OR/19/052 Research infrastructure

Kingdon, A, Fellgett, M W, and Spence, M J. 2019. UKGEOS Cheshire Energy Research Field Site - Science infrastructure. *British Geological Survey Internal Report*, OR/19/052. *Contributors:* Midgley, J, Elsome, J W, Dearden, R A, Chapman, C, Burke, S P, Hough, E, Luckett, R R, and Bianchi, M.

Overview of science infrastructure

The Cheshire Energy Research Field Site research infrastructure will comprise of four borehole-based experimental facilities, or arrays, where science can be undertaken:

- Array 1 Groundwater baseline
- Array 2 Seismic Baseline
- Array 3 Deep well
- Array 4 Multiscale array

The infrastructure also includes the following science installations:

- Ground motion sensors
- Air quality monitoring station

(Array 1 groundwater baseline to Array 4 multiscale array overview) provide an overview of the infrastructure and instrumentation available for science with a summary of the information for each array available in the document annexes.

Array 1 groundwater baseline

Overview

Array 1 provides groundwater baseline data allowing researchers to study and understand the regional groundwater regime. The array and its associated monitoring will allow scientists to consider the temporal and spatial variability across the study area. The aim of the array is to:

- Improve scientific understanding of the subsurface and near-surface environment
- Provide the public with easily accessible and understandable evidence and information on aquifer conditions
- Establish a long-term archive of baseline groundwater data to monitor environmental change resulting directly or indirectly from anthropogenic influences
- Facilitate the development of new sensor technologies for environmental monitoring.

Locations

The groundwater baseline array comprises clusters of boreholes at nine locations across the facility area, which measures some 4 by 5 kilometres. Three locations are to the west of the Dungeon Banks Fault, three are on the horst block and three are to the east of the Waverton Fault. This distribution of boreholes is designed to allow groundwater flow and geochemistry to be studied within and between each fault block.

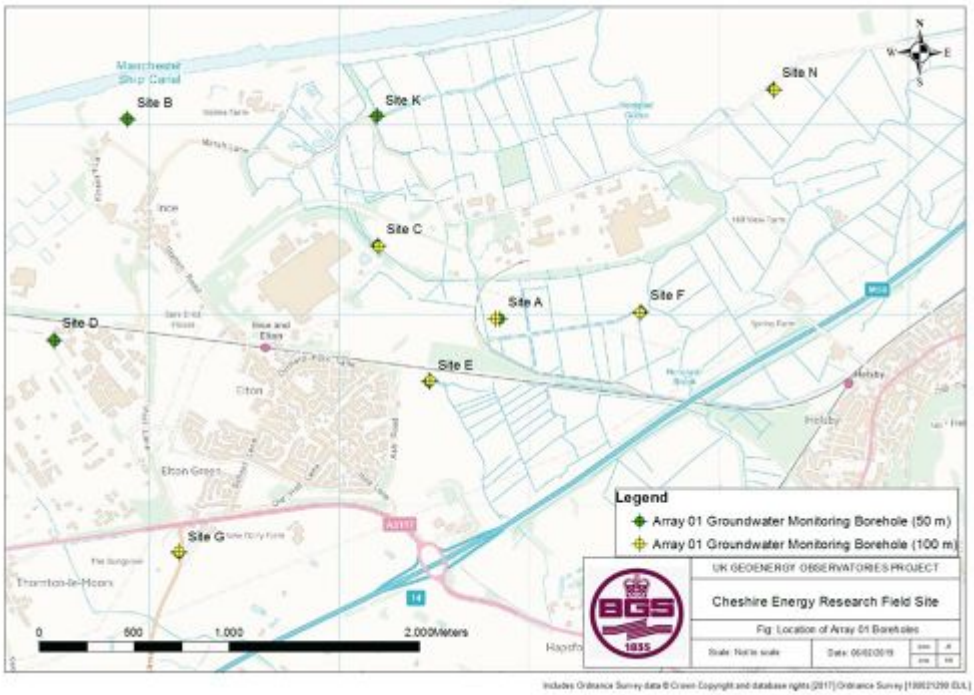

Figure 8 Array 1 Groundwater baseline monitoring locations. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved 2019. Ordnance Survey [100021290 EUL].Created using ArcGIS. Copyright © Esri. All rights reserved.

Infrastructure

All groundwater boreholes are anticipated to penetrate through the Quaternary deposits and terminate in the Sherwood Sandstone. At each of the nine locations there will be a pair of groundwater boreholes screened at different depths within the Sherwood Sandstone. One borehole will be 50 metres deep, have a minimum diameter of 216 mm and a 6 metre screened interval near its base. The other will be 100 metres deep, have a minimum diameter of 216 mm and be cased to ca. 50 m, with the lower 50–100 m left uncased (formation competence permitting) to provide direct access to the formation for hydraulic testing.

The boreholes are available for the deployment of groundwater equipment and are equipped with a box above the borehole providing anchors, which can be used to hang equipment. Some locations will also be fitted with cabinets where subsurface sensors and data transmitting equipment can be stored.

Scientific instrumentation

All groundwater baseline boreholes have been designed to allow for the installation of scientific instrumentation including, for example:

- Multi-parameter water quality probes
- Pressure transducers
- Submersible sampling and high flow pumps

Scientific data acquisition

CERFS will deliver the following data from the groundwater baseline boreholes:

- Hydraulic head — measured via pressure transducers and manual depth measurements.

- Aquifer properties — a series of hydraulic tests, including pump tests and falling head tests will be undertaken
- Groundwater sampling — a groundwater sampling campaign will collect and analyse samples from the boreholes. Sampling will be undertaken bimonthly until a static baseline is obtained and will continue long-term, though reduce in frequency. Analysis will include on-site measurements of pH, Oxidation Reduction Potential (ORP), dissolved oxygen and electrical conductance.
- Samples will be obtained and analysed for: major ions (ion chromatography), a broad suite of trace elements (ICP-MS), dissolved organic carbon (TOC analyser), stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$), TDIC, stable isotopes of methane ($\delta^{13}C$, $\delta^{2}H$), dissolved gases (CH_4, CO_2, O_2, radon, noble gases), organic compounds (GC-MS/LC-MS), groundwater 'age' indicators/ environmental tracers (e.g. CFCs, SF_6) and naturally occurring radioactive material (NORM; uranium and thorium decay series).
- Continuously monitored groundwater parameters — A subset of the groundwater boreholes will be equipped with sensor probes that monitor groundwater quality and head at 15 minute intervals. Groundwater parameters measured by these probes may include electrical conductivity, methane, BTEX, PAHs, temperature and barometric pressure. At selected locations this data will be telemetered from the site in real-time and be available via the online data portal.
- Geological core data
- Geophysical borehole logging
- All data collected at the site will be made available openly to researchers, including future data produced by the science community.

Intended sampling regime

Full operational details including frequency of sampling have yet to be finalised, details of intended analytical proposals are incorporated in Appendix 3a - Array 1 Borehole descriptions as guidance though are subject to revision.

Sampling programmes will typically be undertaken at an initial monthly interval, moving over time to a quarterly cycle with each sampling campaign taking approximately 1 week to complete.

Array 2 seismic overview

Array 2 provides a seismic monitoring network that will improve understanding of the seismic activity within the Cheshire Energy Research Field Site area. The data will form the natural baseline against which future seismic activity will be compared and contrasted. The network will be one of the highest resolution seismic monitoring arrays in the world. It aims to detect earthquakes of -0.6 to -1.0 magnitude — this type of quake is 1000 times smaller than a quake someone is likely to feel.

Locations

The baseline seismic monitoring array comprises instrumentation at ten locations and at an average spacing of 1 kilometre, across an area measuring approximately 4 by 4 kilometres. The area is centred on the defining geological structure of the area and is designed for optimal detection of seismicity on the two main faults. The seismic boreholes are anticipated to penetrate through the Quaternary deposits and terminate in the Sherwood Sandstone Group.

Due to local infrastructure including windfarms, motorways, railways and factories that produce background noise, the seismic monitoring network will be installed in boreholes at a depth of at least

200 metres to reduce the impact of ambient noise on the seismic response.

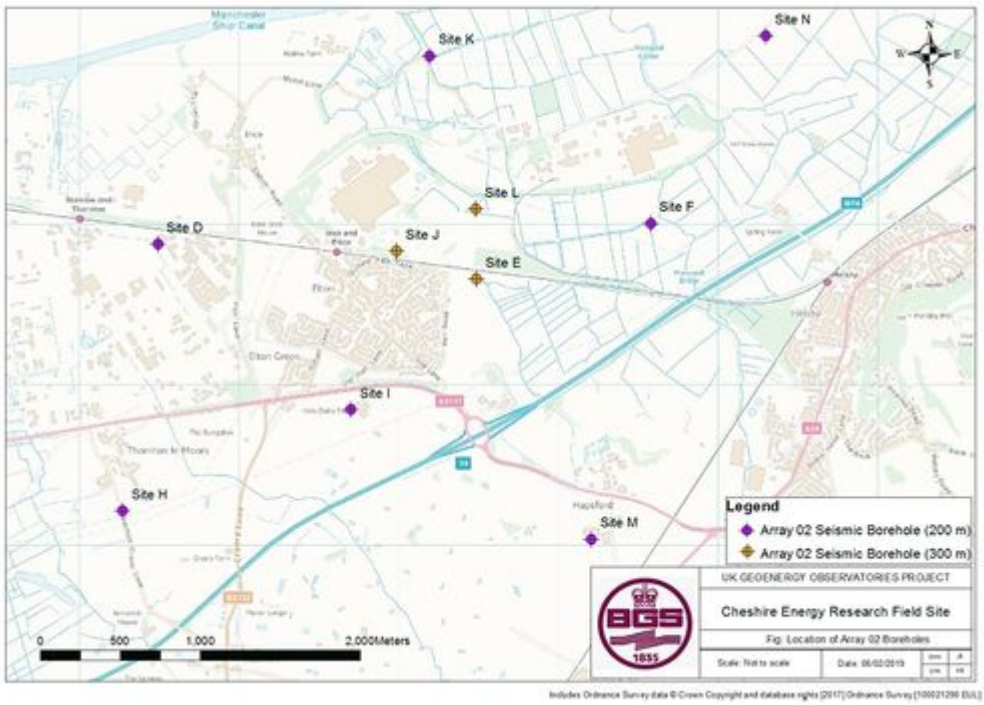

Figure 9 Array 2 Seismic baseline monitoring locations. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved 2019. Ordnance Survey [100021290 EUL]. Created using ArcGIS. Copyright © Esri. All rights reserved.

Infrastructure

The 10 boreholes of Array 2 are as follows:

- Three boreholes to a depth of 300 metres. These are equipped with two seismometers, one at 300 metres and one at 200 metres. Up to three 300 metre deep boreholes will also be equipped with acoustic fibre optic from surface to total depth.
- Seven boreholes to a depth of 200 metres. These are equipped with one seismometer each.

Note: A further seismometer (part of Array 3) will be installed in a 1200 metre borehole of terminating in the Millstone Grit Group.

Scientific instrumentation

The seismometers are Guralp Radian broadband seismometers that record 3-component acceleration data at 1000 Hz, with a sensitivity of 3000 V/m/s. The seismometers are lowered into the boreholes via a cable and are backfilled with sand, or mechanically held against the borehole wall with a clamp to ensure that the instrument has a good connection with the rock mass. The seismic data are logged at the surface and telemetered in real-time to the online data portal.

In the seismic boreholes fibre optic cable will be installed (as well as in other arrays). This is a leading edge technology that enables seismic data to be collected by firing a laser beam through the fibre optic cable and monitoring the backscattered light returned.

To protect the expensive seismic instrumentation and in particular the fibre optic cables, these boreholes will not generally be available for the deployment of other scientific equipment.

Scientific data acquisition

The following data will be available from the seismic array:

- Continuous seismographs
- Geophysical borehole logging
- Geological core and cuttings

All data collected at the site will be made openly available to researchers, including data generated by the science community from information provided by this array.

Array 3 deep well overview

Array 3 comprises a single 1200 metre deep borehole. It will characterise the broad geological succession including Permo-Triassic sandstones overlying Carboniferous Warwickshire Group, Pennine Coal Measures Group, terminating in the strata of the Millstone Grit Group. The borehole trajectory is expected to cross-cut a major fault and so there is uncertainty with regard to the exact sequence of geological units that will be encountered during drilling. Collectively these rocks represent potential barriers to vertical fluid flow, which is an important consideration in the development of subsurface energy resources such as coal bed methane (currently extracted 20 kilometres away near Warrington).

The Array 3 borehole will terminate in the Carboniferous Millstone Grit at 1200 metres and have a diameter of between 100 and 150 mm. The borehole will be cored either from the surface or ca. 550 metres (dependent on the drilling technology) to terminal depth and will be cased throughout the Permo-Triassic succession. Where cased, the borehole will be completed with fibre optic cable installed behind the casing for high resolution measurement of temperature and vibration.

Locations

There will be one deep well located near to the centre of the study area at the location of the main array (where Array 4 is also located). The exact specification of the surrounding Array 4 wells will be determined by the findings from the Array 3 well, particularly the fault geometry.

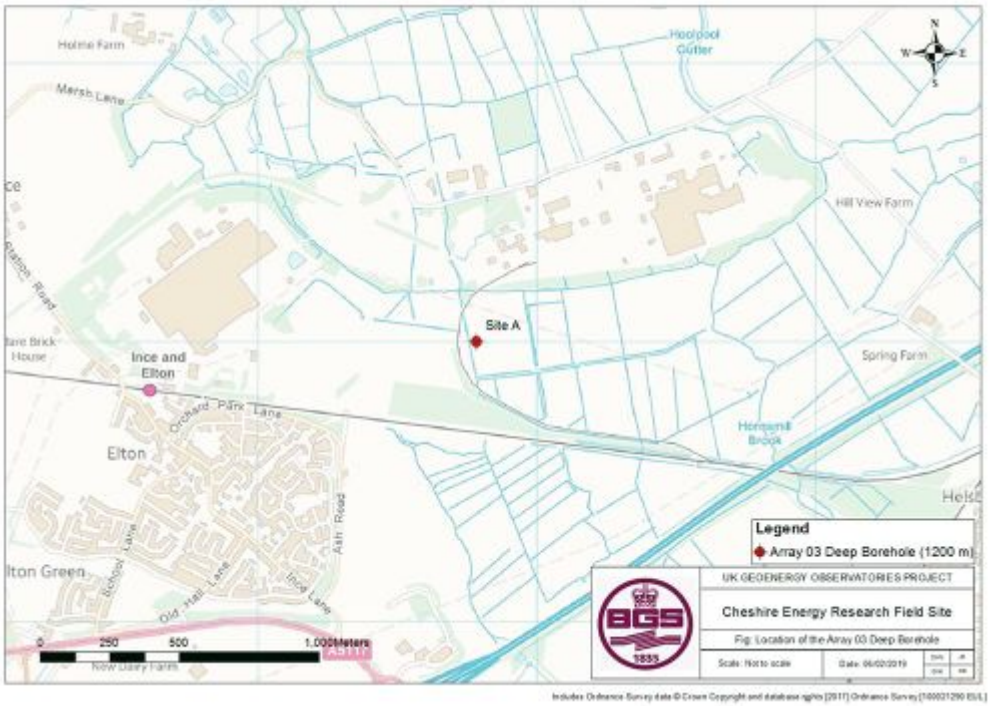

Figure 10 Location of Array 3 Deep borehole. Array 4 is immediately adjacent. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved 2019. Ordnance Survey [100021290 EUL]. Created using ArcGIS. Copyright © Esri. All rights reserved.

Infrastructure

A seismometer will be installed, together with geo-electric cabling and fibre-optic cabling. The borehole will then be back-filled and sealed with engineering cement to avoid the need to maintain such a deep borehole for the duration of the project.

Scientific instrumentation

At the terminal depth of the borehole a Guralp Radian broadband seismometer (the same type as described in (Scientific instrumentation) will be installed. The seismic data will be logged at the surface and telemetered in real-time to the online data portal.

Fibre optic cable, for use in Distributed Temperature Sensing and Distributed Acoustic Sensing will be installed alongside the borehole casing. The fibre optic cable allows for a continuous temperature profile or seismic activity to be measured along its length.

Scientific data acquisition

The deep borehole will yield the following data:

- Continuous seismographs
- Continuous vertical profiles of temperature and strain along the length of the fibre optic cable.
- Check shot survey
- Flow testing
- Geological core and cuttings
- Geophysical logging (see later)
- Physical and geochemical core scans (see later)
- Geochemical and microbiological characterisation of core material

All data, including core scan data, will be made available to researchers, including data generated by the science community from information provided by this array.

Array 4 multiscale array overview

Array 4 is designed to increase scientific understanding of the effects of geological heterogeneity at different scales on subsurface processes. The rock mass will be characterised in detail during the installation phase using the latest core scanning technologies and borehole logging tools. During the operational phase the array will be instrumented to support a range of experimental activities including:

- Hydrogeological characterisation via hydraulic tests (e.g. pumping tests, packer tests, slug tests) and tracer injection experiments (e.g. dilution tests, single-well injection-withdrawal tests, horizontal and vertical dipole tracer tests).
- Geophysical characterisation of formation properties using cross-borehole and surface-borehole 2D and 3D geoelectrical imaging technologies.
- Time-series imaging of fluid processes in the near surface including natural (e.g. near surface infiltration, fresh-saline water interface dynamics etc.) and induced changes (e.g. experimental — pumping/tracer tests).
- Integrated hydrogeological and hydro-geophysical experiments consisting of controlled and continuously monitored perturbations of the natural groundwater flow regime, subsurface temperature and hydrochemical composition of groundwater

Infrastructure

The design of Array 4 can be broken down into the following functional elements:

- **Dungeon Banks deep array:** 3 deep boreholes drilled to ca. 600 m (dependent on the encountered geology) along a line perpendicular to the Dungeon Banks fault zone. The casings of these wells will be designed to provide access to the various fault zone structures that may be encountered, to enable their hydrogeological and hydrogeophysical characterisation
- **Thermal/tomography array:** 20 boreholes drilled to 50 and 100 m in the Dungeon Banks fault zone and completed with casing, screen and sensor cables. These will be installed in a grid pattern to support tracer migration experiments in the Sherwood Sandstone. Dependent on the fault zone width and geometry, some of these wells could intersect shallow fault structures

    - One of the 100 m wells in the DB shallow array will be completed for ground source heat research. A U-tube will be installed to permit recirculation of heat exchange fluids together with sensor cables to monitor gradients in subsurface temperature and electrical conductivity. The exact location of this well within the thermal/tomography array will be decided during the installation phase when the location of the major fault structures has been confirmed. Currently it is anticipated that the well will be near the SE corner of the array to allow any heat migration to be monitored in wells to the north and west (the regional groundwater flow direction being W or NW)

Location

Array 4 will comprise a network of boreholes installed in faulted Permo-Triassic strata at relatively shallow depths (50–100 m) and at greater depths (ca. 600 m). The wells will be located within a relatively small area (ca. 200 x 200 m) and close to the 1200 m Array 3 borehole to facilitate detailed geological, hydrogeological and hydrogeophysical characterisation of the subsurface (Figure 11).

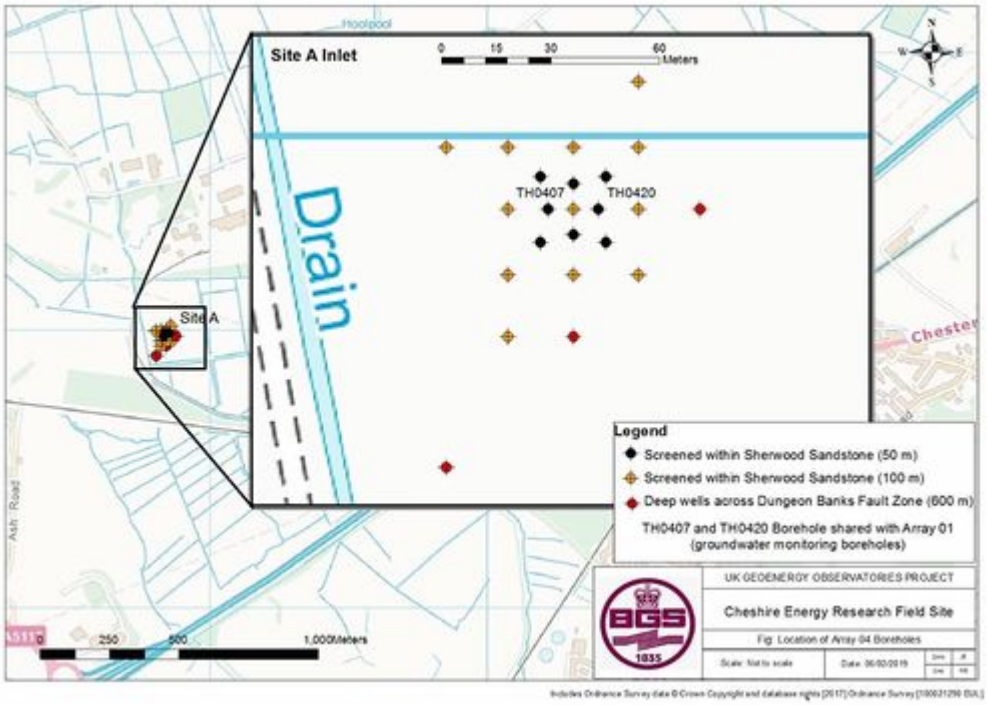

Figure 11 Close up location of Array 4, showing proximity to Array 3. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved 2019. Ordnance Survey [100021290 EUL] Created using ArcGIS. Copyright © Esri. All rights reserved.

Well designs

All boreholes are anticipated to penetrate the Quaternary deposits and Sherwood Sandstone Group (faulted). The 600 metre boreholes may also penetrate the Collyhurst Sandstone Formation, the Halesowen Formation and the Pennine Coal Measures. The depth of screen sections will be decided during drilling according to the formation properties-in general more permeable horizons will be targeted in view of their importance for aquifer flow and solute transport.

Fibre optic and electro resistivity cables installed into the boreholes will be laid in trenches and connected together in a data centre located at Site A. From this building, computing infrastructure will stream data to scientists working remotely. Scientists will largely be able to control this array and collect data remotely from their desktops.

Groundwater monitoring boreholes in thermal/tomography array

The eleven 100 m boreholes will be completed with PVC casing and screen, with multiple screen sections to provide access to the aquifer at different depths. Outside of the casing, the boreholes will be instrumented with max. 80 electro-resistivity tomography sensors and a temperature-sensitive fibre optic cable. These boreholes will be positioned in a regular grid at a spacing of 25 m.

The eight 50 m boreholes will be completed with PVC casing and screen, with multiple screen sections to provide access to the aquifer at different depths. Outside of the casing, the boreholes will

be instrumented with max. 40 electro-resistivity tomography sensors spaced evenly with depth and a temperature-sensitive fibre optic cable. The boreholes will be positioned in a regular grid at a spacing of 10 m, nested within the 100 metre deep borehole grid

Ground source heat research borehole in thermal/tomography array

A ground source heat research borehole will be installed in Array 4 to support the assessment of low enthalpy geothermal resource and the effect of heat addition and extraction on subsurface conditions. It will be completed as a Thermal Response Test (TRT) well according to a standard industry specification so that can be used by geothermal operators to calibrate equipment and understand the influence of subsurface conditions (e.g. GW flow) on thermal response. The design concept for this TRT well is shown in Figure 12.

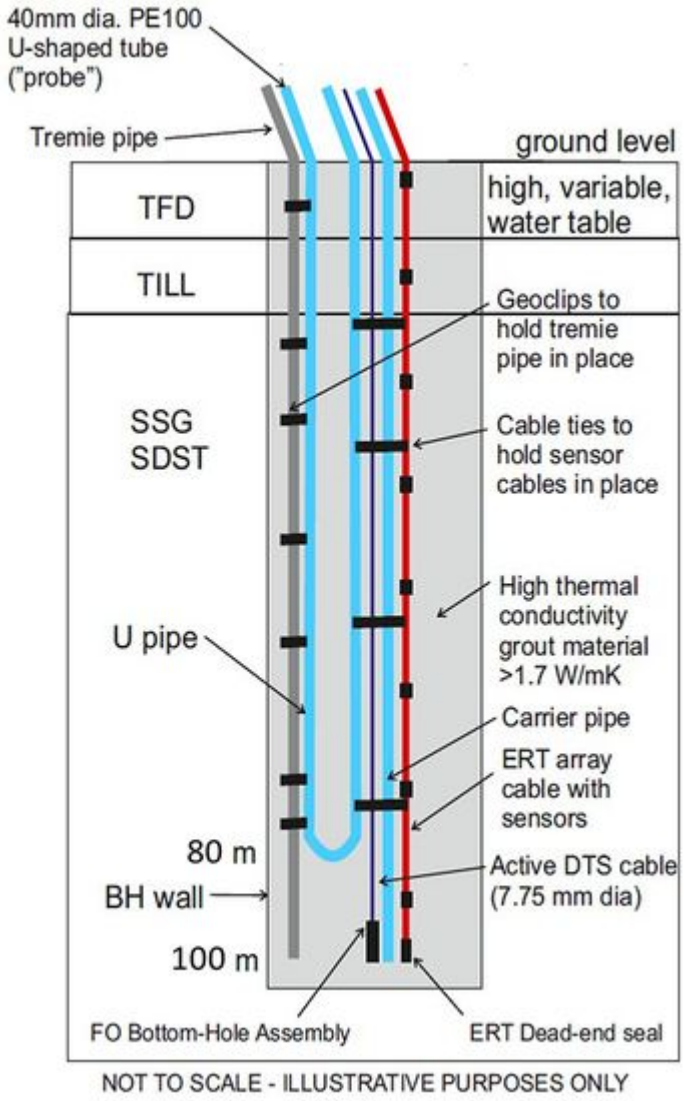

Figure 12 Schematic well design for Thermal Response Test (TRT) well showing positioning of DTS and ERT cables on outside of 40 mm diameter PE100 U-shaped tube.

3 x ca. 600 metre boreholes in the dungeon banks deep array

The three 600 m boreholes will be positioned along a line approximately perpendicular to the Dungeon Banks fault at a spacing of 10–50 metres. The two outer boreholes will incorporate an open section to provide direct access to fault structures. The middle borehole will be cased to permit the

installation of max. 120 electro-resistivity tomography sensors and a temperature-sensitive fibre optic cable. The 600 m well spacing, together with the permanent casing depth, base grout depth and open interval will depend on findings from the drilling of the 1200 m Array 3 borehole. The design of the these boreholes, labelled A, B, C on Figure 14, is as follows:

Boreholes A, C
Electrically insulated steel casing will be installed into competent bedrock ca. 50m above the fault structures of interest. The casing will then be cemented into the annulus with DTS and ERT cables installed along the outside. The borehole will then be advanced by rotary coring through the cement plug and underlying fault zone structures to final depth. The borehole will be left open through the fault zone to provide access for research investigations, with a cement seal emplaced from final depth to below the fault zone to prevent any fluid migration from depth.

Borehole B
Steel casing will be installed to the shallow competent bedrock. The borehole will then be advanced through underlying fault zone structures to final depth. A second electrically insulated steel casing will then be cemented into the annulus with DTS and ERT cables installed along the outside to final depth.

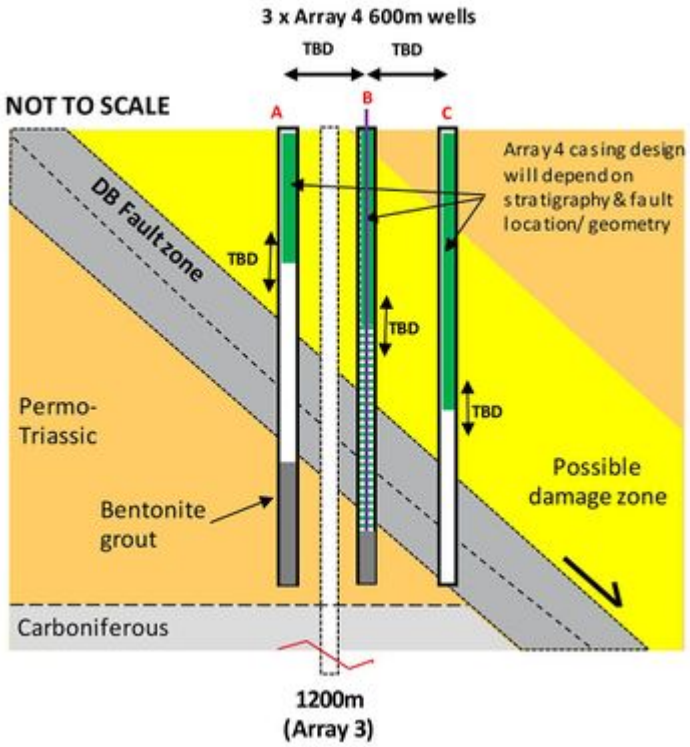

Figure 13 Design concept for 3 x 600 m Array 4 boreholes: the middle 600m borehole is installed with a well casing/screen instrumented with DTS & ERT cables to support online monitoring of fluid flow. Note that the 1200 m array 3 borehole is located out of the plane of section.

Scientific instrumentation

The Array 4 scientific instrumentation will comprise:

- Electrical Resistivity Tomography (ERT) sensors installed on the outside of the borehole casing, connected to a Proactive Infrastructure Monitoring and Evaluation (PRIME)

instrument. The ERT sensors comprise metallic electrodes mounted on multi-core cables, with each cable supporting 40 discrete sensors. The sensors can be used to monitor temporal changes in the 3D distribution of electrical resistivity in the area of the array.
- Fibre optic cables for Distributed Temperature Sensing (DTS) installed on the outside of the borehole casing. Distributed temperature measurements are primarily required for calibration of ERT imaging data. One fibre optic cable will form a continuous loop down all boreholes of the array such that measurements can be made with the same DTS unit.

The array has been designed to allow for flexible deployment of borehole tools and instrumentation including, for example:

- Pressure transducers/loggers to monitor water level
- Submersible pumps, to collect groundwater samples and induce flow
- Multi-parameter groundwater monitoring probes

Scientific data acquisition

The following data types are anticipated from the construction and operation of Array 4:

- Wireline logs of geophysical properties
- Data generated from the logging and analysis of rock core (e.g. permeability, porosity, geochemistry, geomicrobiology)
- 3D resistivity data, which can highlight zones of saturation and be used to track injected tracers. Changes in the resistivity profile can also be monitored over time for 4D characterisation
- Formation flow and transport properties from hydraulic and tracer testing
- Time series data on groundwater elevation, temperature, geochemistry and geomicrobiology
- Seismic data
- Gas data

Data collected during array 4 construction and commissioning, including data generated by UKRI funded research projects (as per NERC data management policy), will be made available to the science community via the UKGEOS website.

Ground motion

Overview

Ground motion monitoring in the Cheshire area is designed to detect the occurrence of any superficial instability (subsidence, uplift or stability) of the target area before, during, and following subsurface activities using Synthetic Aperture Radar (SAR) images, which have been acquired periodically since 1995.

The interferometric processing of the available SAR imagery (InSAR) has been designed to provide displacement measurements at different times with millimetre accuracy over an area of approximately 1,100 km^2.Two passive and one active InSAR reflector will be installed.

Infrastructure

To facilitate calibration and accuracy of the ground motion data, two types of radar reflectors will be installed: passive and active. Passive reflectors are large metal reflectors, usually trihedral in shape,

with the open end of the reflector typically orientated towards the satellite line-of-sight. They return the back-scattered electromagnetic radiation, transmitted from the passing satellite, through a double bounce scattering reflection. Active reflectors provide a stronger response to an over passing satellite by increasing the amplitude of the received radar signal.

The installed reflectors provide a location where electromagnetic energy from the ground surface is backscattered and observable by satellite to provide the Synthetic Aperture Radar output. This strong scatterer on the terrain, measured through the Radar Cross Section parameter, facilitates the measurement of terrain deformation from SAR imagery especially where land cover lacks good radar scatterers (in this case marshy land).

Figure 14 Passive InSAR reflector.

Data availability

The data generated from this facility includes:

- InSAR results of the average ground motion and relative time-series
- Geological interpretation of the InSAR data in order to identify the extent and origin of any possible ground movement

All data collected at the site will be made available to researchers, including future data produced by the science community that may utilise this array.

Air quality

Air quality monitoring will be undertaken during facility operation, however at the time of writing details of the planned monitoring infrastructure are not yet available beyond the summary provided in Table 2. Air quality monitoring data will be made available to researchers, including data subsequently generated by the science community from information provided.

Table 2 Analytical outputs from air monitoring programme.

Proposed Instrumentation	Analytical Measurements
Teledyne UP200 NOx analyzer	Nitrogen Oxides
Thermo Scientific Model 49i Ozone Analyzer	Ozone

Fidas 200 particulate matter monitoring system	Particulates
Thermo Scientific Model 450i Hydrogen Sulfide and Sulfur Dioxide Analyzer	Hydrogen Sulphide
To be confirmed	Methane/CO_2
Anemometer	Wind speed
Met station	Weather conditions

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