. The alkathene pipe also stretched and parted when the airlift pipe dropped. POOH to 50.0 m and repaired. Ran back into 95.0 m and completed additional air lift (total of 16,000 L of formation water drawn from the well in 3 airlifts). Well dipped at 100.1 m.	Airlifting is being trialled in this well to gauge effectiveness of the technique for cleaning up the wells. Compressed air is introduced to the inside of the airlift string using alkathene pipe which is run in hole attached to the airlift pipe. The air reduces the hydrostatic pressure inside the airlift string, causing formation fluid, cuttings and sediment to be drawn up inside the pipe due to the pressure differential. The returns exit the pipe at surface where a large diameter hose routes the flow from the wellhead to a collecting tank.	Air lift string dropped at 83.0 m and had to be fished. The lifting sub was checked, and the threads were OK – the conclusion is that the fault was with the box coupling of the airlift pipe which was then removed from service.
29/11/22	100.6 m	Well dipped at 99.75 m. Ran back to 95.0 m with air lifting string and performed additional lift at this depth. POOH assembly. Well dipped at 100.6 m. EGS arrived, set up over TH0409 and ran full suite of logs from TD to surface. EGS rig down and de mobilised from site. Ran crosswire check before recovering the 273 mm OD (10 ¾”) casing. Rig moved to TH0413.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 100.3 m.	
03/01/23	98.4 m	Well dipped at 98.4 m. Comacchio previously set up on TH0409, commenced RIH with 2” air lifting assembly.		No significant increase in depth was recorded despite airlifting from two different depths.

		Commenced airlifting with string at 95.5 m and subsequently lowered to 98.0 m, for 30 minutes at each station. Well dipped at 98.40 m, no improvement.		
TH0409 ERT/DTS install				
04/01/23	101.1 m	Repeated air lifts as above. Well dipped at 101.1 m. Prepared for running the installation. Spotted cable spoolers and associated equipment. Commenced RIH tremie pipe (60 mm) down to 91.0 m.		
05/01/23	101.1 m	Well dipped at 101.1 m. Lowered tremie pipe from ~ 91.0 m to 100.56 m. Set up the installation scaffolding tower with wooden cable reel system holding the ERT/FO cables. Held a pre-installation meeting with all parties. Commenced installation with the base (77 mm length) screwed into the plain sump and screen casing and lowered with attached cables as per the installation sheet. Completed running the deep ERT string in the well. BGS tested the functionality of the bottom ERT cable set of electrodes, all tested ok. Continued and completed running the installation to total depth to casing joint no. 42. Repeated the functionality test of the ERT cable, all tested ok. Base of install at 100.0 m.	PVC centraliser was fixed on the PVC casing at intervals of 3.0 m. Pipe tally generated before commencing will all tubing lengths known. However, it should be noted that during testing, some electrodes tested negative, indicating they were above the water level (~ 14.6 m).	
06/01/23	92.36 m	Commenced backfilling with MGS filter gravel. Summary of backfilling: 2 bags of filter gravel = 101.0 m - 99.9 m. 5 bags of 1-2mm filter sand = 99.9 m - 96.9 m. 2 bags of Bentonite = 96.9 m – 95.27 m. 3 bags of Bentonite cement = 95.27 m - 92.36 m.	All backfills were within tolerance (0.15m) as defined in scope.	Tremie pipe blocking during back fill process. Flushing down the Tremie pipe with water removed.
11/01/23	92.36 m	Set tremie above backfill and prepared for grouting operations. Mixed first lift (8.5 bags of Geotherm X GR with 100 L of water) was mixed in the mixer and weighed at 1.795 sg. Added 25 L to dilute Mix and reweighed at 1.69 sg. Viscosity funnel flow test = 103 seconds Mix deemed too thick by BGS to pump so dumped. Risk to great of getting tremie pipe plugged.		Mix 1 failed the viscosity funnel test as it was difficult to flow through, and therefore unpumpable. The label on each bag of the geotherm x GR state 25 kg instead of 24 kg required in the scope. Consequently, BGS refused to pump the grout into the Borehole until issue investigated and was dumped into an IBC container.
12/01/23	92.36 m (before grouting no dip taken after)	Top of Bentonite cement at 92.36 m. Measured and confirmed the weight of each bag of grout (Geotherm-X GR) as 24.75 kg. Also measured and confirmed the capacity of the cement mixer hopper to contain 99 L of water.	Stage grouting undertaken to avoid loading fractures with excessive weight. Lifts calculated based on wireline logs and known	

		Mixed grout cement (2 mixes were done), measured viscosity and density, and pumped lift 1. Summary of grout cement pumped (Lift 1) **Mix 1:** Weight = 1.71 sg Viscosity test = 103 seconds Start pumping = 12.30 hrs End of pumping = 12.35 hrs **Mix 2:** Weight = 1.72 sg Viscosity test = 84 seconds Start pumping = 12.47 hrs End of pumping = 12.50 hrs Pulled back tremie and flushed through.	fractures bringing TOC a few metres above large fractures in each case. Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
13/01/23	83.4 m (before grouting no dip taken after)	Well dipped at 83.4 m. Continued with stage grouting operations as follows: Set tremie at 82.64 m, Summary of grout pumped (Lift 2): **Mixes = 1** Weight = 1.67 sg Start pumping = 11.00 hrs End of pumping = 11.02 hrs Pulled back tremie. Flushed grout pump and lines and WOC.	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
16/01/23	79.7 m (before grouting no dip taken after)	Well dipped at 79.7 m (vs 81.0 m as calculated from lift 2). Continued with stage grouting operations as follows: Positioned tremie pipe at 78.7 m. Summary of grout pumped (Lift #3): **Mix 1:** No of bags = 7.5 with 100 L of water Weight = 1.55 sg Adjusted recipe for 10 bags of grout and 150 L of water, giving final weight of 1.68 sg. Unable to pump slurry, pump stalling. Succeeded to pump first mix 1 of lift 3. **Mix 2:** No of bags = 7.5 with 100 L of water Weight = 1.67 sg **Mix 3:** No of bags = 7.5 with 100 L of water Weight = 1.73 sg Mixing hopper plugged with cement when mixing batch #4, worked to unblock the system. Diluted cement in hopper with water and adjusted mix 4 grout slurry as follows: **Mix 4:** No of bags = 11.5 with 150 L of water		Note: the plan for lift 2 was for 5 batches but due to some mixing issues, 2 of the batches were 50% larger than planned – therefore a total of 4 batches were pumped, the equivalent volume of 5 standard batches. Mixing hopper plugged.

		Weight = 1.67 sg POOH 13 lengths of 2.5 m tremie pipe and secured with a clamp. Flushed through, washed cement mixer, and equipment. WOC.		Tremie pipe jumped and pulled tight during recovery.
19/01/23	56.23 m (before grouting no dip taken after)	Well dipped at 56.23 m. Tremie pipe confirmed to have parted and has been left in the hole. POOH remaining 60 mm tremie pipe. Run tremie back in through another segment between the centraliser ribs, tremie at 55.0 m, top of grout at 56.25 m. Continued with stage grouting operations as follows: Summary of grout pumped (Lift #4): **Mix 1** = 1.67 sg from 08:50 hrs - 09:22 hrs **Mix 2** = 1.70 sg from 09:22 hrs - 09:40 hrs **Mix 3** = 1.70 sg from 09:40 hrs - 09:51 hrs Pulled tremie back to 31.56 m. Flushed through string and cleaned grout pump and lines. WOC.	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	RIH tremie between the centraliser rib was aimed to prevent stuck issues during and post-grouting operation. Lost section of 60 mm tremie pipe from 44.0 m to 78.0 m.
20/01/23	42.0 m (before grouting no dip taken after)	Well dipped at 42.0 m. Operations suspended waiting on instruction from Marriotts / Aecom to continue. Delay due to tremie pipe snapping and being lost in several of the ERT/DTS wells.		
23/01/23	42.0 m (before grouting no dip taken after)	Well dipped at 42.0 m. Picked up new 40 mm pipe due to numerous failures of the 60 mm pipe and RIH. Continued with stage grouting operations as follows: Summary of grout pumped (Lift #5): **Mix 1**: 1.68 sg, 7.5 bags and 104 L of water Pulled back 2 joints of tremie. **Mix 2**: 1.68 sg, 7.5 bags and 104 L of water Flushed line and pulled back 2 joints of tremie. WOC. Summary of grout pumped (Lift #6): Mixed and pumped 2 batches of grout to cover interval ~32.0 m to 22.0 m. limited information reported. Pulled back 6 joints of tremie pipe. Flushed grout pump and lines and WOC.		
24/01/23	5.7 m (before final grout dip taken)	Continued with stage grouting operations as follows: Summary of grout pumped (Lift #7): **Mix 1:** 1.67 sg, 7.5 bags, 104 L pumped at 10:57 hrs. Pulled back 2 joints. **Mix 2:** 1.69 sg. 7.5 bags, 104 L pumped at 11:15 hrs, Pulled back 2 joints. **Mix 3:** 1.68 sg. 7.5 bags, 104 L pumped at 11:22 hrs, Pulled back 1 joint		

		Mix 4: 1.69 sg, 7.5 bags, 104 L pumped at 11:32 hrs, Pulled back 1 joint **Mix 4.5:** 1.69 sg, 3.75 bags, 52 L pumped at 11:38 hrs. All tremie pipe sections recovered out of hole. Water level visible at ~3.0 m. Flushed grout pump and lines and WOC. Dipped TOC at 5.7 m. Topped up grout level in well with an additional 1.5 mixes (7.5 bags of geotherm X GR + 100 L of water per mix.) to bring back inside the 24” surface casing.		
25/01/23	1.94 m Final tag 0.88 m	Well dipped at 2.35 m after lift #7. Well later topped up offline and TOC tagged at 0.88 m.		
TH0409 complete				

4.19 ERT AND DTS MONITORING WELL – TH0411 SUMMARY OF OPERATIONS

4.19.1 Key Well Data

Table 87 TH0411 Key well data

Well name	TH0411		
Well classification	Electrical resistance Tomography (ERT) and Distributed Temperature Sensing (DTS) monitoring wells with deep sampling port		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.547 m AOD Top 24" to GL - 0.023 m		
Start date	Intermediate section started on the 08/12/22 and completed on 08/12/22. Lower section started on the 08/12/22.		
End of drilling date	15/12/22.		
Install dates	Air lifted 20/12/22. Installed on 09/01/23. Staged grouted between 12/01/23 and 24/01/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 7.0 m Reamed to 6.1 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.1 m
Final section to TD Cored in 146 mm then opened out to 200 mm	Cored to 105.7 m Reamed to 105.0 m	n/a	n/a
Installation	n/a	3" Boode PVC tubing 75 mm OD 67.8 mm ID Screen section between 98.03 and 98.98 m	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344947.946 Northing Y: 375863.772	
Ordnance Survey Grid Reference		Latitude N: 53°16′37″ Longitude W: 002°49′37″	
12 Character National Grid Reference		SJ 44948 75864	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344947.69 Northing Y: 375864.38 Step out - 0.66 m (inclination 0.49 deg / azimuth 347 deg)	

4.19.2 Summary of Drilling Operations

The rig was moved over TH0411 on the 08th December 2022 and setup. A string of 7" temporary casing was RIH and centralised inside the 24" surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 7.0 m with good returns (70%). The assembly was POOH and the 7" temporary casing recovered.

Made up and RIH a 311 mm reamer assembly. The hole was opened out down to 6.1 m before circulating the hole clean and POOH. A 273 mm (10 ¾") temporary string of casing was RIH to 6.1 m and centralised within the 24" casing. The base was sealed with Bentonite. The 146 mm coring assembly was picked backup and cored from 7.0 m to total depth at 105.7 m. The Scope required a 100.0 m hole to be drilled but a sump was drilled by Marriotts to accommodate any sediment remaining in the hole. Verticality readings were found to be out of tolerance (0.5729 deg) from around 60.0 m so the ROP and WOB were reduced to try and improve and E-Totco surveys were increased to every 6.0 m to monitor the situation. Maximum recorded deviation was 0.76 deg at 101.0 m. The hole was circulated clean before POOH the assembly.

EGS were mobilised to site on 14th December 2022 to log the well, predominantly in the cored hole from 2.0 m to 105.7 m. Full details of the tools run can be found in **Section 4.19.4**.

Figure 102 EGS wireline rigged up over TH0411

Once logging operations had been completed, EGS were rigged down off the well and demobilised from site.

A 200 mm reamer assembly was made up and RIH and opened out the hole from 146 mm down to TD at 105.0 m with no flush returns. A crosswire verticality survey was undertaken before circulating the hole and POOH and recovering the 273 mm casing. Borehole dipped at 104.55 m.

The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. A 2" air lifting assembly was RIH, and a three-stage air lift was completed. The depths of each stage were 50.0 m, 75.0 m and 95.0 m. The assembly was POOH and the well dipped to 100.25 m.

4.19.3 Materials, Flush and Drilling Additive Used

TH0411 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.19.4 Geophysical Logging Undertaken

Table 88 Geophysical logging summary TH0411

Wireline logging undertaken	Tools run
Well logged after temp casing recovered in cored 146 mm hole to from 2.0 m to 105.7 m. (14/12/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.66 m and within the 1/100 tolerance.

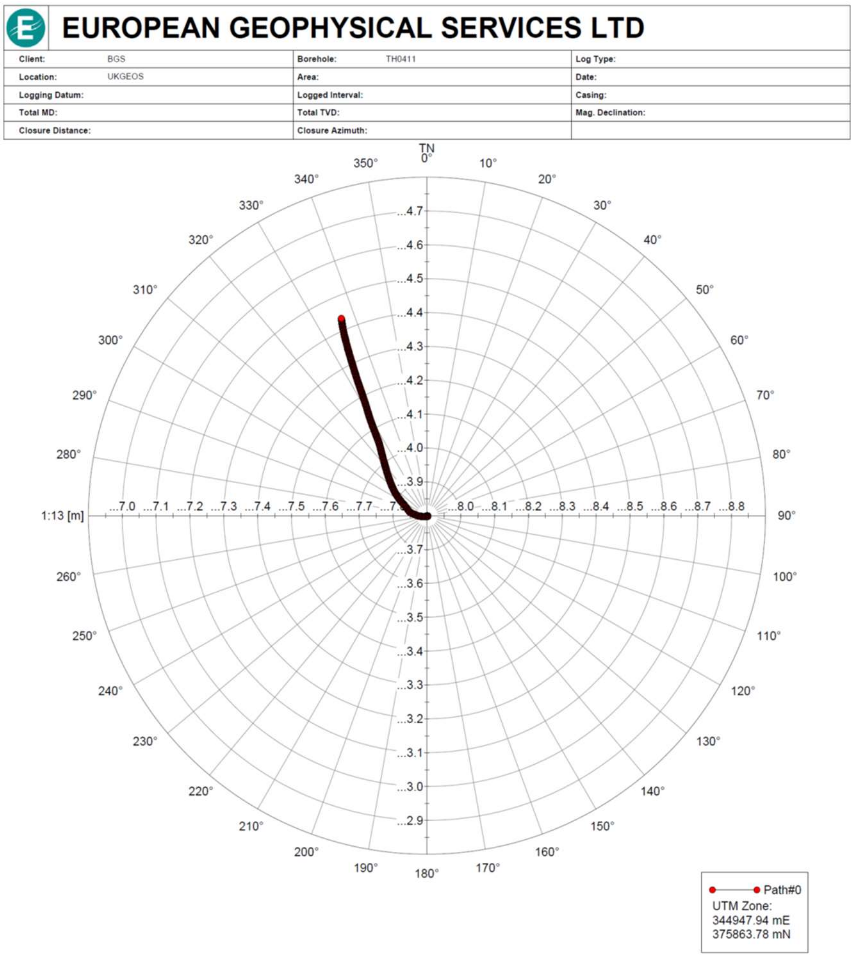


Figure 103 Verticality bullseye plot for TH0411, © European Geophysical Services Ltd

4.19.5 Summary of Installation Operations

Installation criteria for TH0411:

- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography and fibre optic cables on the outside of the tubing ensuring that ERT electrodes are at correct depths.
- Ensure the tubing run is large enough to allow a pump to be deployed in future to sample a screen section at the base of the well.
- Accurately monitor the deployment maintaining accurate records throughout.
- Backfill with grout, with uniform density to ensure consistent thermal properties as per supplier's specifications.
- Ensure the install is centralised in the borehole and maintained in tension during grouting operations.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared the installation BHA and setup the cable reel stands and equipment in preparation for running. A 60 mm retrievable tremie pipe was RIH 97.18 m.

Figure 104 TH0411 installation setup

Held a pre-installation meeting with all parties before commencing. Made up the ERT BHA with the base plug, screen section and first full joint of 75 mm OD pipe and lowered into the well with both the ERT and fibre optic cables attached to the outside. The assembly was RIH as per the installation sheet putting the base of the installation at 100.0 m and securing on surface.

The two ERT cables were functions tested with a pause halfway to test the deep ERT string and once total depth had been reached for the shallow string. All electrodes tested ok.

Back filling operations then commenced. See **Section 4.19.6** for the backfill materials and grout lifts undertaken. During the deployment of the filter sand and Bentonite pellets for the lower section the tremie pipe became plugged on more than one occasion. This blockage was removed by running a 30 mm pipe through the centre and constantly introducing water from surface. Stage grouting was undertaken to avoid high volumes of grout being lost to fractures. Each grout lift volume was calculated based on wireline logs to identify large fractures, assumed gauged hole and grout mix yields based on cement concentration. In each case the TOC was planned to be a few metres above the known large fractures. By taking this approach, it avoided having a large hydrostatic pressure generated by the grout column acting on open fractures. The risk of permanently sealing fractures across the site was very high if this approach wasn't taken due to the known connectivity of fractures and communication between boreholes seen during the drilling phase.

After the completion of lift #3 the string pulled tight and parted, 41.0 m of 60 mm tremie pipe was lost in hole from 30.0 m to 71.0 m. A second shorter section of 60 mm tremie was also lost when the swivel used to pull each section broke, a sling was attached but the tremie had become stuck and 7 joints were lost from 7.5 m to 25.0 m. All sections of tremie pipe are fully cement in the well.

Figure 105 left had image is of a snapped pin connection of 60 mm tremie pipe, right hand image shows the pin end shearing off completely as a clean break

Following numerous tremie pipe failures in this and other ERT/DTS wells the site operations were suspended on the 20th January 2023 to allow a forward plan to be developed. The decision was taken to remove all 60 mm pipe from the wells, quarantine onsite and use 40 mm pipe going forward.

After each grout lift was completed the tremie pipe was pulled back above the TOC and flushed cleaned. All four ERT/DTS wells had been drilled and the installation run in advance of the grouting operations commencing to allow all four wells to be grouted in sequence. The grout unit was positioned in the centre and lines were rigged up to each well.

Grouting operations on TH0411 were completed on the 24th January 2023 with a TOC at 2.10 m. The well was later topped up to 0.86 m below ground level offline.

4.19.6 Backfill and grouting operations

The ERT/DTS wells were grouted in stages to avoid overloading fractures with grout. Each stage is detailed in the table below. Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a temporary tremie pipe that was retracted as the grout was pumped. The tremie pipe was kept toward the top of the grout and pulled above after each stage was completed. The distances to pull back were based on hole volume calculations. Two sections of tremie pipe were lost and grouted in place as they couldn't be recovered. The final grout levels within the 24" surface casing were dipped and topped up to final levels during completion of the headworks.

Table 89 Stage grouting summary table TH0411

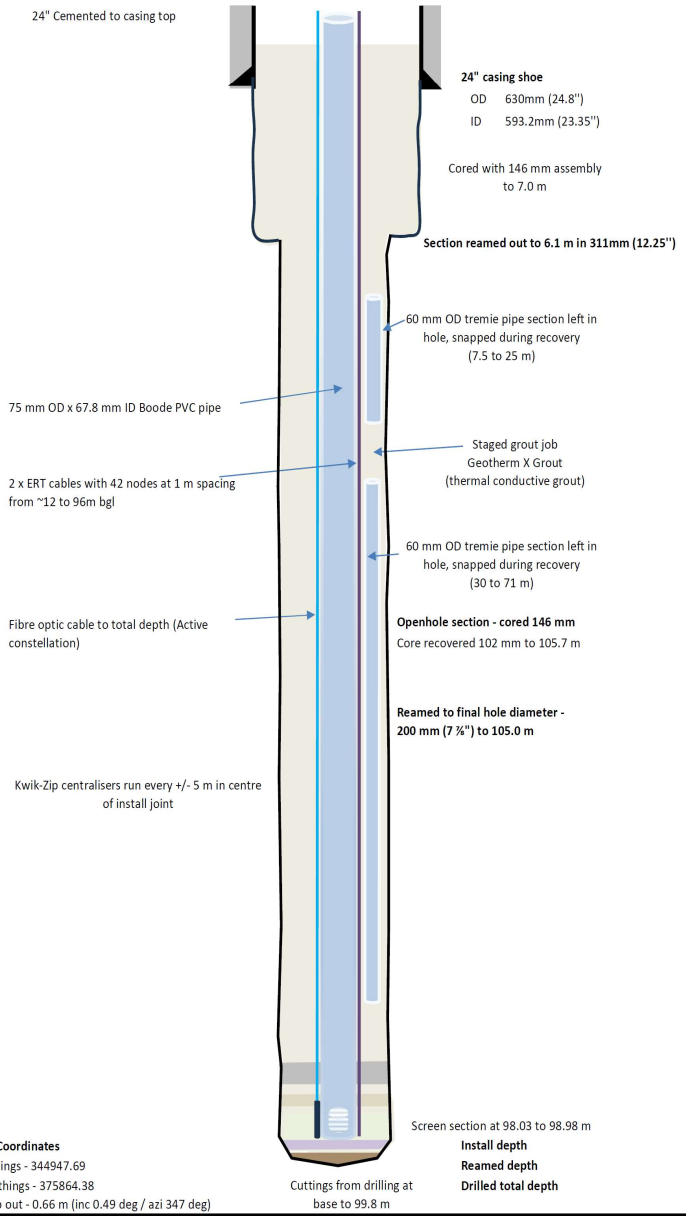
Grout lift	Base (m)	Top (m)	Comments	Number of batches pumped	Grout weights SG	Recipe	Lift height per 100 L mix (m)	Dip inside install to top of 24" casing
	99.8	99.45	MGS filter gravel					
	99.45	97.1	1-2mm MGS filter sand					
	97.1	95.3	Bentonite pellets					
	95.3	92.85	Bentonite/ cement pellets					
1	92.85	77.6		3.3	1.69 / 1.74 / 1.70 / 1.67	7.5 bags	4.62	
2	77.6	71.4		1	1.67	7.5 bags	6.20	
3	71.4	52.2	Tremie parted / left in hole	4	1.74 / 1.69 / 1.71 / 1.70	7.5 bags	4.80	100.05
4	52.2	42.2		3	1.67 / 1.70 / 1.71	7.5 bags	3.33	100.03
5	42.2	13.3	Tremie parted / left in hole	5	1.67 / 1.67 / 1.70 / 1.67 / 1.70	7.5 bags / 105 L for all batches	5.45	99.98
6	13.3	3.6		2.2	1.69 / 1.69	7.5 bags / 104 L for both batches	4.08	
7	3.6	2.1				7.5 bags		99.97
8	2.1				Topped up with bucket mix			

4.19.7 TH0411 Borehole Well Schematic

Borehole coordinates: **Eastings - 344947.946** **Northings - 375863.772** **Top 24" depth ref - 20.547 m AOD** **Top 24" to GL - 0.023 m**	Well Schematic TH0411 ERT/DTS Monitoring Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Well logged after temp casing recovered in cored 146 mm hole to from 2 to 105.7 m. 14/12/22	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

Ground Level



TD Coordinates
Eastings - 344947.69
Northings - 375864.38
Step out - 0.66 m (inc 0.49 deg / azi 347 deg)

Depths m MD-BCT	Comments	Backfill depths
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)		
0.86m	Grout stage #8	0.86 to 2.10 m
	Bedrock encountered at 1.75 m	
2 m	24" surface casing	
	Grout stage #7	2.10 to 3.60 m
	Grout stage #6	3.60 to 13.30 m
6.1 m	Open hole size remaining after 10 3/4" temp casing recovered	
	Grout stage #5	13.30 to 42.20 m
	Grout stage #4	42.20 to 52.20 m
	Grout stage #3	52.20 to 77.40 m
	Grout stage #2	71.40 to 77.60 m
	Grout stage #1	77.60 to 92.85 m
	Bentonite Cement Pellets	92.85 to 95.30 m
	Bentonite Pellets (Mikolit 300)	95.30 to 97.10 m
	1 - 2 mm MGS filter sand	97.10 to 99.45 m
	4 - 10 mm MGS filter gravel	99.45 to 99.80 m
100.0 m		
105.0 m	Additional metres drilled for sump - debris in well and for logging tools	
105.7 m		

Figure 106 TH0411 Well Schematic

4.19.8 Wellhead / Well Chamber Status

Figure 107 Wellhead chamber image TH0411

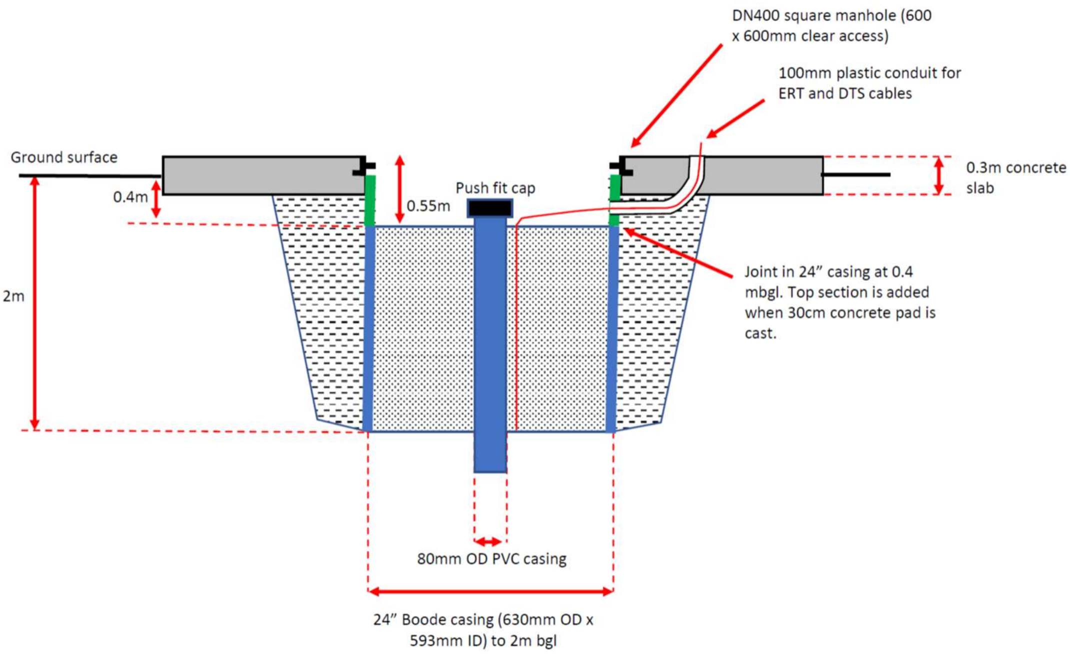


Figure 108 Wellhead chamber schematic TH0411

4.19.9 Daily Activity Summary

Table 90 Daily activity summary TH0411

Date	Depth M BGL	Operation	Parameters	Issues
08/12/22	26.21 m	Moved the rig over TH0411, levelled the ground and setup. Ran temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Made up 146 mm Geobore coring assembly. Cored well from 2.0 m to 7.0 m with an average of 70% flush returns. Flushed hole and POOH 146mm Geobore and 7" temporary casing. Made up and RIH 311 mm (12 ¼") reaming assembly, reamed hole from 2.0 m to 6.1 m. POOH reamer and laid down. Installed 273 mm (10 ¾'' OD) casing to 6.1 m and sealed with Bentonite pellets. RIH with 146 mm Geobore and cored from 7.0 m to 26.21 m.	Flush return was consistently stable with an average flush return of 70% until 23.2 m, reduced to 60% from 23.3 m to 24.2 m, and further reduced to 40% from 24.7 m to 26.2 m.	Soilmec rig developed hydraulic leakage from filter, Marriott's engineer worked to fix it from 12:40 hrs to 13:30 hrs.
09/12/22	50.2 m	Continued coring with 146 mm Geobore assembly from 26.21 m to 29.2 m with no flush return. Rig break down – see issues column. Continued coring from 29.2 m to 50.2 m. All core and fluid samples were retained as per scope.	Verticality checks: 0.30 deg @ 29.0 m. 0.36 deg @ 35.0 m. 0.50 deg @ 41.0 m. 0.28 deg @ 47.0 m.	Soilmec rig was paused from drilling for almost 4 hours (09.30-14:30 hrs) due to hydraulic leakage.
12/12/22	78.7 m	Continued to core ahead from 50.2 m to 78.7 m with no flush return. Observed that the 146 mm Geobore bit was blocked with the outer barrel worn out. POOH Geobore and changed the bit.	No returns. Verticality checks: 0.53 deg @ 53.0 m. 0.61 & 0.65 deg @ 64.0 m. 0.20 deg @ 68.0 m. 0.72 & 0.65 deg @ 77.0 m.	Inclination was observed to be out of tolerance, over 0.57 deg at 64.0 m and it was discussed to reduce ROP and increase the survey interval to closely monitor the trend.
13/12/22	105.7 m	Replaced worn out section of the outer core barrel, RIH Geobore (146 mm), and resumed coring from 78.7 m to 105.7 m. E-Totco verticality surveys taken every 6.0 m. No flush return. Once TD reached circulated the hole before POOH.	No returns. Verticality checks: 0.56 deg @ 81.0 m. 0.35 deg @ 86.0 m. 0.71 deg @ 92.0 m. 0.69 deg @ 98.0 m. 0.76 deg @ 101.0 m.	E-Totco reading outside tolerance of 0.5729 deg.
14/12/22	105.7 m	EGS arrived, set up over TH0411 and ran a full suite of logs from TD to surface. EGS rig down and de mobilised from site.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 105.7 m.	

		Made up and RIH a 200 mm reaming assembly and opened out the hole from 146 mm down to 105.0 m. No flush return.		
15/12/22	104.55 m	Performed crosswire verticality survey in borehole. POOH reaming assembly and recovered 273 mm (10 ¾") temporary casing. Borehole dipped at 104.55 m.		
20/12/22	104.55 m	Set up Comacchio rig on TH0411, connected and positioned the 2" air lifting pipe at 50.0 m, performed air lifting with flush return diverted to the 5,600 L capacity waste tank. Lowered the assembly to performed two additional lifts at 75.0 m and 95.0 m before POOH airpipe. No record of the well being dipped after final air lift stage.	At 50.0 m, there was no significant accumulation of cutting recorded in the waste tank. At 75.0 m, some cutting recorded in waste tank. At 95.0 m, ~ 4 cm of cuttings were recorded.	
23/12/22	100.25 m	Well dipped at 100.25 m.		
TH0411 ERT/DTS install				
09/01/23	100.1 m	Well dipped at 100.1 m. RIH tremie pipe (60 mm) down to 97.18 m. BGS ERT and Silixa personnel arrived. Set up cable reels and stands. Made up ERT BHA with base plug and screen section with first full length joint above. Installed centralisers. Tested deep ERT cable continuity. All tested ok. RIH completion string as per tally to 53.44 m. Tested shallow ERT cable (good test) before running the completion to depth (100.0 m). Secured at surface with clamp.	PVC centraliser was fixed on the PVC casing at intervals of 3.0 m. Pipe tally generated before commencing will all tubing lengths known.	
10/01/23	97.10 m	Well dipped at 99.8 m. Commenced backfilling. Summary of backfilling: ½ bag of filter gravel = 99.45 m 3 ⅔ bags of 1-2mm filter sand = 97.1 m 1 bag of Bentonite. Operation stopped @ 17:30 hrs.	Confirmed hang off depth of the completion to be 0.418m below the top of the 24'' Boode surface casing.	Bentonite blocked the tremie at 39.0 m. RIH a 30 mm tremie through the 60 mm tremie, working up and down with water head to clear blockage. Although they manage to clear Bentonite smearing was observed along the 60 mm tremie from 39.0 m to depth. Risk: remnants of Bentonite smearing could result in future blockages. Tremie to be cleaned fully before being re-run in another well.
11/01/23	92.85 m	Resumed backfilling operations. Summary of backfilling: ⅕ bag of Bentonite pellets = 95.3 m 4 bags of Bentonite cement = 92.85 m	All backfills were within tolerance (0.15 m) as defined in scope.	

12/01/23	92.85 m (before grouting no dip taken after)	Set tremie above backfill and prepared for grouting operations. Mixed and pumped grout. Summary of grout cement pumped (Lift 1) Mixes = 3.3 **Mix 1**: Weight = 1.69 sg Start pumping = 16.15 hrs End of pumping = 16.30 hrs **Mix 2**: Weight = 1.74 sg Start pumping = 16:20 hrs End of pumping = 16:36 hrs **Mix 3**: Weight = 1.70 sg Start pumping = 16:38 hrs End of pumping = 16:48 hrs **Mix 3.3**: Weight = 1.69 sg Start pumping = 16:55 hrs End of pumping = 17:10 hrs Pulled back tremie to 66.0 m and flushed tremie with water.	Each mix = 7.5 bags of geotherm X GR + 100 L of water.	
13/01/23	77.6 m (before grouting no dip taken after)	Top of Bentonite cement = 77.6 m. Set tremie at 76.96 m and pumped lift 2. Summary of grout pumped (Lift 2) Mixes = 1 **Mix 1**: Weight = 1.67 sg Start pumping = 12.22 hrs End of pumping = 12.25 hrs Pulled up tremie to 64.12 m and flushed with water.	Stage grouting undertaken to avoid loading fractures with excessive weight. Lifts calculated based on wireline logs and known fractures bringing TOC a few metres above large fractures in each case. Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
16/01/23	71.4 m (before grouting no dip taken after)	Well dipped at 71.4 m (73.0 m calculated from lift plan). Continued with stage grouting operations as follows: Set tremie at 71.0 m, Summary of grout pumped (Lift 3) Mixes = 4 **Mix 1**: 1.74 sg. **Mix 2**: 1.69 sg. **Mix 3**: 1.71 sg. **Mix 4**: 1.70 sg. Flushed grout hose, pulled back 10 joints of tremie pipe to 29.6 m. Observed tremie pipe parted at the pin coupling of the 10th joint recovered. Tremie pipe left in hole ~ 41.0 m.	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	Circa 41.0 m of tremie pipe lost in hole – string parted (from 30.0 to 71.0 m).
17/01/23	52.2 m	Well dipped at 52.2 m.	Unable to recover tremie so decision taken to leave in hole.	

18/01/23	52.2 m (before grouting no dip taken after)	Well dipped at 52.2 m. Continued with stage grouting operations as follows: Set tremie at 51.28 m. No issues passing the lost tremie pipe. Summary of grout pumped (Lift #4): Mixes = 3 **Mix 1**: Weight = 1.67 sg Start pumping = 15:25 hrs End of pumping = 15:40 hrs **Mix 2**: Weight = 1.70 sg Start pumping = 15:40 hrs End of pumping = 15:45 hrs **Mix 3**: Weight = 1.71 sg Start pumping = 15:47 hrs End of pumping = 15:55 hrs Pulled back 3 joints, tremie got stuck, flushed with water, jacked and worked up the string, freed tremie, and pulled all back to surface. Clean up of tremie, and equipment, including cement mixer.	Received 40 joints of new 60 mm (OD) tremie. Each batch = 7.5 bags of geotherm X GR + 100 L of water.	
19/01/23	42.2 m (before grouting no dip taken after)	Well dipped at 42.2 m. Continued with stage grouting operations as follows: Set tremie at 37.48 m. Summary of grout pumped (Lift #5): Mixes = 5 **Mix 1**: Weight = 1.67 sg Start pumping = 11:10 hrs End of pumping = 11:30 hrs **Mix 2**: Weight = 1.67 sg Start pumping = 11:30 hrs End of pumping = 11:40 hrs **Mix 3**: Weight = 1.70 sg Start pumping = 11:40 hrs End of pumping = 11:50 hrs **Mix 4**: Weight = 1.67 sg Start pumping = 11:50 hrs End of pumping = 12:05 hrs **Mix 5**: Weight = 1.70 sg Start pumping = 12:05 hrs End of pumping = 12:15 hrs Pulled up tremie by six joints, swivel broke, connected hose to tremie, flushed with water, connected sling to jack up tremie. However,	Each batch = 7.5 bags of geotherm X GR + 100 L of water.	7 additional joints of tremie pipe lost in hole.

		tremie snapped at the base of the 7th joint above the thread with seven joints left in hole. Attached sling to the tremie stick up below top of the Boode casing, progressively jacked up tremie string. However, tremie broke with two additional joints out of hole. Tremie stuck from ~ 25.26 m.		
20/01/23	6.80 m	Well dipped at 6.8 m. Operations suspended waiting on instruction from Marriotts / Aecom to continue. Delay due to tremie pipe snapping and being lost in several of the ERT/DTS wells.		
23/01/23	13.3 m (before grouting no dip taken after)	Well dipped at 13.3 m. RIH 40 mm tremie pipe and continued with stage grouting operations as follows: Summary of grout pumped (Lift #6): Mixes = 2 **Mix 1**: Weight = 1.69 sg Mix = 7.5 bags and 104 L water Start pumping = 14:32 hrs Flushed line, pulled back 1 joint of tremie. **Mix 2**: Weight = 1.69 sg, Mix = 7.5 bags and 104 L water Start pumping = 14:43 hrs. Flushed line, pulled back 2 joints of tremie (all tremie out of the well). Washed down equipment and tidied site.		
24/01/23	3.6 m (before final grout dip taken)	Well dipped at 3.6 m. Continued with stage grouting operations as follows: Topped up grout level in well with an additional mix at 1.67 sg (lift #7) (7.5 bags of geotherm X GR + 100 L of water per mix.) to bring back inside the 24” casing.		
25/01/23	2.1 m Final tag 0.86 m	Well dipped at 2.10 m after lift #7. Well later topped up offline and TOC tagged at 0.86 m.		
TH0411 complete				

4.20 ERT AND DTS MONITORING WELL – TH0413 SUMMARY OF OPERATIONS

4.20.1 Key Well Data

Table 91 TH0413 Key well data

Well name	TH0413		
Well classification	Electrical resistance Tomography (ERT) and Distributed Temperature Sensing (DTS) monitoring wells with deep sampling port		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.331 m AOD Top 24" to GL - 0.146 m		
Start date	Intermediate section started on the 06/09/22 and completed on 30/11/22. Lower section started on the 30/11/22.		
End of drilling date	06/12/22.		
Install dates	Air lifted 07/12/22. Installed 10/01/23. Backfilling and staged grouted between 11/01/23 and 24/01/23.		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 146 mm then opened out to 311 mm	Cored to 17.1 m Reamed to 6.4 m	Temporary 10 ¾" casing used (273 mm OD x 250 mm ID) recovered before completion run	6.4 m
Final section to TD Cored in 146 mm then opened out to 200 mm	Cored to 105.7 m Reamed to 105.0 m	n/a	n/a
Installation	n/a	3" Boode PVC tubing 75 mm OD 67.8 mm ID Screen section between 98.03 and 98.97 m	99.99 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344959.089 Northing Y: 375840.915		
Ordnance Survey Grid Reference	Latitude N: 53°16′36″ Longitude W: 002°49′37″		
12 Character National Grid Reference	SJ 44959 75841		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344958.84 Northing Y: 375840.25 Step out - 0.71 m (inclination 0.14 deg / azimuth 191 deg)		

4.20.2 Summary of Drilling Operations

The rig was moved over TH0413 on the 06th September 2022 and setup. A string of 7" temporary casing was RIH and centralised inside the 24" surface casing and sealed to the base with Bentonite. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

Made up and RIH the 146 mm Geobore S coring assembly and cored from 2.0 m to 17.1 m with inclination surveys taken every two core runs. The core was collected and sent to the BGS onsite core processing unit as TH0413 was selected as a sub sampling well. The assembly was POOH and the 7" temporary casing recovered.

EGS were mobilised to site on 22nd September 2022 to log the well in the cored hole from 2.0 m to 15.1 m. Full details of the tools run can be found in **Section 4.20.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The Soilmec rig was mobilised back to TH0413 on the 30th November 2022 and the 311 mm reamer assembly was made up and RIH. The hole was opened out down to 6.4 m before circulating the hole clean and POOH.

A 273 mm (10 ¾") temporary string of casing was RIH to 6.38 m and centralised within the 24" surface casing. The annulus was sealed with Bentonite.

Figure 109 Lefthand image is of the 311 mm reamer assembly being picked up. The righthand image is the 311 mm reamer before make up

The 146 mm coring assembly was picked backup and cored from 17.1 m to 21.2 m where the core barrel became struck. The string was worked (2.75 hours) and became free. The string was POOH and inspected before rerunning and continuing coring operations. The well was cored to total depth at 105.7 m with fluid returns being lost at 23.2 m. The assembly was POOH and laid out.

The core recovered from 17.1 m to TD was not subsampled as originally planned by BGS. Based on evidence and borehole sequencing onsite another well was selected to be sub sampled that would provide a greater level of data for the site and indicate the level of damage if any the drilling activities have had on the flow characteristic of the aquifer.

The Scope required a 100.0 m hole to be drilled but a sump was drilled by Marriotts to accommodate any sediment remaining in the hole. Verticality readings were within tolerance throughout.

A 200 mm reamer assembly was made up and RIH and opened out the hole from 146 mm down to 60.0 m where a crosswire verticality survey was undertaken to confirm verticality. Reaming operations then continued down to 105.0 m. The well was circulated before pulling back and allowing the well time to settle. The well was dipped at 105.15 m. A second crosswire verticality check was completed (100.0 m, 80.0 m and 60.0 m stations) before POOH the reaming assembly.

The decision was taken to air lift and attempt to clean up the fractures further by remove any remaining cuttings. The air lifting assembly was RIH, and a two-stage air lift was completed. The depths of each stage were 70.0 m and 83.0 m. The assembly was POOH and the well dipped to 104.65 m.

The 273 mm (10 ¾") temporary casing was recovered and the rig moved off location.

EGS were mobilised back to site on 09th December 2022 to log the lower section of the well down to 102.0 m. Full details of the tools run can be found in **Section 4.20.4**.

Once logging operations were completed, EGS were rigged down off the well and demobilised from site.

The well dipped at 100.8 m.

4.20.3 Materials, Flush and Drilling Additive Used

TH0413 was drilled with water only from start to finish. No mud additives or LCM materials were deployed in this well.

4.20.4 Geophysical Logging Undertaken

Table 92 Geophysical logging summary TH0413

Wireline logging undertaken	Tools run
Upper Section logged in cored 146 mm hole to 15.1 m. (22/09/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW
Lower section logged in reamed 200 mm hole to 102.0 m. (09/12/22)	GR, CALI, ACBI, LRES, TEMP, COND, FLOW

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.71 m and within the 1/100 tolerance.

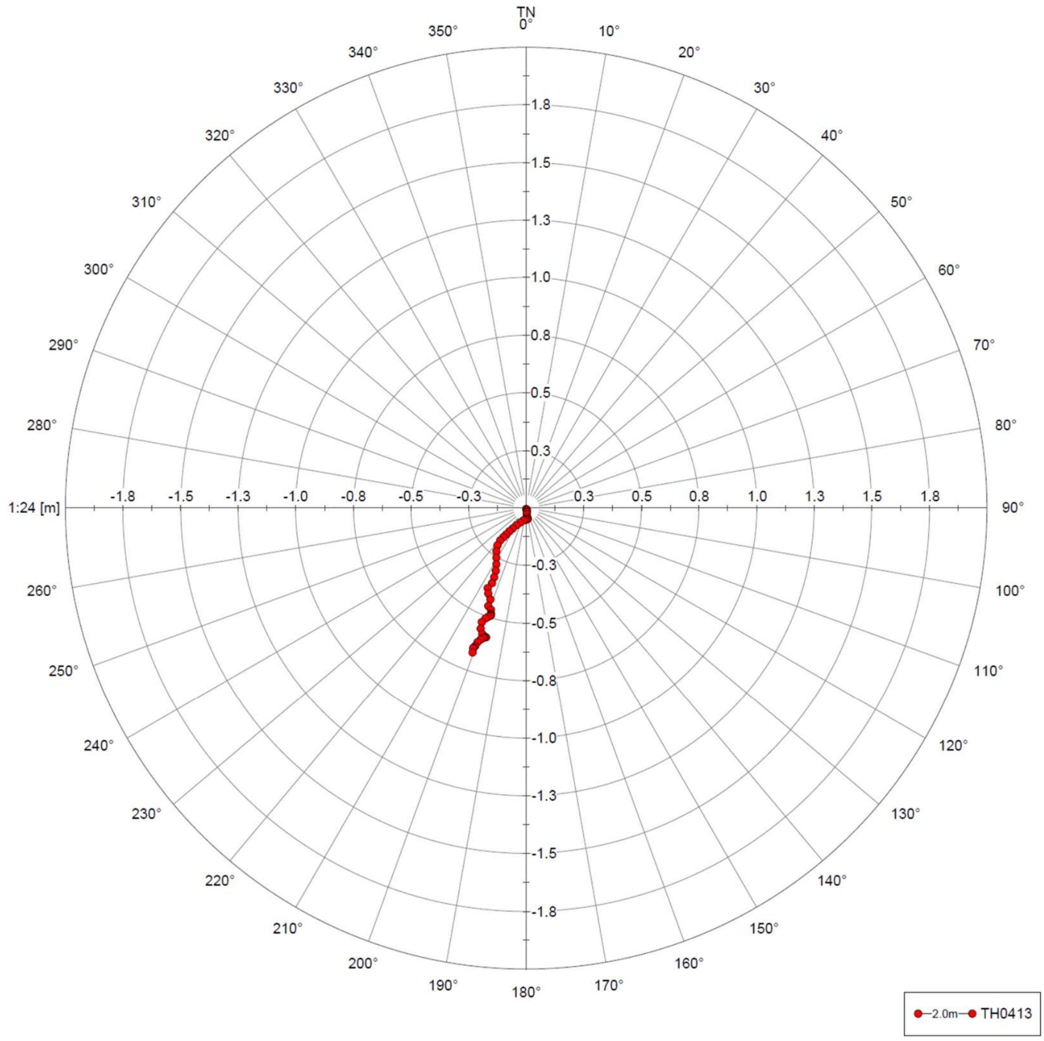


Figure 110 Verticality bullseye plot for TH0413, © European Geophysical Services Ltd

4.20.5 Summary of Installation Operations

Installation criteria for TH0413:

- Produce a detailed install protocol detailing sensor placement depth and final install depths.
- Run resistance tomography and fibre optic cables on the outside of the tubing ensuring that ERT electrodes are at correct depths.
- Ensure the tubing run is large enough to allow a pump to be deployed in future to sample a screen section at the base of the well.
- Accurately monitor the deployment maintaining accurate records throughout.
- Backfill with grout, with uniform density to ensure consistent thermal properties as per supplier's specifications.
- Ensure the install is centralised in the borehole and maintained in tension during grouting operations.
- Prevent loss of grout into open fractures.
- Emplace grout using tremie pipe to ensure accuracy.

Summary of operations:

Prepared the installation BHA and setup the cable reel stands and equipment in preparation for running. A 60 mm retrievable tremie pipe was run to bottom.

Held a pre-installation meeting with all parties before commencing. Made up the ERT BHA with the base plug, screen section and first full joint of 75 mm OD pipe and lowered into the well with both the ERT and fibre optic cables attached to the outside. The assembly was RIH as per the installation sheet putting the base of the installation at 99.99 m and securing on surface.

The ERT and fibre optic cables were functions tested with a pause halfway to test the deep ERT string and once total depth had been reached for the shallow string. All electrodes and the fibre optic cable tested ok.

Back filling operations then commenced. See **Section 4.20.6** for the backfill materials and grout lifts undertaken. During the deployment of the filter sand and Bentonite pellets for the lower section the tremie pipe became plugged on more than one occasion. This blockage was removed by running a 30 mm pipe through the centre and constantly introducing water from surface.

Figure 111 75 mm installation pipe run. 30 mm tremie (blue) being run through the 60 mm tremie (yellow) to push through a Bentonite blockage during back filling operations.

All backfill material levels were within tolerance (0.15 m as per Scope).

Stage grouting was undertaken to avoid high volumes of grout being lost to fractures. Each grout lift volume was calculated based on wireline logs to identify large fractures, assumed gauged hole and grout mix yields based on cement concentration. In each case the TOC was planned to be a few metres above known large fractures. By taking this approach, it avoided having a large hydrostatic pressure generated by the grout column acting on open fractures. The risk of permanently sealing fractures across the site was very high if this approach wasn't taken due to the know connectivity of fractures and communication between boreholes seen during the drilling phase.

Following numerous tremie pipe failures on other ERT/DTS wells the site operations were suspended on the 20th January 2023 to allow a forward plan to be developed. The decision was taken to remove all 60 mm pipe and quarantine and use 40 mm pipe going forward.

After each grout lift was completed the tremie pipe was pulled back above the TOC and flushed cleaned. All four ERT/DTS wells had been drilled and the installation run in advance of the grouting operations commencing to allow all wells to be grouted in sequence. The grout unit was positioned in the centre and lines were rigged up to each well.

Grouting operations on TH0413 were completed on the 24th January 2023 with a TOC at 2.28 m. The well was later topped up to 1.0 m below ground level offline.

4.20.6 Backfill and grouting operations

The ERT/DTS wells were grouted in stages to avoid overloading fractures with grout. Each stage is detailed in the table below. Geotherm-X GR grout used was mixed with water to a ratio of 7.5 bags (24 kg each) to 100 L of water. This produced a grout mix with a minimum specific gravity of 1.67 sg. Each batch was checked before pumping with a mud balance. The grout was delivered via a temporary tremie pipe that was retracted as the grout was pumped. The tremie pipe was kept toward the top of the grout and pulled above after each stage was completed. The distances to pull back were based on hole volume calculations.

Table 93 Stage grouting summary table TH0413

Grout lift	Base (m)	Top (m)	Comments	Number of batches pumped	Grout weights SG	Recipe	Lift height per 100 L mix (m)	Dip inside install to top of 24" casing
	101.7	100.03	MGS filter gravel					
	100.03	97.1	1-2mm MGS filter sand					
	97.1	96.0	Bentonite pellets					
	96.0	91.95	Bentonite/ cement pellets					
1	91.95	83.6		2	1.67 / 1.74	7.5 bags	4.175	99.97
2	83.6	59.7		5	1.70 / 1.72 / 1.72 / 1.72 / 1.73	7.5 bags	4.78	99.97
3	59.7	40.35		4.5	1.68 / 1.71 / 1.70 / 1.71 / 1.69	7.5 bags	4.30	
4	40.35	20.4		4.5	1.67 / 1.70 / 1.69 / 1.67 / 1.67	7.5 bags / 105 L 7.5 bags / 105 L 7.5 bags / 105 L 7.5 bags / 110 L 3.75 bags / 52.5 L	4.43	100.01
5	20.4	15.6		1	1.69	7.5 bags/104L	4.8	
6	15.6	5.8		2.6	1.67 / 1.69 / 1.68	7.5 bags / 104 L 7.5 bags / 104 L 3.75 bags / 52 L	3.77	
7	5.8	2.6		1.5				99.96
8	2.6	1.0			Topped up with bucket mix			

The final grout levels within the 24” surface casing was dipped and topped up to final levels during completion of the headworks.

4.20.7 TH0413 Borehole Well Schematic

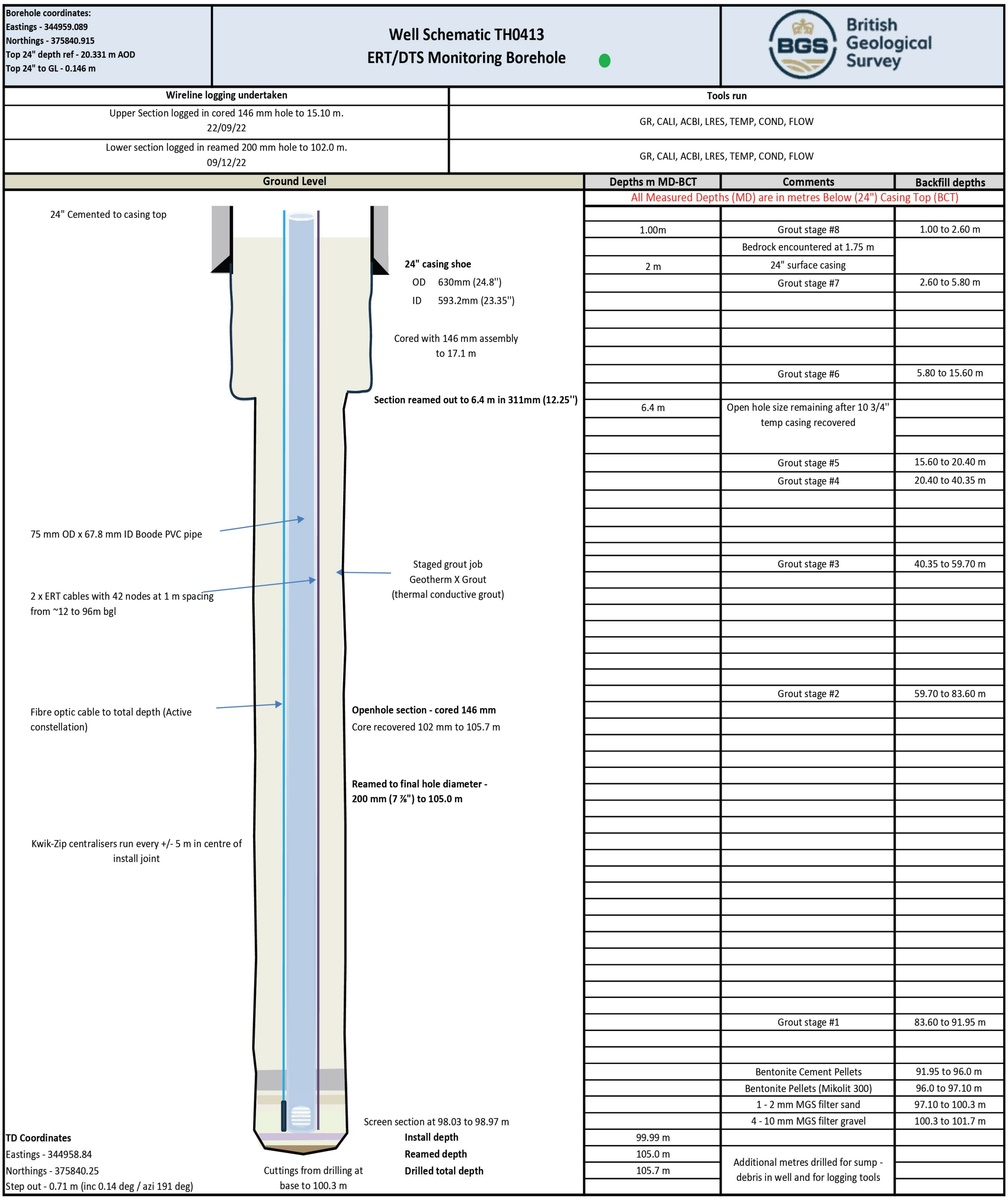


Figure 112 TH0413 Well Schematic

4.20.8 Wellhead / Well Chamber Status

Figure 113 Wellhead chamber image TH0413

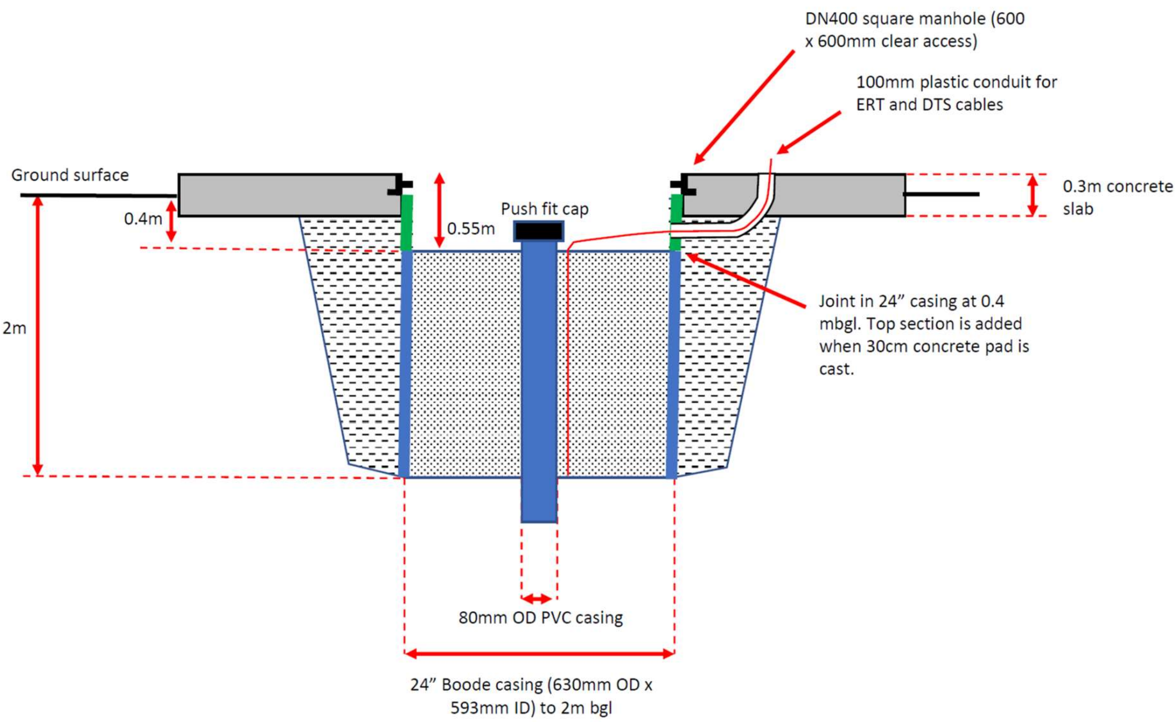


Figure 114 Wellhead chamber schematic TH0413

4.20.9 Daily Activity Summary

Table 94 Daily activity summary TH0413

Date	Depth M BGL	Operation	Parameters	Issues
06/09/22	2.0 m	Moved the rig over TH0413, levelled the ground and setup. Ran temp 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations.		
07/09/22	17.1 m	Made up 146 mm Geobore coring assembly. Cored well from 2.0 m to 17.1 m with verticality surveys after every two core runs. Flushed hole and POOH 146 mm Geobore and 7" temporary casing. Rigged down and moved rig off well to TH0421.	BGS onsite subsampling every 4th core recovered. Verticality checks: 0.17 deg @ 5.1 m. 0.03 deg @ 7.6 m. 0.41 deg @ 10.6 m. 0.17 deg @ 13.5 m. 0.12 deg @ 16.6 m.	Poor core recovery in the first run.
22/09/22	17.1 m	EGS arrived, set up over TH0413 and ran a full suite of logs from section TD to surface. EGS rig down and de mobilised from site.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 15.1 m.	
30/11/22	21.2 m	Setup the Soilmec rig over TH0413. Made up and RIH 311 mm (12 ¼") reaming assembly and opened out the hole from 2.0 m to 6.4 m. POOH reamer and laid down. Installed 273 mm (10 ¾'' OD) temporary casing to 6.38 m and sealed annulus with Bentonite pellets. Made up and RIH the 146 mm Geobore assembly and cored from 17.1 m to 21.2 m where the core barrel became stuck. Worked string (2.75 hours) until free. Recovered to surface and inspected – OK	Flush returns were 100% to 18.7 m, then 90% from 18.7 m. No verticality measurements taken. The next survey is due at 22.6m.	TH0413 started as a well to be subsampled and the first 17.1 m was sampled accordingly. However, the plan was changed and the remainder of TH0413 will not be subsampled. Fluid sample frequency was reduced as a result from 1.5 m to 6.0 m.
01/12/22	69.7 m	RIH with 146 mm Geobore assembly to 20.05 m where a small amount of fill was encountered. Washed down to bottom at 21.2 m and flushed hole clean. Continued coring with 146 mm Geobore assembly from 21.2 m to 69.7 m. Flush returns lost at 23.2 m. Pulled back 3.0 m at end of shift.	Flush returns lost at 23.2 m. Verticality checks: 0.41 deg @ 23.0 m. 0.35 deg @ 29.0 m. 0.28 deg @ 35.0 m. 0.42 deg @ 41.0 m. 0.24 deg @ 47.0 m. 0.41 deg @ 53.0 m. 0.38 deg @ 59.0 m. 0.50 deg @ 65.0 m.	
02/12/22	84.7 m	Continued to core ahead from 69.7 m to 84.7 m with no flush return.	No returns. Verticality checks: 0.34 deg @ 71.0 m. 0.25 deg @ 77.0 m.	

			0.06 deg @ 83.0 m.	
05/12/22	105.7 m	Continued to core ahead from 84.7 m to 105.7 m (well TD) with no flush return. Once TD reached circulated the hole before POOH. Made up and RIH a 200 mm reaming assembly and opened out the hole from 146 mm down to 60.0 m. Flushed hole before POOH the reaming assembly and performing a crosswires deviation survey from surface to 60.0 m.	No returns. Verticality checks: 0.14 deg @ 89.0 m. 0.32 deg @ 95.0 m. 0.31 deg @ 101.0 m.	The required TD is 101.2 m and a further 3 x 1.5 m core runs have been made to provide a 4.5 m sump for cuttings.
06/12/22	105.15 m	Ran back in hole the 200 mm reamer assembly and continued to open out the hole down to 105.0 m. Pulled back reaming assembly to 100.0 m, wait for borehole to settle down for ~ 1.0 hour, dipped at 105.15 m. POOH and performed crosswire survey at 60.0 m, 80.0 m, 100.0 m, 100.0 m, 80.0 m, and 60.0 m. recovered assembly to surface. RIH air lifting assembly to 70.0 m to lift cuttings from the well. Unfortunately, the air compressor developed a blown fuse.	From 60.0 m to 85.0 m, there was no flush return. However, 20-30% flush return seen between 85.0 m and 95.0 m, this increased to 50-60% from 96.0 m to 100.0 m.	Air compressor failure resulting in lost time and suspended air lifting operations.
07/12/22	104.65 m	Commenced airlifting with the assembly at 70.0 m (first stage) moving down to 83.0 m (second stage). Well dipped at 104.65 m. POOH the air lifting assembly before recovering the 273 mm temporary casing. Rigged down and moved the rig to TH0407.	A small volume of cuttings were recovered from 70.0 m with very little from 83.0 m. Tanks to be checked once settled for actual volumes.	
09/12/22	104.65 m	EGS arrived, set up over TH0413 and ran a full suite of logs from TD to surface. EGS rig down and de mobilised from site.	Wireline logs run: GR, CALI, ACBI, LRES, TEMP, COND, FLOW. Logged to 102.0 m.	
23/12/22	100.80 m	Well dipped at 100.80 m.		
TH0413 ERT/DTS install				
10/01/23	100.8 m	Set up scaffolding frame, cable drums and stand at TH0413 with Comacchio 405 rig supporting. Made up the ERT BHA with base plug and screen section with the first full length joint above. Installed centralisers. Tested deep ERT cable continuity - OK. Commenced RIH with ~2.44 m lengths of 75 mm carrier pipe with FO and ERT cables attached. RIH with ERT-FO installation to depth. Last ERT electrode on PVC casing no. 37. BGS/Silixa tested ERT/FO cables, all tested ok.	PVC centralisers were fixed on the PVC casing every 3.0 m. Pipe tally generated before commencing will all tubing lengths known.	Delay to completing the install due to no excess 75 mm pipe being available onsite and joints still being used on other wells for back filling.
11/01/23	96.0 m (last confirmed depth)	Resumed installation once final joints became available, completed lowering all cables in the borehole with base of install at 99.99 m. Well dipped at 101.7 m.		Bentonite bridged tremie at 88.0 m. It was noted that the Bentonite cement pellets had obvious

		Commenced backfilling. Summary of backfilling: 2 bags, 2 tubs of filter gravel to 100.03 m. 6 bags of 1-2mm filter sand to 97.1 m. 1 bag, 4 tubs of Bentonite to 96.0 m. 3 bags of Bentonite cement pellets – see issues column and as a result depth not determined.		lumps in a hand sample taken. Attempt to free blockage with running water failed. Tried further to run the smaller (30 mm) pipe through the larger (50 mm) pipe, worked up and down with running water, unfortunately, the smaller pipe got stuck at 88.0 m. Further attempt to use the rig (Comacchio) to pulled up and free the tremie resulted in the rig breaking down with a hydraulic leakage.
12/01/23	91.95 m	Fixed hydraulic hose of Comacchio rig, dipped tremie at 85.0 m. Recovered the stuck tremie pipe. Ran back in hole the cleared tremie pipe to 94.0 m and pull back to 88.0 m. Resumed backfilling operations. Summary of backfilling: 2 bags of Bentonite cement to 91.95 m. Secured tremie pipe and moved the rig off location to TH0411.	The bottom 5.0 m of the tremie pipe that was pulled out was found to be blocked by cement. All backfills were within tolerance (0.15 m) as defined in scope.	
13/01/23	91.95 m (before grouting no dip taken after)	Rig back over borehole. Set tremie above backfill at 91.0 m and prepared for grouting operations. Mixed and pumped grout. Summary of grout cement pumped (Lift 1) Mixes = 2 **Mix 1**: Weight = 1.67 sg Start pumping = 09:58 hrs End of pumping = 10:01 hrs **Mix 2**: Weight = 1.74 sg Start pumping = 10:23 hrs End of pumping = 10:25 hrs Pulled back tremie and flushed tremie with water. WOC.	Stage grouting undertaken to avoid loading fractures with excessive weight. Lifts calculated based on wireline logs and known fractures bringing TOC a few metres above large fractures in each case. Each mix = 7.75 bags of geotherm X GR + 100 L of water.	7.5 bag, density was found to be 1.65 sg, which is lower than the required 1.67 sg, hence topped up with an additional 0.25 bag to increase the density. Viscosity was not tested because this was done on previous mixes to check the thickness and pumpability, which is consistent with the required density range. One wet sample tub representing the base of grouting in the borehole was collected.
16/01/23	83.6 m	Well dipped at 83.6 m (vs 80.0 m calculated from lift 1). Commenced moving Comacchio rig from TH0407 to TH0413 to perform a top up grout mix as TH0413 had not achieved the minimum depth required.		

17/01/23	83.6 m (before grouting no dip taken after)	Well dipped at 83.6 m. Continued with stage grouting operations as follows: Set tremie at 71.0 m. Summary of grout pumped (Lift 2) Mixes = 5 **Mix 1:** Weight = 1.70 sg Start Mixing = 13:00 hrs Start pumping = 13:24 hrs End of pumping = 13:25 hrs **Mix 2:** Weight = 1.72 sg Start Mixing = 13:25 hrs Start pumping = 13:35 hrs End of pumping = 13:36 hrs **Mix 3:** Weight = 1.72 sg Start Mixing = 13:40 hrs Start pumping = 13:51 hrs End of pumping = 13:53 hrs **Mix 4:** Weight = 1.72 sg Start Mixing = 13:54 hrs Start pumping = 13:58 hrs End of pumping = 13:59 hrs **Mix 5:** Weight = 1.73 sg Start Mixing = 14:03 hrs Start pumping = 14:11 hrs End of pumping = 14:13 hrs Pull back and flushed tremie, cleaned and cleared grouting equipment. WOC. Rig moved to TH0407.	Each batch = 7.5 bags of geotherm X GR + 100 L of water. Once each mix had been pumped the tremie was pulled back 2 joints and flushed with water.	
18/01/23	59.7 m (before grouting no dip taken after)	Well dipped at 59.7 m. Continued with stage grouting operations as follows: Set tremie above TOC. Summary of grout pumped (Lift #3): Mixes = 4.5: **Mix 1**: Weight = 1.68 sg Start pumping = 12:40 hrs End of pumping = 12:57 hrs **Mix 2**: Weight = 1.71 sg Start pumping = 12:57 hrs End of pumping = 13:05 hrs **Mix 3**: Weight = 1.70 sg Start pumping = 13:05 hrs End of pumping = 13:15 hrs **Mix 4**: Weight = 1.71 sg	Each batch = 7.5 bags of geotherm X GR + 100 L of water. Note: Mix 1 was mixed with 7.75 bags. Mix 4.5 was mixed with 3.75 bags.	

		Start pumping = 13:15 hrs End of pumping = 13:25 hrs **Mix 4.5**: Weight = 1.69 sg Start pumping = 13:25 hrs End of pumping = 13:34 hrs Pulled back 4 joints, connected hose, and flushed tremie string clean with water. Lowered mast, preparing to move rig to next location (TH0411).		
19/01/23	40.35 m (before grouting no dip taken after)	Well dipped at 40.35 m. Continued with stage grouting operations as follows: Summary of grout pumped (Lift #4): Mixes = 4.5: **Mix 1**: Weight = 1.67 sg Start pumping = 15:50 hrs End of pumping = 16:05 hrs **Mix 2:** Weight = 1.70 sg Start pumping = 16:05 hrs End of pumping = 16:15 hrs **Mix 3:** Weight = 1.69 sg Start pumping = 16:15 hrs End of pumping = 16:25 hrs **Mix 4:** Weight = 1.67 sg Start pumping = 16:25 hrs End of pumping = 16:38 hrs **Mix 4.5:** Weight = 1.67 sg Start pumping = 16:38 hrs End of pumping = 16:45 hrs Flushed hole and pulled back 4 joints, connected the hose and flushed well clean. Washed down and secured equipment.	Each batch = 7.5 bags of geotherm X GR + 100 L of water. Bottom of tremie pipe at 8.8 m (theoretical top grout at 17.5 m).	
20/01/23	20.40 m	Well dipped at 20.4 m. Operations suspended waiting on instruction from Marriotts / Aecom to continue. Delay due to tremie pipe snapping and being lost in several of the ERT/DTS wells.		
23/01/23	15.6 m (before grouting of stage 6)	Well dipped at 20.4 m. Prepared 40 mm tremie pipe lengths. POOH 60 mm tremie pipe and RIH 7 joints of 2.96 m 40 mm tremie. Connected grouting hose to the 40 mm tremie. Continued with stage grouting operations as follows: Summary of grout pumped (Lift #5): Mixes = 1 **Mix 1:**		Tremie pipe changed out due to failures in other ERT/DTS boreholes.

		Weight = 1.68 sg Mix = 7.5 bags and 104L water Flushed grout line, broke connection at wellhead and pulled back tremie pipe. Re-connected tremie and flushed hole clean. WOC. Well dipped at 15.6 m. Continued with stage grouting operations on night shift as follows: Summary of grout pumped (Lift #6): Mixes = 2.6 **Mix 1:** Weight = 1.67 sg Mix = 7.5 bags and 104L water **Mix 2:** Weight = 1.69 sg Mix = 7.5 bags and 104L water **Mix 2.6:** Weight = 1.68 sg Mix = 3.75 bags and 52L water Flushed grout line, broke connection at wellhead and pulled back tremie pipe. Re-connected tremie and flushed hole clean. WOC.		
24/01/23	5.8 m (before grouting no dip taken after)	Well dipped at 5.8 m. Continued with stage grouting operations as follows: Topped up grout level in well with an additional 1.5 mixes at 1.70 sg (lift #7) (7.5 bags of geotherm X GR + 100 L of water per mix.) to bring back inside the 24” surface casing.		
25/01/23	2.28 m Final tag 1.0 m	Well dipped at 2.28 m after lift #7. Well later topped up offline and TOC tagged at 1.0 m.		
TH0413 complete				

4.21 ISSUES ENCOUNTERED AND SOLUTIONS – ERT/DTS WELLS

Table 95 Summary table of issues encountered – ERT/DTS wells

Well number	Issue	Solution / lessons learned
All ERT/DTS wells	The high thermal conductivity sand-Bentonite grout (>1.3W/m/K) that was proposed for the GSH boreholes (Connect +) is a liquid thermal grout that doesn't set hard. BGS flagged this as a concern once the extent of fractures was understood that this could be washed out either during drilling or when the site becomes operations.	Use Geotherm-X GR for all the ERT/DTS boreholes which is a fully setting grout with a great thermal conductivity.
All ERT/DTS wells	Grout migration into fractures altering the natural groundwater flow paths across the site permanently.	Staged grouting approach adopted for all ERT / DTS wells to bring each stage to just above a known fracture as identified in either the core or wireline logs to reduce the hydrostatic head of grout on these fractures. This was managed so that all four ERT/DTS wells were drilled and installed first and then grouted in stages switching between each well with the grouting equipment positioned in a central location. This approach was taken because the fractures remained open as the wells had been drilled with water only, no LCM materials deployed.
All ERT/DTS wells	Voids around and below the 24" surface casing before grouting operations.	Surface casing not set on cement and just installed on a bed of sand to aid levelling. This resulted in the casing competent shoe not being competent and lead to voids appearing. These voids were produced by the flow of returning drilling fluid going sideways causing these washouts. Look to cement the 24" surface casing from the base and set on a bed of cement rather than sand alone. This would avoid any possible subsidence of the surface string as a result.
All ERT/DTS wells	Risk of temporary casing becoming stuck.	Installed temporary casing to the shallower depth of 6.0 m to 7.0 m rather than 15.0 m as per the original Scope. This was instructed after the temporary casing string run to 15.0 m in TH0420 became stuck and had to be over drilled. The shallower casing depth provided the level of protection against any migration

Well number	Issue	Solution / lessons learned
		downwards of any potential near surface contamination.
TH0409 and TH0411	Snapped tremie pipe	60 mm pipe quarantined after snapping on more than one occasion, changed for smaller 40 mm pipe. After each grout stage the string was pulled back above TOC and flushed clear significantly reducing the chance of plugging or getting stuck.
Wireline / geophysical logging	Vertical scoring on wireline logs undertaken in reamed holes	Undertaking acoustic image logging within reamed boreholes has resulted in vertical lines on the acoustic image log. The exact cause was never identified as its common practice to log in a reamed hole. Measurements were taken of reamer, all stabilisers run, and the pulling technique was changed from straight pull to back reaming out of hole. Geophysical logging was undertaken in the cored borehole where possible once this issue had been identified.
All ERT/DTS wells	When installing the ERT/DTS borehole the exact number of 75 mm OD pipe sections had been ordered with no spares resulting in lost time whilst they were recovered from other boreholes as they were utilised for backfilling operations to bring the pipe above GL for ease. The risk in removing the top section of pipe before the back filling / grouting was complete is backing out a joint deeper down. If a joint had been dropped / threads crossed, then one of the installs would have been delayed.	Not factored in when ordering the installation pipe. Order at least a few joints or 10% contingency for deeper wells to consider damaged, cross threaded joints etc.

4.22 UNCASED BEDROCK BOREHOLE – TH0404 SUMMARY OF OPERATIONS

4.22.1 Key Well Data

Table 96 TH0404 Key well data

Well name	TH0404		
Well classification	Uncased Bedrock Borehole		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 19.694 m AOD Top 24" to GL - 0.130 m		
Start date	Intermediate section started on the 08/02/23 and completed on 15/02/23. Lower section started on the 19/04/23.		
End of drilling date	20/04/23.		
Install dates	20/07/23 (post drilling).		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 311 mm	Cored to 16.25 m Reamed to 15.2 m	8" Boode PVC casing 200 mm OD 180.8 mm ID	15.0 m (shoe partially backed out)
Sleeve casing	n/a	Sleeve Casing OD 165 mm ID 155 mm Boode B type (upset) PVC casing.	15.58 m
Final section to TD Cored in 152 mm	100.5 m	n/a	n/a
Installation	n/a	FLUTe liner – 6" / 840 denier liner	99.86 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344919.211 Northing Y: 375835.615	
Ordnance Survey Grid Reference		Latitude N: 53°16′36″ Longitude W: 002°49′39″	
12 Character National Grid Reference		SJ 44919 75836	
Well TD Coordinates:			
Easting / Northing (OS GRID)		Easting X: 344919.03 Northing Y: 375836.09 Step out - 0.51 m (inclination 0.88 deg / azimuth 295 deg)	

4.22.2 Summary of Drilling Operations

Operations on TH0404 commenced on the 08th February 2023. The rig and associated equipment were rigged up and a string of 7” temporary casing run and centralised within the 24” surface casing. This was sealed at the base with Bentonite pellets. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 16.5 m with full returns throughout. Verticality surveys taken every second core run. The hole was circulated clean before POOH the assembly and the temporary casing was recovered.

The hole was opened out down to 15.2 m using a 311 mm reamer assembly and circulated clean. No reported fluid losses during this operation.

The permanent PVC intermediate (200 mm OD x 180 mm ID) casing was run to 15.0 m (0.2 m off bottom) with both ERT and fibre optic cables attached to the outside. The casing was centralised in the well with plastic centralisers and once on depth checked using the crosswire technique for verticality.

Figure 115 Installation of the 200 mm OD intermediate casing string

The annulus was grouted using thermally enhanced grout which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water. This produced a grout with a minimum Specific Gravity of 1.67. A total of 6 mixes were pumped to grout the annulus back to surface. Full details of this operation can be found in the daily activity summary in **Section 4.22.9**.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe run on the outside of the casing. Dry and wet samples of grout were taken as per the specification.

A diver logger was deployed into an adjacent well (TH0412) to monitor and check for any communication between boreholes during drilling via fracture flow.

Once the grout had achieved a sufficient hardness a rotary assembly was RIH to drill out the shoe track (cement plug pre-installed in the shoe joint). Once through the assembly was recovered and the 152 mm Geobore S coring assembly was made up and RIH. The well was advanced coring ahead to 100.5 m with no returns from 43.2 m but with no drilling issues, verticality issues, overpulls or tight spots being reported.

The well was circulated for 20 minutes before POOH the coring assembly and laying down. The rig was moved off location on the 20th April 2023.

4.22.3 Sleeve casing installation

On the 30th May 2023 EGS were mobilised to site, and a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the casing shoe had partially backed out / detached. The remnants of the precast grout plug inside the casing shoe (cement collar following drilling out) remained however no cement was present below, see images in **Section 4.25**.

The Comacchio rig was moved back over TH0404 on the 27th June 2023 and prepared for sleeving operations. A stepped drag bit assembly was RIH on drill rod to remove the cement collar from inside the shoe. The TOC was tagged inside the detached section, and the string was worked successfully removing the cement from the casing shoe. The stepped drag bit was advanced, and a socket was generated on the shoulder to accept the sleeve casing down to 15.58 m. The assembly was then recovered.

Made up and RIH the sleeve casing with an A type socket (175 mm OD x 165 mm ID) at the base, landing off in the newly generated socket to a depth of 15.58 m. The sleeve casing run was Boode PVC 165 mm OD x 155 mm ID, B Type upset jointed casing. Annulus clearance between intermediate and new casing is 7.9 mm.

The Marriotts downhole camera was run and confirmed the sleeve casing was sitting fully central in the well. Sleeve casing accepted by BGS.

4.22.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0404 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 97 Drilling fluid summary table – TH0404

	TH0404
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	216
Ultrabore additive lost (kg)	3.1
Purebore additive lost (kg)	1.5

Once the intermediate section was drilled the well was cased with 165 mm OD (8”) Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section and water was used throughout.

No LCM pills were deployed in this well.

4.22.5 Geophysical Logging Undertaken

Table 98 Geophysical logging summary TH0404

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD. (27/04/23)	Gyro survey

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.51 m and within the 1/100 tolerance.

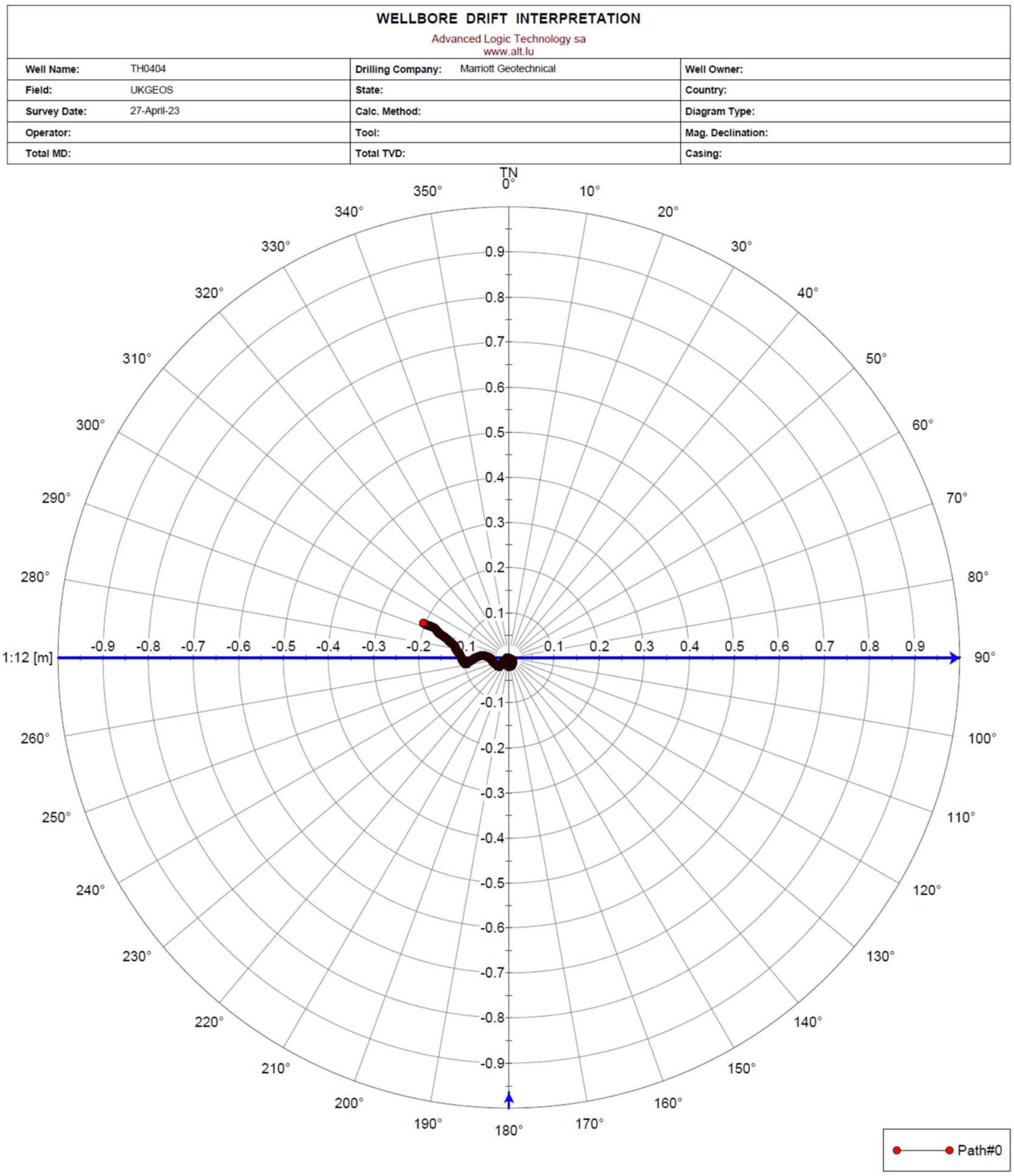


Figure 116 Verticality bullseye plot for TH0404, © European Geophysical Services Ltd

4.22.6 Summary of Installation Operations

Installation criteria for TH0404:

- Deploy a FLUTe liner to seal the well and prevent vertical flow in the borehole.
- Protect the borehole for future research opportunities.

Summary of operations:

The Green Machine and associated equipment needed for the deployment of the liner was rigged up and a toolbox talk with all parties held before commencing. The FLUTe liner was installed without issue as per the manufacturer’s instructions to 99.86 m. The liner and tether were secured at surface before making the well safe and rigging down.

Figure 117 FLUTe liner deployment into TH0404

4.22.7 TH0404 Borehole Well Schematic

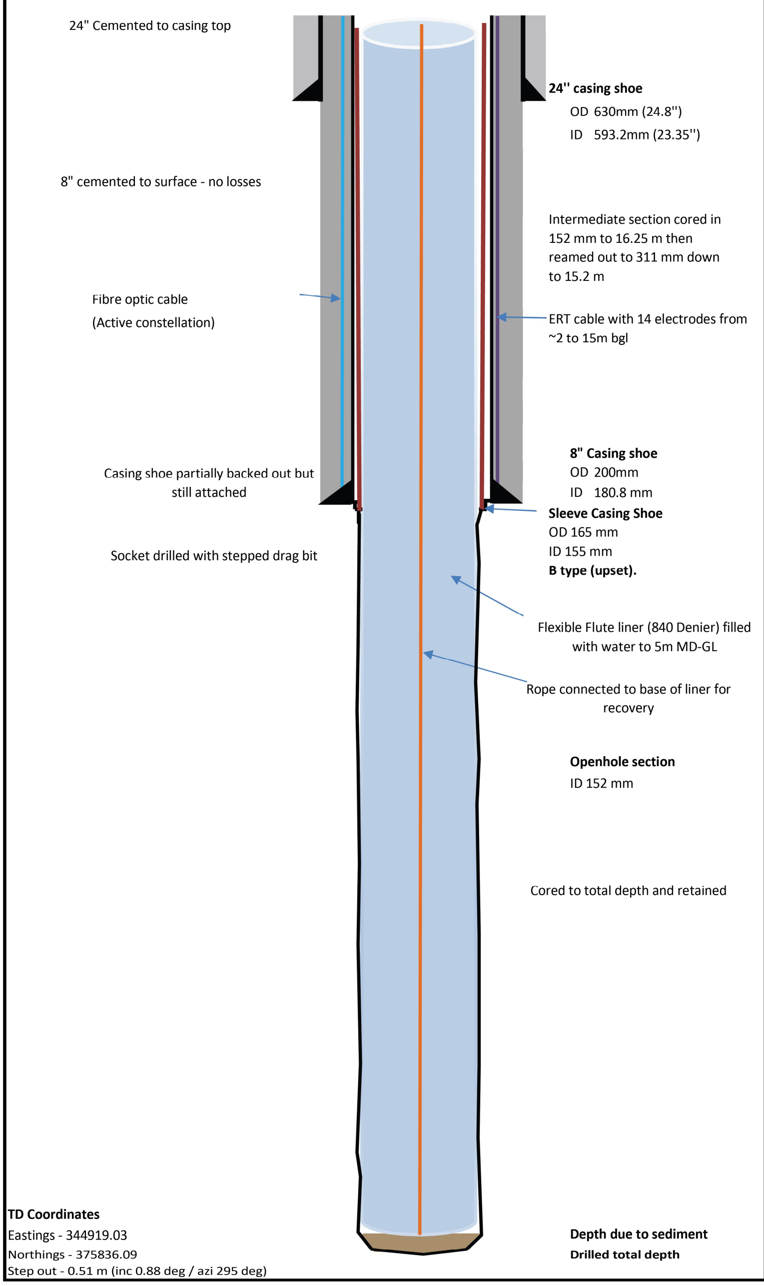
Borehole coordinates:
Eastings - 344919.211
Northings - 375835.615
Top 24" depth ref - 19.694 m AOD
Top 24" to GL - 0.130 m

Well Schematic TH0404
Uncased Bedrock Borehole ●

British Geological Survey

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD	Gyro survey

Ground Level



Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
15.0 m	Permanent 200mm PVC casing with FO & ERT cables attached. 15.075 m running length - 7.5 cm above top of 24" casing
15.58 m	A type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID
	7.9 mm either side of sleeve casing
99.86 m	
100.5 m	Additional 0.5 m drilled for sump - debris in well

Figure 118 TH0404 Well Schematic

4.22.8 Wellhead / Well Chamber Status

Figure 119 Wellhead chamber image TH0404

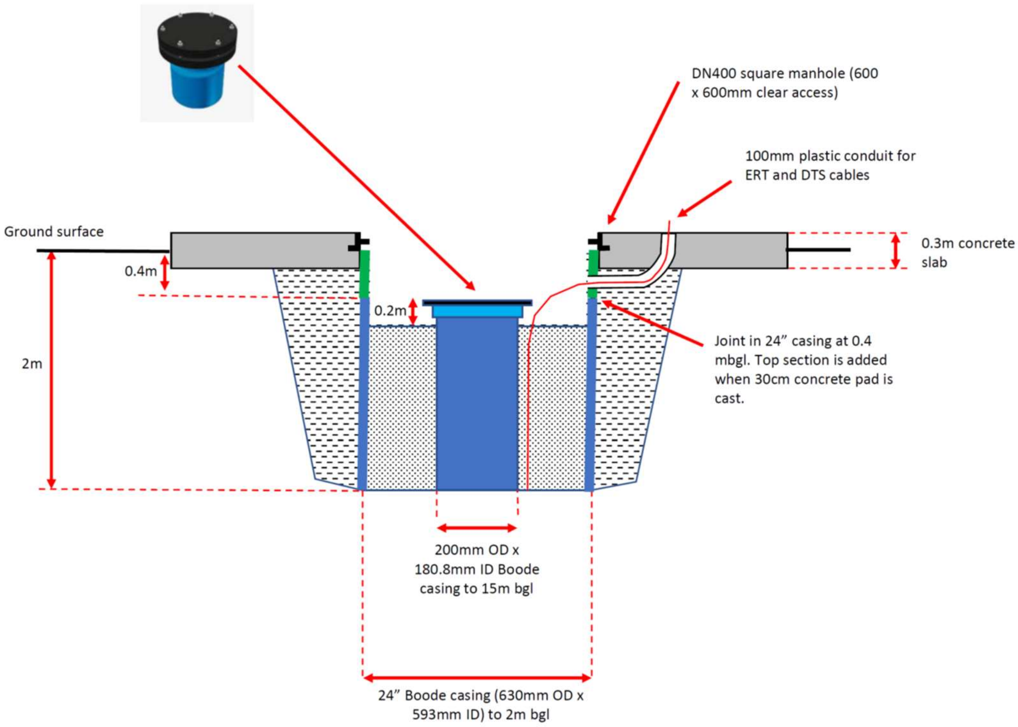


Figure 120 Wellhead chamber schematic TH0404

4.22.9 Daily Activity Summary

Table 99 Daily activity summary TH0404

Date	Depth M BGL	Operation	Parameters	Issues
08/02/23	2.0 m	Moved the rig over TH0413, levelled the ground and setup. Ran 7" temporary casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations.		
09/02/23	16.25 m	Made up 152 mm Geobore coring assembly. Cored well from 2.0 m to 16.25 m with verticality surveys after every other core runs. Flushed hole and POOH the Geobore and 7" temporary casing. Made up and RIH a 311 mm (12 ¼") reaming assembly and opened out the hole from 2.0 m to 15.2 m. POOH reamer and laid down. Rig moved off location.	Verticality checks: Not reported. No reported flush loss.	
14/02/23	15.3 m	Set the Soilmec rig back over TH0404. Held pre-job briefing for casing running operations with all site personnel. RIH tremie pipe and set up cable drums and scaffolding tower for the installation. Added fresh polymer mix to the mud in the active tank. RIH 7'' temporary casing. Commenced circulating the hole. POOH 7" casing and dipped well at 15.3 m. Picked up the first 200 mm OD x 180.8 mm ID PVC casing joint into mast using the lifting head and winch. Installed centralisers (2 per joint) and ERT/FO cables on opposite sides of the Boode casing. Filled the first joint with water and RIH. Ran the 2 additional joints and set at 15.0 m and secured at surface.	Note: TH0404 - permanent casing was installed to 15.0 m. 2 cables, (one Fibre Optic and one ERT) are attached to the outside of the 200 mm OD permanent PVC casing which is grouted in position. Note: It was decided to run 7'' temporary casing to increase annular velocity and add polymer to the mud to increase the carrying capacity to try to lift sediment from the bottom of the hole.	
15/02/23	15.0 m	Marriotts performed crosswire check before rigging up the grouting equipment. Grouted 200 mm intermediate casing as follows: • 10:20 hrs pumped 1st mix @ 1.68 sg • Pulled back 1 ½ lengths of tremie pipe. • 10:30 hrs pumped 2nd mix @ 1.67 sg • Pulled back 1 length of tremie pipe • 10:40 hrs pumped 3rd mix @ 1.69 sg • Pulled back 1 length of tremie pipe • 10:57 hrs pumped 4th mix @ 1.70 sg • Pulled back 1 length of tremie pipe • 11.07 hrs pumped 5th mix @ 1.68 sg • Pulled back 1 length of tremie pipe • 11:22 pumped 6th mix @ 1.70 sg	Each grout mix = 100 L water with 7.5 bags of Geotherm X grout.	Observed 200 mm Boode casing becoming neutrally buoyant. Filled casing with water and installed clamp around the casing. Lowered rig clamp on top to prevent upward movement during grouting.

Date	Depth M BGL	Operation	Parameters	Issues
		Observed good grout returns at the top of the 24'' surface casing and stopped pumping grout after 6 mixes. Pulled back final length of tremie pipe. Weighed down casing with sandbags to prevent possible upwards movement during the grout setting time due to buoyancy. Lowered mast and moved Soilmec rig off location and over to TH0405. Bailed out excess grout from inside the 24'' surface casing to lower the level to approximately 1.0 m below top of casing.		
18/04/23	15.0 m	Moved rig back over TH0404 and rigged up. RIH with rotary bit and drilled through the shoe of the 200 mm OD Boode casing. POOH with rotary assembly.	Casing ID 180 mm so no requirement for temporary 7" casing to be run.	
19/04/23	100.5 m	RIH with 152 mm Geobore assembly and commenced coring the lower section from 16.25 m to 100.5 m. Returns lost initially at 26.0 m, partially regained at 29.7 m and then lost totally from 43.2 m. Circulated well for 20 minutes once TD reached before pulling back Geobore string off bottom.	Flush returns lost at 43.2 m. Verticality checks: Survey interval from 12.0 m to 46.2 m. 0.24 deg @ 19.2 m 0.31 deg @ 22.2 m. 0.16 deg @ 28.2 m. 0.09 deg @ 34.2 m. 0.23 deg @ 40.2 m. 0.20 deg @ 46.2 m. 0.35 deg @ 58.2 m. 0.09 deg @ 70.2 m. 0.47 deg @ 82.2 m. 0.32 deg @ 88.2 m. 0.54 deg @ 100.2 m.	Diver logger deployed in TH0412 to monitor for possible fluid communication between TH0404 and TH0412.
20/04/23	100.5 m	POOH coring assembly and laid out. Moved rig from TH0404 to TH0415.		
27/04/23	100.5 m	EGS mobilised to site and rigged up over the well and a gyro survey was run to confirm the inclination and trajectory of the borehole. No other tools were run. EGS rigged down.	Gyro survey undertaken.	
TH0404 casing shoe issue / sleeve casing				
30/05/23	100.5 m	EGS mobilised back to site and rigged up over the well. A downhole camera was deployed to get a clear image of the status of the intermediate casing shoe. Casing shoe partially backed out / detached, grout collar preset inside shoe, no cement below. EGS rigged down.		See **Section 4.25** issues encountered and solutions for full details on detached shoe.
27/06/23	100.5 m	Moved rig over and setup.		

Date	Depth M BGL	Operation	Parameters	Issues
		Commence running in s stepped drag bit assembly on drill rod to remove the cement collar from inside the shoe. Tagged top of cement inside detached collar. Succeeded in knocking the cement out of the shoe before working the stepped drag bit downwards and generating a socket for the sleeve casing to 15.58 m. POOH.		
28/06/23	100.5 m	Made up and RIH 165 mm OD sleeve casing with 175 mm OD A type socket at base and set at 15.58 m into socket made by drag bit. Secured at surface.	Sleeve Casing: OD 165 mm ID 155 mm B type (upset). A type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID.	
29/06/23	100.5 m	Ran the Marriotts downhole camera into the well to confirm status of sleeve casing. Ran down to the base of the casing sleeve. Video showed the casing is fully centralised in the well. Sleeve casing accepted by BGS.		
TH0404 FLUTe liner install				
20/07/23	99.86 m	Well dipped at 99.86 m. Rigged up Green Machine for running FLUTe liner. Ran liner in hole as per manufacturers procedure, filling with clean water from surface to 99.86 m. Anchored the tether and rigged down Green Machine.		
TH0404 complete				

4.23 UNCASED BEDROCK BOREHOLE – TH0405 SUMMARY OF OPERATIONS

4.23.1 Key Well Data

Table 100 TH0405 Key well data

Well name	TH0405		
Well classification	Uncased Bedrock Borehole		
Depth measurement units	Metres		
Depth reference point	Top of 24" casing		
Depth reference details	Top 24" depth ref - 20.018 m AOD Top 24" to GL - 0.130 m		
Start date	Intermediate section started on the 06/02/23 and completed on 07/02/23. Lower section started on the 04/05/23.		
End of drilling date	05/05/23.		
Install dates	26/07/23 (post drilling)		
Casing & Drilled Hole Depths			
Hole section and size	**Drilled depth (m BGL)**	**Casing size**	**Casing shoe depth (m BGL)**
Top hole n/a	n/a	24" Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 311 mm	Cored to 16.1 m Reamed to 15.0 m	8" Boode PVC casing 200 mm OD 180.8 mm ID	15.0 m (14.7 m without shoe after failure)
Sleeve casing	n/a	Sleeve Casing OD 165 mm ID 155 mm Boode B type (upset) PVC casing.	19.55 m
Final section to TD Cored in 152 mm	100.5 m	n/a	n/a
Installation	n/a	FLUTe liner – 6" / 840 denier liner	100.0 m
Surface Location Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344953.256 Northing Y: 375823.895		
Ordnance Survey Grid Reference	Latitude N: 53°16′35″ Longitude W: 002°49′37″		
12 Character National Grid Reference	SJ 44953 75824		
Well TD Coordinates:			
Easting / Northing (OS GRID)	Easting X: 344953.31 Northing Y: 375824.06 Step out - 0.17 m (inclination 0.1 deg / azimuth 330 deg)		

4.23.2 Summary of Drilling Operations

Operations on TH0405 commenced on the 06th February 2023. The rig and associated equipment was rigged up and a string of 7” temporary casing run and centralised within the 24” surface casing. This was sealed at the base with Bentonite pellets. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 16.1 m with full returns throughout and no LCM pills deployed. Verticality surveys were taken with all readings within tolerance. The hole was circulated clean before POOH the assembly and recovering the temporary casing.

The hole was opened out down to 15.0 m using a 311 mm (12 ¼”) reamer assembly and circulated clean. No reported fluid losses occurred during this operation.

Operations on TH0405 were suspended on the 8th February due to a failure of the mud pump seals on the Soilmec rig.

Work recommenced on the 15th February 2023 with the 311 mm reamer assembly being picked backup and RIH to perform a wiper trip. The string was worked down to 15.5 m before circulating. The well was dipped at 16.0 m (cored sump) which was satisfactory for the installation of the intermediate casing. The string was recovered and laid down.

A string of permanent PVC intermediate (200 mm OD x 180.8 mm ID) casing was run to 15.0 m (0.5 m off bottom) with both ERT and fibre optic cables attached to the outside. The casing was centralised in the well with plastic centralisers (2 x per joint).

The annulus was grouted using thermally enhanced grout which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water. This produced a grout with a minimum weight of 1.67 sg. Grout returns were observed inside the 24” surface casing after 6.25 mixes had been pumped. Grouting operations were stopped, the tremie pipe recovered and excess grout was bailed out of the surface casing to put the TOC at circa 1.0 m below GL. Full details of this operation can be found in the daily activity summary.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe run on the outside of the casing. Dry and wet samples of grout were taken as per the specification.

Grouting operations were completed on the 16th February 2023. The rig was moved off location once the intermediate casing had successfully been grouted.

The rig was moved back over TH0405 on the 03rd March 2023 and a rotary assembly was RIH to drill out the shoe track (cement plug pre-installed in the shoe joint). Once through the assembly was recovered and the 152 mm Geobore S coring assembly was made up and RIH. The well was advanced coring ahead to 100.5 m with a reduction in returns from 30.0 m and no returns by 43.2 m. Core recovery was poor in the top section down to circa 32.0 m and then again deeper in the well from 58.0 m to 63.0 m (core very fractured containing large pebble). No drilling issues, verticality issues, overpulls or tight spots were reported.

Figure 121 Lefthand image shows the 152 mm Geobore assembly, righthand image shows the fracture sandstone at circa 63.0 m.

The well was circulated before POOH the coring assembly and laying down. The rig was moved off location on the 09th March 2023.

4.23.3 Sleeve casing installation

On the 30th May 2023 EGS were mobilised to site, and a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the casing shoe had become fully detached and dropped with no grout present around the shoe joint, see images in **Section 4.25**.

The rig was moved back over TH0405 on the 19th June 2023 and prepared for sleeving operations. Made up and RIH 3 x joints of sleeve casing (pin down) plus a 1.0 m pup joint. The sleeve casing run was Boode PVC 165 mm OD x 155 mm ID, B Type upset jointed casing. The casing didn't land off at the shoulder and continue to RIH. Decision taken to recover the casing and run box down, but the casing still did not shoulder out. The gauge of the open hole should be 152 mm however the upset box of the sleeve casing at 165 mm was seeing no resistance when RIH. Operations suspended to allow a forward plan to be formulated.

The Marriotts downhole camera was deployed to the base of the sleeve casing to confirm the status, but it was difficult to gauge. The decision was taken to add additional joints of sleeve casing and continue to RIH. The string was advanced down to 34.0 m and still advancing so the operation was stopped and the sleeve casing recovered.

A larger belled out shoe (A type socket) was added to the sleeve casing which had an OD of 175 mm. The sleeve casing was re-run and held up at 15.51 m. The string was secured at surface and the Marriotts downhole camera was deployed. The image showed the casing was sitting slightly off centre but acceptable as access into the lower section wasn't impeded.

The sleeve casing was cut down to the required height but during this process the string dropped circa 1.0 m indicating the A type socket was not holding. The risk of the string being lost in the well was high if not repositioned. An additional joint of sleeve casing was made up and the casing advanced to 19.55 m where it held up. The casing was secured with a Speedclamp. The camera was rerun, and no obvious ledge or protrusion was seen that the casing was sitting on, but it did appear the sleeve was wedged in the open hole section. A short section of casing was added to the top to bring the top of casing to 350 mm below GL.

In addition to the Speedclamp and as extra security 4 x bolts were installed through the sleeve casing, above the casing clamp to prevent it moving / dropping further into the well. The rig was moved off location on the 20th July 2023.

4.23.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0405 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 101 Drilling fluid summary table – TH0405

	TH0405
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	240
Ultrabore additive lost (kg)	3.4
Purebore additive lost (kg)	1.4

Once the intermediate section had been drilled the well was cased with 200 mm OD x 180.8 mm ID Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section and water used throughout.

No LCM pills were deployed in this well.

4.23.5 Geophysical Logging Undertaken

Table 102 Geophysical logging summary TH0405

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD. (02/06/23)	Gyro survey

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.17 m and within the 1/100 tolerance.

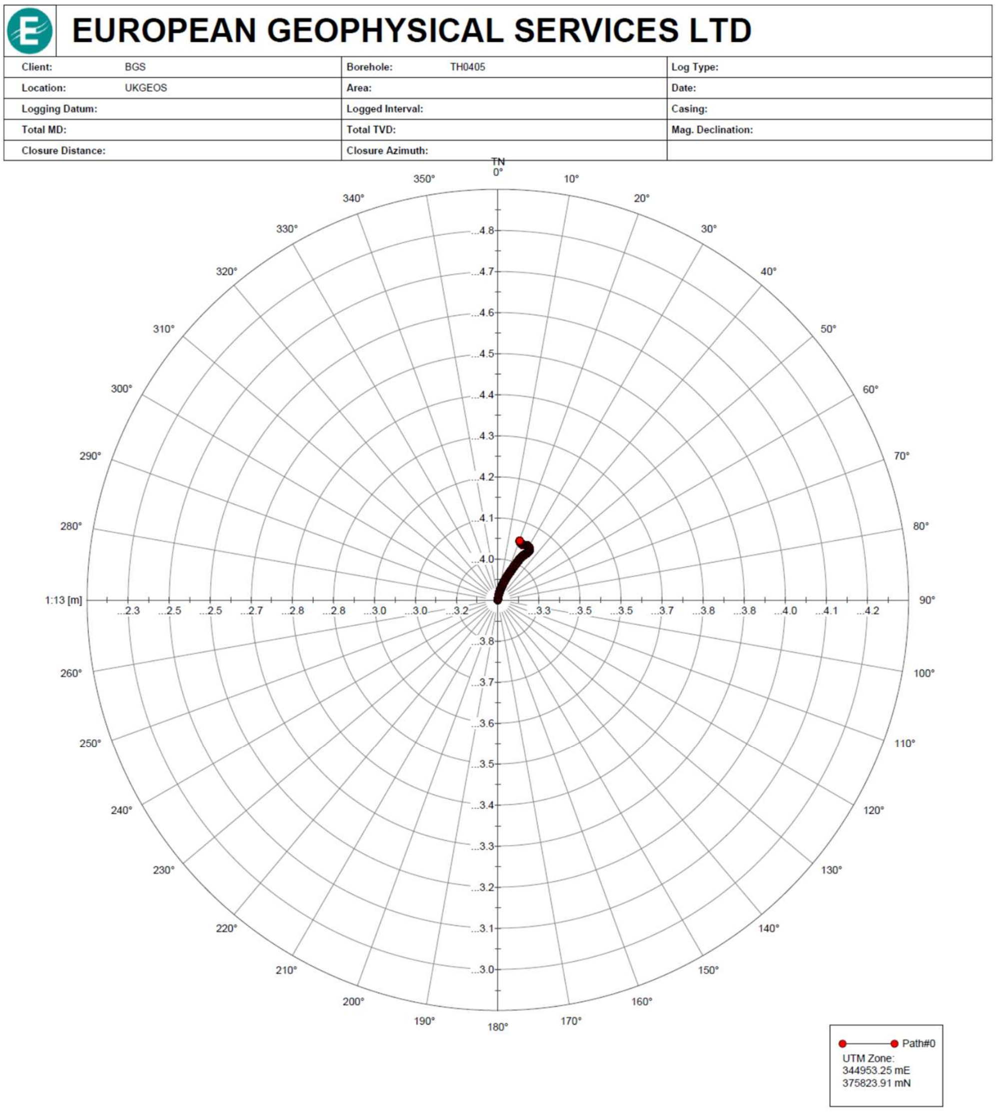


Figure 122 Verticality bullseye plot for TH0405, © European Geophysical Services Ltd

4.23.6 Summary of Installation Operations

Installation criteria for TH0405:

- Deploy a FLUTe liner to seal the well and prevent vertical flow in the borehole.
- Protect the borehole for future research opportunities.

Summary of operations:

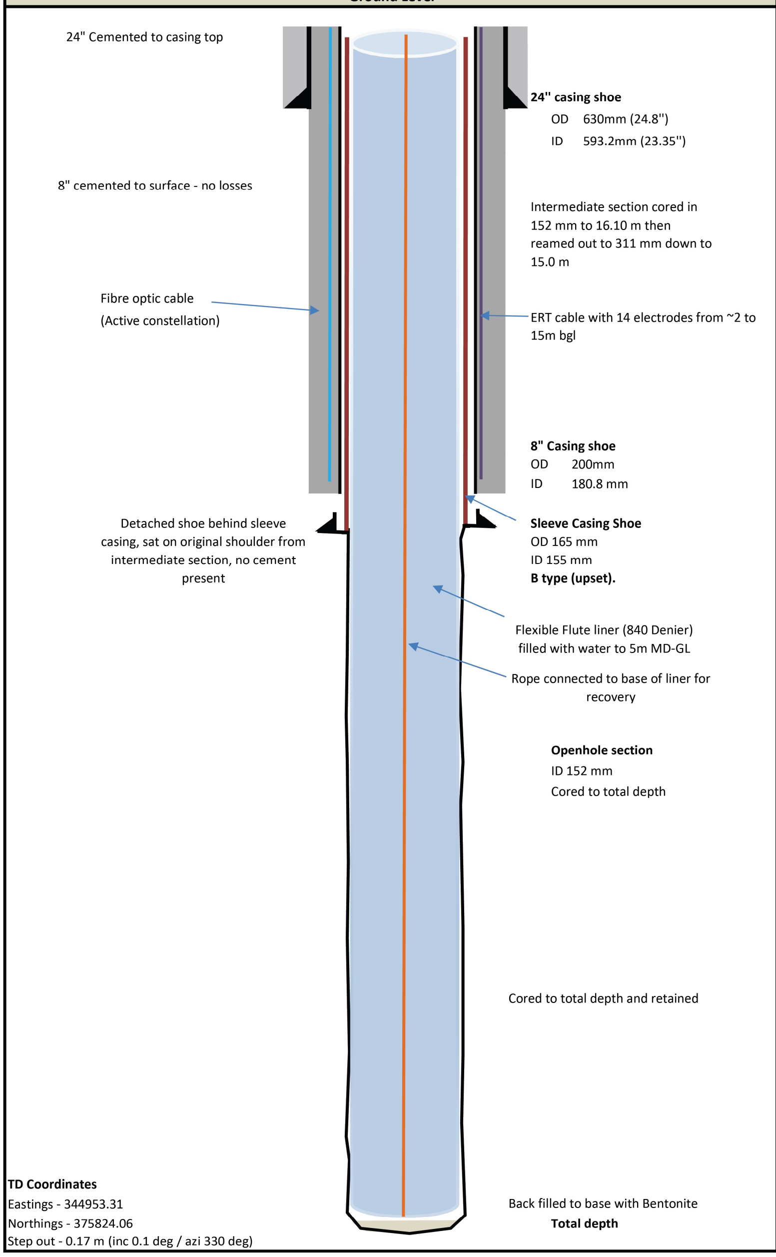
The Green Machine and associated equipment needed for the deployment was rigged up and a toolbox talk with all parties held before commencing. Bentonite was introduced into the well to bring the base of the borehole up to 100.0 m. The FLUTe liner was installed without issue as per the manufacturer's instructions to 100.0 m. The liner and tether were secured at surface before making the well safe and rigging down.

Figure 123 Green machine installed over the well during FLUTe liner deployment.

4.23.7 TH0405 Borehole Well Schematic

Borehole coordinates: Eastings - 344953.256, Northings - 375823.895, Top 24" depth ref - 20.018 m AOD, Top 24" to GL - 0.130 m	Well Schematic TH0405 Uncased Bedrock Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD	Gyro survey



Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
	Core not retained in upper section just photos taken onsite
14.7 m	End of intermediate casing without shoe
19.55 m	A type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID
	7.9 mm either side of sleeve casing
100 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

Figure 124 TH0405 Well Schematic

4.23.8 Wellhead / Well Chamber Status

Figure 125 Wellhead chamber image TH0405

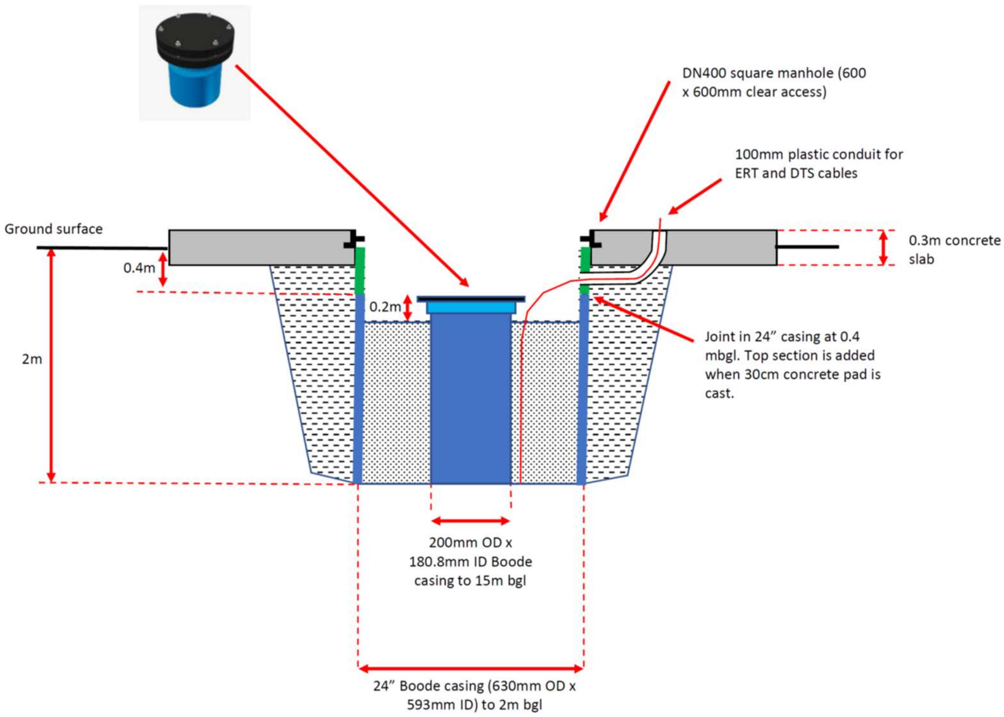


Figure 126 Wellhead chamber schematic TH0405

4.23.9 Daily Activity Summary

Table 103 Daily activity summary TH0405

Date	Depth M BGL	Operation	Parameters	Issues
06/02/23	13.1 m	Moved the Soilmec rig from TH0409 and positioned over TH0405. Raised mast. Ran temporary 7" casing centralised inside the 24" to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Established circulation with drilling mud. Cored from 2.0 m to 13.1 m. 100% returns.	Verticality checks: 0.28 deg @ 4.1 m. 0.19 deg @ 10.1 m. 0.29 deg @ 13.1 m.	Issue with latching core barrel. Had to POOH with Geobore and recover the core from outer barrel manually. Note: Core from TH0405 was not in Scope to be retained.
07/02/23	16.1 m	Continued coring with 152 mm Geobore from 13.1 m to 16.1 m. No mud losses. No LCM pills used. Circulated the hole clean and POOH the Geobore assembly. Made up and RIH a 311 mm (12 ¼") reaming assembly and opened out the hole from 2.0 m to 15.0 m. Circulated clean before POOH the reamer and laid down.	Verticality checks: 0.2 deg @ 16.1 m.	
08/02/23	16.1 m	Carried out repair work on Soilmec rig, replacing seals on the mud pump. Moved rig from TH0405 to TH0404.		
15/02/23	16.0 m	Set the Soilmec rig back over TH0405. Mixed new polymer mud. Picked up 311 mm reaming assembly and RIH on drill rods to clean out the well. Worked down to 15.5 m. Circulated hole clean. Dipped the hole at 16.0 m (into cored sump) – satisfactory for install. RIH tremie pipe and set up cable drums and scaffolding tower for the installation. Picked up the first 200 mm OD PVC casing joint into the mast using lifting head and winch. Installed centralisers (2 per joint) and ERT/FO cables on opposite sides of the Boode casing. Filled the first joint with water and RIH. Ran the 2 additional joints and set the shoe at 15.0 m (0.5 m off bottom) and secured at surface.	Note: TH0405 - permanent casing was installed to 15.0 m. 2 cables, (one Fibre Optic and one ERT) are attached to the outside of the 200 mm OD permanent PVC casing which is grouted in position.	
16/02/23	15.0 m	Rigged up grout hose from mixer to TH0405. Commenced mixing and pumping grout batches to fill the annulus between 200 mm Boode casing and the 311 mm open hole. Pumped 6 ¼ x 100 L mixes to bring the grout back to surface. Pulled back 1 joint of tremie pipe after pumping each batch. Weight of mixes: **Mix 1**: 1.68 sg **Mix 2**: 1.69 sg **Mix 3**: 1.69 sg	Each grout mix = 100 L water with 7.5 bags of grout powder.	

Date	Depth M BGL	Operation	Parameters	Issues
		Mix 4: 1.70 sg **Mix 5**: 1.68 sg **Mix 6**: 1.68 sg **Mix 6.25**: 1.68 sg Observed good grout returns at the top of the 24'' surface casing and stopped pumping grout after 6.25 mixes. Pulled back final length of tremie pipe. Bailed out excess grout from inside the 24'' surface casing to lower the level to approx. 1.0 m below top of casing.		
03/05/23	15.0 m	Moved rig back over TH0405 and rigged up.	Casing ID 180 mm so no requirement for temporary steel 7" casing to be run.	
04/05/23	58.2 m	Levelled the rig, filled tanks and positioned equipment ready to commence coring. RIH with rotary bit and drilled through concrete shoe of the 200 mm OD intermediate Boode casing. POOH with rotary assembly. RIH with 152 mm Geobore assembly and commenced coring the lower section from 16.25 m to 58.2 m. Flush returns decreased with depth, 60% at 30.0 m, 40% at 34.0 m, 30% at 35.0 m, 10% at 41.0 m and zero returns below 43.2 m.	Verticality checks: 0.37 deg @ 19.2 m 0.32 deg @ 22.2 m. 0.43 deg @ 28.2 m. 0.45 deg @ 35.7 m. 0.41 deg @ 40.2 m. 0.05 deg @ 46.2 m. 0.03 deg @ 52.2 m. No returns from 43.2 m.	Very poor rubbly core recovery in the top section of the well. Core recovery improved below 32.0 m, full 1.5m being recovered.
05/05/23	100.5 m	Continued coring the lower section from 58.2 m to 100.5 m with no returns. Zero core recovery from 58.2 m to 59.7 m 50% core recovery from 59.7 m to 61.2 m Approx. 1.4 m of core recovered between 61.2 m and 62.7 m but core very fractured. Once TD reached well circulated before pulling back the Geobore string to 49.0 m.	Verticality checks: 0.15 deg @ 62.7 m. 0.27 deg @ 76.2 m. 0.35 deg @ 88.2 m. 0.28 deg @ 100.2 m.	The core is very fractured, sometimes containing large pebbles and the RPM had to be reduced at times due to excessive string juddering.
09/05/23	100.5 m	POOH coring assembly and laid out. Lowered mast and moved the rig off location.		
TH0405 casing shoe issue / sleeve casing				
30/05/23	100.5 m	EGS mobilised to site and rigged up over the well. Downhole camera deployed to get clear images of the status of the shoe. Casing fully detached and dropped, no grout present around the shoe joint. EGS rigged down.	Reviewed the camera footage and formulated a plan to resolve.	See **Section 4.25** issues encountered and solutions for full details on detached shoe.
02/06/23	100.5 m	EGS mobilised to site and rigged up over the well and performed trajectory survey.		Unable to produce bullseye plot of trajectory due to missing software module. To be

Date	Depth M BGL	Operation	Parameters	Issues
				produced by EGS on return to the office.
19/06/23	100.5 m	Moved rig over and setup. RIH with 3 joints of sleeve casing pin down plus a 1.0 m length. Unable to land out, the casing was passing through into the open hole. POOH and re-ran the casing box down but the casing still did not shoulder out. Installed clamp and held casing in winch pending further operations.	Sleeve Casing Shoe OD 165 mm ID 155 mm B type (upset).	Gauge of open hole section larger than expected, drilled with 152 mm bit however 165 mm seeing no resistance.
20/06/23	100.5 m	Ran Marriotts downhole camera down to beyond the base of the sleeve casing to confirm status. Video captured before POOH.		
21/06/23	100.5 m	Continue to work sleeve casing in hole to 24.0 m, still with no resistance. Decision taken to add an additional 5.0 m length and RIH to 29.0 m and re access. No resistance so continued in hole to 34.0 m and still advancing so operation stopped. Decision taken to pull all the sleeve casing out whilst waiting on a decision. Rig moved off location.		
28/06/23	100.5 m	Rigged up over well with the Comacchio rig. RIH sleeve casing with larger OD ‘belled out’ shoe (A Type socket with 175 mm OD). Sleeve casing held up at 15.51 m. Secured at surface.	Sleeve Casing: OD 165 mm ID 155 mm B type (upset). A Type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID.	
29/06/23	100.5 m	Ran the Marriotts downhole camera into the well to confirm status of sleeve casing. Ran down to the base of the casing sleeve. Video show the casing to be slightly off centre but acceptable.		
11/07/23	100.5 m	Cut down casings as per plan in TH0405. Observed the sleeve casing drop approximately 1.0 m. A Type socket was not holding. Risk the string could drop if not repositioned.		Sleeve casing has dropped 1.0 m.
14/07/23	100.5 m	Positioned the telehandler over the well (night shift) and attached an additional joint of sleeve casing and lowered to 19.55 m where it held up. Secured sleeve casing with Speedclamp. Ran camera in and checked the area where the casing is seated. No obvious protrusion for the casing to sit on or fracture visible. It appears that the sleeve is wedged into the open hole.		
20/07/23	100.5 m	Added a short section to the sleeve casing in TH0405 to bring the top of the casing up to 350 mm below GL. Lifted casing using Telehandler and drilled/Installed 4 x bolts at 90 deg intervals on the sleeve casing just above the casing clamp to prevent any movement of the casing downhole.		

Date	Depth M BGL	Operation	Parameters	Issues
		Lowered the casing back down to original position at 19.55 m. Installed wellhead cover.		
TH0405 FLUTe liner install				
26/07/23	100.0 m	Rigged up Green Machine for running the FLUTe liner. Back filled the borehole with Bentonite to 100.0 m. Installed the FLUTe liner as per manufacturer's instructions. Final stage of install resulted in dip tape becoming caught around the tether rope. Managed to pull the liner back to surface by circa 6.0 m and removed. An air lift was attempted to reduce the head before pulling but this was unsuccessful. Anchored the tether and rigged down the Green Machine.		
TH0405 complete				

4.24 UNCASED BEDROCK BOREHOLE – TH0415 SUMMARY OF OPERATIONS

4.24.1 Key Well Data

Table 104 TH0415 Key well data

Well name	TH0415
Well classification	Uncased Bedrock Borehole
Depth measurement units	Metres
Depth reference point	Top of 24” casing
Depth reference details	Top 24" depth ref - 20.496 m AOD Top 24" to GL - 0.118 m
Start date	Intermediate section started on the 17/02/23 and completed on 09/03/23. Lower section started on the 20/04/23.
End of drilling date	24/04/23.
Install dates	24/07/23 (post drilling).

Casing & Drilled Hole Depths

Hole section and size	Drilled depth (m BGL)	Casing size	Casing shoe depth (m BGL)
Top hole n/a	n/a	24” Boode PVC casing 630 mm OD 593.2 mm ID	2.0 m
Intermediate section Cored in 152 mm then opened out to 311 mm	Cored to 16.10 m Reamed to 15.5 m	8” Boode PVC casing 200 mm OD 180.8 mm ID	15.5 m
Sleeve casing	n/a	Sleeve Casing OD 165 mm ID 155 mm Boode B type (upset) PVC casing.	15.46 m
Final section to TD Cored in 152 mm	100.4 m	n/a	n/a
Installation	n/a	FLUTe liner – 6” / 840 denier liner	99.86 m

Surface Location Coordinates:	
Easting / Northing (OS GRID)	Easting X: 344930.933 Northing Y: 375869.656
Ordnance Survey Grid Reference	Latitude N: 53°16′37″ Longitude W: 002°49′38″
12 Character National Grid Reference	SJ 44931 75870
Well TD Coordinates:	
Easting / Northing (OS GRID)	Easting X: 344930.28 Northing Y: 375869.38 Step out - 0.71 m (inclination 0.9 deg / azimuth 184 deg)

4.24.2 Summary of Drilling Operations

Operations on TH0415 commenced on the 17th February 2023. The Soilmec rig and associated equipment was rigged up and a string of 7” temporary casing run and centralised within the 24” surface casing. This was sealed at the base with Bentonite pellets. Temporary casing was used to ensure the centre of the hole is drilled and to maintain verticality and assists centralisation of the drilling assembly.

A polymer mud system was prepared to firstly aid in cuttings removal and secondly to allow simultaneous drilling operations to occur onsite. The original Scope only allowed for a single borehole to be drilled at any one time and should be completed before moving to the next location. This was relaxed for the upper section only due to programme time concerns. The use of drilling mud mitigated the risk of communication between wells reducing the risk of becoming stuck because of sediment flowing between boreholes due to their proximity. A mud system has a much greater carry capacity for cuttings and sediment removal than water alone and the polymers helps to seal the shallow fractures. The upper section was only instructed to be drilled in this way and before the lower section was drilled all mud had to be displaced out and switched to water only.

Made up and RIH the 152 mm Geobore S coring assembly and cored from 2.0 m to 16.1 m with full returns throughout and no LCM pills deployed. Verticality surveys were taken with all readings within tolerance. The hole was circulated clean before POOH the assembly and recovering the temporary casing.

The hole was opened out down to 15.5 m using a 311 mm (12 ¼”) reamer assembly and circulated clean. No fluid losses were reported during this operation.

Operations on TH0415 were suspended whilst the rig was moved to TH0406 on the 22nd February 2023.

Work recommenced on the 07th March 2023 and the borehole dipped to 14.8 m. The decision was taken to run a cleanout assembly comprising of a 6” (150 mm) drill bit on drill rods. The assembly was washed down to bottom at 16.1 m. No resistance was seen washing to bottom. The well was circulated with clean polymer mud with some sediment seen over the shakers. POOH the cleanout assembly.

The well was allowed to settle and dipped at 14.2 m. A string of 7” casing was RIH to 15.5 m and the well circulated again with viscosified drilling mud. The string of casing was POOH and the well dipped to 15.4 m which was satisfactory for the installation of the intermediate casing.

A string of permanent PVC intermediate (200 mm OD x 180.8 mm ID) casing was run to 15.0 m (0.5 m above shoulder) with both ERT and fibre optic cables attached to the outside. The casing was centralised in the well with plastic centralisers (2 x per joint) and secured at surface.

A crosswire check was undertaken on the intermediate casing to confirm it was vertical before grouting in place. Both the ERT and fibre optics cables were surface tested and confirmed good.

The annulus was grouted using thermally enhanced grout which satisfied the Specification for the intermediate casing string. The grout product used was “Geotherm-X GR,” which was mixed with water to a ratio of 7.5 bags (24 kg) to 100 L of water. This produced a grout with a minimum weight of 1.67 sg. A total of 3 x 100 L mixes were pumped to bring the grout level back to surface in the annulus. Full details of this operation can be found in the daily activity summary.

Grout was delivered from the bottom of the well, via a retractable 40 mm tremie pipe run on the outside of the casing. Dry and wet samples of grout were taken as per the specification. Grouting operations were completed on the 09th March 2023 and the rig moved off location.

The rig was moved back over TH0415 on the 20th April 2023 and a rotary assembly was RIH to drill out the shoe track (cement plug pre-installed in the shoe joint). Once through the assembly was recovered and the 152 mm Geobore S coring assembly was made up and RIH. The well was advanced coring ahead to 100.4 m with returns being lost at 23.9 m and higher inclinations readings from 60.0 m which were above the set tolerance. No drilling issues, overpulls or tight spots were reported.

The well was circulated before POOH the coring assembly and laying down. The rig was moved off location on the 24th April 2023.

Figure 127 E-Totoc survey being taken

4.24.3 Sleeve casing installation

On the 30th May 2023 EGS were mobilised to site, and a downhole camera was RIH to check the condition of the intermediate casing for damage and noticed the casing shoe was still attached, grout partially present with evidence of detached blocks of grout indicating a poorly cemented shoe, see images in **Section 4.25**.

The rig was moved back over TH0405 on the 15th June 2023 and prepared for sleeving operations. Made up and RIH 3 x joints of sleeve casing (pin down) plus a 2.0 m pup joint. The sleeve casing run was Boode PVC 165 mm OD x 155 mm ID, B Type upset jointed casing. The casing didn't land off and continue to RIH. The casing was secured with 16.55 m in the ground whilst a forward plan could be determined. Decision taken to recover the casing and run box down (upset coupling). The casing was rerun and successfully landed off on the shoulder at 15.46 m. The casing was secured with a Speedclamp.

The Marriotts downhole camera was deployed to inspect the status of the sleeve casing. The images showed the casing was sitting slightly off centre but acceptable as access into the lower section wasn't impeded.

The sleeve casing was cut down to the required height, and the rig was moved off location on the 11th July 2023.

4.24.4 Materials, Flush and Drilling Additive Used

The intermediate section of TH0415 was drilled with a polymer mud system to allow two wells to be drilled simultaneously onsite. This reduced the risk of cross borehole flow due to the close well spacing and reduced the risk of sediment / cuttings flowing into the adjacent borehole.

Table 105 Drilling fluid summary table – TH0415

TH0415	TH0405
Type of drilling mud used	Polymer mud
Section of well used	Intermediate section only
Recorded drilling mud losses (L)	240
Ultrabore additive lost (kg)	3.4
Purebore additive lost (kg)	1.7

Once the intermediate section had been drilled the well was cased with 200 mm Boode casing to 15.0 m and cemented in place. The well was then displaced to clean water before drilling out the casing shoe and starting the lower section. No additives or polymers were introduced in the lower section and water used throughout.

No LCM pills were deployed in this well.

4.24.5 Geophysical Logging Undertaken

Table 106 Geophysical logging summary TH0415

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD. (27/04/23)	Gyro survey

The inclination of the well was checked once total depth had been achieved and this is shown in the bullseye plot below. The maximum step out recorded was 0.71 m and within the 1/100 tolerance.

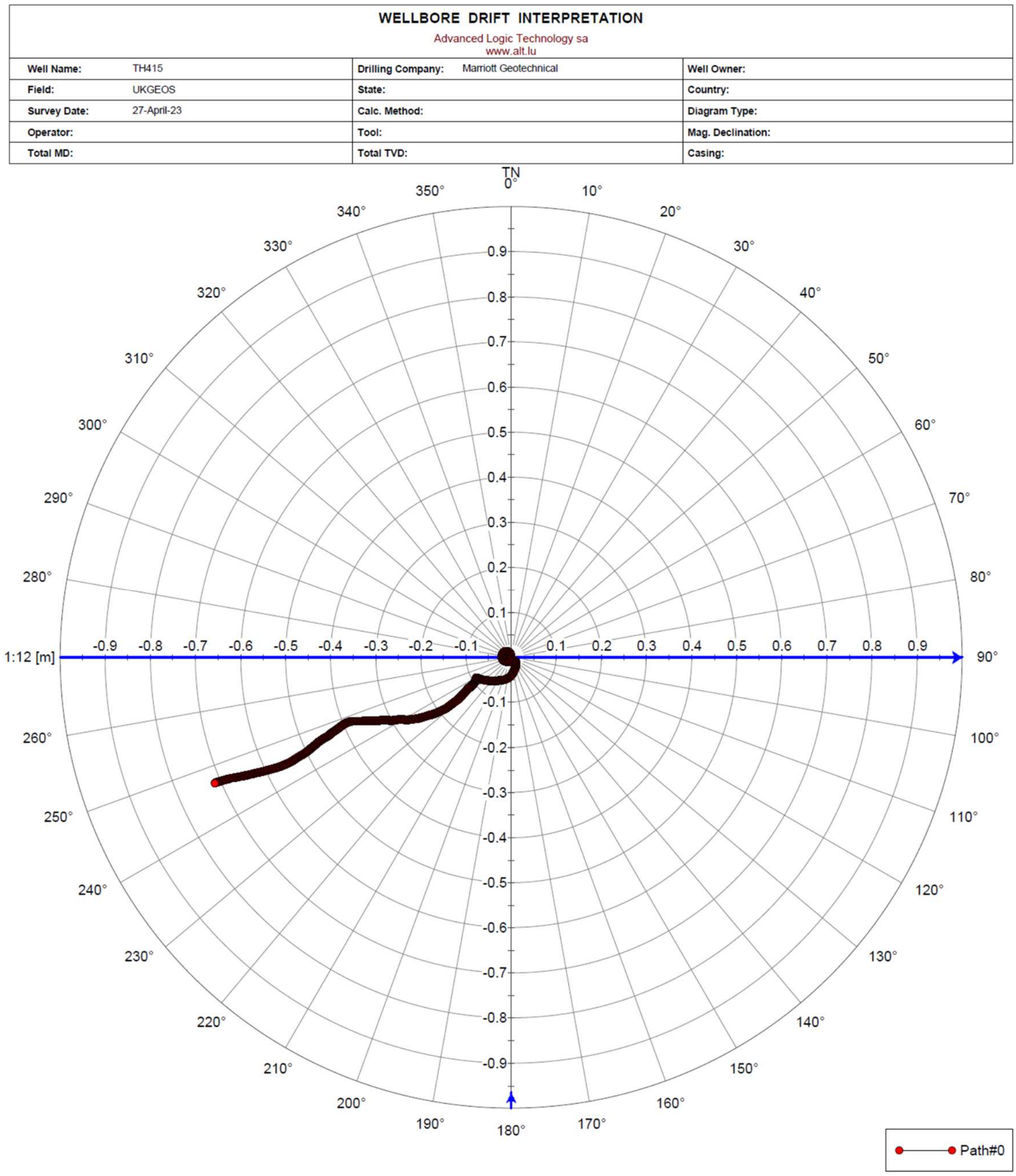


Figure 128 Verticality bullseye plot for TH0415, © European Geophysical Services Ltd

4.24.6 Summary of Installation Operations

Installation criteria for TH0415:

- Deploy a FLUTe liner to seal the well and prevent vertical flow in the borehole.
- Protect the borehole for future research opportunities.

Summary of operations:

The Green Machine and associated equipment needed for the deployment was rigged up and a toolbox talk with all parties held before commencing. The well was dipped at 99.86 m. The FLUTe liner was installed without issue as per the manufacturer's instructions to total depth. The liner and tether were secured at surface before making the well safe and rigging down.

4.24.7 TH0415 Borehole Well Schematic

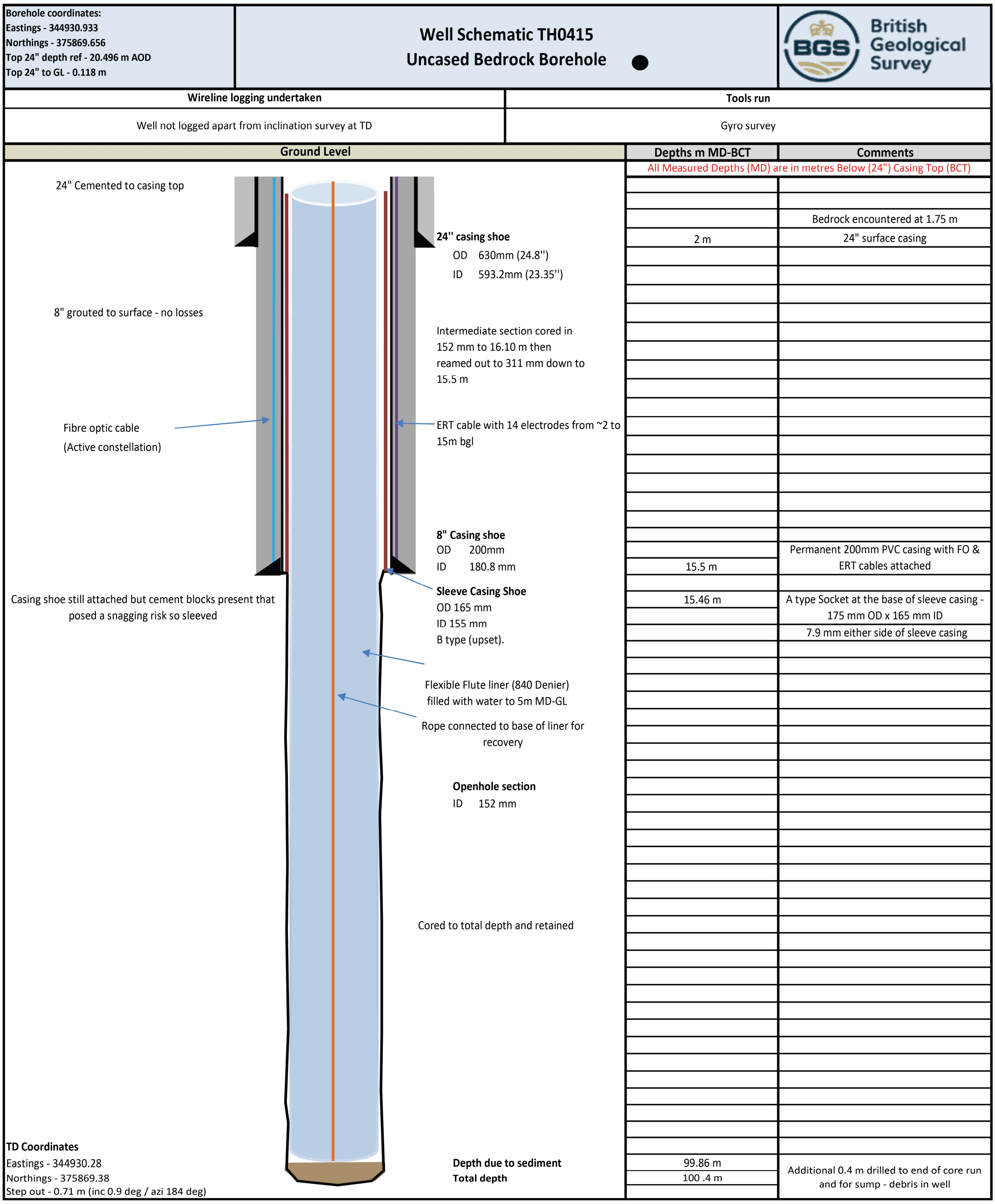


Figure 129 TH0415 Well Schematic

4.24.8 Wellhead / Well Chamber Status

Figure 130 Wellhead chamber image TH0415

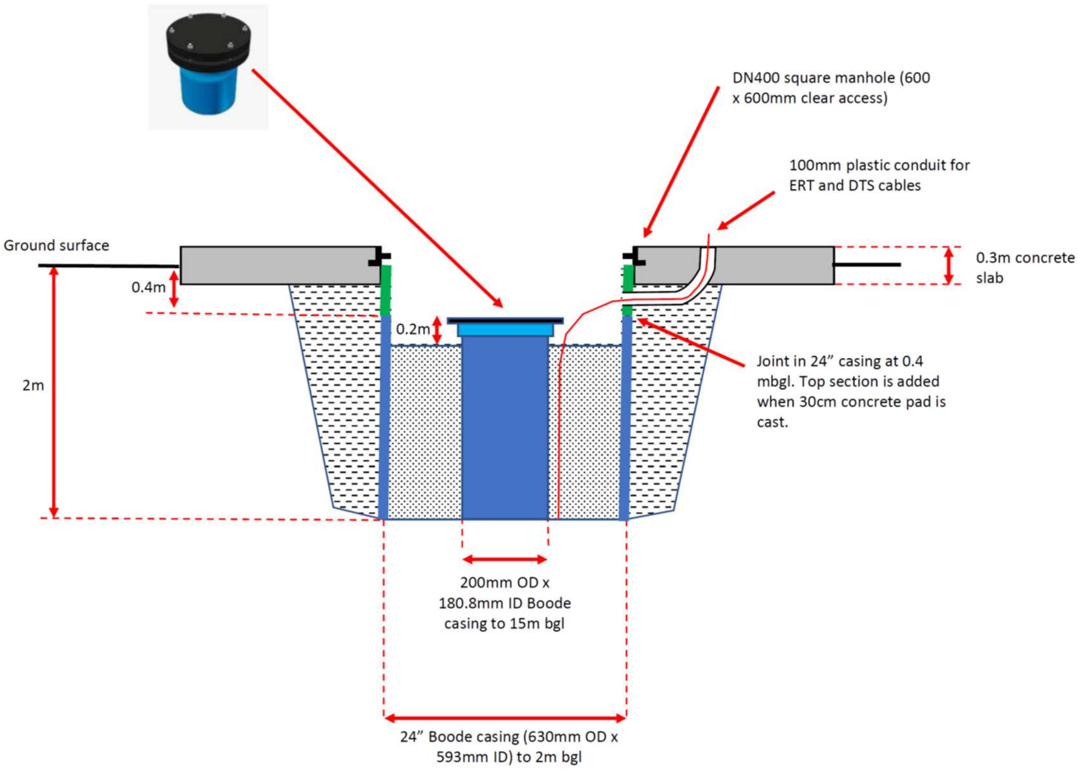


Figure 131 Wellhead chamber schematic TH0415

4.24.9 Daily Activity Summary

Table 107 Daily activity summary TH0415

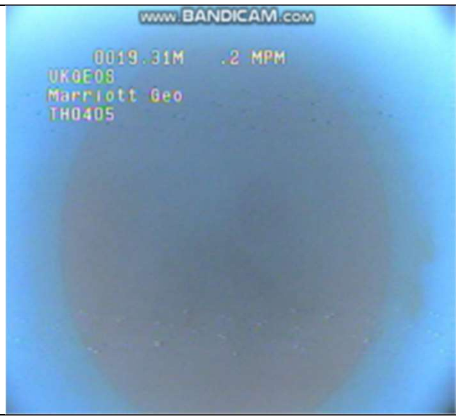
Date	Depth M BGL	Operation	Parameters	Issues
17/02/23	16.10 m	Moved Soilmec from TH0405 to TH0415 and set up over the well. Ran temporary 7" casing centralised inside the 24" surface casing to 2.0 m and sealed with Bentonite to the base. Prepared for coring operations. Established circulation with drilling mud. Cored from 2.0 m to 16.1 m. 100% returns. Circulated the hole clean before POOH.	Verticality checks: 0.61 deg @ 5.6 m. 0.16 deg @ 8.6 m. 0.34 deg @ 11.6 m. 0.48 deg @ 14.6 m.	
21/02/23	16.10 m	Made up and RIH a 311 mm (12 ¼") reaming assembly and opened out the hole from 2.0 m to 15.5 m. Circulated the hole clean, POOH reamer and laid down.		
22/02/23	16.10 m	Rigged down and moved Soilmec rig from TH0415 to TH0406.		
06/03/23	16.10 m	Well dipped at 14.8 m below top of 24'' surface casing. Moved Soilmec rig to TH0415, positioned over the well and raised the mast. Prepared for operations. Made up a 150 mm (6'') drill bit and RIH on drill rods and washed down to TD at 16.1 m. Circulated the hole clean with fresh polymer mud. Some sediment was circulated out but there was no resistance when washing in hole. POOH assembly.		Well dipped shallow resulting in cleanout trip being required.
07/03/23	15.5 m	Well dipped and found to be 14.2 m compared to 14.8 m prior to the cleanout trip. RIH with 7'' temporary casing to 15.5 m. Circulated the hole clean with fresh polymer mud before POOH.	TH0415 dipped shallow at 14.2 m, and it was decided to perform another cleanout trip with clean mud, this time using 7'' casing instead of drill rods to improve the annular velocity and lift more material from the well.	
08/03/23	15.4 m	Well dipped at 15.4 m. Moved cable reels to TH0415 and prepared for install. Picked up the first 200 mm PVC casing joint into the mast using lifting head and winch. Installed centralisers (2 per joint) and ERT/FO cables on opposite sides of the Boode casing. Filled the first joint with water and RIH. Ran the 2 additional joints and set at 15.0 m and secured at surface. Tested ERT and FO cables. All tested ok.	Intermediate casing: 200 mm OD 180.8 mm ID	

09/03/23	15.0 m	Ran crosswires to check casing verticality. Rigged up grout hose from mixer to TH0405. Commenced mixing and pumping Geotherm X grout in batches to fill the annulus between 200 mm Boode casing and the 311 mm open hole. Pumped 3 x 100 L mixes to bring the grout to surface. Pulled back 1 joint of tremie pipe after pumping each batch. Washed down the rig and grout mixing equipment. Lowered mast of Comacchio rig and prepared to move to next location (TH0417).	Each grout mix = 100 L water with 7.5 bags of grout powder.	
20/04/23	35.9 m	Moved the rig back over TH0415 and rigged up. Levelled the rig, filled tanks and positioned equipment ready to commence coring. RIH with rotary bit and drilled through concrete shoe of the intermediate 200 mm OD Boode casing. POOH with rotary assembly. RIH with 152 mm Geobore assembly and commenced coring the lower section from 16.1 m to 35.9 m.	Casing ID 180 mm so no requirement for temporary 7” steel casing to be run. Verticality checks: 0.39 deg @ 35.9 m. 0.47 deg @ 26.9 m. 0.45 deg @ 32.9 m. Returns lost at 23.9 m.	
21/04/23	95.6 m	Continued coring the lower section from 35.9 m to 95.6 m with no returns.	Verticality checks: 0.24 deg @ 38.9 m. 0.70 deg @ 44.9 m. 0.53 deg @ 50.9 m. 0.38 deg at 56.9 m. 0.62 deg @ 62.9 m. 0.59 deg @ 68.9 m. 0.83 deg @ 74.8 m. 0.73 deg @ 80.9 m. 0.86 deg @ 86.9 m. 0.79 deg @ 92.9 m	Monitoring of fluid levels ongoing between TH0415 and TH0404 with the logger in TH0404. Slight rise in fluid level reported in 404 possibly due to activity in TH0415. Higher than normal E-Totco readings experienced on this well below 60.0 m.
24/04/23	100.4 m	Continued coring the lower section from 95.6 m to 100.4 m with no returns. Circulated the hole before POOH the coring assembly and laid out. Lowered mast and moved Comacchio 405 from TH0415 to TH0414.	Verticality checks: 0.63 deg @ 98.9 m.	
27/04/23	100.4 m	EGS mobilised to site and rigged up over the well and a gyro survey was run to confirm the inclination and trajectory of the borehole. No other tools were run. EGS rigged down.	Gyro survey undertaken.	
TH0405 casing shoe issue / sleeve casing				
30/05/23	100.4 m	EGS mobilised back to site and rigged up over the well. Downhole camera deployed to get clear images of the status of the shoe. Casing shoe attached; grout partially present with evidence of detached blocks of grout / poor shoe cement job. EGS rigged down.	Review camera footage and formulate a plan to resolve.	See **Section 4.25** issues encountered and solutions for full details on detached shoe.

15/06/23	100.4 m	Moved rig from TH0406 to TH0415.		
16/06/23	100.4 m	Made up and RIH 3 x joints of sleeve casing pin down plus a 2.0 m length. Unable to land out, the casing continued to enter the lower open hole section. Operation stopped with the casing suspended / clamped and secured at surface with 16.55 m in the ground. Wait on decision on how to proceed. Decision taken to recover the casing and run the string box down as the casing has an upset. Casing ran in hole box down to 15.46 m and landed on a hard shoulder with 20 cm stickup. Total length of pipe run was 15.76 m (3 x full joints and a 1.0 m pup joint). Casing secured with a Speedclamp over the weekend until a decision on final securing method at surface is confirmed.	Sleeve Casing Shoe OD 165 mm ID 155 mm B type (upset).	Gauge of open hole section larger than expected, drilled with 152 mm bit however 165 mm seeing no resistance.
29/06/23	100.4 m	Ran the Marriotts downhole camera into the well to confirm status of sleeve casing. Ran down to the base of the casing sleeve. Video showed the casing to be slightly off centre but acceptable.		
11/07/23	100.4 m	Cut down casings as per plan.	The final headworks configuration is as follows: Top of grout ~1.0 m. Intermediate casing cut at 70 cm below GL. Sleeve casing cut at 37 cm below GL. This left enough room for a Speedclamp above the top of grout (clamp height 8 cm) and 25 cm stick up of the sleeve casing to accommodate the FLUTe liner.	
TH0415 FLUTe liner install				
24/07/23	99.86 m	Well dipped at 99.86 m. Rigged up Green Machine for running FLUTe liner and installed without issue as per the manufacturer's instructions. Anchored the tether and rigged down the Green Machine.		
TH0415 complete				

4.25 ISSUES ENCOUNTERED AND SOLUTIONS – UNCASED BEDROCK BOREHOLES

Table 108 Summary table of issues encountered – uncased bedrock boreholes

Well number	Issue	Solution / lessons learned
TH0404, TH0405 and TH0415. TH0424 drilled before main works (GI well) intact.	Failed casing shoes. See below for full details of each well and measures taken to resolve.	Shoes failed both when coring through and also reaming, not linked to reaming alone. It was noted during the that the temporary casing dropped when coring on at least one well which suggest the shoe had failed during this operation. Review methods of setting and grouting the casing for future operations. Review casing shoe (precast cement plug method) to see if a better option is available. Look to thread lock and also order a left-hand threaded shoe track. Set the casing in tension just off bottom, ensure tremie pipe is level with shoe, do not advance pilot hole deeper than instructed (0.5 m max) to avoid a large sump below that which will impact the cement job and quality.
TH0404	 Casing shoe partially backed out / detached, grout plug preset inside casing remains, no cement below.	 Sleeve casing run into socket made with drag bit, sleeve casing 165 mm x 155 mm ID.
TH0405	 Casing fully detached and dropped,	

	no grout present around the shoe joint.	Poor image but bell-shaped adaptor installed. RIH and seated at 19.55 m. A previous attempt to seat at 15.49 m saw the casing drop so the casing has been secured further at surface with bolts above the Speedclamp to avoid the string dropping. A Type socket at base (175 mm x 165 mm) sleeve casing 165 mm x 155 mm ID.
TH0415	 Casing shoe attached, grout partially present with evidence of detached blocks of grout / poor shoe.	 Sleeve casing seated at 15.46 m with A Type socket at base (175 mm x 165 mm) sleeve casing 165 mm x 155 mm ID.

5 Lessons Learned

This section details lessons learned from the Cheshire drilling programme in terms of successful vs unsuccessful strategies and approaches. The Observatory was installed to time and budget despite various technical and operational difficulties, and this was made possible by excellent project management, good communication and teamworking.

General lessons learned include the importance of working to detailed, mutually agreed RAMS and ensuring that all parties are working to the latest versions. Scenario planning and pre-install meetings were essential to avoiding delays to the drilling: for operations with higher technical risk a range of "what if" scenarios were developed to agree optimal responses in advance and avoid costly delays.

Drilling project delivery under the NEC4 contract framework was found to be highly demanding of staff resource due to the constant need for management of change, which is an inherent characteristic of drilling operations due to geological uncertainty. Attention to detail in management of change is valuable for keeping the project on track but must be adequately resourced in order for the NEC4 contractual framework to function effectively.

Tables 110 and **111** below detail the technical and operational lessons learned during the drilling programme.

Table 109 Technical lessons learned

Number	Item	Issue	Why	Solution
1	Successful installations performed safely.	None, good learning.	Good preplanning and detailed procedures (RAMs) produced for each install type. Anything that was questionable was trialled / tested before the installation commenced and solutions implemented.	Follow the same procedure for bespoke one-off installations.
2	Threading FO cable through heat exchanger.	None – believed to be the first time this has been done and was completed successfully without any issues.	Good communication and teamwork with all parties involves.	To send a thin Kevlar rope though by using an air compressor and rag on the end. Once this was passed through a larger rope was pulled around the heat exchanger that was eventually attached to the FO and pulled round. This was secured with a gland and the loop pressure tested. The FO was tested to ensure no damage had occurred before being respooled onto the drum ready for deployment by the Loop Master. FO tested at numerous stages to ensure it wasn't damaged before and during deployment.

Number	Item	Issue	Why	Solution
3	GSH loop deployment.	Loop master was suspended above working area on telehandler.	Required to allow tremie pipes to be installed with the centralisers and all the cables attached as the loop was fed into the well.	If the installation is just a heat exchanger loop look to use a ground deployment spooling system. If the installation is the same as UKGEOS then follow the same work exclusion zones so no one is working under a suspended load.
4	First section of heat exchanger needed to be braced.	Residual bend from being coiled remained in the heat exchanger loop resulting in the first section needing to be braced to ensure it hung straight and wouldn't hang up in the hole on ledges / in fractures when RIH.	Residual bend from being coiled remained in the heat exchanger loop.	Braced with additional sections of pipe and secured.
5	Bentonite collar remained after casing recovered.	Bentonite had the potential to fall into the well and create a bridge before the install was run.	Not removed.	Jet the affected area inside the 24" casing and ream the upper section again and remove any Bentonite from the well. Ensure the Bentonite hasn't been pushed into the hole and if this is a concern run an assembly to bottom and circulate the hole clean.
6	Review of core at base of hole.	Good practice to see if large fractures were present that needed to be addressed before the installation was run.	Depth of problematic fractures became better understood as drilling advanced. Total losses of drilling fluids were being lost toward the base of the hole.	If the basal fractures are taking significant amounts or the remaining flush returns these could be treated with either a heavy LCM pill or grouted up with a single cement pill placed on the bottom through a tremie pipe and drilled out once set.
7	Drilling mud.	Not maintained and checked to ensure the products introduced were working optimally.	Muds not checked for various parameters and on occasions water was being fed into the active tank diluting the system with products not being added.	Have someone onsite who is trained and understands the products being used, the concentrations required and the tests to take to ensure the mud system remains in spec.
8	LCM at total depth.	Losses remain and well not static during grouting operations.	Fracture zones still taking fluid.	Fracture zones can be treated with LCM and sealed before advancing deeper which is the normal drilling practice. If, however, it can be confirmed the wells can be drilled with water with minimal returns and no risk of packing off due to the majority of the material being removed by coring a single LCM could be adopted at TD. This pill would need to be large enough the treat the loss zones.
9	Grout losses.	Grout losses to fractures altering the natural	Numerous open fractures were identified during drilling	1. Use of LCM to seal fractures and have the well

Number	Item	Issue	Why	Solution
		groundwater flow paths across the site permanently.	which resulted in total losses during drilling.	standing full and static before grouting. 2. Adopt a staged grouting approach to bring each stage to just above a known fracture as identified in either the core or wireline logs to reduce the hydrostatic head of grout on these fractures. 3. Monitor the grout and water interface as the grout migrated up the borehole with the installed ERT array. This was adopted when no fluid returns were seen at surface and operations stopped when the trace didn't advance suggesting sideways movement of grout to fractures.
10	Grout mixing.	Continuous grouting (GSH wells) and grout consistency.	Due to the size and delivery rate of the primary grouting equipment it wasn't possible to deliver a continuous grout lift and avoid stopping.	Splitting the mix into two separate batches for mixing purposes (they are combined when sent) was identified to make the mix easier to work. Adding more water (4L) to bring sg down closer to 1.67 sg to make the mix easier to pump. This approach was taken to avoid the grout curing and getting thicker during grout weight checks.
11	ERT and grout.	Grout losses to fractures altering the natural groundwater flow paths across the site permanently.	Due to the issues running a mud system and LCM, it was agreed to drill two GSH wells with water and LCM where needed to limit losses. Because the wells weren't standing full and still on losses the ERT system was used as a backup and the only means with no returns to confirm grout continued to fill the annulus and not fractures.	The use of the ERT system was adopted to monitor the grout level migration up the well with no fluid returns at surface. Water / grout provided a better interface for ERT to pick up than mud / grout. If possible, displace the well to clean water before grouting if this technique of grout migration is to be used.
12	Parted tremie pipe.	The 60mm tremie pipe parted in 2 wells (TH0409 and TH0411) when recovering after placing a 20m grout lift.	The breakage occurred immediately upon picking up to recover the first joint - with +/- 20.0 m of tremie within the grout. Subsequently, occasional instances of sticking occurred, even with only a few metres of tremie in the grout. The mechanism was not clear but could have been differential sticking caused by grout exiting the borehole to the formation, pulling the tremie over to	Changed from a 60 mm to a 40 mm tremie. Although the grouting was near to surface and the technique was to pull tremie joints after every batch pumped, no further problems were encountered. It would be proposed to continue to use the 40 mm tremie.

Number	Item	Issue	Why	Solution
			contact the borehole - or perhaps it was due to the friction of pulling through the grout.	
13	Casing shoe defects	By chance when running the BGS downhole camera, it was observed that some of the casing shoes had unscrewed and become detached. This occurred in the open bedrock and abstraction/reinjection wells where an intermediate casing was set before coring to TD.	The casings had a homemade cement shoe approx. 30 cm long screwed onto a joint and the PVC casing, right hand threaded with no sealing compound or glue applied to the threads. In theory the casings should have been set almost on bottom, held firmly in position with grout on the outside. The casings were hung up to 0.5 m above the reamed shoulder and the deeper cored hole below. The grout job was not of sufficient quality or coverage to secure the casings. The result was during drilling out the cement in the shoes with a PDC style bit, the righthand rotation of the bit and vibration caused the shoe joints to gradually unscrew.	Remedial operation had to be performed involving an additional casing string (sleeve casing) and drilling an additional socket at the bottom of the hole in which to seat the sleeve. A downhole camera had to be sourced from Marriott to inspect the remedial work and confirm the open hole/casing interfaces were fit for purpose. For any future operation, a left-hand threaded shoe joint could be used to prevent unscrewing. The grouting and casing hanging procedure also need to be examined to determine why the grout did not hold the casing. In addition, a thread locking or glue compound could be investigated to prevent unscrewing.
14	Stuck temporary casing.	Temporary casing in TH0420 became stuck resulting in several days lost time and equipment and additional personnel mobilised to site to recover.	Diameters not questioned even through the string was noted as being tight when RIH. When the casing was reported as being tight and knowing this was temporary casing this should have been reported to all parties and reviewed.	Communication from site to the larger group before proceeding if any concerns are voiced. Checks by site supervisors to be made on all items being RIH including checks on the OD and ID to ensure no discrepancies / miss communications occur. If following these checks, the annulus clearance was deemed to be too tight the hole should be reamed out to an acceptable diameter before running the casing.
15	Dimensional confusion.	Internal dimensions of casing strings being referenced instead of the outside diameter as per normal drilling practices.	Unclear.	To ensure the OD and ID of each is stated so it is clear and no confusion arises. Maybe one unit should also be used instead of swapping from inches to mm.
16	Fishing operations.	BHA components / drill bits lost in hole resulting in lost time whilst they were fished / recovered.	BHA components not fully torqued or checked prior to running in hole. Drill bits difficult to makeup without bit breaker etc.	Ensure all BHA components and bits are made up to the optimum torque before RIH.

Table 110 Operational lessons learned

Number	Item	Issue	Why	Solution
1	Installation time.	Longer than anticipated due to complexity.	Several of the installations were either bespoke and never run in boreholes before or not run by the contractors. Not enough time allocated in the programme.	Review time taken during the UKGEOS project and use to inform future programme development and project timings.
2	Grout waiting time.	The stated grout setting time on the products used was adopted rather than checking surface samples onsite resulting in lost time.	Manufacturers guidance followed by Principal Contractor.	Although the official waiting time between lifts was 12 hours it was possible to obtain a reasonably accurate dip on the well after 5 hours, so it may be considered to reduce the grout waiting time.
3	Assembly components.	A 222 mm reamer was used in TH0420 when the scope required a 200 mm hole.	Several reamers were onsite but not checked before using.	Ensure all BHA components are measured and as per Scope before running in hole. All reamers were colour coded by the drilling contractor to avoid this happening again.
4	Spare joints for installs.	When installing the ERT/DTS borehole the exact number of joints had been ordered with no spares resulting in lost time whilst they were recovered from other boreholes to allow backfilling to commence and leaving final joint below GL. Risk in removing before the back filling is complete is backing out a joint deeper down. Also, if a joint had been dropped / threads crossed then one of the installs couldn't be completed.	Not factored in when ordering the installation pipe.	Order at least a few joints or 10% contingency for deeper wells to consider damaged, cross threaded joints etc.
5	Time management.	Loss of drilling time per shift. 24/7 was allowed under planning and should have been utilised to avoid significant downtime. Loss of half a shift every Friday was also common due to travelling times and working hours.	2 x shifts sometimes used but loss of time after morning briefing, handovers and end of night shift not optimal. Would have allowed drilling to be completed ahead of schedule but resource may not have been available to cover.	Confirm planned shift patterns with Principal Contractor and how they plan to manage. The optimal shift pattern to avoid lost time is 24/7 on a crew rotation but this may not be allowed under planning or due to crew resources for shallow well drilling.

6 Appendix

6.1 BOREHOLE LOCATIONS

6.2 BOREHOLES SCHEMATICS

6.3 RECORD OF DRILLING ADDITIVES USED AND SPEC SHEETS

6.4 VERTICALITY RECORDS

6.5 WIRELINE LOGS

6.6 CORE AND SAMPLES COLLECTED

6.7 INSTALLATION MATERIALS

6.8 INSTALL DETAILS

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Appendix #	Document name	Copyright holder	Date on which permission was granted
6.3 Drilling Additives	Clear-Stab® ULI EU SDS v.01 Drilling Additives_FINAL PDS - Pure-Bore® Liquid Ultrabore EU SDS v.03 WEBSAFE-Clear-Solutions-Product-Brochure-210x210-Singles	Clear Solutions	16-04-2026
6.5 Wireline logs	All wireline logs data collected	European Geophysical Services	19-02-2026

6.7 Installation Materials	170 mm BGS PACKERS 160222 Model (1) Geopro MANIFOLD INFLATION AND VALVE CONTROL 20.09.23 INFLATION CONTROL PANEL Operated Valve detail 01-02-2022 PACKER HEAD DETAIL 13-01-22 larger power cable Valve detail	Geopro	05-03-2026
6.7 Installation Materials	3 inch rising main spec BOODE_Brochure_EN Boode_pvc_screencasing_ENG2024	Boode	16-04-2026
6.7 Installation Materials	GeoScreen-V1.2 Bentonite-Cement-Pellets-V1.2 Quartz-Filter-Media-V1.2 Mikolit-300-V1.1 Portland-Cement-V1.1 Silica-Sand-V1.2 MGS Connect-Plus-V1.1	MGS	16-04-2026
6.7 Installation Materials	Digital-Temperature-Cable-Specification-Sheet	Beadedstream	17-04-2026
6.7 Installation Materials	EZ-snaps 60125XT_Shop Drawing 2022	Geo-Energie	17-04-2026
6.7 Installation Materials	401-User-Guide 4500_Series_VW_Piezometers 8002Dataloggers	Geokon	17-04-2026
6.7 Installation Materials	Heat Pulse System spec sheet 2025 HS-3S2M1X2C-2PE081-01-B iDAS MG Datasheet 2025 ULTIMA_DTS_Datasheet_2025	Silixa	17-04-2026
6.7 Installation Materials	Solinist 401 Waterloo Multilevel System	Solinst	17-04-2026
6.7 Installation Materials	kwikzip_info_sheets_155 kwikzip_info_sheets_hd_vert	Kwik-Zip	20-04-2026

6.7 Installation Materials	Geotherm-X GR Technical data sheet	Euroquartz	21-04-2026
6.7 Installation Materials	SP 46-5	Grundfos	23-04-2026

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Acronym Glossary

Table 112 Acronym glossary

Abbreviation	Description	Specific Unit Requirements
ACBI	Acoustic borehole imaging	n/a
AOD	Above ordinance datum	n/a
BGL	Below ground level	n/a
BHA	Bottom hole assembly	n/a
BMR	Borehole magnetic Resonance Image Log (Geophysical Survey)	n/a
BOP	Blow out preventer	n/a
CALI	Caliper	mm
CAT	Cable avoidance tool	n/a
CBL	Cement bond Log	n/a
CDM	The Construction (Design and Management) Regulations 2015	n/a
CE	Compensation event	n/a
CEMAR	Contract Event Management and Reporting (software)	n/a
COND	Fluid conductivity (may be derived from resistivity tool)	Siemens.m^{-1}
CSI	Client site instruction	n/a
CSS	Check shot survey	n/a
DENS	Density	gcm^{-3}
DFLOW	Dynamic Groundwater Flow Log (Geophysical Survey)	n/a
DTC	Digital Temperature Cable	n/a
DTS	Distributed Temperature Sensing (Fibre Optic)	n/a
DUCAL	Dual caliper	mm
EC	Electrical Conductivity	n/a
EGS	European Geophysical Services Ltd.	n/a
ERT	Electrical Resistivity Tomography	n/a
FLUTE	Flexible Liner Underground Technologies	n/a
FO	Fibre optics	n/a
FTS	Formation pressure testing and sampling	PSI/PSIA
FWS	Full Waveform Sonic (Including, P-Wave, S-Wave and Stoneley wave)	μsft^{-1}
GPS	Global Positioning System	n/a
GR	Gamma Ray	GAPI
GSH	Ground Source Heat (Heat Exchanger Borehole)	n/a
HAKA	HAKA Gerodur AG (Geothermal System Supplier)	n/a
HE	Heat exchanger	n/a
HRBI	High coverage, high resolution micro resistivity borehole imaging	n/a
ID	Internal diameter	n/a

IRES	Induction Resistivity Logging (Geophysical Survey)	n/a
ITP	Inspection test plan	n/a
LCM	Lost circulation material	n/a
LOT	Leak off test	n/a
LRES	Laterolog Resistivity Log (Geophysical Survey)	n/a
m AOD	Meters Above Ordnance Datum	m
m BGL	Meters Below Ground Level	m
m BCT	Meters below Casing Top (i.e. top of 24” diameter Boode surface casing)	m
MLS	Multilevel [groundwater monitoring] system	n/a
NEUT	Neutron porosity	pu ("percentage porosity")
NTU	Nephelometric Turbidity Units (Groundwater Turbidity)	n/a
OBI	Optical borehole imaging	n/a
OD	Outside diameter	n/a
OPC	Ordinary Portland cement	n/a
PC	Principal contractor	n/a
POOH	Pull out of hole	n/a
PPB	Pounds per barrel	n/a
PVC	Poly-Vinyl Chloride	n/a
RES	Resistivity Logs at multiple depths of investigation (shallow, medium and deep)	ohm.m
RIH	Run in hole	n/a
SGR	Spectral Gamma Ray	GAPI, % (K), ppm (U,Th)
SP	Spontaneous Potential (if incorporated with resistivity tool)	ohm.m
TD	Target depth	m
TDS	Total dissolved solids	n/a
TEMP	Temperature	°C
TOC	Top of cement	n/a
TSP	Thornton Science Park	n/a
TVD	Total vertical depth	m
UKGEOS	UK Geoenergy Observatories	n/a
UKRI	UK Research and Innovation	n/a
USI	Ultrasonic imaging for casing and cement integrity	n/a
VWT	Vibrating Wire Transducer	n/a
WL	Water level	n/a
WOC	Wait on cement	n/a