Information and guidance on the planning of field experiments at the UK Geoenergy Observatory in Cheshire

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Aerial image of the Cheshire Observatory.

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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 information and guidance on the planning of field experiments at the UK Geoenergy Observatory in Cheshire. The guidance is provided to help users design experiments that are technically feasible and safe in terms of risks to users, the research infrastructure and the local environment.

Acknowledgements

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A big thank- you to 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.

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Summary

This report provides information and guidance on the planning of field experiments at the UK Geoenergy Observatory (UKGEOS) in Cheshire. The guidance is divided into the following sections, which reflect typical research activities at the Observatory:

- Use of the permanently installed sensor systems
- Deployment of borehole sensors / geophysical logging
- Deployment of temporary surface devices
- Use of the closed loop heating and cooling system
- Use of the groundwater abstraction and reinjection system
- Groundwater sampling
- Use of tracers
- Other hydrogeological tests
- Water disposal

The guidance cannot address all possible uses of the Observatory and so is a starting point for planning and discussion. Researchers interested in using the Observatory should contact the UKGEOS team at ukgeosenquiries@bgs.ac.uk to ensure that planned experiments are feasible, to identify any permits that are required and to understand the likely access costs.

1 Introduction

This report provides information and guidance on the planning of field experiments at the UK Geoenergy Observatory in Cheshire. The guidance is provided to help users design experiments that are technically feasible and safe in terms of risks to users, the research infrastructure and the local environment.

The document is subdivided into sections that reflect typical research activities at the Observatory. Major risks and permitting requirements are identified and guidance notes are provided to support the planning of experiments. Where applicable, contact with the relevant regulatory authorities is recommended from an early stage in the planning process to ensure that required permissions are in place for when they are needed.

This document will be reviewed and updated on a regular basis to reflect improved understanding of risk at the observatory. Please check www.ukgeos.ac.uk for the most recent version.

2 Overview of the Observatory infrastructure

The Cheshire Observatory comprises an array of 21 boreholes drilled to ~100 m below ground level (bgl) and instrumented to either ~15m or ~100 m with fibre optic cable, resistance tomography electrodes and thermistor strings (Figure 1). The ground investigation borehole TH0424 is not permanently instrumented but is open in the bedrock below 20 m and so can be equipped with sensors if required. Please refer to the as- built well schematics in the appendices for the detailed borehole designs.

Boreholes with permanent fibre optic, resistance tomography and thermistor cables are connected to interrogators and loggers in the Observatory data centre. The Observatory is equipped with the following monitoring systems:

- a Silixa Ultima™ distributed temperature sensing (DTS) interrogator (https://silixa.com/technology/ultima-dts/)
- a Silixa distributed acoustic sensing (iDAS™) interrogator (https://silixa.com/technology/idas-intelligent-distributed-acoustic-sensor/)
- a Silixa pulsed heating unit (https://silixa.com/technology/heat-pulse-system/) for active DTS measurements
- 2 x 512 channel BGS PRIME interrogators (https://www.bgs.ac.uk/geology-projects/geophysical-tomography/technologies/prime/)
- A Trend iQ™4E building management system (BMS) (https://buildings.honeywell.com/gb/en/products/by-category/control-panels/building-controls/plant-and-integration-controllers/iq4e-controller)
- 4 x GEOKON 8002-16 loggers monitoring variation in ground water elevation and temperature at each port of the four 8- port multilevel wells (https://www.geokon.com/8002-16)
- 12 Beaded stream digital thermistor cables (DTCs) each with 100 thermistors connected to an RSTAR logger unit (https://www.beadedstream.com/product/digital-temperature-cables/)

The Silixa cabinet has 72TB of data storage capacity and incorporates the Silixa Edge platform (https://silixa.com/technology/edge-computing/) for advanced data processing, analytics and visualisation. The Silixa cabinet can also accommodate a Carina® Interrogator (https://silixa.com/technology/carina-sensing-system/) for use with the installed Constellation fibre (high signal to noise ratio DAS).

The Trend BMS system is used to control and log the operation of the surface infrastructure and record water level variation in the 4 abstraction-reinjection wells.

Five of the Observatory boreholes (TH0404, TH0405, TH0415, TH0424, TH0410) are cased to 15- 20 m and then open in the bedrock to ~100 m bgl. They are equipped with flexible liners (www.solinst.com/flute) to prevent vertical flow that can be removed when needed for groundwater sampling or tool/ sensor deployment. Deployed tools or sensors could include seismic sources and detectors, wireline logging tools, electrical or fibre optic sensor cables and borehole data loggers.

Groundwater samples can be collected from the four 8 port Waterloo 401 type (https://www.solinst.com/instruments/multilevel-systems/401-waterloo-multilevel-system/) multilevel wells (TH0418, TH0419, TH0420, TH0421), from taps on the groundwater abstraction-reinjection surface pipework, or from the 5 open bedrock boreholes when the liner has been removed. There are also 4 deep piezometer wells (TH0407, TH0409, TH0411, TH0413) that can provide groundwater samples from 98-99 m bgl.

The Observatory includes 4 single loop HakaGerodur GEROtherm®-RT (https://www.hakagerodur.ch/en/geothermal-probes/) borehole heat exchangers (TH0416, TH0417, TH0422, TH0423), which can be independently cooled or heated from ~0ºC to ~50ºC. There are also 4 abstraction- reinjection wells with depth adjustable packers for control of the groundwater flow velocity (TH0406, TH0408, TH0412, TH0414).

Groundwater flow velocity in the sandstone below the Observatory can be controlled using 4 abstraction/ reinjection wells (TH0406, TH0408, TH0412, TH0414). These allow groundwater to be abstracted from any one well and reinjected into up to 3 other wells. Groundwater is circulated through insulated 100 mm ID surface pipework instrumented with temperature and pressure sensors and flowmeters. Water is fed into the abstraction main on the steel gantry. It then flows through a jet filter unit to remove coarse particulate material before entering the reinjection main. The flow path from the abstraction to the reinjection wells is controlled using manual valves. Reinjection flowrates to multiple wells are regulated using pressure independent control valves (PICVs) at the wellheads, which are operated from the BMS control panel in the data centre. The interval over which groundwater is abstracted and reinjected is controlled using hydraulic packers that can be moved up and down the wellbore.

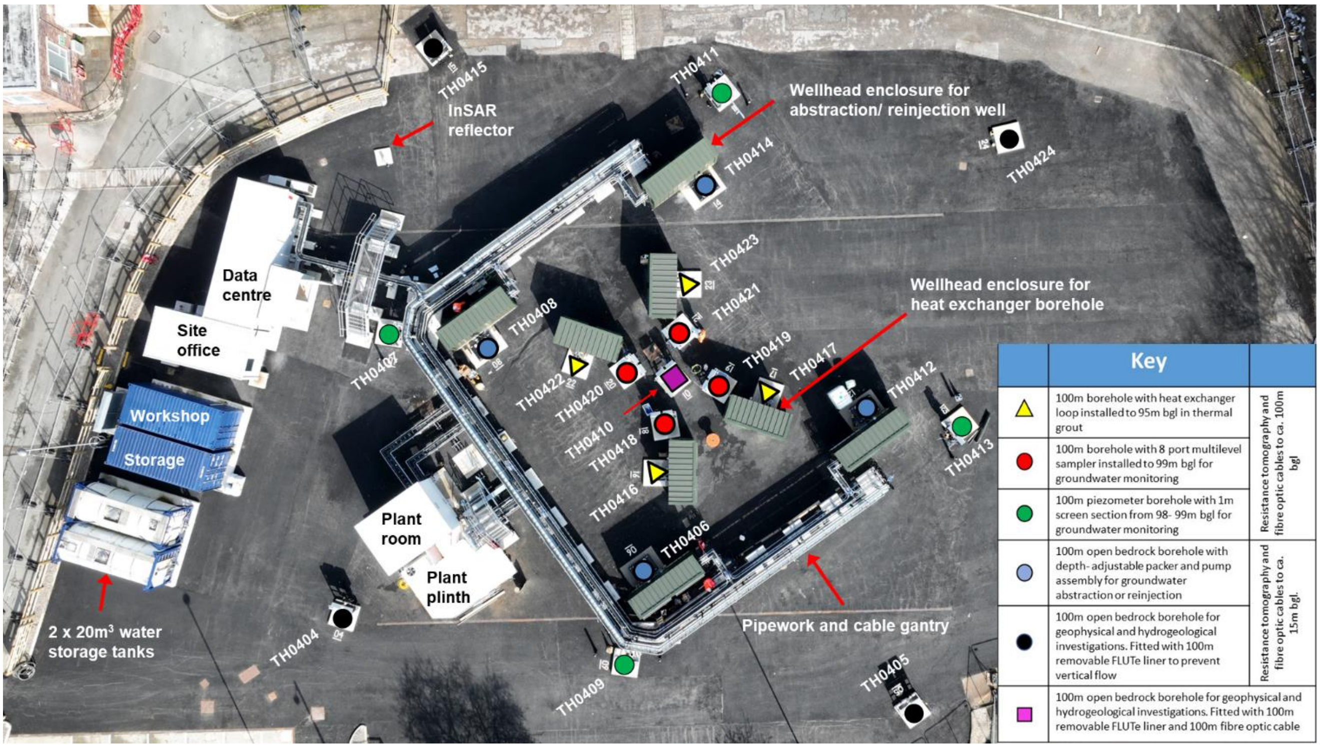


Figure 1. Cheshire Observatory aerial view showing borehole types and locations

The Observatory working hours are 08:30 hrs to 16:30 hrs Monday to Friday. Any work that is to be undertaken outside of these hours will need to be agreed in advance. Ongoing site monitoring and experiments can however run 24/7 if needed, provided this is technically feasible and does not require staff to be present on site.

3 Guidance for science activities

3.1 USE OF THE PERMANENTLY INSTALLED SENSOR SYSTEMS

BGS site staff will operate the permanent site monitoring and control systems in accordance with established protocols to mitigate health and safety risks and prevent damage to equipment through incorrect use.

Reconfiguration of ERT array cable connections may be necessary for some experiments in order to target specific geological features. In this case consultancy support will be needed from BGS geophysics experts, which will need to be factored into the Observatory access costs.

Physical changes to other onsite sensor systems, such as the fibre optic systems will only be considered under exceptional circumstances due to the specialist contractor support that is needed and the need for system recalibration.

BGS can advise on optimum monitoring schedules for experiments, and if needed can request expert advice from the system technology providers. In the case of the fibre optic and ERT systems there is a trade- off between the frequency of monitoring and measurement precision, which needs to be taken into account when planning experiments. Researchers applying for funding should contact BGS well in advance of the deadline for proposal submission to ensure that the scope of the proposed work is feasible and can be accurately costed.

The Silixa pulsed heating unit is used in conjunction with the Silixa DTS system to heat the down hole fibre optic cable and its immediate surroundings. The rise and fall in cable temperature (after the unit is turned off) can be used to calculate the local thermal conductivity, or to introduce heat as a thermal tracer. Higher power delivery, and so higher ground temperatures, are possible in cold weather because the temperature of the DTS sensor cable is limited to 50^{o}C to prevent cable damage: on hot days the surface section of cable rapidly reaches 50^{o}C, which limits the power that can be applied.

3.2 DEPLOYMENT OF BOREHOLE SENSORS / GEOPHYSICAL LOGGING

The 5 wells that are open in the bedrock below 15-20 m (TH0404, TH0405, TH0415, TH0424, TH0410) can be used for the deployment of additional tools and sensors. Applications to BGS to deploy tools and sensors need to demonstrate that the following risks are mitigated, where applicable:

Key Risks

- If the tool is incorrectly deployed, damaged or poorly constructed all or parts of it could be lost down the borehole, which could impact future research activities.
- If the tool is not correctly deployed there could be a manual handling risk, or a risk from the incorrect use of lifting equipment.
- If the tool emits a pulse of energy or cause a vibration, there is potential risk to the condition and stability of the borehole and casing cement bond.
- Deployed sensors or tools might cause interference or damage the permanently installed electrical resistivity tomography (ERT) or fibre optic cables located on the outside of the shallow cased section of the borehole.
- Deployed tools might damage the permanent casing during deployment if the tool dimensions are close to the internal diameter of the casing.

- Deployed tools might become stuck if they are close to the dimensions of the borehole.

Control measures

Downhole tools and sensors with radioactive sources cannot be used at the Cheshire Observatory.

High power electrical discharges to earth are not permitted at the Observatory as these could damage the installed sensor systems.

Guidelines

BGS will collaborate as and when needed with researchers and the manufacturers of the individual tools to understand the risk associated with each deployment.

Tool/ sensor risk assessment:

Requests to deploy researcher tools or sensors on site will be subject to a risk assessment to confirm that the planned deployment is in accordance with the intended use of the equipment, and that the equipment has the required manufacturer certificates of compliance, maintenance records and relevant electrical and mechanical safety documentation. In the event that downhole tools or sensors are constructed from, or contain, hazardous materials material safety data sheets (MSDS) and a COSHH risk assessment will also be needed. In the event that the equipment requires a trained operator proof of in-date training must be provided.

Tool/ sensor deployment:

- Tools or sensors will be assessed in terms of their potential to adversely affect permanently installed ERT and fibre optic cables and other Observatory sensor systems
- Tools or sensors that are lowered into the borehole on winch cables must be deployed by qualified persons using LOLER compliant lifting apparatus (evidence of compliance required).
- Details of any tools deployed in any of the boreholes must be provided specifying the outside diameter (OD) of each tool run in the string. The largest OD tool will be reviewed to ensure a suitable annulus remains in the borehole for the deployment to minimise the potential of becoming stuck. The diameter of all of the boreholes can be found in the well schematics in the appendices. The use of centralisers on the logging tools must be clearly stated in a method statement with detailed information regarding the deployment method.
- The clamping of tools designed for use with steel casing to the PVC well casing is not allowed due to the risk of casing damage. If tools are designed specifically for use with PVC casing then deployment may be possible subject to a risk assessment.
- Tools or sensors cannot be deployed in wells that still have a FLUTe liner installed. Currently the central borehole (TH0410) and all 4 x uncased bedrock boreholes have liners deployed. The liners have a tether line that runs to the base and the risk of getting tools stuck is very high so they will need to be removed in advance of any geophysical logging or sensor deployments.

Information required from researchers for risk mitigation

The following information is needed by BGS to risk assess researcher tools and devices:

- Information on how the tool/ sensor works
- Design/ supplier documentation and dimensions
- Proposed method and location of deployment and operating parameters
- Planned duration of deployment

- Where relevant: Manufacturer certificates of compliance, maintenance records and relevant electrical, mechanical and chemical safety documentation
- Potential interactions with subsurface environment or other Observatory equipment (if applicable)

If the use of the tool/ sensor is agreed then a task specific risk assessment will need to be developed by the researchers in advance of the planned research activity.

to Risk assessment and method statements

BGS reserves the right to refuse the deployment of any tool or sensor if the associated risk is deemed to be high. The duration of time a sensor is deployed within a borehole will be dependent on the usage of the site and availability of the borehole.

3.3 DEPLOYMENT OF TEMPORARY SURFACE DEVICES

Additional tools or sensors may be placed within the Observatory boundary, either directly onto the ground surface or fastened to a permanent part of the infrastructure (e.g. temporary seismometers, air monitors, surface resistivity cables). It may also be possible to deploy temporary tools and sensors outside the Observatory boundary (subject to securing the required permissions).

Key Risks

- Damage to the Observatory infrastructure during device installation or operation.
- Interference with the science equipment that is permanently on site.
- Health and safety risks caused by surface power or communication cables.
- Risk of conflict with TSP site operations or vehicle movements in the case of devices deployed outside the Observatory area.

Regulations

The location of the Cheshire Observatory is shown by the red outline on Figure 2. If you think you may require access outside this area for survey work or sensor deployment please contact BGS at ukgeosenquiries@bgs.ac.uk so we can arrange a call to discuss any access permissions that are needed.

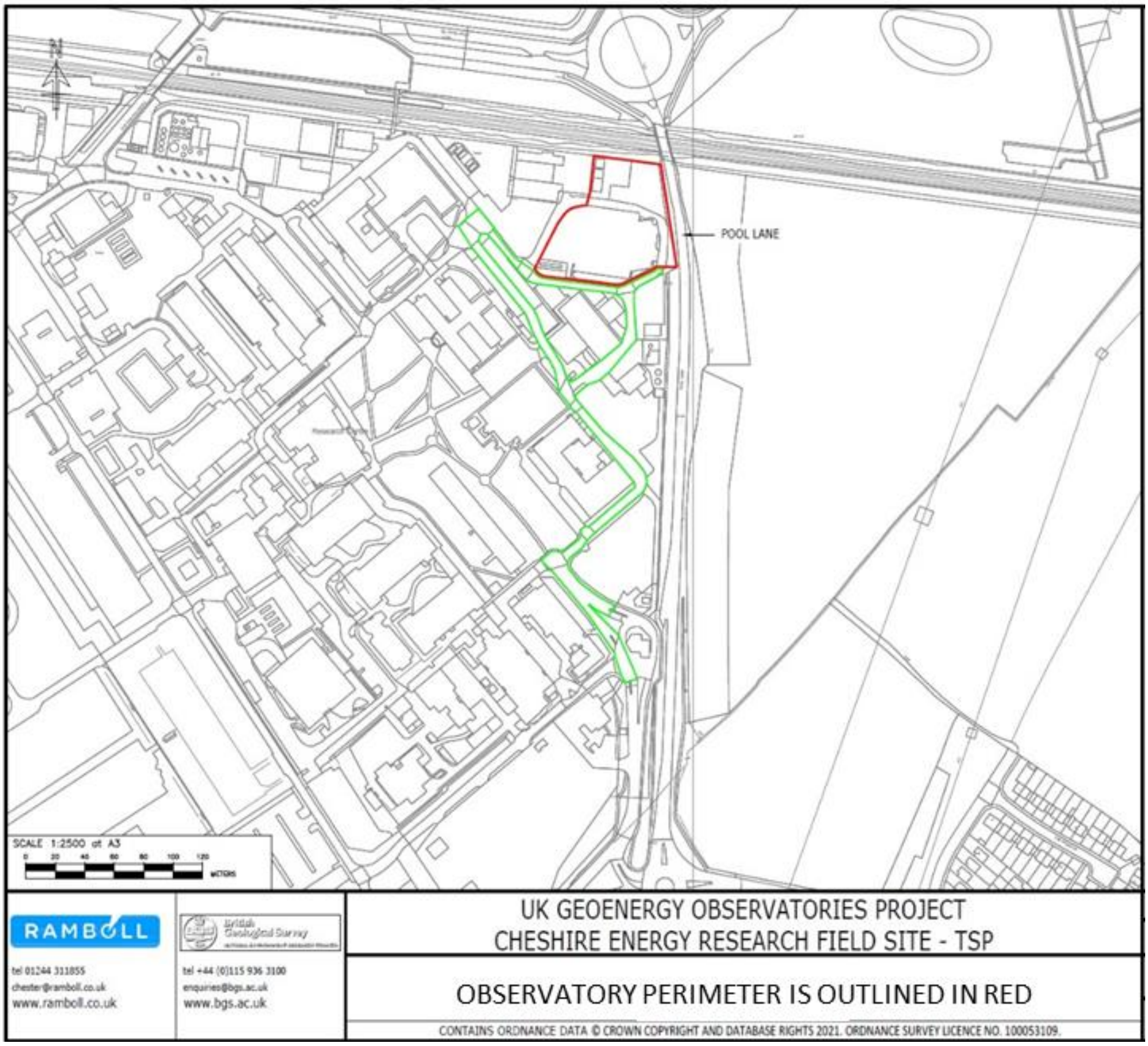


Figure 2. Map showing the area of the Cheshire Observatory at Thornton Science Park (outlined in red). © Ramboll UK Ltd

Guidelines

No radioactive tools or sources are to be used.

No explosive sources or air guns are to be used.

Permission to install tools or sensors in the ground will be subject a BGS risk and feasibility assessment and damage to any paved surfaces will need to be repaired on completion. The Cheshire Observatory has been constructed on an existing car park that overlays approx. ½ m of demolished building rubble. A full geophysical survey of the site, undertaken before construction, is available. The bedrock is around 2 m below ground level.

The area of the Observatory has been covered with tarmac and permission to excavate tarmac is unlikely to be granted due to the cost and difficulty of reinstatement. The Observatory site is surrounded by grass borders that might allow the installation of buried devices, subject to TSP permission.

A risk assessment will need to be completed for the use of seismic sources to confirm that these do not present a risk to the infrastructure. Stability of the boreholes is paramount and therefore the use of such tools will be reviewed on a case-by-case basis.

Information required from researchers for risk mitigation

The following information must be submitted to BGS prior to deploying surface-based devices (including survey tools):

- Sensor types used and the mode of deployment.
- Planned location and duration of surface device deployment.
- Operational parameters for the device and associated data sheets, including information on noise and vibration.
- Risk assessment and method statements.
- Whether access will be needed to areas outside the Observatory area (Figure 2).

BGS reserves the right to refuse deployment of any device if the associated risk is deemed to be high. The length of time that a device can be deployed will be dependent on the device type and whether it places constraints on other site activities.

3.4 USE OF THE CLOSED LOOP HEATING AND COOLING SYSTEM

Four of the Observatory boreholes are equipped with borehole heat exchangers (TH0416, TH0417, TH0422 and TH0423). Manual valves at each heat exchanger allow it to be connected to either a 24kW heated fluid circuit or a 15kW chilled fluid circuit. Multiple boreholes can connect with flow balancing achieved through the use of PIC valves at the wellheads, which are operated from the BMS control panel in the data centre. The fluid circulation pipes are pressurised to 2.5 bar with a commercial monoethylene glycol based heat exchange fluid with corrosion, scale and biological inhibitors (approx. 30% concentration in water). Boreholes can be heated or cooled to different temperatures, with the temperature achieved being dependent on the heater or chiller power setting and the flow split to each heat exchanger. The closed loop system can be operated at heat exchange fluid temperatures ranging from 0 to 50^{o}C.

3.4.1 Borehole infrastructure

The borehole heat exchangers are 40 mm OD PE100-RT-RC Haka-Gerodur geothermal loops. They are installed to 95 m bgl and are equipped with fibre- optic distributed temperature sensing (DTS) cable inside the heat exchanger loop. Digital thermistor cables (DTC) are also attached to the outside of each limb of the heat exchanger. A permanent tremie pipe is installed to total depth (100 m) and this is instrumented with active DTS, a thermistor string and electrical resistance tomography electrodes (ERT), allowing temperature and resistivity to be monitored below the base of the loop.

3.4.2 Surface infrastructure

Chiller
A floor standing air-cooled chiller unit is connected to the cooled closed loop fluid circuit. The chiller is located on the plant plinth and has cooling capacity of 15kW. The cooled circuit includes a 400L buffer vessel to reduce chiller cycling and provide better fluid temperature control.

Electrical thermal resistance heater
An electric tube heater is connected to the heated closed loop thermal circuit. The heater is housed within the plant kiosk and has a heating capacity of 24kW. The unit has a thyristor-based controller that regulates the output of the heater to circulate water at the BMS setpoint temperature.

Circulation Systems
Tandem variable speed pumps are fitted on both the heated and cooled circuits of the closed loop system to allow circulation of the heat exchange fluid around the system. These pumps take their operational signals from the BMS. The two pumps operate on a duty cycle and the tandem arrangement allows the system to remain operational if one pump fails. Each circuit has a

pressurisation/ glycol dosing unit to keep the circuit filled and permit additional glycol to be added to the system periodically to maintain the 2.5 bar operating pressure.

The 15kW chilled circuit is typically circulated at flowrates ranging from 0.17 to 0.87 l/s, dependent on the number of connected borehole heat exchangers and the target power transfer. This is for a flow vs return temperature difference of 3°C. The 24kW heated circuit is typically operated at higher circulation flowrates ranging from 0.3 to 1.4 l/s reflecting the higher power output of the heater. To ensure turbulent flow and efficient heat transfer the flow rate in any borehole heat exchanger should not be lower than 0.15 l/s.

Key Risks

- Heat exchanger or surface pipework is pushed beyond its operating temperature window.
- Hydraulic pressure is applied to the heat exchanger loops or surface pipework exceeding the commissioning pressure test value of 3.75 bars.
- Uncontained surface spillage of monoethylene glycol based heat exchange fluid entering an open borehole and resulting in groundwater contamination.
- Manual flow control valves are incorrectly configured leading to cross- flow between the heated and cooled circuits, or excessive system backpressure.

Regulations

The closed loop system is fully sealed, does not take water from the environment and does not discharge water or fluids to the environment and so does not require a groundwater abstraction licence or reinjection (discharge) permit.

Environment Agency (EA) guidance for the operation of closed loop ground source heating and cooling systems restricts the operating temperature to ±10°C of the background aquifer temperature. There is also an upper temperature limit of 25°C. These limits are set with a view to limiting the effect of long- term commercial heating and cooling systems on aquifer temperatures.

Guidelines

Heat storage experiments with a planned duration of more than 1 week, and where the heat exchange fluid temperature is >25°C, will require an estimate to be made of the subsurface thermal gradient to confirm that the temperature limits mentioned above will not be exceeded. If modelling indicates that this limit may be exceeded researchers will need to contact the EA for permission to proceed. During experiments BGS will monitor the aquifer temperature at adjacent monitoring boreholes to ensure that it does not deviate by more than 10°C from the initial (pre-test) temperature.

Information required from researchers for risk mitigation

The following information must be submitted to BGS prior to using the heat exchanger boreholes:

- Details of the planned heating and cooling programme.
- An estimate of the temperature profile vs distance from the borehole if the experiment is to be run for more than 1 week at >25°C.
- Any required EA permissions (if temperature profile indicates aquifer temperature change of ±10°C from background or >25°C).
- Information regarding the planned use of the Observatory permanent monitoring systems.
- Details of any additional monitoring that is planned.
- Risk assessment and method statements.

The feasibility of the planned research will be assessed at a high level at the time that access is initially applied for, with the detailed experimental design agreed when it is confirmed that funding has been secured.

3.5 USE OF THE GROUNDWATER ABSTRACTION AND REINJECTION SYSTEM

3.5.1 Borehole infrastructure.

The abstraction/ reinjection system comprises four wells (TH0406, TH0408, TH0412 and TH0414; Figure 1) and surface pipework, pumps and control/ monitoring systems. The wells are fitted with grouted PVC casing to 15-20 m bgl and open in the bedrock at 222 mm diameter to ca. 100 m. Groundwater can be abstracted from any one of the 4 wells and reinjected into up to 3 of the others. Each well has an inflatable packer and pump assembly that can be set at different depths to control the depth interval that water is abstracted from or reinjected to. The packers are currently set at ca. 35 m bgl in all 4 wells to separate the shallow unconfined and deeper confined aquifers. A manual bypass valve is located between the packer and the pump in all 4 wells. When open this allows water to be reinjected above the pump. The bypass valve is controlled by 2 hydraulic lines that run through the packer to surface. Reinjected water cannot flow through the pumps as they are fitted with non-return valves.

3.5.2 Surface infrastructure

The abstraction/ reinjection wells are connected to a 100 mm diameter flow network comprising plastic pipework and valve gear carried by a pipework and cabling gantry. The pipework comprises an abstraction main that receives groundwater from abstracting wells and a reinjection main that feeds reinjecting wells. A high flow capacity jet filter is installed between the abstraction and reinjection mains to remove coarse particulate matter that could damage sensor equipment.

The surface flow network has several manual isolation valves and Pressure Independent Control (PIC) valves controlled by the site building management system (BMS). Before the system is operated the manual valves must be set in accordance with the planned abstraction and reinjection flow. The PIC valves are only actuated if there is a need to split the reinjection flow across multiple wells. Otherwise, the PIC valves should remain fully open (100% on BMS). The borehole pumps for the abstraction and reinjection system are designed to operate at a minimum speed of 60% (equivalent to a flowrate of approx. 3 l/s) to ensure sufficient cooling of the pump motor. Work is ongoing to determine if lower flow rates can be achieved by partially opening the manual bypass valve above the pump so that some of the pumped water flows out of the rising main and back into the borehole. Information on maximum permitted flowrates is provided in the Regulations section below.

Any manual valves that do not need to open to connect active abstraction and reinjection wells to their respective mains should be fully closed. This is essential to prevent unintended flow to other wells, or short circuiting of flow through the system.

Additional manual valves are located at the wellheads to permit purging of air from the system during initial operation. These must be fitted with the hoses provided when in use to prevent purge water from flooding the headworks enclosures. Purge water is collected in a 1 m^3 IBC container on a pallet so that any residual sand can be allowed to settle before the water is discharged to waste.

The 100 mm pipework at the jet filter is equipped with additional manual valves and flange connections to permit the connection of additional equipment (e.g. heater/ chiller unit) or allow the purging of groundwater to waste. Groundwater samples may be collected during purging, or from the small spigot taps located in each wellhead enclosure, or from the main outflow spout at discharge.

Key risks

- Failure of the rising main during packer adjustment or maintenance leading to the packer, pump bypass valve, water level sensor and borehole pump falling down the well. Potential consequences being loss of abstraction- reinjection function, equipment damage, equipment stuck inside the well and the need to decommission the borehole by backfilling.
- Damage to the packer, pump bypass valve, water level sensor, borehole pump or failure of the rising main during maintenance or packer depth adjustment.
- Health and safety risk from coiled hydraulic pipes and cables being rapidly pulled into the well if the rising main was to fail.
- Abstracted groundwater with high sand content is reinjected leading to clogging of the reinjection well(s) and excessive backpressure, leading to system shutdown and the need to redevelop (clean) the reinjection well(s).
- Damage to the borehole pump if the water level is allowed to fall too far and the pump runs dry.

Regulations

BGS is planning to apply for a long-term abstraction licence to allow water to be abstracted and reinjected at the Observatory at a total flowrate of up to 4 l/s (345.6 m^3/day). **Until this licence is in place the maximum volume that can be abstracted within any 24-hour period is 20 m^3.**

The abstraction licence maximum flowrate has been selected on the basis that it produces a strong hydraulic gradient between the abstraction and reinjection wells but avoids excessive water table drawdown or mounding. A discharge licence is not required provided groundwater is reinjected into the same strata at natural background quality and unaltered (c.f. de-minimis exemption criteria as set out in EA permitting guidelines).

If abstracted water is to be stored for any length of time prior to reinjection, or amended in any way, researchers will need to either register an exemption or secure permission from the EA (see section 3.7 on use of tracers).

Note that further regulations apply if groundwater is to be reinjected at a different temperature (see section below).

Guidelines

BGS will monitor drawdown and mounding in the abstraction and reinjection wells during experiments to ensure that this remains within allowed limits. Excessive drawdown or mounding can lead to adverse effects including increased water turbidity, destabilisation of the wellbore, erosion of weakly cemented lithologies and excessive stress on downhole and surface equipment. The specific yield of the abstraction- reinjection wells varies, and so wells may exhibit differential drawdown and mounding at any given flowrate. In general drawdown or mounding will not be allowed to exceed 10 m, however lower limits may apply dependent on the design of the experiment. The BMS will be programmed to shut down the pump if drawdown and mounding limits, or setpoint limits for the surface flowlines are exceeded.

Information required from researchers for risk mitigation

The following information must be submitted to BGS prior to use of the abstraction and reinjection system:

- Information regarding which borehole(s) will be used for abstraction and reinjection.
- Proposed operating parameters – flow rate and temperature vs time.
- Proof that required EA exemptions or permits are in place.
- Risk assessments and method statements.
- Any water or waste disposal considerations.

BGS reserves the right to change abstraction and reinjection flowrates during an experiment, or to stop an experiment if there is excessive drawdown or mounding of groundwater, or if the system parameters indicate a risk of damage to the Observatory infrastructure.

3.5.3 Use of mobile heating or cooling plant in conjunction with the groundwater abstraction and reinjection system

The Observatory abstraction and reinjection pipework is equipped with connection points at the plant plinth to permit the connection of a user-supplied in-line heater or chiller unit. Heated or cooled groundwater could then be reinjected to simulate an open loop ground source heat pump system.

It is envisaged that heating and cooling equipment will be brought to site and installed in the space available on the plant plinth. Equipment must be weatherproof, protected against excessive heating or cooling and shut down automatically in the event that pressure, water flow or or temperature are outside setpoint limits. A 250-amp 3 phase power supply is available in the plant room to power this unit.

Key risks

- Observatory infrastructure is damaged during the installation of heating or cooling equipment.
- Observatory infrastructure is damaged or made unsafe because of incorrectly designed heating or cooling equipment
- Groundwater is heated or cooled outside the permitted limits, leading to infrastructure damage through freezing or overheating, or adverse changes in groundwater chemistry.
- Generation of steam due to malfunction of a heater unit over pressurises and damages the ground water circulation pipework.

Permitting

Experiments that involve the heating or cooling of recirculating groundwater may be exempt from needing an environmental permit to discharge if the experiment meets certain criteria. EA guidance (as of 26/03/25) states that an open loop heat pump system may be exempt from needing an environmental permit to discharge if it is:

- A cooled aquifer system with a volume of less than 1,500 *m*^{3}*/day* (*this should allow a mobile* *<u>cooling</u>* *plant to be connected to the abstraction & reinjection system. The Observatory operates at a maximum abstraction rate of 4 l/s or 345.6 m*^{3}*/day which is well below the 1,500 limit*).
- A balanced system with a volume of less than 430 *m*^{3}*/day* (*this criterion could not be met unless a combined* *<u>heating and cooling</u>* *plant was connected to the Observatory abstraction & reinjection system).*
- A heated aquifer system with a volume of less than 215 *m*^{3}*/day (this could be met by abstracting and reinjecting at a reduced rate of 2.5 l/s).*

Conditions of the exemption

To be eligible for the EA exemption the reinjected water cannot go above 25°C and cannot vary by more than 10°C compared to that in the aquifer from which it was abstracted. The water must also be abstracted and discharged within the same aquifer: in the context of the Cheshire Observatory hydrogeology this means that water abstracted from the unconfined aquifer cannot be reinjected into the semi-confined aquifer, and vice versa. The water must not have anything added to it, for example additives used for descaling and must not be used for any other purpose. If these conditions cannot be met, then a bespoke permit will be needed.

Note: see the EA exemption form and guidance notes for more detail on these systems. Exemptions must be registered with the EA and open loop heating and cooling must be able to meet the conditions of the exemption.

It is the researcher's responsibility to either register their activity as being exempt or apply for a bespoke permit. BGS will require written evidence that an EA exemption or permit is in place before heated or cooled open loop experiments can proceed.

Information required from researchers for risk mitigation

The following information must be submitted to BGS prior to undertaking open loop heating or cooling experiments:

- Information regarding which borehole(s) will be used for abstraction and reinjection.
- Proposed operating parameters – flow rate and temperature vs time.
- Proof that required EA exemptions or permits are in place.
- Risk assessments and method statements.
- Any water or waste disposal considerations.

BGS reserves the right to change abstraction and reinjection flowrates during an experiment, or to stop an experiment if there is excessive drawdown or mounding of groundwater, or if the system parameters indicate a risk of damage to the Observatory infrastructure.

3.6 GROUNDWATER SAMPLING

Groundwater samples may be collected from the four Waterloo 401 multilevel wells, the four deep piezometers, the abstraction- reinjection system pipework or from the five open bedrock boreholes if the liner has been removed. BGS undertakes periodic monitoring of groundwater levels and chemistry in the area of the Observatory and this data is published in reports and datasets on the UKGEOS website.

3.6.1 Use of the deep piezometer boreholes with active DTS and ERT cables

Four of the Observatory boreholes (TH0407, 409, 411 and 413) have been installed with 68 mm ID PVC piezometer casing. The casing has a slotted screen section from 98 to 99 m bgl that is within a 1-2mm sand filter pack that extends from ~97 to ~100 m bgl. Above this depth is a bentonite pellet seal followed by Geotherm X-GR thermal grout from ~90 m bgl to surface. The outside of the piezometer casing is instrumented with active DTS and ERT sensor cables. The as built well schematics in the appendix of this report show the exact filter pack and seal interval for each borehole.

Each deep piezometer borehole is equipped with a downhole logger that records long- term variation in groundwater head, temperature and electrical conductivity. These can be removed if access is needed for groundwater sampling or the deployment of tools or sensors.

Key risks

- Damage to permanently installed sensor cables or connected surface equipment due to energy or vibration emitted by deployed tools or sensors.
- Loss of access due to pump, tool or sensor becoming stuck inside the casing or lost downhole.
- Damage to the plastic 75 mm OD pipe.

Guidance on the use of the permanent sensor systems and the deployment of downhole tools is provided in section 3.1 and 3.2.

Collection of groundwater samples for research projects is done under the supervision of the BGS site technician or other site staff. For one- off sample collection it is often easier for the site technician to collect samples due to the training that is needed in the use of the sampling equipment. For longer experiments the researcher may be able to acquire their own samples after undertaking a short on-site training session. There is also an opportunity for PhD students and early career researchers to work alongside the Site Technician during sample collection.

Key Risks

- Accidental contamination of groundwater through spillage of preservative chemicals or the use of contaminated sampling pumps or hoses.
- Sampling the Waterloo 401 multilevel wells involves the use of 200 bar nitrogen gas cylinders to operate downhole pneumatic water pumps. Only trained personnel will be permitted to handle the gas cylinder and pump controller.

Guidelines

Groundwater samples can be collected according to standard BGS protocols developed for the Cheshire Observatory, or according to the researcher's own methodology. If BGS protocols are followed then the Site Technician can collect the samples on the researcher's behalf or provide training in sample collection. The responsibility for sample collection must be agreed prior to arrival on site.

Any downhole equipment used by researchers must be clean and will be inspected by BGS staff prior to deployment. The deployment of pre-used plastic pipework or hosing will not normally be permitted due to the risk of cross- contamination, except by prior agreement.

In the event that samples are to be collected using researcher protocols these will need to be agreed with BGS in advance and a full risk assessment and method statement will be required.

The provision of appropriate sample collection vessels, packaging and the arrangement of shipping/ analysis is the responsibility of researchers unless agreed otherwise with BGS.

Information required from researchers for planning and risk mitigation

Researchers are requested to contact BGS at ukgeosenquiries@bgs.ac.uk discuss the scope of the planned sampling. The following aspects will be to be agreed beforehand:

- The groundwater sampling schedule and any associated Observatory activities.
- BGS/ researcher roles and responsibilities for the sampling.
- Requirements around borehole purging, groundwater parameter monitoring and waste disposal.
- Sample collection method statement and risk assessment including COSHH RA for any preservative chemicals.
- Arrangements for sample shipment.

BGS reserves the right to refuse sample collection if the associated risk is deemed to be high.

3.7 USE OF TRACERS

Geological controls on heat and fluid flow are fundamental to many aspects of research at the Cheshire Observatory. Groundwater tracer tests can be used in conjunction with the monitoring systems at the Observatory to identify flow zones, determine aquifer hydraulic properties and monitor the interaction of groundwater solutes with the rock matrix.

Key Risks

- A tracer might be a hazardous substance which is defined as being toxic, persistent or liable to bio-accumulate. This would present a health and safety risk and potentially have an adverse impact on groundwater quality.
- Large quantities of saline or biodegradable tracer could lead to long- term changes in the groundwater chemistry that could limit the value of the site to future researchers.
- Solvents based or reactive/ corrosive tracers could damage the Observatory infrastructure.

Permitting

If the tracer type is approved by BGS it is then the responsibility of the researcher to obtain any necessary approvals from the EA. It is advised that the researcher contacts ukgeosenquiries@bgs.ac.uk in the first instance, clearly stating in the title that tracer approval is being sought. The UKGEOS Operations team will advise on whether use of the proposed tracer is feasible and any follow up enquiries that need to be made with the EA. Any further correspondence will be between the EA and the researcher.

Guidelines

Use of radioactive tracers is not permitted at the Cheshire Observatory.

Tracers that would lead to significant long- term changes to the flow and transport characteristics of the aquifer are not permitted at the Cheshire Observatory.

The following online resources may be useful when determining the type of tracer to be used and the associated monitoring that may be required. Section 2.2. of the EA guidance document at the first link below (Groundwater activity exclusions from environmental permits) defines discharges to boreholes that would be considered de-minimis and so not requiring a discharge licence. The second link is to EA guidance and information on groundwater hazardous substances.

EA guidance on groundwater activity exclusions from environmental permits (https://www.gov.uk/government/publications/groundwater-activity-exclusions-from-environmental-permits/groundwater-activity-exclusions-from-environmental-permits)

EA guidance on minimum reporting values (MRVs) for selected hazardous substances in clean groundwater (https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments/hazardous-substances-to-groundwater-minimum-reporting-values)

Information required from researchers for risk mitigation

The following information must be submitted to the BGS prior to using a tracer on site:

- Full list of all substances present in the tracer and their concentrations, according to the IUPAC naming convention.
- Biodegradability according to REACH (https://echa.europa.eu/information-on-chemicals), or from peer- reviewed publications.
- Potential subsurface reactions and impacts.
- Detailed methodology for tracer deployment including:
    - Mode of injection (method, locations, injection concentration, injected mass or volume).
    - Mode of detection (method, locations, timescale).
    - Evidence that the methodology is informed by valid estimates or models of tracer dispersion.
- Risk assessment and method statements.
- Confirmation from EA that activity is exempt, or discharge licence where required.

BGS reserves the right to prevent the use of any tracer if the time required for the tracer to dissipate from the system is deemed excessive, or the tracer has the potential to cause harm to the infrastructure.

3.8 OTHER HYDROGEOLOGICAL TESTS

Hydrogeological tests that could be performed at the Observatory (with appropriate funding and regulatory permissions) include:

- Straddle packer tests (in the five 100 m boreholes TH0404, TH0405, TH0410, TH0415, TH0424 that are open in the bedrock below ca. 15 m bgl).
- Constant rate or step drawdown pumping tests.
- Push-pull tests.
- Slug tests.

Key risks

- Damage to the FLUTe liners currently installed in the open- bedrock boreholes TH0404, TH0405, TH0410, TH0415, TH0424 as these need to be removed and reinstated to gain access to the borehole.
- Loss of equipment down hole leading to damage to the equipment or Observatory infrastructure
- Groundwater pollution arising from use of contaminated borehole equipment
- Injury to site staff or users from unsafe equipment or operating procedures
- Interference with the science equipment that is permanently on site.

Permitting

Discharge licences or exemptions may need to be agreed with the EA if tracers are to be used (see section 3.7).

Guidelines

The five 100m boreholes that are open in the bedrock below ca. 15 m bgl are fitted with flexible liners when they are not in use to limit vertical flow of groundwater. In order to access these wells BGS will need to remove the liners and then redeploy them at the end of the experiment. 4 days of site time is needed <u>per liner</u> for liner removal and reinstatement due to the complexity of this operation.

Due to the need to limit vertical flow, experiments involving these wells should be planned to minimise the time that the liners are removed.

Budget permitting, researchers can apply to replace the blank liners with removable custom borehole liners equipped with sensors or sampling ports. Custom flexible liners are available at the time of writing from Solinst in Canada (e.g. https://www.solinst.com/instruments/solinst-flute/405-water-flute/). Deployment and removal of instrumented liners will require on-site technical support from the vendor, the cost of which would need to be covered by the researchers.

Information required from Researchers for risk mitigation

The following information must be submitted to BGS prior to undertaking hydrogeological tests:

- The design of the proposed test(s) referencing any modelling that has been undertaken to inform the test design or monitoring programme.
- The planned use of the Observatory permanent monitoring systems.
- Any temporary sensor deployments.
- Confirmation from EA that the planned activity is exempt, or any required permits or discharge licences.
- Method statements and risk assessments for the proposed tests.

3.9 WATER DISPOSAL

Groundwater pumped from boreholes for purging purposes should be disposed direct to foul sewer unless it has a visibly high sand content (dark brown and turbid). In this case the water should be discharged into two or more IBC's linked together so that excess sand has time to settle out prior to the water being discharged to foul sewer (e.g. figure 3).

The Observatory is equipped with 2 x 20 m^3 stainless steel horizontal water tanks, which are provided in case there is a need to store groundwater for tracer dosing or wastewater recovery/ disposal. Due to the work involved in cleaning these are not used for routine storage of borehole purge water. Costs associated with the hire or purchase of connecting hoses, tank cleaning after use and any wastewater disposal are not included in the daily observatory access tariffs and must be factored in when costing experiments.

Key Risks

- Groundwater sent to foul sewer has excessive sediment loading leading to blockage and the need for remedial action.
- Potential non- compliance with EA discharge permit conditions means that planned experiments cannot proceed.

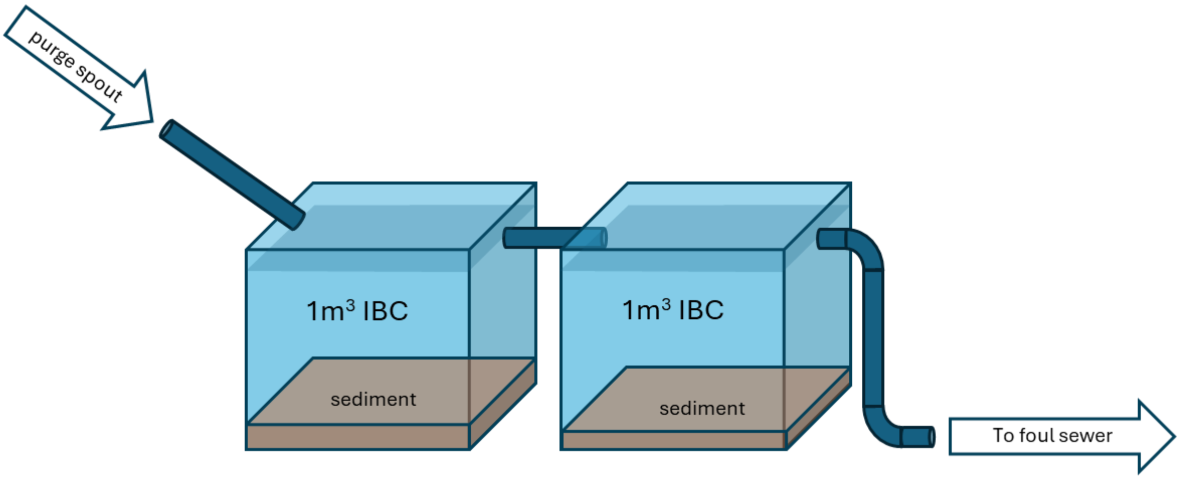


Figure 3. Example settling tank arrangement

Regulation

Wastewater will be either disposed to foul sewer (noting the need to remove excess sediment) or removed from site by an authorised water disposal company. If groundwater contains added tracer the disposal route will be in accordance with the requirements of the EA permit (see section 3.7 on use of tracers). The researcher is responsible for organising the disposal and the cost will be additional to the access costs.

Information required from researchers for risk mitigation

The following information must be submitted to BGS prior to any activity that will require wastewater discharge or disposal:

- Confirmation from EA that the planned activity is exempt, or a discharge licence where required.
- Methodology and risk assessment for wastewater handling and disposal that is in accordance with any permit conditions, including any requirements for analysis prior to discharge.
- Waste transfer notes in the case of wastewater collection by a haulage company detailing the disposal route and location.

4 Appendix

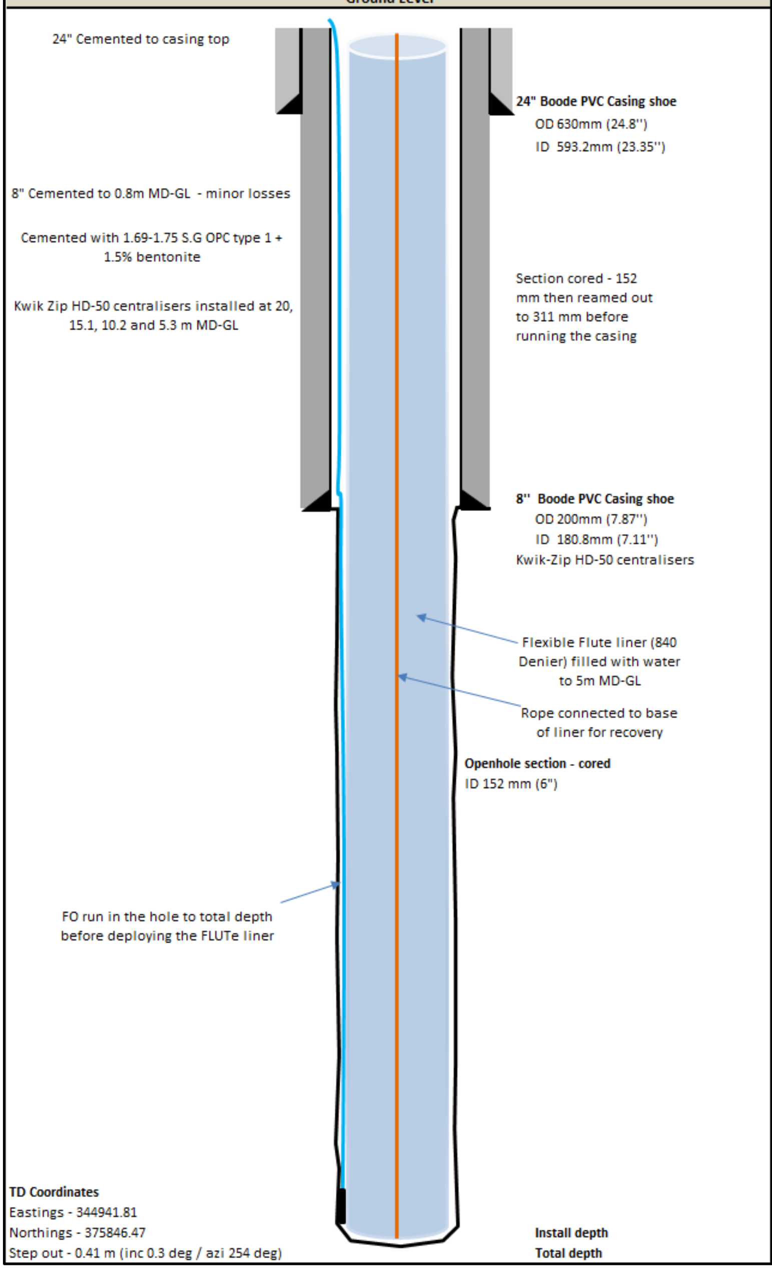
4.1 APPENDIX 1 – AS BUILT WELL SCHEMATICS

4.1.1 Central uncased bedrock borehole (TH0410)

Borehole coordinates:
Eastings - 344942.088
Northings - 375846.772
Top 24" depth ref - 20.181 m AOD
Top 24" to GL - 0.09 m

Well Schematic TH0410
Central Borehole / FLUTe liner

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



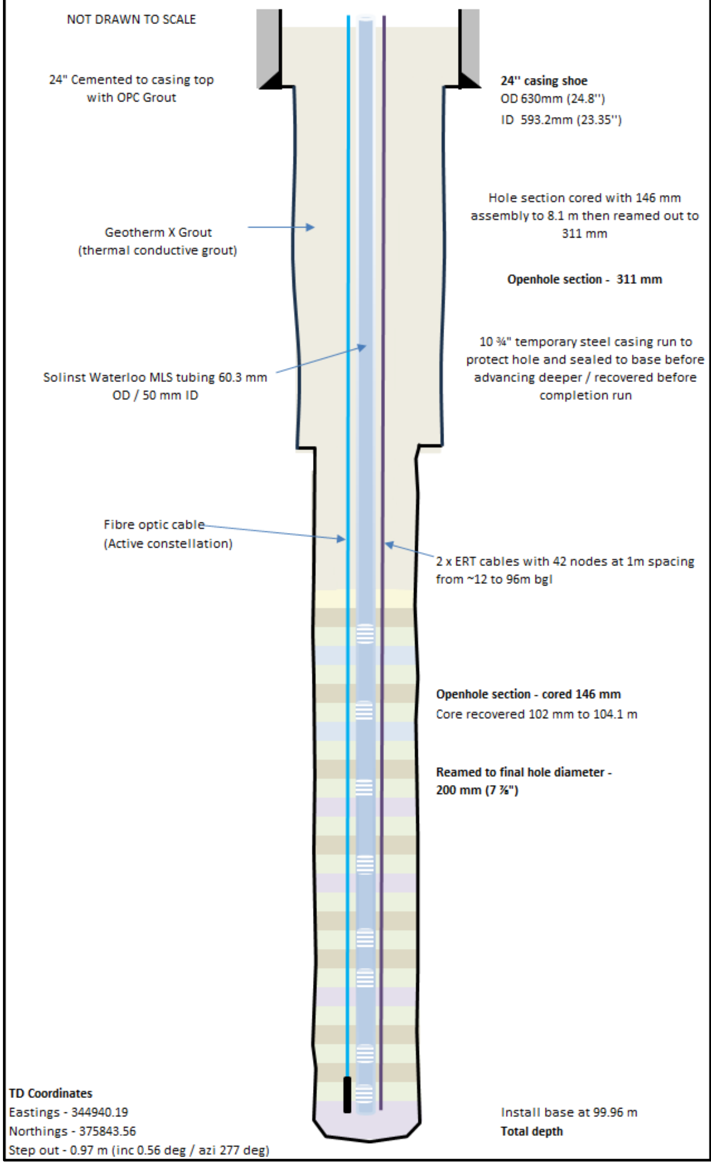
Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
20.2 m	Base of reamed upper section
100.15 m MD-GL (dip)	Additional 2.7 m drilled for sump - dipped at 100.15m before Flute liner installation
102.70 m MD-GL	

4.1.2 Multilevel sampling wells (TH0418, TH0419, TH0420, TH0421)

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



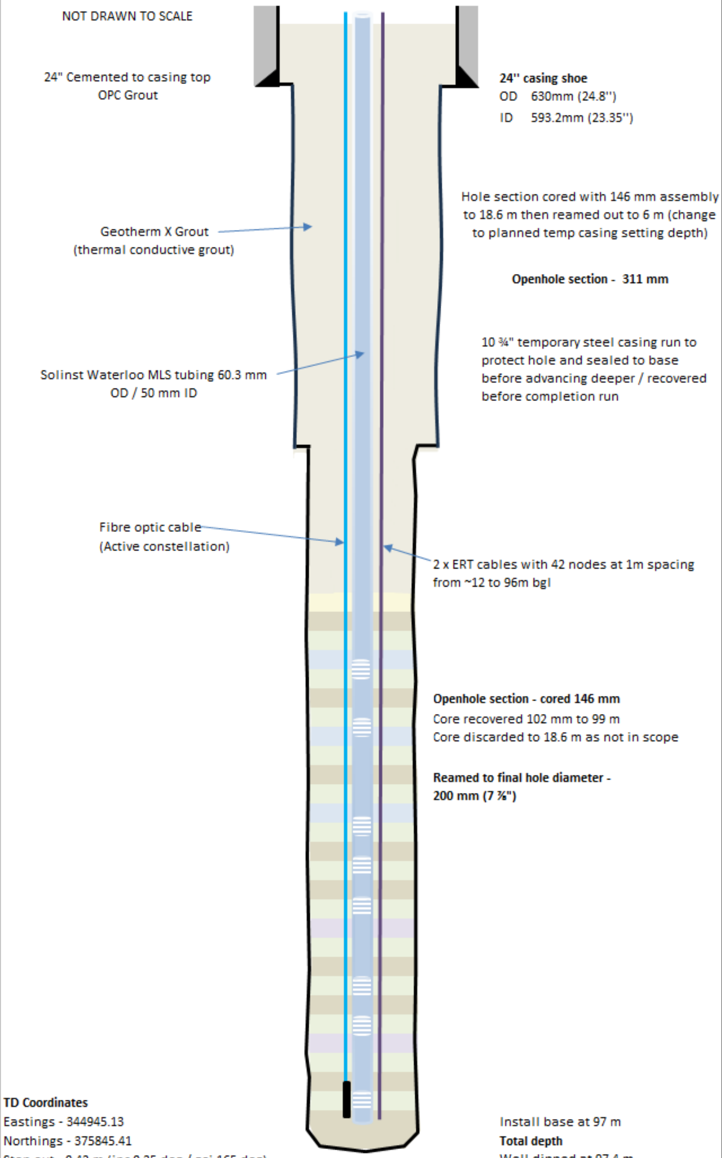
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
	Bedrock encountered at 1.75 m	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		

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



TD Coordinates
Eastings - 344945.13
Northings - 375845.41
Step out - 0.42 m (inc 0.35 deg / azi 165 deg)

Install base at 97 m
Total depth
Well dipped at 97.4 m

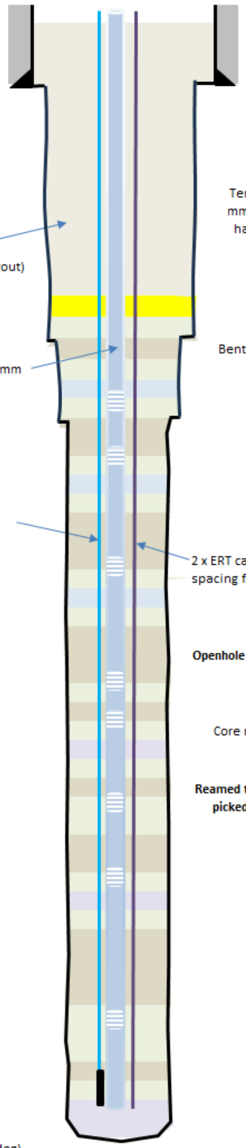
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
	Bedrock encountered at 1.75 m	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	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		

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



TD Coordinates
Eastings - 344939.50
Northings - 375847.63
Step out - 0.30 m (inc 0.31 deg / azi 110 deg)

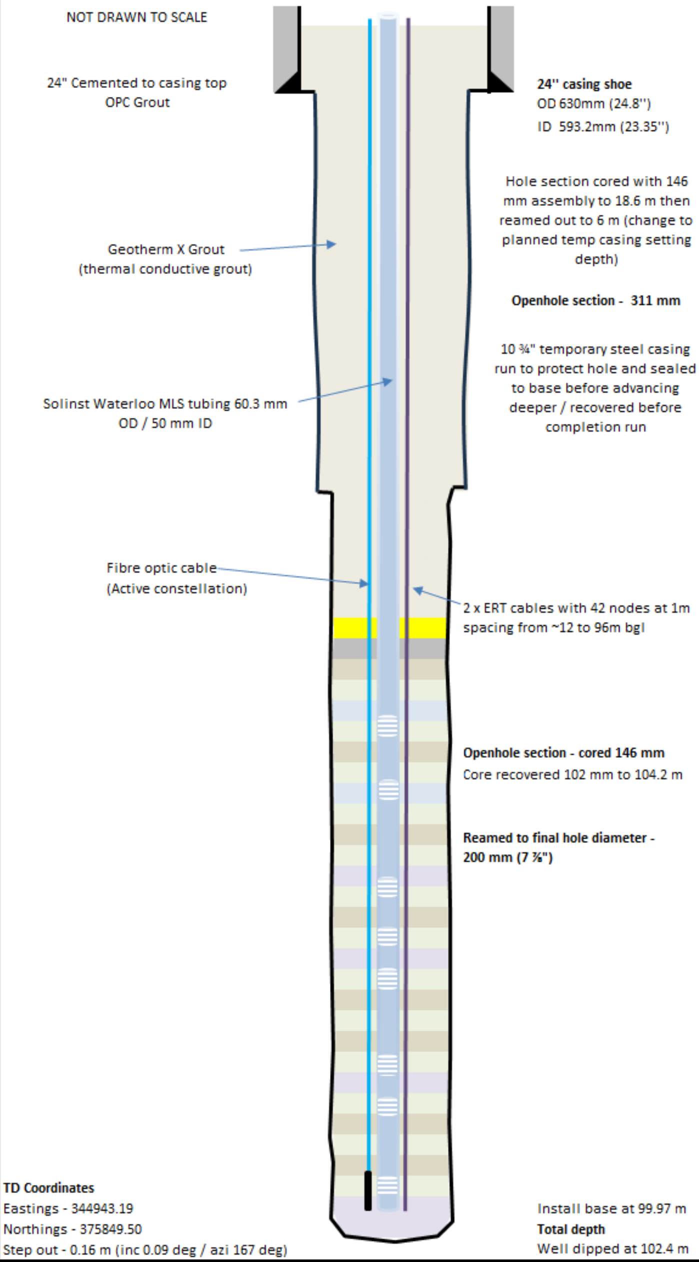
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

Depths m MD-BCT	Comments	Backfill depths
	Bedrock encountered at 1.75 m	
2 m	24" shoe depth	
		Connect plus grout (thermal conductive non setting grout)
	Sharp sand	8.45 to 9.47 m
	1 - 2 mm MGS filter sand	9.47 to 10.55 m
12.0 m	Overdrilled with 304.8 mm shoe	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 - 94.43 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		

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

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



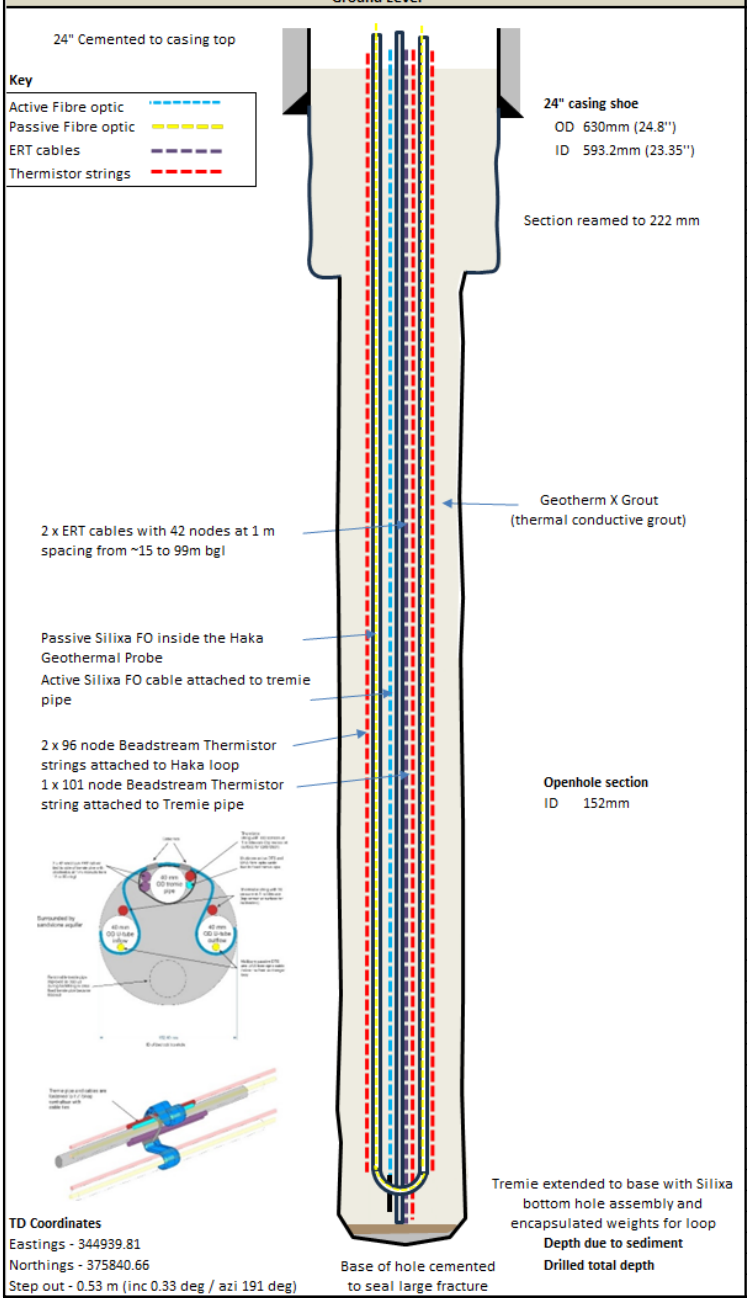
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

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	12.35 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
MLS Port 7 - 47.51 m	6-10 mm Derby Gravel	38.40 to 40.00 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		

4.1.3 Ground source heat boreholes (TH0416, TH0417, TH0422, TH0423)

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

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



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	Additional metres drilled for sump - debris in well and for logging tools
101.5 m	

Borehole coordinates:	Well Schematic TH0417	
Eastings - 344947.757 Northings - 375844.796 **Top 24" depth ref - 20.251 m AOD** **Top 24" to GL - 0.056 m**	**GSH Borehole**	British Geological Survey

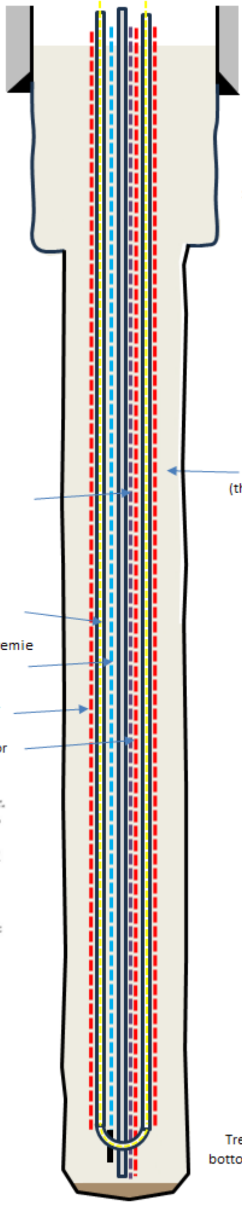
Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 101.5 m. 17/03/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level

24" Cemented to casing top

Key

Active Fibre optic	blue dashed line
Passive Fibre optic	yellow dashed line
ERT cables	purple dashed line
Thermistor strings	red dashed line



24" casing shoe
OD 630mm (24.8")
ID 593.2mm (23.35")

Section reamed to 222 mm

Geotherm X Grout (thermal conductive grout)

2 x ERT cables with 42 nodes at 1 m spacing from ~15 to 99m bgl

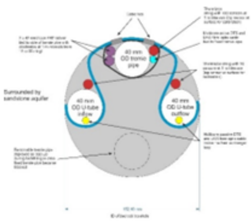
Passive Silixa FO inside the Haka Geothermal Probe

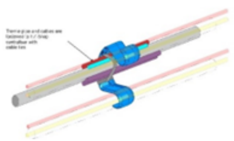
Active Silixa FO cable attached to tremie pipe

2 x 96 node Beadstream Thermistor strings attached to Haka loop

1 x 101 node Beadstream Thermistor string attached to Tremie pipe

Openhole section
ID 152mm





Tremie extended to base with Silixa bottom hole assembly and encapsulated weights for loop

Depth due to sediment

Drilled total depth

TD Coordinates
Eastings - 344947.63
Northings - 375844.75
Step out - 0.14 m (inc 0.47 deg / azi 268 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
101.4 m	Additional metres drilled for sump - debris in well and for logging tools
101.9 m	

Borehole coordinates: Eastings - 344936.425 Northings - 375848.714 Top 24" depth ref - 20.065 m AOD Top 24" to GL - 0.126 m	**Well Schematic TH0422** **GSH Borehole**	British Geological Survey

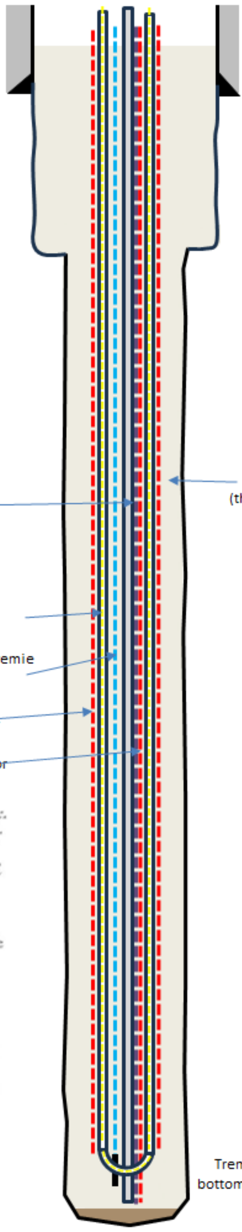
Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 98.6 m. 03/02/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level

24" Cemented to casing top

Key

Active Fibre optic	
Passive Fibre optic	
ERT cables	
Thermistor strings	



24" casing shoe
OD 630mm (24.8")
ID 593.2mm (23.35")

Section reamed to 222 mm

Geotherm X Grout
(thermal conductive grout)

2 x ERT cables with 42 nodes at 1 m spacing from ~15 to 99m bgl

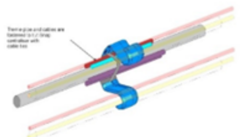
Passive Silixa FO inside the Haka Geothermal Probe

Active Silixa FO cable attached to tremie pipe

2 x 96 node Beadstream Thermistor strings attached to Haka loop

1 x 101 node Beadstream Thermistor string attached to Tremie pipe

Openhole section
ID 152mm



Tremie extended to base with Silixa bottom hole assembly and encapsulated weights for loop

Depth due to sediment

Drilled total depth

TD Coordinates
Eastings - 344936.38
Northings - 375849.41
Step out - 0.80 m (inc 0.74 deg / azi 349 deg)

Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
0.89 m	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
	Well drilled with a polymer WBM
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
100.38 m	Additional metres drilled for sump - debris in well and for logging tools
101.4 m	

Borehole coordinates:	Well Schematic TH0423	
Eastings - 344944.045 Northings - 375852.444 **Top 24" depth ref - 20.174 m AOD** **Top 24" to GL - 0.159 m**	**GSH Borehole**	British Geological Survey

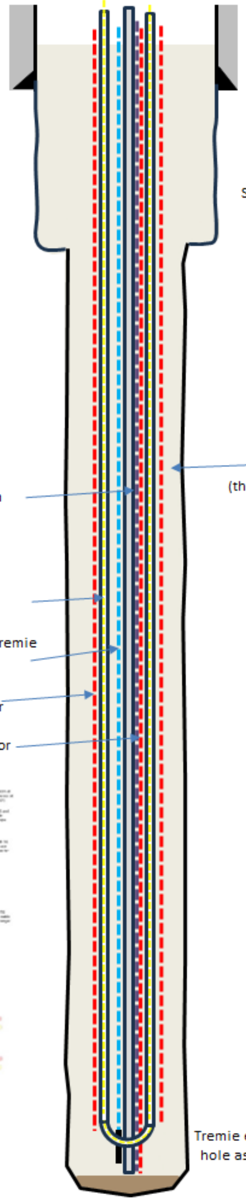
Wireline logging undertaken	Tools run
Section logged in cored 152 mm hole to 100.4 m. 02/03/23	GR, CALI, ACBI, LRES, TEMP, COND

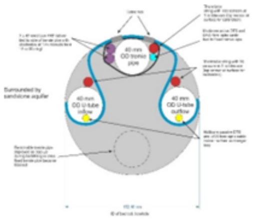
Ground Level

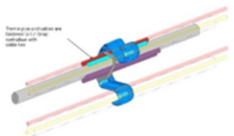
24" Cemented to casing top

Key

Active Fibre Optic	(blue dashed line)
Passive Fibre Optic	(yellow dashed line)
ERT cables	(purple dashed line)
Thermistor strings	(red dashed line)







TD Coordinates
Eastings - 344943.91
Northings - 375852.50
Step out - 0.15 m (inc 0.31 deg / azi 273 deg)

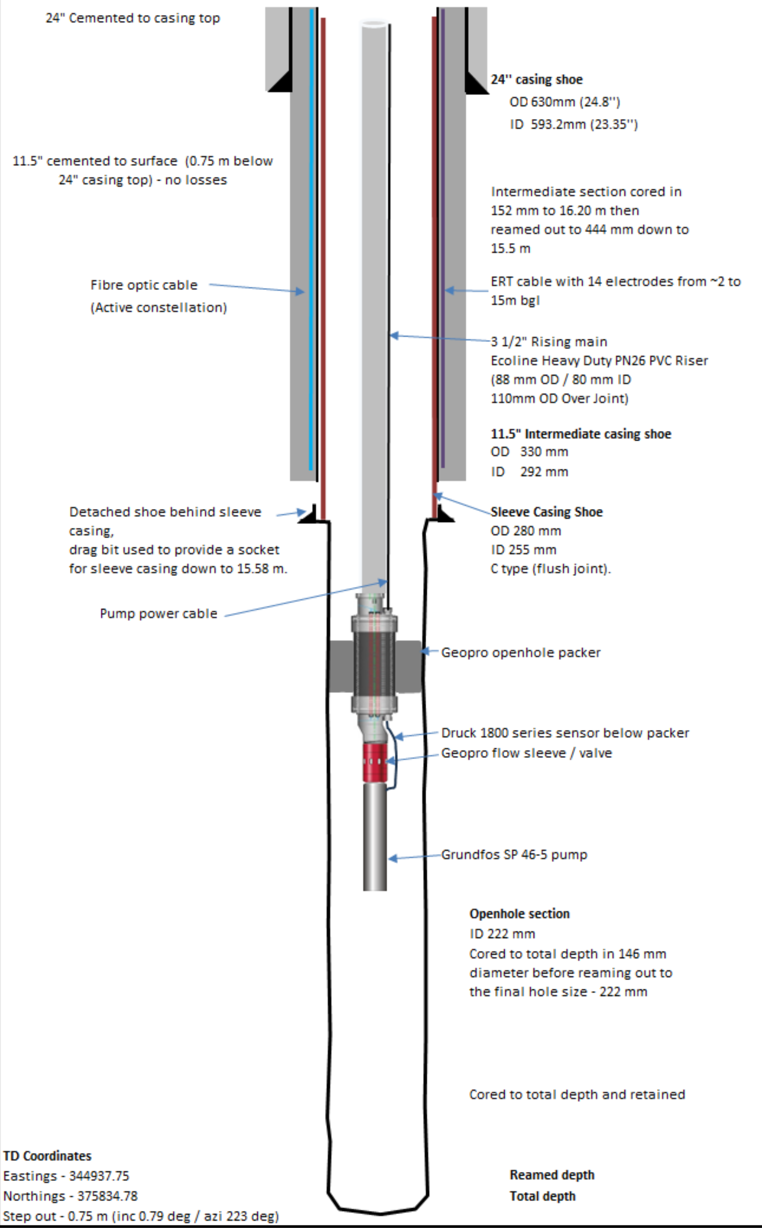
Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
0.89 m	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
	Well drilled with a polymer WBM
6 m	Base of reamed upper section
	Loss zones were cured as they occurred with LCM
	Centralisers used on the install were EZ Snap 60125 XT at 3 m spacing for the 40 mm OD Haka heat exchanger loop
100.0 m	Install depth
100.3 m	
100.4 m	No sump drilled in this well

4.1.4 Abstraction & reinjection boreholes (TH0406, TH0408, TH0412, TH0414)

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



TD Coordinates
Eastings - 344937.75
Northings - 375834.78
Step out - 0.75 m (inc 0.79 deg / azi 223 deg)

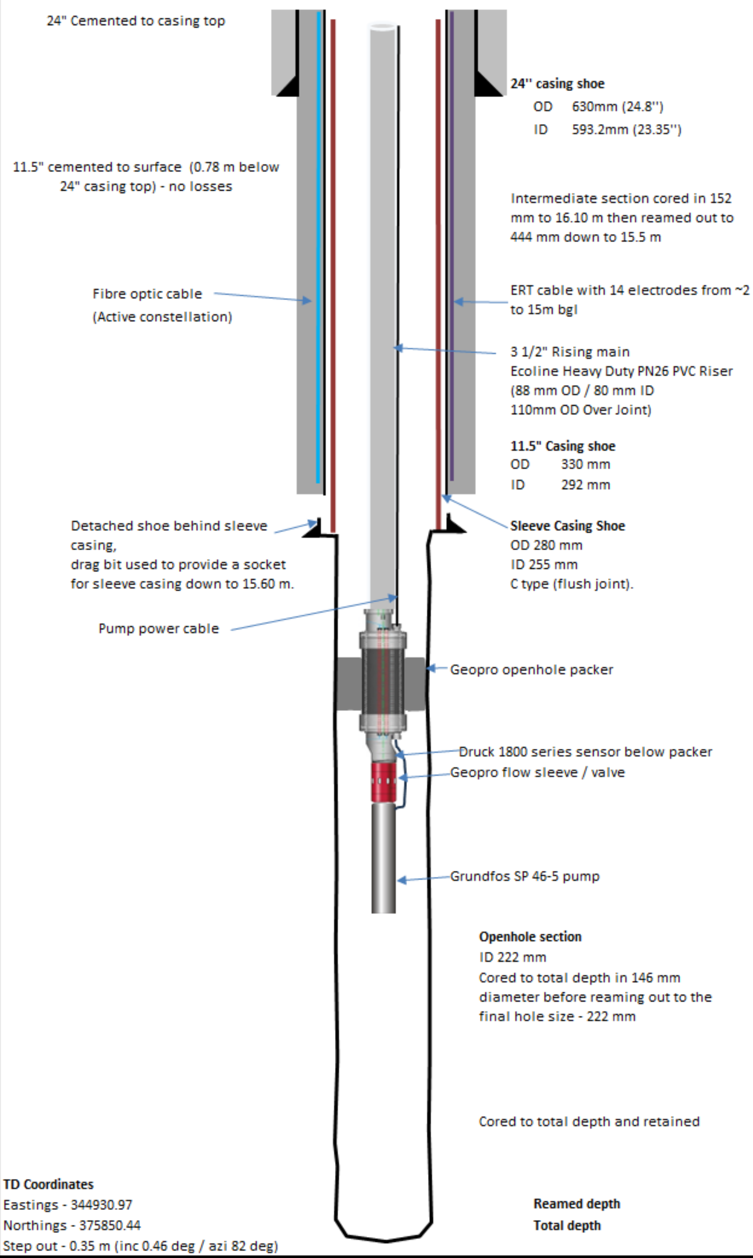
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

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
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	

Borehole coordinates: Eastings - 344930.719 Northings - 375850.685 Top 24" depth ref - 20.086 m AOD Top 24" to GL - 0.085 m	Well Schematic TH0408 Abstraction / Reinjection Borehole	British Geological Survey

Wireline logging undertaken	Tools run
Section logged from 2 to 98.2 m. Top section from 2 to 15 m through casing, lower section to TD in cored 146 mm hole. (05/05/23)	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



TD Coordinates
Eastings - 344930.97
Northings - 375850.44
Step out - 0.35 m (inc 0.46 deg / azi 82 deg)

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
15.60 m	Sleeve casing run with 6.0 mm clearence either side inside the intermediate casing and landed on
33.11 m	Geopro packer (mid element)
34.50 m (base)	Druck 1800 series pressure sensor
34.98 m	Geopro valve / sleeve
36.63 m	Grundfos SP 46-5 pump
100.0 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

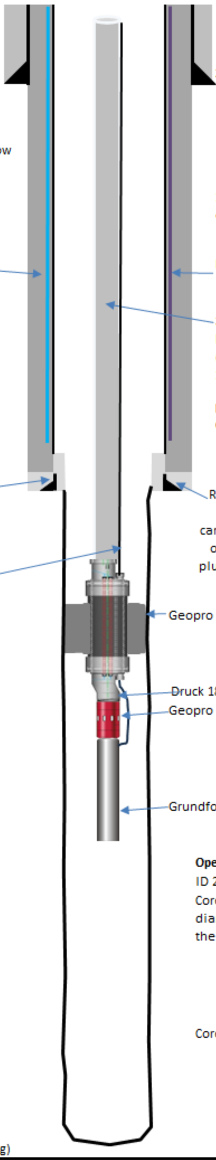
Borehole coordinates:
Eastings - 344953.443
Northings - 375842.839
Top 24" depth ref - 20.288 m AOD
Top 24" to GL - 0.070 m

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



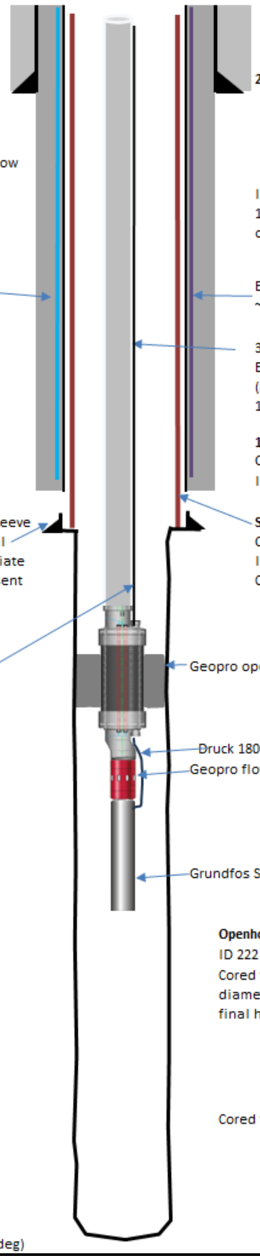
Depths m MD-BCT	Comments
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
14.69 m	End of intermediate casing without
15.30 m	Detached 330 mm intermediate PVC casing shoe
34.12 m	Geopro packer (mid element)
35.48 m (base)	Druck 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	

TD Coordinates
Eastings - 344953.19
Northings - 375842.84
Step out - 0.25 m (inc 0.8 deg / azi 258 deg)

Borehole coordinates: Eastings - 344945.995 Northings - 375858.124 **Top 24" depth ref - 20.404 m AOD** **Top 24" to GL - 0.070 m**	**Well Schematic TH0414** **Abstraction / Reinjection Borehole**	British Geological Survey

Wireline logging undertaken	**Tools run**
Section logged from 0 to 99.5 m. Top section from 2 to 15 m through casing, lower section to TD in cored 146 mm hole. 27/04/23	GR, CALI, ACBI, LRES, TEMP, COND

Ground Level



TD Coordinates
Eastings - 344945.72
Northings - 375858.69
Step out - 0.63 m (inc 0.53 deg / azi 328 deg)

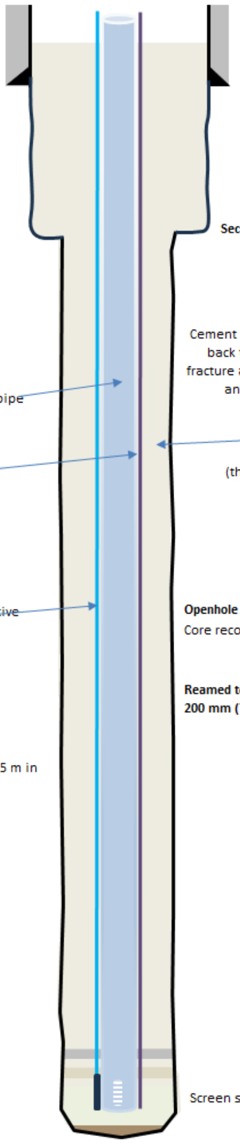
Depths m MD-BCT	**Comments**
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)	
	Bedrock encountered at 1.75 m
2 m	24" surface casing
14.70 m	End of intermediate casing without
15.44 m	Sleeve casing run with 6.0 mm clearence either side inside the intermediate casing and landed on
34.98 m	Geopro packer (mid element)
36.34 m (base)	Druck 1800 series pressure sensor
36.85 m	Geopro valve / sleeve
38.46 m	Grundfos SP 46-5 pump
100.0 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

4.1.5 ERT & DTS monitoring boreholes (TH0407, TH0409, TH0411, TH0413)

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

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



TD Coordinates
Eastings - 344924.13
Northings - 375852.94
Step out - 0.99 m (inc 0.66 deg / azi 314 deg)

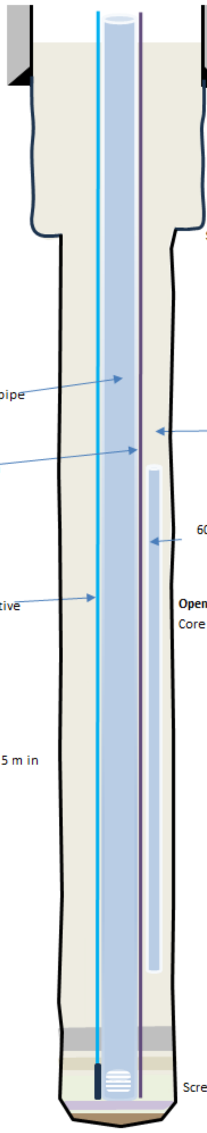
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)

	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
Install depth	99.44 m		
Reamed depth	105.0 m	Additional metres drilled for sump - debris in well and for logging tools	
Drilled total depth	106.4 m		

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)

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

Depths m MD-BCT	Comments	Backfill depths
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		

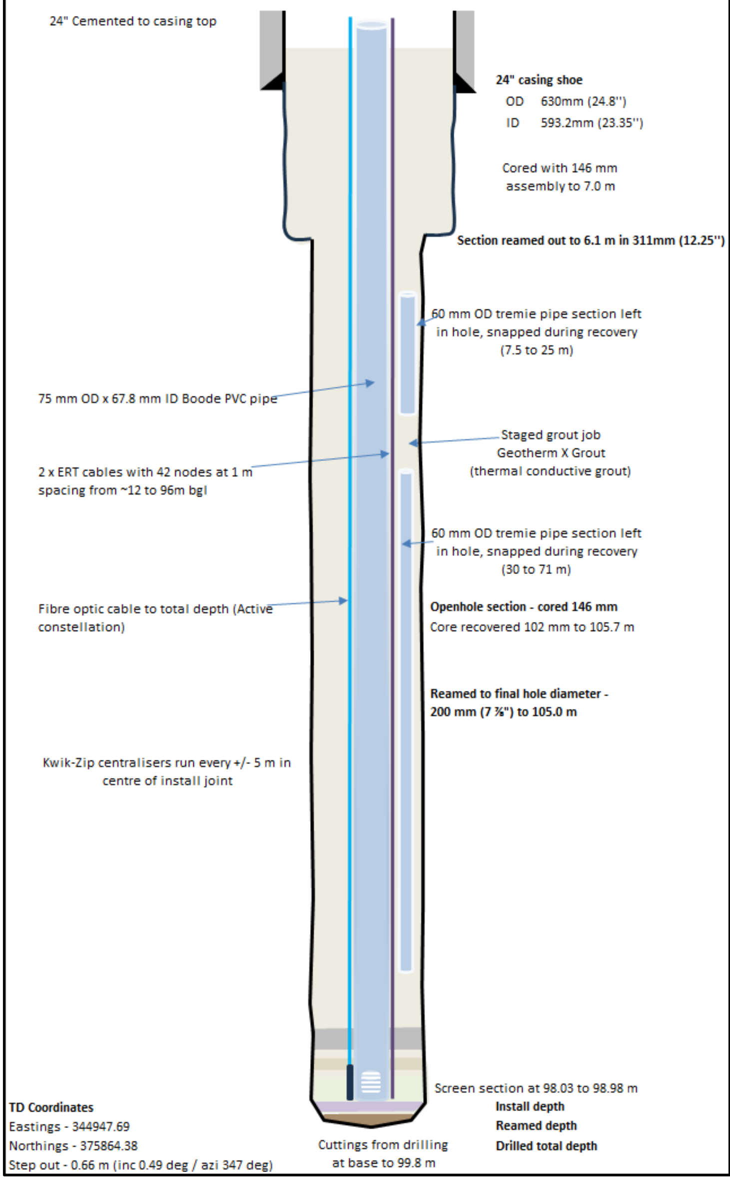
Borehole coordinates:
Eastings - 344947.946
Northings - 375863.772
Top 24" depth ref - 20.547 m AOD
Top 24" to GL - 0.023 m

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



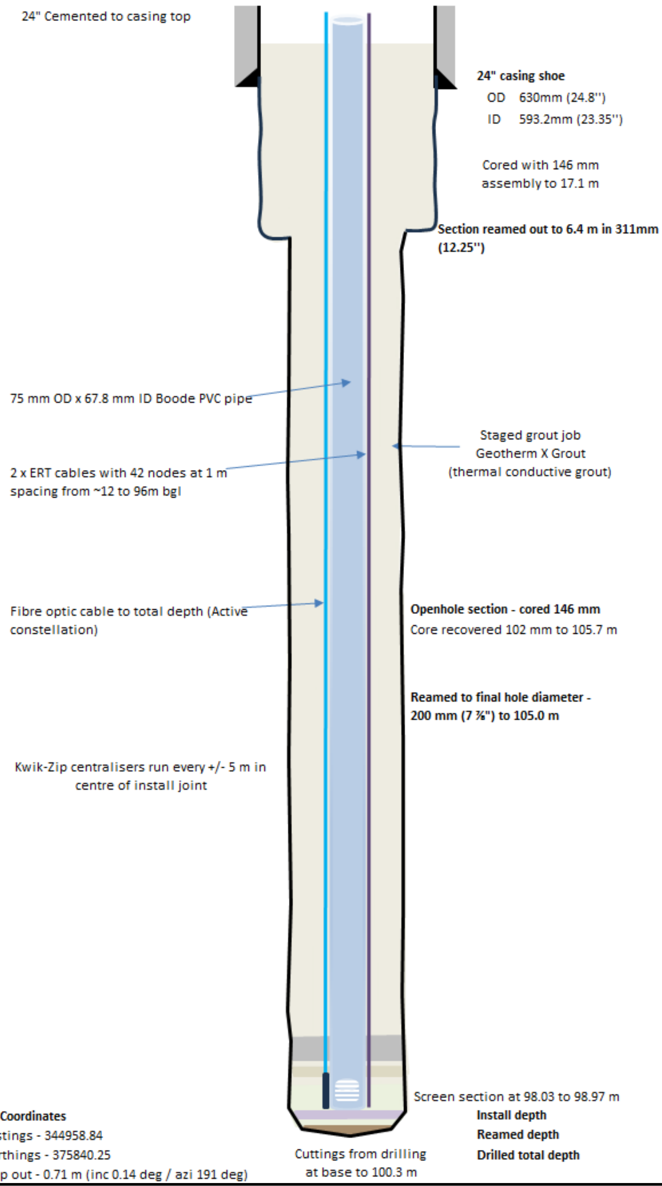
TD Coordinates
Eastings - 344947.69
Northings - 375864.38
Step out - 0.66 m (inc 0.49 deg / azi 347 deg)

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		

Borehole coordinates:	Well Schematic TH0413	
Eastings - 344959.089 Northings - 375840.915 **Top 24" depth ref - 20.331 m AOD** **Top 24" to GL - 0.146 m**	**ERT/DTS Monitoring Borehole**	British Geological Survey

Wireline logging undertaken	Tools run
Upper Section logged in cored 146 mm hole to 15.10 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

Ground Level



TD Coordinates
Eastings - 344958.84
Northings - 375840.25
Step out - 0.71 m (inc 0.14 deg / azi 191 deg)

Depths m MD-BCT	Comments	Backfill depths
All Measured Depths (MD) are in metres Below (24") Casing Top (BCT)		
1.00m	Grout stage #8	1.00 to 2.60 m
	Bedrock encountered at 1.75 m	
2 m	24" surface casing	
	Grout stage #7	2.60 to 5.80 m
	Grout stage #6	5.80 to 15.60 m
6.4 m	Open hole size remaining after 10 3/4'' temp casing recovered	
	Grout stage #5	15.60 to 20.40 m
	Grout stage #4	20.40 to 40.35 m
	Grout stage #3	40.35 to 59.70 m
	Grout stage #2	59.70 to 83.60 m
	Grout stage #1	83.60 to 91.95 m
	Bentonite Cement Pellets	91.95 to 96.0 m
	Bentonite Pellets (Mikolit 300)	96.0 to 97.10 m
	1 - 2 mm MGS filter sand	97.10 to 100.3 m
	4 - 10 mm MGS filter gravel	100.3 to 101.7 m
99.99 m		
105.0 m	Additional metres drilled for sump - debris in well and for logging tools	
105.7 m		

4.1.6 Outer uncased bedrock boreholes (TH0404, TH0405, TH0415, TH0424)

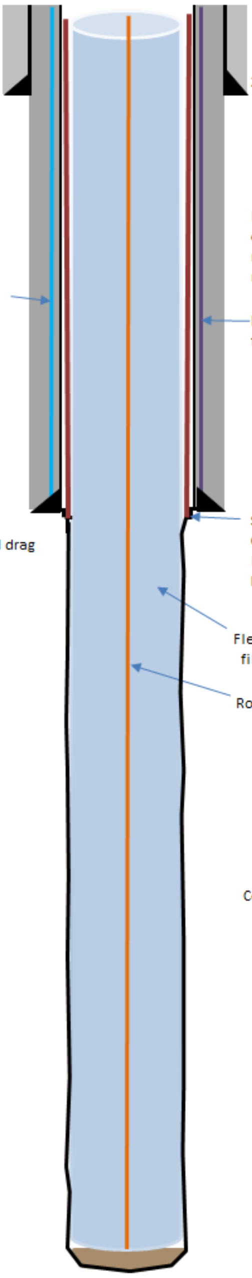
Borehole coordinates:
Eastings - 344919.211
Northings - 375835.615
Top 24" depth ref - 19.694 m AOD
Top 24" to GL - 0.130 m

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



TD Coordinates
Eastings - 344919.03
Northings - 375836.09
Step out - 0.51 m (inc 0.88 deg / azi 295 deg)

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
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
	6.5 mm either side of sleeve casing
99.86 m	
100.5 m	Additional 0.5 m drilled for sump - debris in well

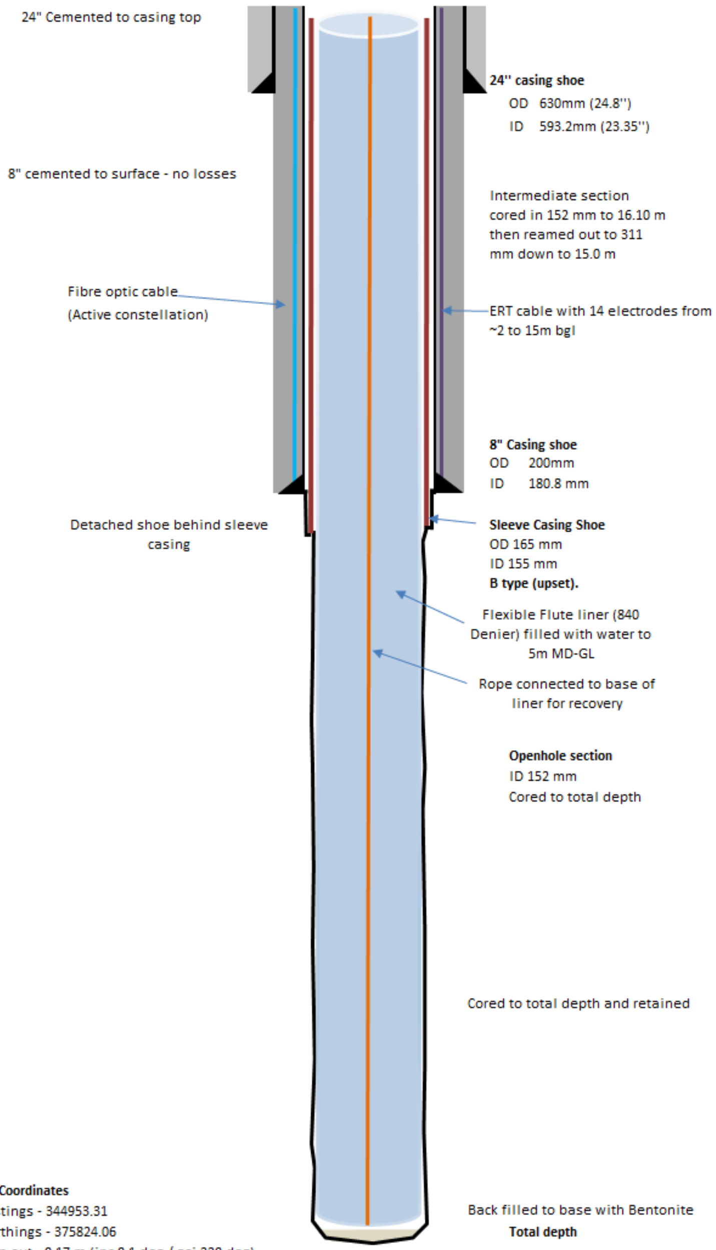
Borehole coordinates:
Eastings - 344953.256
Northings - 375823.895
Top 24" depth ref - 20.018 m AOD
Top 24" to GL - 0.130 m

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

Ground Level



TD Coordinates
Eastings - 344953.31
Northings - 375824.06
Step out - 0.17 m (inc 0.1 deg / azi 330 deg)

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
15m	Permanent 200mm PVC casing with FO & ERT cables attached
19.55 m	A type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID
	6.5 mm either side of sleeve casing
100 m	Additional 0.5 m drilled for sump - debris in well
100.5 m	

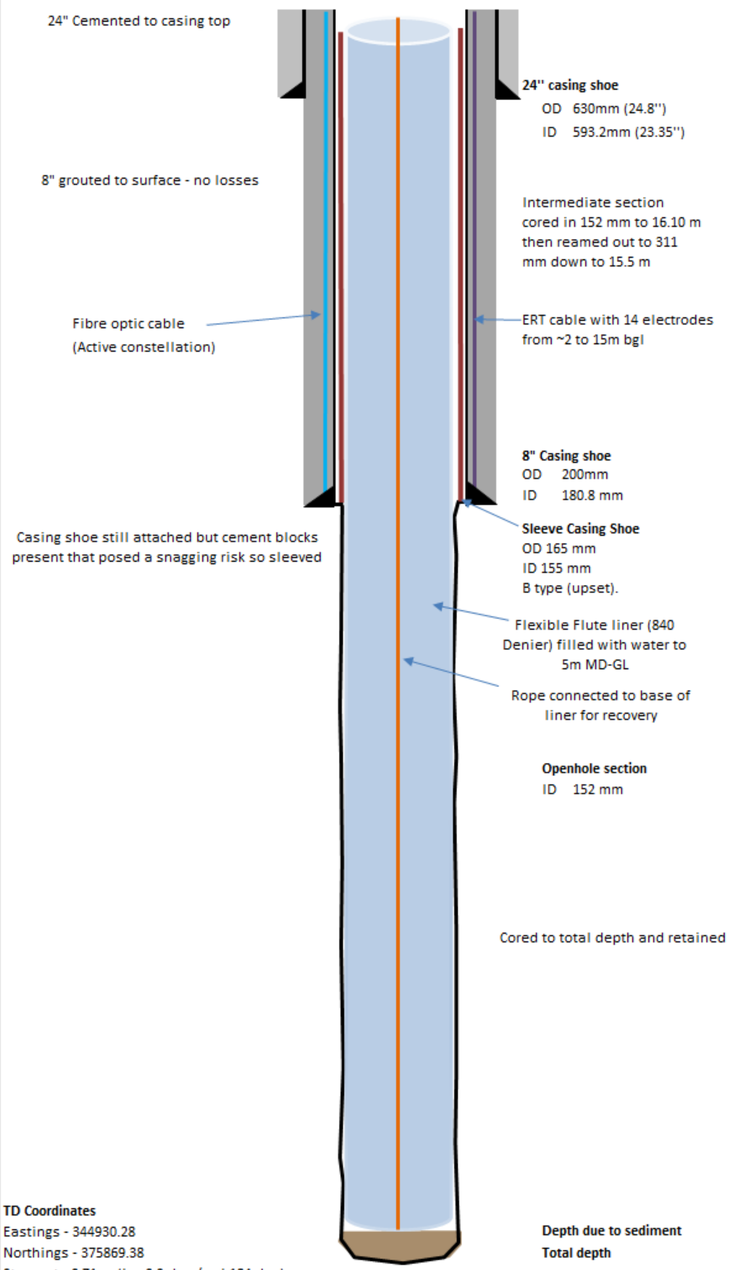
Borehole coordinates:
Eastings - 344930.933
Northings - 375869.656
Top 24" depth ref - 20.496 m AOD
Top 24" to GL - 0.118 m

Well Schematic TH0415
Uncased Bedrock Borehole

British Geological Survey

Wireline logging undertaken	Tools run
Well not logged apart from inclination survey at TD	Gyro survey

Ground Level



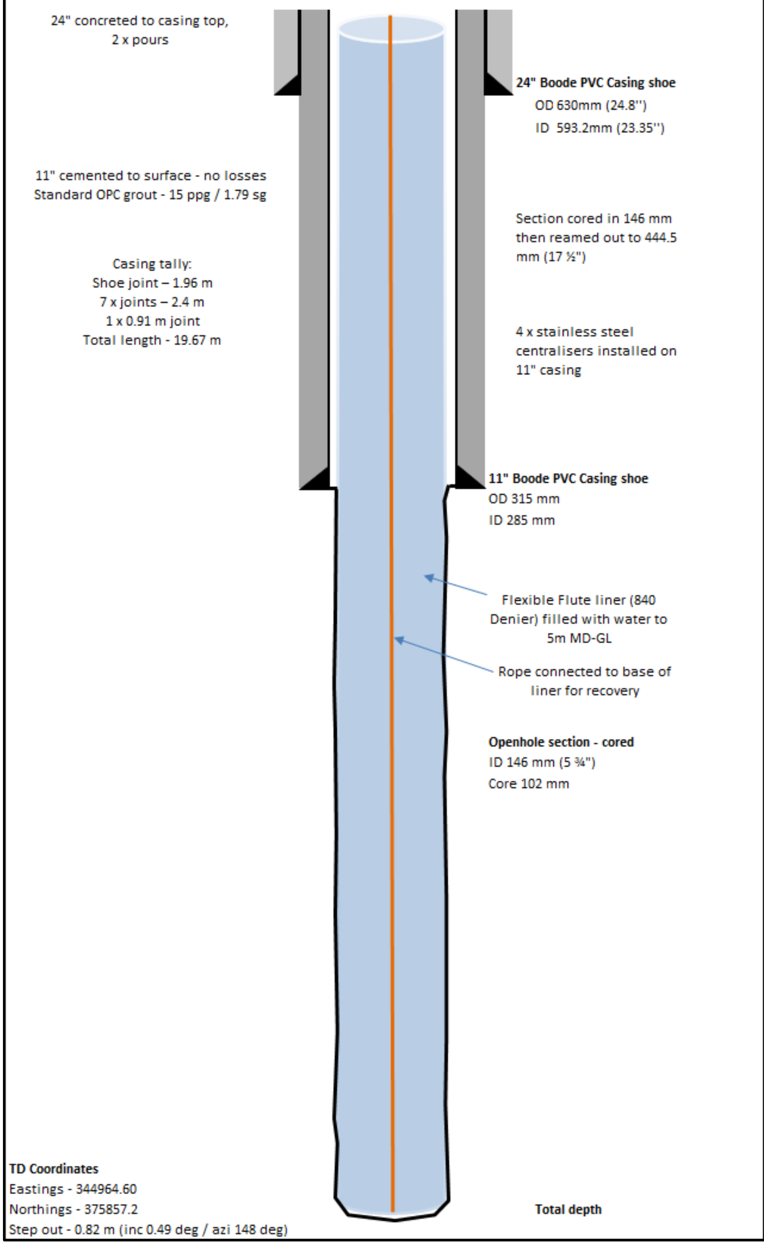
TD Coordinates
Eastings - 344930.28
Northings - 375869.38
Step out - 0.71 m (inc 0.9 deg / azi 184 deg)

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
15.5 m	Permanent 200mm PVC casing with FO & ERT cables attached
15.46 m	A type Socket at the base of sleeve casing - 175 mm OD x 165 mm ID
	6.5 mm either side of sleeve casing
99.86 m	Additional 0.4 m drilled to end of core run and for sump - debris in well
100 .4 m	

Borehole coordinates: Eastings - 344964.96 Northings - 375857.91 **Top 24" depth ref - 20.526 m AOD** **Top 24" to GL - 0.143 m**	**Well Schematic TH0424** **GI Borehole / Uncased Bedrock** ●	British Geological Survey

Wireline logging undertaken	**Tools run**
Upper section logged in 146 mm to 20.8 m before reaming out (12/11/21)	Acoustic imager, Caliper, Natural Gamma, Resistivity, Fluid temp and conductivity, P&S wave, flow
Lower section 21 to 101 m 16/12/21 and 17/12/21	Optical imager, Acoustic imager, Caliper, Natural Gamma, Resistivity, Fluid temp and conductivity, P&S wave, flow
Additonal logging from 21 m to 95 m. 22/03/22	Heat pulse / BMR

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
	Cored to 21 m before opening out to provide sump for pilot bit on reamer assembly
	Centrailisers placed on the bottom joint, 11.5 m, 6.7 m and 2 m MD-GL
20 m	Pre cast concrete plug dislodged from lead casing length when running resulting in a two stage cement job being required. First stage back to 18 m and allowed to set before cementing to surface. Evidence of this can be seen on image log.
47 m	Total losses reported
101 .14 m	Additional m drilled for sump - debris in well and for logging tools

Version control

Version Number	Date issued	Author	Update information
V0	06-11-24	Dave Hetherington	First revision for comment
V1	13-11-24	Mike Spence	Second version for comment
V2	05-08-25	Mike Spence	Third version for external release

Glossary

Abbreviation	Description
ACBI	Acoustic borehole imaging
AOD	Above ordinance datum
BGL	Below ground level
BHA	Bottom hole assembly
BMR	Borehole magnetic Resonance Image Log (Geophysical Survey)
BMS	Building management system
CALI	Caliper
CAT	Cable avoidance tool
CBL	Cement bond Log
COND	Fluid conductivity (may be derived from resistivity tool)
CSS	Check shot survey
CT	Casing Top [referencing the 24" diameter Boode PVC surface casing]
DAS	Distributed Acoustic Sensing
DENS	Density
DFLOW	Dynamic Groundwater Flow Log (Geophysical Survey)
DTC	Digital Temperature Cable
DTS	Distributed Temperature Sensing (Fibre Optic)
DUCAL	Dual caliper
EA	Environment Agency
EC	Electrical Conductivity
ERT	Electrical Resistivity Tomography
FLOW	Fluid flow velocity (wireline logging tool)
FLUTE	Flexible Liner Underground Technologies
FO	Fibre optics
FTS	Formation pressure testing and sampling
FWS	Full Waveform Sonic (Including, P-Wave, S-Wave and Stoneley wave)
GL	Ground Level
GPS	Global Positioning System
GR	Gamma Ray
GSH	Ground Source Heat (Heat Exchanger) Borehole
HE	Heat exchanger
IBC	Intermediate Bulk Containers
ID	Internal diameter
IRES	Induction Resistivity Logging (Geophysical Survey)
LCM	Lost circulation material
LOLER	Lifting Operations and Lifting Equipment Regulations 1998
LOT	Leak off test
LRES	Laterolog Resistivity Log (Geophysical Survey)
M AOD	Metres Above Ordnance Datum
M B	Metres Below

MLS	Multilevel system (for groundwater monitoring)
MRV	Minimum reporting value
NEUT	Neutron porosity
NTU	Nephelometric Turbidity Units (Groundwater Turbidity)
OBI	Optical borehole imaging
OD	Outside diameter
OPC	Ordinary Portland cement
PE100	High-density polyethylene (HDPE) with a minimum required strength of 10 MPa
PICV	Pressure independent control valve
POOH	Pull out of hole
PRIME	Proactive Infrastructure Monitoring and Evaluation
PVC	Poly-vinyl chloride
RC	Resistance to Cracking
REACH	European Union regulation concerning the Registration, Evaluation, Authorisation and restriction of Chemicals
RES	Resistivity logs at multiple depths of investigation (shallow, medium and deep)
RIH	Run in hole
RT	Raised Temperature resistance
SGR	Spectral Gamma Ray
SP	Spontaneous Potential (if incorporated with resistivity tool)
TD	Target depth
TDS	Total dissolved solids
TEMP	Temperature
TSP	Thornton Science Park
TVD	Total vertical depth
UKGEOS	UK Geoenergy Observatories
UKRI	UK Research and Innovation
USI	Ultrasonic imaging for casing and cement integrity
VWT	Vibrating wire transducer
WL	Water level

References

The British Geological Survey holds most of the references listed and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at https://of-ukrinerc.olib.oclc.org/folio/

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