

GeoEnergy NI - Stormont

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Borehole Drilling and Geophysical Logging Report

Issue V1

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1.0 INTRODUCTION

Tetra Tech was commissioned by the Department for the Economy (the client) on February 13, 2023, to conduct exploratory drilling, hydrogeological and thermogeological investigations at the Stormont Estate (the site) as part of a geothermal demonstrator project (GeoEnergy NI).

The primary objective of this project is to assess the potential and feasibility of harnessing geothermal energy in Northern Ireland, encapsulated in the initiative to "unearth the heat beneath our feet." The feasibility study at the Stormont site set out to investigate what type of shallow geothermal system would be suitable for the decarbonisation of buildings within the estate.

This document reports on the exploratory borehole drilling, hydrogeological testing and geophysical logging undertaken at the site. The main objectives for the works were as outlined in Appendix D – Specification for Geothermal Demonstrator Project - Annex C & D. In summary the scope of works comprised the drilling and testing/instrumentation of 4 No. boreholes, completed to up to a maximum depth of 250m and the drilling and coring of 1 No. geological stratigraphic borehole up to a maximum depth of 500m.

The investigation strategy was designed to collect relevant data necessary for evaluating the feasibility of implementing closed-loop and/or open-loop geothermal systems at the Stormont Estate site. This investigation yields critical insights into the local geological and hydrogeological system beneath Stormont and subsurface thermal properties. The investigations completed included the drilling and geophysical logging of boreholes, a groundwater pumping test to assess hydrogeological properties and the installation of closed-loop pipework in one of the exploratory boreholes, to allow the testing of the ground thermal properties.

2.0 SITE SELECTION AND PLANNING LEGISLATION REQUIREMENTS

Based upon available geological mapping, land ownership and potential for geothermal resource end-use for office building heating/cooling, the Stormont Estate was identified as a suitable site to investigate shallow geothermal resource potential. The site, located east of Belfast in County Antrim at Irish Grid Reference J 40317 74144, features parliamentary and council buildings, roads, amenity grassland, mixed woodland, and parkland. It is partially accessible to the public with walking trails, a dog park, and a children's park, situated near Upper Newtownards Road and southeast of Belfast Lough.

The site location and planning boundary is shown on **Figure 1**.

Following consultation with Belfast City Council planners on the nature of proposed works, it was determined that a planning application would be required to be submitted prior to any works being carried out.

The planning application and supporting environmental/ecological reports were subsequently submitted to Belfast City Council and planning permission was granted on 30/4/24. Associated documents relating to planning permission can be viewed on the Northern Ireland planning portal [Northern Ireland Public Register](#) under planning reference LA04/2023/3856/F.

The originally specified works plan for Stormont comprised:

- Drilling of 4 No boreholes (EB1 – EB3, EB5) each to a depth of up to 250m;
- Drilling of 1 No cored borehole to a depth of up to 500m deep (STRAT);
- Geophysical Logging of all boreholes;
- Potential packer testing of selected boreholes;
- Installation of closed loop pipework in one of the up to 250m deep boreholes and testing for thermal properties;
- Yield testing of two of the 250m deep boreholes.



Figure 1 Site Location and Planning Boundary

3.0 GEOLOGICAL SETTING

3.1 SUPERFICIAL GEOLOGY

The published 1:10,000 scale geological map (GSNI GeoIndex) for the site and wider surrounding area is presented on Figure 2. All proposed borehole locations and the surrounding local area are underlain by superficial (largely unconsolidated) Quaternary and Recent (alluvium and peat) deposits overlying the bedrock.

Figure 1 indicates broadly that the northern part of the Stormont Castle/Stormont Estate is underlain by glacial till formed below an ice sheet. The till in this region comprises an irregular layer of variable lithology, with a matrix of poorly sorted clay, silt and sand grade material, containing cobbles and boulders, with occasional sand and gravel horizons Robins (1996).

The southern part of the Stormont Estate and extending along the Dundonald/Enler Valley out to Comber, is mapped as being predominately glaciofluvial ice contact deposits at surface, which comprises unlithified silt, sand, gravel and boulders. Areas of glacial till are also mapped at surface with minor areas of more recent alluvium and peat deposits also present.

Recent (GSNI, 2023¹) site-specific field reconnaissance mapping and desktop assessment of available borehole and site investigation data of the Stormont Estate area by GSNI indicated that glacial till is expected to be present beneath glaciofluvial deposit across most of the area and sits directly on the underlying bedrock. This more detailed assessment of the site also indicated the presence of areas of glaciolacustrine deposits. No peat was observed across the assessed Stormont area although one borehole record (130SE92) did record the presence of 7 m of peat at IGR 339875 374314.

With respect to the proposed borehole locations, all borehole sites are in areas mapped as being directly underlain by sand and gravel-rich, glaciofluvial ice contact deposits.

¹ GSNI, 2023 Mark R. Cooper, Rob Raine, Sam L. Roberson and Rebecca in Chonchubhair Geological Survey of the Stormont Estate Geothermal Demonstrator AOI

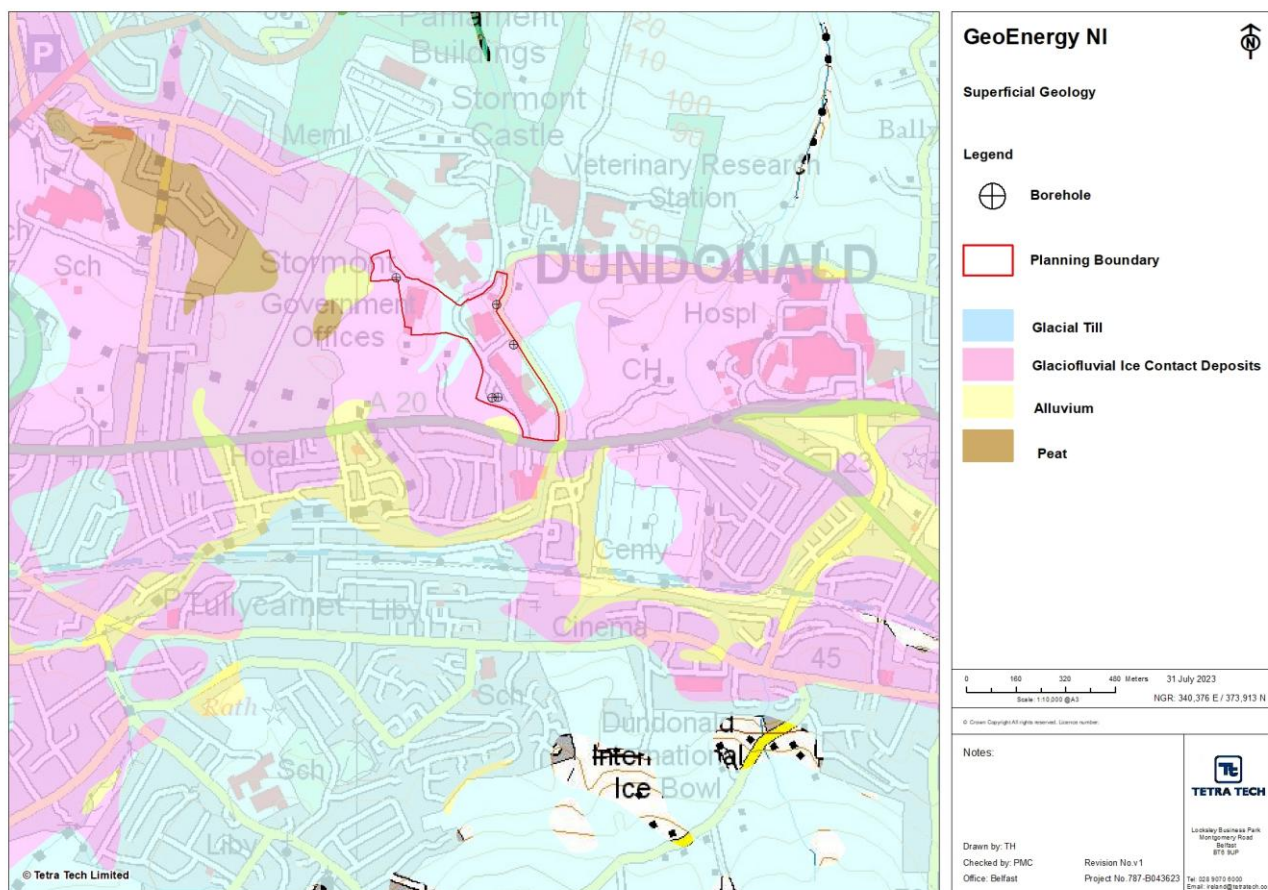


Figure 2 Superficial Geology Map (GSNI GeoIndex 1:10000 Mapping)

3.2 BEDROCK GEOLOGY

Published 1:10,000 scale bedrock geological mapping (GSNI GeoIndex) (see Figure 3) indicates that all borehole locations are sited over Triassic-age Sherwood Sandstone Group. This sandstone underlies much of Belfast, the Lagan Valley and extends east as far as Newtownards. The Sherwood Sandstone in the area is characterised as a reddish-brown to buff coloured fine to medium grained sandstone. It shows abundant sedimentary structures, interbedded mudstones, siltstones, mudstone breccia and clay galls (Smith et al., 1991²).

The sandstone can reach a thickness of 300 m at the centre of the Lagan Valley (Manning et al, 1970³). The Sherwood Sandstone east of the study area at Newtownards is inferred in cross-section to reach up to ~600 m thickness downdip, adjacent to the Newtownards Fault⁴.

² Smith, R.A. Johnston, T.P. & Legg, I.C. 1991. Geology of the country around Newtownards: Memoir for 1:50,000 geological sheet 37 and part of 38 (Northern Ireland). HMSO, London

³ Manning, P.I.; Robbie, J.A. & Wilson, H.E. 1970. Geology of Belfast and the Lagan Valley (one-inch geological sheet 36) (Second edition) (reprinted 1987). HMSO, Belfast

⁴ GSNI 1987. Newtownards 1:50000 Solid Geology Map Sheet 37 and part of 38 – Cross Section B

The northern portion of the Stormont Estate, on higher ground, is directly underlain by older, Ordovician-age greywackes and mudstones of the Leadhills Supergroup. The boundary between these strata and the Sherwood Sandstone is defined by a series of steeply dipping faults, with the main east–west trending structure (the Newtownards Fault) and additional minor north–south trending offset faults.

South of the Upper Newtownards Road older, Permian-age, mudstones and sandstones of the Belfast and Enler groups are mapped as being present. The Belfast Group is represented by a carbonate unit (Belfast Harbour Evaporite Formation) and an overlying mudstone-dominated unit (Connswater Marl Formation). Both these units thin towards the east and south of the site, where only the mudstone is present. The Enler Group in this part of the valley is poorly exposed but likely contains sandstone and/or breccia of the Carnamuck Sandstone Formation and the Coolbeg Breccia Formation (Smith et al., 1991). The locality lies close to the boundary of two different sedimentary basins, and it may be that units recorded from the Newtownards Trough (Haw Hill Borehole Formation, Kennel Sandstone Formation and Newforte Breccia Formation) are also present. The overall dip direction of the Permian and Triassic strata is to the north/north-east, and as such the Belfast Group (Connswater Marl Formation) and the Enler Group strata are expected to be present at depth directly beneath the Sherwood Sandstone. Across the wider area covered by the 1:50,000 Newtownards geological sheet (GSNI, 1987⁵) has limited measurements of dip. Based on available data, the Sherwood Sandstone dip ranges from 8° to 18° generally to the north-east. The nearest measurement to the Stormont site is ~3km east, with a recorded dip of 10° to north-east.

To the south, the Permian rocks rest unconformably on older, Ordovician-age greywackes and mudstones of the Leadhills Supergroup and Silurian-age Gala Group.

⁵ GSNI 1987. Newtownards 1:50000 Solid Geology Map Sheet 37 and part of 38

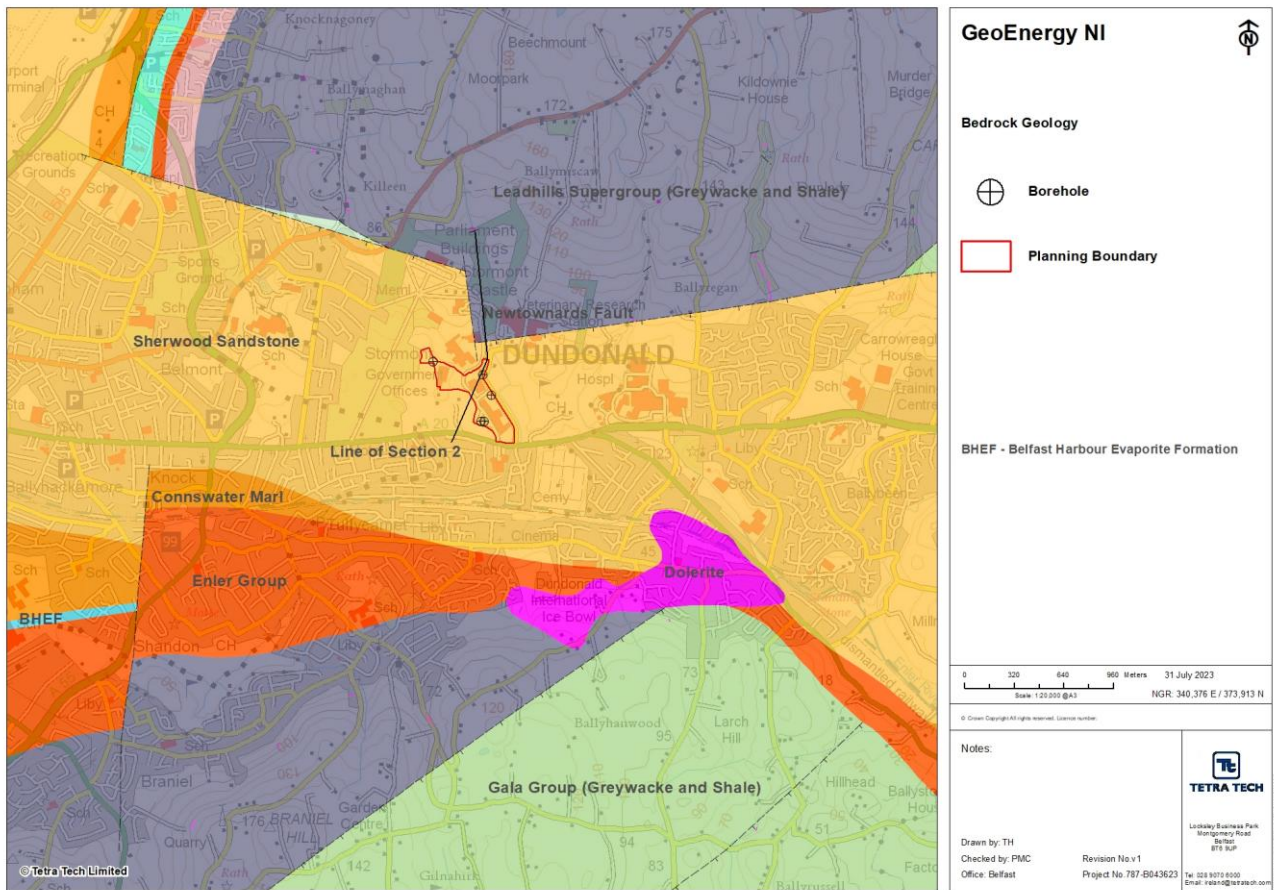
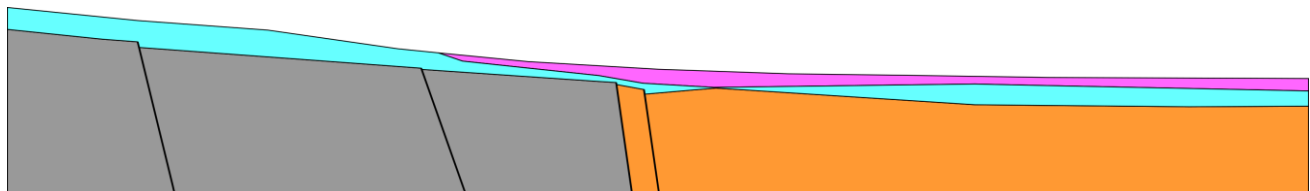


Figure 3. Bedrock Geology Map (GSNI Geoindex 1:10000 Mapping)



Sherwood Sandstone
 Leadhills Supergroup
 Glacial Till
 Glaciofluvial Ice Contact Deposits

Insert 1: Interpreted Cross Section 2 (see Figure 2) through the geological setting from the North (LHS) to the South (RHS) GSNI, 2023⁶

Drawn to -100m OD. Black lines are faults

Also mapped as being present ~1 km to the south-east of the Stormont Estate is dolerite rock formed by igneous intrusions (Dundonald Sill). Such features are also present towards Newtownards and contribute to the formation of Scrabo Hill where the igneous intrusions into the Sherwood Sandstone bedrock can be

⁶ GSNI, 2023 Mark R. Cooper, Rob Raine, Sam L. Roberson and Rebecca ni Chonchubhair Geological Survey of the Stormont Estate Geothermal Demonstrator AOI

observed. From coastal exposures, borehole records and regional geological mapping it is known that igneous dyke intrusions are common throughout the Belfast and Newtownards areas (as well as elsewhere in Northern Ireland) with more recent, unpublished-to-date studies by GSNI ⁷ indicated an average separation distance of ~ 80 m. These are vertical/sub-vertical intrusions of basalt/dolerite into country rock, of centimetres to several metre thickness, with a predominately NW–SE trend.

⁷ Personal Communication, Dr M Cooper, GSNI

4.0 SURVEY WORKS, WORKS CONTROL (CEMP) AND PLANNING REQUIREMENTS

4.1 WORKS CONTROL AND ENVIRONMENTAL PROTECTION REQUIREMENTS

Prior to undertaking the works a Construction Environmental Management Plan (CEMP)⁸ was produced by Tetra Tech in August 2023, identifying potential environmental impacts which could arise from the works and describing the associated mitigation measures to be implemented. The CEMP outlines strategies for protecting environmental receptors during site activities. Key considerations in the CEMP include:

- Management of surface water and groundwater
- Protection of local ecology
- Flood risk and drainage management
- Addressing contaminated land
- Preservation of archaeological and cultural heritage
- Mitigation of noise and vibration
- Safe storage and handling of materials, including hazardous substances
- Pollution, waste, and materials management
- Emergency and contingency planning
- Local sensitivities were also assessed, leading to specific mitigation strategies:

With respect to this site, over and above the standard construction site pollution prevention measures the following local sensitivities were assessed:

- The site is located within a tree protection area and works compounds and borehole drilling were sited to make sure that there were no adverse impact on trees/tree root zones;
- Badger sets are present in the general area and ecological monitoring and exclusion distances were adopted;
- Bird nesting was a factor requiring consideration of the timing of the works and with the requirement for pre-drilling ecological monitoring;
- Some borehole locations (EB1, EB2 and Strat boreholes) were in the vicinity of Dundonald House, which is a grade B+ listed building, and monitoring of vibration was required to assess real time influence from the drilling works.

To comply with environmental regulations and minimise risks, environmental impact assessments were conducted prior to the commencement of the work and consents for water abstraction and water discharge

⁸ Tetra Tech Europe, 2023. Construction Environmental Management Plan – Stormont Estate Drilling.

were secured. Management measures are detailed in the project summary report⁹, and specific mitigations and monitoring was conducted as outlined in Section 4.2 below.

4.2 SITE SURVEY AND UNDERGROUND SERVICE LOCATION

In advance of mobilising the drilling rig assigned to drill the deepest stratigraphic (STRAT) borehole to a depth of up to 500m, site enabling works comprising the following were undertaken:

- GPR service checks at all of the proposed drill locations
- Establishment of a main site compound at EB2 and a drilling compound at the STRAT borehole location
- Installation of below ground concrete manhole chambers at STRAT, EB1 and EB2 borehole locations to facilitate the drilling
- Ecological bird nesting checks at STRAT borehole location in advance of drilling
- Establishment of vibration and noise monitoring equipment at Dundonald House, adjacent to the STRAT drill compound.

Subsequent to the drilling of the STRAT borehole similar site enabling works were undertaken as required in advance of drilling at the other drill sites including:

- Established of fenced off drilling compounds at EB1, EB3 and EB5;
- Installation of a below ground concrete chamber at EB3 and EB5 borehole locations to facilitate drilling;
- Ecological bird nesting checks at each borehole location in advance of drilling during relevant period;
- Establishment of vibration monitor at Dundonald House in proximity to EB1 and EB2 drilling compounds;
- At EB5, permission was obtained from NIEA to allow for the temporary closure of a disused outlier badger sett entrance in proximity to the drill site. This entailed a period of monitoring prior to closure to confirm no activity and ongoing checking for activity throughout the works.

⁹ Tetra Tech Europe, 2025. Project Summary Report – DfE Stormont.

5.0 DRILLING LOCATION, METHODOLOGY AND RATIONALE

5.1 DRILLING LOCATIONS

A range of factors were taken into consideration when selecting the drill locations within the Stormont Estate. These included:

- The potential geological/hydrogeological setting based on available geological datasets, mapping and analyses. There was limited, historical deep borehole records for the area around Stormont which introduced some uncertainty with regard to actual local geological sequence characteristics;
- Siting of boreholes to help our understanding of the geological/hydrogeological and geothermal variability across the site and with regard to potential future operational use of the drilled boreholes;
- Consideration of existing land use, access, works area availability, disturbance;
- Consideration of potential future development plans for the overall Stormont Estate;
- Consideration of environmental and ecological sensitivities and location selection to make sure any potential adverse impact from drilling could be suitably mitigated;
- Consideration of practical elements such as available drainage options for the management/discharge of clean borehole flush water and water pumping during hydrogeological testing.

The final selected/drilled locations are shown on **Figure 4.Error! Reference source not found.**



Figure 4 Borehole Locations

6.0 DRILLING WORKS – PHASE 1 STRATIGRAPHIC BOREHOLE (STRAT)

6.1 STRATIGRAPHIC BOREHOLE DRILLING CONTRACTOR / RIG / EQUIPMENT AND TIMELINE OF WORKS

The stratigraphic ‘STRAT’ borehole was drilled using a mineral exploration drilling rig. The rig was selected for its ability to core. The core drilling rig operates a closed loop water/mud flush system which prevents the discharge of drilling arisings or mud to the environment. The exploratory core drilling was completed by Priority Drilling UK Limited over a period of 11 working days (14th May 2024 to 27th May 2024). An experienced Tetra Tech engineering geologist provided full time supervision of the borehole drilling activities undertaken across the dates stated.

Priority Drilling UK Limited mobilised to site on Monday 13th May 2024. Equipment brought to site included;

- Drill Rig M70 CT20 Self Pro Steel Track
- Circulation/Settlement tanks
- Centrifuge system for drill cuttings separation
- Circulation/grout pumps
- Other ancillary equipment
- Sufficient drill rods to achieve 500m depth.

Prior to the arrival of Priority Drilling UK limited, each drill location was checked for services by completing a targeted Ground Penetrating Radar (GPR) survey. The upper 2m of made-ground/soils/subsoils at each borehole location were excavated by a Hitachi excavator and fitted with a concrete manhole ring, complete with cover / manhole biscuit lid. This acted as a helpful well chamber during the drilling and helped with the drill set up and water/mud flush management.

6.2 STRATIGRAPHIC BOREHOLE DESIGN

The objective of the stratigraphic borehole was to obtain a detailed record of the Triassic Sherwood Sandstone and Permian sequences below the Stormont Estate, to a depth of up to 500m. Existing geological mapping indicated Glaciofluvial Ice Contact Deposits overlying Triassic Sherwood Sandstone bedrock at the drill location. Beneath this it was expected that Permian bedrock comprising mudstones, sandstones and breccia would be encountered with the possible presence of Carboniferous bedrock below this or with the Permian bedrock resting uncomfortably on older Ordovician bedrock. Based on geological mapping of igneous sills and dykes in the area and from interpretation of TELLUS geophysical datasets the potential to encountered igneous intrusions within the drilled sequence was also present.

Given this borehole location was to be cored and was to be the deepest, it was programmed to be drilled first to allow this more comprehensive investigation of the geological sequence. The data gathered from the stratigraphic borehole could then be used to inform the drilling of all subsequent boreholes.

The drill design for the stratigraphic borehole was to case out the upper superficial deposits and any unconsolidated/weathered upper bedrock and to core on from that point to final or Total Depth (TD).

Drilling commenced on 14th May 2024 with a final TD of 302 mbgl reached on 27th May 2024. On-site examination of drill cuttings and drill core concluded that the full sequence of superficial deposits and Triassic and Permian strata at this location had been encountered, with the underlying ‘basement’ greywacke bedrock encountered at 288.9mbgl depth.

6.3 STRATIGRAPHIC BOREHOLE DRILL LOG / SUMMARY OF GEOLOGICAL CONDITIONS AND BOREHOLE COMPLETION

The complete stratigraphic borehole log is presented at Appendix A. The borehole construction details are summarised in Table 1 below:

Table 1 Summary details of STRAT Borehole

Borehole ID	Completion date	Elevation Ground level	Top of casing	Total depth	Casing depth	Borehole diameter	Casing diameter
STRAT	27/05/2024	29.103 mAOD	29.081 mAOD	302.60 mbgl	58.50 mbgl	140 mm to 58.8 m, 114 mm to 64.35 m, 89 mm to TD	140 mm to 58.8m

Drilling was initially advanced using a PQ sized tricone drill bit complete with water flush drilling method. During the early stages of drilling, large cobbles were encountered from the ground surface, with the lithology reported as gravelly sand and silt. These conditions persisted to a depth of 34.5 mbgl, followed by the presence of 24 meters of reddish silty sand inferred to be the Sherwood Sandstone, encountered from 34.5 m to 58.2 mbgl. Upon encountering this weathered sandstone it was decided to begin coring. The PQ borehole was then over drilled to this depth using PW casing – extending to 58.50 mbgl.

From 58.50 mbgl, the borehole was cored. The driller experienced issues removing the third run of core from approximately 61 - 62 meters, due to the presence of soft sand above this section. The sand had moved

down the casing and gripped it, causing it to become stuck and necessitating recovery. It was agreed to leave the PW casing at the level it was at (58.50 m) and grout seal it in place after the PQ core recovery.

The grout plug was cored out on 20 May 2024, and further coring proceeded with a HQ barrel. The encountered rocks included breccia and mottled green-grey mudstone interbedded with fine-grained sandstone and occasional conglomerate layers, continuing to 288.9mbgl. In this sequence dolerite intrusions were also encountered, between 148.15 – 149.12mbgl and 163.5 - 169.63mbgl. The borehole was terminated at 302.6mbgl, upon reaching the greywacke basement at 288.9mbgl.

The borehole was flushed on the 29th May 2024 for approximately 25 minutes to make sure that the casing was not getting stuck in borehole. The HQ casing was pulled and the casing shoe removed and then the HQ casing was reinstalled close to the base of the borehole to preserve its integrity prior to geophysical logging. All HQ casing was removed again on 3 June 2024 to allow geophysical logging to take place on 4th June 2024. The HQ casing was re-installed for temporary periods during the logging (see Section 6.5) and then fully removed as part of demobilisation from site.

At the end of drilling the upper portion of the borehole casing (inside the drill chamber) was extended by 1m and fitted with a secure cover. This can be accessed via a manhole which has been completed with a concrete chamber cover.

6.4 STRATIGRAPHIC BOREHOLE SAMPLE COLLECTION

Cutting samples and 244m of core were recovered from the STRAT borehole. A photolog of the core recovered is provided at Appendix B. All samples and cores were transferred to the GSNI core store for further inspection and long-term storage following the works.

6.5 STRATIGRAPHIC BOREHOLE GEOPHYSICAL LOGGING

European Geophysical Services (EGS) completed the geophysical logging of the STRAT borehole over a period of three working days, from 4 June 2024 to 6 June 2024. All logging was recorded digitally using a digital logging system with a 600-meter capacity motorised winch mounted inside a 4x4 van. Geophysical logging began on Tuesday, 4 June, initially using an optical image televiewer. This was run to 202mbgl to where the borehole was now partially collapsed. This coincided with where unstable conditions had been noted during the drilling phase.

The logging completed is listed in Table 2.

Table 2 STRAT Borehole Geophysical Logging

Tool/Log Unit		Log Depths (mb datum)	Log Depths (mb datum)
Static Fluid Temperature / Conductivity ($\mu\text{S}/\text{cm}$)	T ($^{\circ}$ C) / EC25	60.0	232.5
Static Impellor Flowmeter (mm/s)	Fluid Velocity	60.0	202.4
Heat Pulse Flow Meter	HPFM (mm/s)	90.0	130
Focused Resistivity (Deep / Shallow) (ohm.m)	Resistivity	64.6	199
Natural Gamma	Gamma (API)	0.0	260.9
Full Wave Sonic (m/s)	Formation Velocity	64.6	202.2
Optical Imager	Optical Image	64.6	2002.1
Acoustic Imager Time	Acoustic Image / Travel	64.6	202.5
Verticality Deg)	Tilt / Azimuth ($^{\circ}$)	0.0	202.1
Four Arm Caliper (mm)	Cal X / Cal Y	64.6	271.7
Borehole Magnetic Resonance	BMR	67.2	202

Due to the borehole instability and the risk to the different geophysical sondes being used, different depths of logging was achieved. The most significant instability zone was at 202 meters below ground level (mbgl). An attempt was made on 6th June 2024 to allow logging of the lower section of the borehole by running HQ casing down through the blockage. This was taken to 291m and could not be progressed further. Once the borehole was confirmed open, the casing was pulled back to allow open hole logging. After the casing was lifted to 200m, a further restriction was encountered at 232.5mbgl beyond which logging could not proceed. A further attempt was made to open the hole using the HQ casing but this could only now be taken to

273mbgl. This casing was pulled back to 237mbgl to allow caliper logging to be undertaken down to 273mbgl. Based on the information observed on the caliper log and the instability of the hole the logging team considered it high risk to continue logging in the unsupported hole section, with respect to potential loss of logging equipment. At this point it was agreed that no further attempts to log would be made.

Temperature gradually increased down the borehole, from approximately 12°C at 66 mbgl to approximately 14.3°C at 202 mbgl.

Processed geophysical logs from the STRAT borehole can be found at Appendix C.

A subsequent inspection of the borehole was completed in December 2024 by GSNI staff using a borehole camera. This survey indicated that the borehole was blocked at 150 m depth.

6.6 STRATIGRAPHIC BOREHOLE: ISSUES ARISING PRE / DURING WORKS AND HOW THOSE ISSUES WERE ADDRESSED / LESSONS LEARNED

The borehole was left open hole following coring. Weak zones in the bedrock sequence were noted during drilling and observed in some of the cores recovered.

During the geophysical logging of the STRAT borehole, initial logging indicated constraints in relation to the borehole open hole condition and identified a risk to the logging equipment. The borehole was unstable at a depth of ~ 202mbgl. Efforts were made to remove the blockage by running casing back down to open up the borehole however running a full suite of geophysical tools below 202m was not possible due to unstable borehole condition.

Potentially, fuller geophysical logging may have been achieved if the geophysical logging unit had been on standby towards the end of drilling and able to start logging within ~ 24 hours. Given the limited number of specialist core drilling rigs and down hole geophysical logging companies available in UK and Ireland to undertake this work and the logistics involved in mobilising to site, it can be difficult to co-ordinate the same. There is a cost associated with keeping the drilling rig on site during the geophysical logging, but it definitely helped maximise the extent of logging that was achieved and was able to assist with re-opening the borehole in sections where collapsing formations were observed.

7.0 DRILLING WORKS – PHASE 2 WATER WELLS - EB2

7.1 EB2 DRILLING CONTRACTOR / RIG / EQUIPMENT AND TIMELINE OF WORKS

Geo Drilling Solutions (GDS) undertook the drilling of borehole EB2. GDS mobilised a Drillmec G25 rotary drilling rig to the site, and drilling commenced on 28 August 2024. The drilling works continued until 26 November 2024, when the instruction to terminate the borehole was received. Drilling was not continuous during this period for various factors. The drilling period was exacerbated by subsurface conditions, which required variations to the drilling method, as discussed in Section 7.3. To support these changes there were delays in obtaining additional equipment and rig set-up modifications required which introduced additional delays. An experienced Tetra Tech engineer supervised all borehole drilling activities during the active site period.

Equipment brought to site included;

- Drill Rig Drillmec G25
- Circulation/Settlement tanks/skips
- Shaker system for drill cuttings separation
- Circulation/grout pumps
- Air compressor
- Other ancillary equipment

7.2 EB2 BOREHOLE DESIGN

The objective of this borehole was to investigate the geological and hydrogeological conditions at this location, in the context of the potential for developing an open loop or closed loop geothermal scheme within the Stormont Estate. Existing geological mapping indicated Glaciofluvial Ice Contact Deposits overlying Triassic Sherwood Sandstone bedrock.

The concept of the borehole was to advance and grout in steel casing from the ground surface down to competent bedrock, to seal out the upper superficial sequence/upper weathered bedrock. Onward drilling in the underlying bedrock was to be undertaken to a depth of ~150m (final depth to be reviewed depending on conditions encountered).

7.3 EB2 BOREHOLE DRILL LOG / SUMMARY OF GEOLOGICAL CONDITIONS AND BOREHOLE COMPLETION

The completed borehole log is presented at Appendix A. The borehole construction details are summarised in Table 3 below:

Table 3 Summary Details of EB2 Borehole

Borehole ID	Completion date	Elevation Ground level	Top of casing	Total depth	Casing depth	Borehole diameter	Casing diameter
EB2	26/11/2024	30.046 mAOD	-	110.4 mbgl	44 mbgl	508mm to 4.1 m 323mm to 5m 308mm to 47.4m 200mm to 110.4m	508mm to 4.1m 323 mm to 5m 219mm to 44 m

An auger was used to try and drill through the shallow unconsolidated sediments. Large cobbles and boulders were encountered at shallow depth within the superficial deposits, which limited the depth of operation of the auger. To facilitate progress, a short length of 508 mm mild steel casing was installed, followed by a short phase of air flush with DTHH to assist with the installation of 323 mm steel casing. This casing was to guide and control follow-on drilling with mud flush using a 308 mm tricone bit.

Drilling proceeded with mud flush and a tricone bit (with stabiliser). Penetration rates were low, with further large cobbles and boulders suspected as drilling progressed. An 8.6 m band of reddish sand was encountered from 28 to 36.6 mbgl, which was identified as possible weathered Sherwood sandstone. This phase of drilling was terminated at 47.36 m. The mud mix created during drilling was sufficient to maintain an open hole during this phase. When the drill rods were pulled from the borehole to inspect the drill bit for wear, some infilling of the hole occurred from 47.36 m back up to 43.34 m.

The mud make-up during drilling comprised primarily bentonite added to water with minor additions of PAC also used.

At this point, GSNI took the opportunity to undertake geological logging of the drilled section with in-house equipment. Based on the drill cuttings and draft logs, it was determined that the hole was now in Permian bedrock, represented as strong mudstone interbedded sandstone bands, and greywacke clasts. The driller indicated that the drilling response observed suggested that the hole was in competent bedrock. Therefore,

a decision was made to install 219 mm steel casing and grout it in. This steel casing was installed to a depth of 44 mbgl.

Due to the bedrock encountered being Permian breccia and marls, with only a possible 8.6 m of overlying weathered Triassic Sherwood Sandstone encountered, progression through this harder stratum was expected to be slow, based on the slow mud flush drill rate experienced in the lower section of the hole. A decision was made to progress the borehole with DTHH using air flush, with water managed at the surface through a diverter transferring arisings into a skip, with water collected by a tanker for disposal at a licensed wastewater treatment works (WWTW).

Drilling progressed from 44 mbgl to 73.5 mbgl. As increased water inflow occurred, additional measures for water management were required (emptying of skips and further tankering). Upon returning to the borehole two days later, it was found that the borehole had collapsed below the casing at 44 mbgl. An initial attempt was made to fully clear the borehole, but low air flush returns were observed, creating a risk of cuttings jamming the rods/DTHH in the hole. At this point, it was decided to return to drilling with mud flush using a tricone (200 mm).

When the drill string was put back down the borehole, it reached 56.2 mbgl prior to encountering resistance, assumed to be wall instability. Drilling resumed from this depth and proceeded with mud flush to a final depth of 110.4 mbgl. Sandstone breccias, with frequent greywacke clasts were encountered throughout this depth.

Drilling rates (mud flush rotary) varied but typically ranged from 3.5m/hr down to 1m/hr in the Permian bedrock sequence.

A 125 mm x 113 mm PVC liner (slotted and plain installed as indicated on borehole log) was installed to 110.4 mbgl. No gravel pack was installed. Following installation a period (2hours) of flushing of the borehole using an eductor system inside the pVC well liner was undertaken (open pipe with air line at base).

Post drilling the upper strings of steel casing were reduced (cut) down to below the chamber cover level and a cap was fitted to the 219mm casing.

7.4 EB2 SAMPLE COLLECTION

Drill cuttings were collected during drilling. This was mainly by collection of cuttings separated from the circulating drill mud as it passed through the shaker system. Samples were used to inform the supervising engineers log and the cuttings were taken to the GSNI core store after the works.

7.5 EB2 GEOPHYSICAL LOGGING

European Geophysical Services (EGS) completed the geophysical logging of EB2 in one working day on 4 February 2025. All logging was recorded digitally using a digital logging system with a 600-meter capacity motorised winch mounted in a 4x4 van. Geophysical logging began initially using an optical image televiewer, to maximum the potential for a clear view prior to possible disturbance of the fluid column by follow on logging. Fluid logs were also completed. Logging proceeded to a depth of 105 meters below ground level (mbgl). Logging to 110 mbgl (the depth of the borehole) was not possible due to the base of the borehole being filled with sediment (~5m at base).

The logging completed is listed in Table 4.

Table 4 EB2 Borehole Geophysical Logging

Tool/Log Unit		Log Depths (mAOD)	Log Depths (mAOD)
Static Fluid Temperature / Conductivity	T (°C) / EC25 (µS/cm)	20.82	-70.18
Static Impellor Flowmeter	Fluid Velocity (mm/s)	-11.58	-54.58
Heat Pulse Flow Meter	HPFM (mm/s)	-20.58	-50.58
Formation Conductivity (Deep / Shallow)	Conductivity (mS.m)	-15.58	-72.28
Natural Gamma	Gamma (API)	27.92	-75.58
Acoustic Imager	Acoustic Image / Travel Time	28.42	-71.98
Verticality	Tilt / Azimuth (°Deg)	28.21	-71.98
Caliper	Cal (mm)	28.52	-74.88
Dual Densities (Long / Short spaced)	LSD / SSD (Apparent g/cm ³)	28.12	-74.18
Neutron Porosity	Porosity (%)	20.72	-73.38

Steel casing was confirmed to be present to 44.0 mbgl, plain PVC to 52 mbgl, and slotted PVC to 105+ mbgl. Fluid temperature was recorded at a maximum of 11.7 degrees Celsius, fluctuating from near maximum at 12 mbgl to a minimum of 11.2 degrees Celsius at approximately 45 mbgl. Temperature steadily increased

from the minimum to near maximum from 45 m to 85 mbgl, before remaining constant thereafter. Large step increases in electrical conductivity (EC) were observed from 80 to 90 mbgl, where EC increased from a stable 850 $\mu\text{S}/\text{cm}$ to 950 $\mu\text{S}/\text{cm}$.

Processed geophysical logs for the EB2 borehole can be found at Appendix C.

7.6 EB2 ISSUES ARISING PRE/DURING WORKS AND HOW ADDRESSED / LESSONS LEARNED

During the drilling of borehole EB2, several challenges emerged that impacted progress with the borehole.

Unanticipated subsurface conditions, including large cobbles and boulders, limited the effectiveness of the initial drilling advancement. Minor equipment malfunctions and delays in receiving replacement parts also led to periods of inactivity as well as the requirement to bring additional equipment to site to facilitate the toggling between different methods of drilling. Also significant was the bedrock geology encountered at the drill location. The mudstones and sandstones/breccia's of the Permian strata encountered resulted in a significantly lower drilling penetration rate with mud flush than originally anticipated for the drilling works. Originally it was expected that the drilling would be through mainly Triassic Sherwood Sandstone.

Increased water inflow during the drilling posed further challenges, necessitating a comprehensive water management plan that included the use of skips for arisings/water and ongoing collection by a tanker for disposal and predominate use of mud flush drilling.

Despite some borehole flushing at the end of the borehole drilling, basal sediment/mud settlement in the borehole (inside and outside the pVC casing) occurred up to 104 mbgl, effectively reduced borehole depth from 110 mbgl to 104 mbgl. This marginally limited geophysical investigations from being conducted to total drilled depth. More extensive flushing may have prevented this basal settlement.

8.0 DRILLING WORKS – PHASE 2 WATER WELLS EB1

8.1 EB1 DRILLING CONTRACTOR / RIG / EQUIPMENT AND TIMELINE OF WORKS

Hanmar Drilling were appointed for the drilling of borehole EB1. They mobilised a Massenza Mi5 rig to the site, and drilling began on 28 November 2024. An experienced Tetra Tech engineer supervised all borehole drilling activities during the active site period.

Equipment brought to site included;

- Massenza Mi5 rig
- Circulation/Settlement tanks/skips
- Shaker system for drill cuttings separation
- Circulation/grout pumps
- Air compressor
- Other ancillary equipment

8.2 EB1 BOREHOLE DESIGN

Existing geological mapping indicated Glaciofluvial Ice Contact Deposits overlying Triassic Sherwood Sandstone bedrock at this location. The original purpose of this investigation location was to drill a water well borehole for testing of hydrogeological conditions. Drilling at the adjacent STRAT borehole had indicated 34.5 m of superficial deposits over a ~ 24m sequence of weathered Sherwood Sandstone underlain by Permian marls, sandstone and breccia, with the base of the Permian confirmed at 288.9mbgl, where basement greywacke rock was encountered.

Using evidence from the STRAT borehole and EB2 that the Sherwood Sandstone thickness may be limited across the site, this location was repurposed, with the revised objective being the installation of a 40mm single U closed loop, for testing of thermal properties.

The concept of the borehole was to advance steel casing through the very upper superfcials and then drill on using mud flush, with the drill muds also used to keep the borehole open through the lower superfcials and bedrock until the closed loop was installed. The revised target depth was 150m.

8.3 EB1 BOREHOLE DRILL LOG / SUMMARY OF GEOLOGICAL CONDITIONS AND BOREHOLE COMPLETION

The completed borehole log is presented at Appendix A. Inspection of drill cuttings indicated a very similar geological sequence to the nearby STRAT borehole. The borehole construction details are summarised in **Table 5:**

Table 5: Summary details of EB1 Borehole (as initially drilled)

Borehole ID	Completion date	Elevation	Top of casing	Total depth	Casing depth	Borehole diameter	Casing diameter
BH1	11/12/2024	29.314 mD	29.23 mbgl	148 mbgl	5 m	160 mm 136 mm	160 mm

In advance of drilling the upper made-ground/soils/subsoils at the borehole location had been excavated to 1.9 m by a tracked excavator, and a concrete ring with biscuit/manhole was set in. This provided a well chamber to assist with drill setup and water/mud flush management.

Steel casing was reamed in to ~5mbgl. The borehole was then drilled on through the superficial deposits using water/mud flush using a 136mm PDC bit. At the end of each drilling day muds were circulated in the hole for ~30 mins and the drill string raised from the base of the borehole. Indications were that borehole was staying open with rods moving freely in the borehole. The borehole was completed at 148m depth.

The mud make-up during drilling comprised water with Matex polymer (Sand-Drill)

Drilling rates varied in the Permian bedrock sequence with rates in the range 9m/hr down to 2.5m/hr.

On the same day as the final depth was reached, the borehole was flushed through the mud circulation system for 2 hours to remove sediment. There was no indication of any instability when the drill string was being removed. An attempt was then made to install the 40mm single U loop, complete with a 20mm grout pipe, which could only be advanced as far as 37 mbgl, with no progress possible beyond this depth. The loop was then removed. On the following day, the drill bit and rods were put back down the borehole to the previous total depth (148 mbgl), with no significant drilling action or obstructions noted. The drill rods went down to the borehole base quite easily, indicating that the hole had remained mostly open.

A second attempt was made to install the loop. On this occasion the loop reached a depth of 83 mbgl and could not be advanced beyond this depth. The loop was removed, and on the following day, the borehole

was cleaned out again. Several further attempts were made, but the loop could not be progressed past approximately 30 mbgl.

At this point, it was agreed that additional steel casing would be installed to the top of the bedrock using symmetrix/air flush, to improve the stability of the upper section of the borehole through the superficial deposits. This casing was installed to a depth of 47 mbgl, prior to switching back to mud flush with a PDC bit to clean out the remaining borehole. Upon recommencing, mud flush drilling continued to 56 mbgl. However, large volumes of water were being used to keep the mud tanks topped up, indicating large losses down the borehole. The mud circulation could not be sustained. One very short attempt was made to progress with air drilling, but limited air returned up the casing. Instead, it was observed coming up the outside of the casing.

On 16/1/25 a final attempt was made secure the borehole for loop install by working to extend the steel casing further. When this was tried the existing casing was observed to be infilled with sediment to 34 mbgl. This was able to be cleaned out to the base of the existing casing at 47 mbgl, but onward drilling with Symmetrix/air flush was unsuccessful, with fluid sediment clogging the DTHH and drill rods. After the rods were pulled from the borehole, sediment was observed to have rapidly infilled back up to 34 mbgl inside the casing, with the water level at 17 mbgl.

It was determined at this stage not to progress further, but to pull the steel casing, seal and reinstate the borehole. The borehole was progressively backfilled with 12mm washed quarry stone with an upper section backfill of bentonite.

8.4 EB1 SAMPLE COLLECTION AND BOREHOLE TESTING

Drill cuttings were collected during drilling. This was mainly achieved through the collection of cuttings separated from the circulating drill mud as it passed across the shaker system. Samples were taken to the GSNI core store for further evaluation and long term storage post drilling works.

As no loop install was achieved, no testing of the EB1 borehole was undertaken.

8.5 EB1 GEOPHYSICAL LOGGING

No geophysical logging of this borehole was undertaken.

8.6 EB1 ISSUES ARISING PRE/DURING WORKS AND HOW ADDRESSED / LESSONS LEARNED

An attempt to install a geothermal loop using a loop reel on 11th December 2024 failed. The exact reason for this could not be confirmed. During initial drilling the indications were that the mud was keeping the

hole open. Later attempts to recover the borehole through securing more of the upper superficial sequence with steel casing also failed.

Symmetrix drilling to install deeper casing process faced complications due to water management issues, particularly with large volumes of water being required to maintain mud circulation due to significant losses down the borehole.

9.0 DRILLING WORKS – PHASE 2 WATER WELLS EB3

9.1 EB3 DRILLING CONTRACTOR / RIG / EQUIPMENT AND TIMELINE OF WORKS

Causeway Geotech were appointed to undertake the drilling of borehole EB3. They mobilised a Comacchio 602 rig to the site on 28 November 2024, and drilling began on 2 December 2024. Drilling works continued until 12 December 2024, when the instruction to terminate the borehole was received. An experienced Tetra Tech engineering geologist supervised all of the borehole drilling activities during the active site period.

Equipment brought to site included;

- Comacchio 602
- Circulation/Settlement tank
- Circulation/grout pumps
- Air compressor
- Other ancillary equipment

9.2 EB3 BOREHOLE DESIGN

Existing geological mapping indicated Glaciofluvial Ice Contact Deposits overlying Triassic Sherwood Sandstone bedrock at this location. The original purpose of this investigation location was to drill a water well borehole for testing of hydrogeological conditions. Given the distance from the other boreholes that had been drilled at this stage of the investigation (STRAT, EB1 and EB2) it was decided that the investigation should proceed as per the original objective.

The concept of the EB3 borehole was to advance and grout in steel casing from the ground surface down to competent bedrock, to seal out the upper superficial sequence. Onward drilling in the underlying bedrock was to be undertaken to a depth of ~150m (final depth to be reviewed depending on conditions encountered).

9.3 EB3 BOREHOLE DRILL LOG / SUMMARY OF GEOLOGICAL CONDITIONS AND BOREHOLE COMPLETION

The completed borehole log for EB3 is presented at Appendix A. The borehole construction details are summarised in **Table 6**.

Table 6: Summary details of EB3 Borehole

Borehole ID	Completion date	Elevation	Top of casing	Total depth	Casing depth	Borehole diameter	Casing diameter	SWL
EB3	18/12/2024	28.83 mAOD	28.997 mAOD	46 mbgl	17.7 mbgl	275 mm 200 mm	275 mm	3.49 mbgl

The upper made-ground/soils/subsoils at the borehole location were excavated to a depth of 1.9 m using a tracked excavator, before a concrete ring complete with biscuit lid/manhole cover was set in. This provided a well chamber to assist with drill setup and water/mud flush management.

Drilling progressed on 2 December 2024 using Symmetrix to install 275mm steel casing to 17.7 mbgl to stabilise the upper section of the borehole. Subsurface conditions to this depth mainly consisted of dense gravelly clay, or clayey gravel, with cobbles also observed. An assessment of the drill cuttings between 12.9m to 16.8m was interpreted as Sherwood Sandstone (possibly altered due to proximity of intrusion), below which mudstone and dolerite was encountered.

Following some rig repairs/equipment sourcing, drilling operations resumed on 12th December 2024 in bedrock with onward drilling of the upper bedrock using a down-the-hole hammer (DTHH) methodology. This method was necessary due to the hard nature of the dolerite bedrock encountered. At 46 mbgl, due to the high production of water in the borehole, the borehole was terminated as it was not possible to continue with DTHH due to water management requirements. It was also becoming difficult, with the on-site compressor, to flush the water to the surface from the base of the borehole to uplift cuttings from the borehole, due to large water volumes being encountered.

With the drilling indicating complex geological conditions with a significant dolerite intrusion and with the confirmation that Sherwood Sandstone was also of limited thickness in this part of the site it was decided to not progress drilling any further.

The borehole was terminated at 46 m below ground level (bgl) and left as an open hole below 17.7mbgl. A short period of flushing of the borehole occurred on 18th December 2024.

Based upon a review of the drill cuttings and the subsequent geophysical logging interpretation it was determined that conditions from the base of the steel casing were:

- 17.85 – 38.6m Dolerite
- 38.60 – 42.20 m Permian Mudstone (dolerite inclusion within mudstone from 40.30-42.20m)
- 42.20 – 46m Permian Sandstone

The dolerite intrusion (sill) is very weathered and fractured. This was considered by GSNI as likely indicating close proximity to a fault. High number of fractures are observed with extensive weathering at these features interpreted as signs of relic fluid flow within the intrusion.

The borehole steel casing was cut down to below the chamber cover and a cover fitted. This borehole can be accessed via a manhole on the concrete chamber cover.

9.4 EB3 SAMPLE COLLECTION AND BOREHOLE TESTING

Drill cuttings were collected during drilling from the air flush arisings. Samples were taken to the GSNI core store after the works.

Hydrogeological testing of the borehole was undertaken between 28 January 2025 and 3 February 2025. Testing followed the scoped outline detailed in Appendix C. This testing is described in *Tetra Tech March 2025 EB3 Hydrogeological Investigation Report*.

9.5 EB3 GEOPHYSICAL LOGGING

European Geophysical Services (EGS) completed the geophysical logging of the EB3 borehole on 5 February 2025. All logging was recorded digitally using a digital logging system with a 600-meter capacity motorized winch mounted in a 4x4 van. Geophysical logging was begun using an optical image televiewer. Fluid logs were also completed. Logging proceeded to a depth of 46 meters below ground level (mbgl), reaching the total depth of the borehole.

Steel casing was confirmed present to 17.7 mbgl. Fluid temperature was recorded at a maximum of 10.3 degrees Celsius, remaining constant from 15 mbgl to the bottom of the borehole. Electrical conductivity (EC) remained relatively constant at approximately 700 $\mu\text{S}/\text{cm}$.

The logging completed is listed in Table 7.

Table 7 EB3 Borehole Geophysical Logging

Tool/Log Unit		Log Depths (mAOD)	Log Depths (mAOD)
Static Fluid Temperature / Conductivity	T (°C) / EC25 ($\mu\text{S}/\text{cm}$)	25.1	-16.1
Static Impellor Flowmeter	Fluid Velocity (mm/s)	11.8	-16.8
Heat Pulse Flow Meter	HPFM (mm/s)	13.8	-16.2

Tool/Log Unit		Log Depths (mAOD)	Log Depths (mAOD)
Focused Resistivity (Deep / Shallow)	Resistivity (ohm.m)	14.3	-15.9
Natural Gamma	Gamma (API)	27.4	-17.1
Full Wave Sonic	Formation Velocity (m/s)	13	-16.4
Optical Imager	Optical Image	10.9	-17.1
Acoustic Imager	Acoustic Image / Travel Time	10.9	-16.5
Verticality	Tilt / Azimuth (°Deg)	27.3	-17.1
Caliper	Cal (mm)	27.9	-16.4
Dual Densities 25.6 (Long / Short spaced)	LSD / SSD (Apparent g/cm ³)	27.2	-16.8
Neutron Porosity	Porosity (%)	25.6	-16.4

Processed geophysical logs for the EB3 borehole can be found in Appendix C.

9.6 EB3 ISSUES ARISING PRE/DURING WORKS AND HOW ADDRESSED / LESSONS LEARNED

Drilling at this location encountered complex geological conditions associated with a ~20m thick igneous intrusion (sill) and also confirmed limited thickness of Sherwood Sandstone, with Permian bedrock encountered at relatively shallow depth. The fractured nature of the bedrock at this location is considered a factor in large volumes of groundwater being encountered as drilling progressed. Further drilling would have required mud flush drilling to limit water management requirements at surface however as the drilling had already confirmed the upper bedrock geological setting (with limited thickness of Sherwood Sandstone confirmed) it was determined there was limited benefit in proceeding deeper.

10.0 DRILLING WORKS – PHASE 2 WATER WELLS EB5

10.1 EB5 DRILLING CONTRACTOR / RIG / EQUIPMENT AND TIMELINE OF WORKS

Causeway Geotech undertook the drilling of EB5. They mobilised a Comacchio 602 rig to site and drilling began on 29/01/25. The borehole drilling was completed on 13/2/25. An experienced Tetra Tech engineering geologist supervised all borehole drilling activities during the active site period.

Equipment brought to site included;

- Comacchio 602
- Circulation/Settlement tank
- Circulation/grout pumps
- Air compressor
- Other ancillary equipment

10.2 EB5 BOREHOLE DESIGN

Existing geological mapping indicated Glaciofluvial Ice Contact Deposits overlying Triassic Sherwood Sandstone bedrock. This was the final borehole location to be investigated. Based upon the findings to date at the other borehole locations (limited Sherwood Sandstone thickness encountered) it was determined that this borehole should be drilled for the purposes of installation of a closed loop to allow testing of thermal properties.

The concept of the borehole was to advance grouted-in steel casing from the ground surface down to competent bedrock, to seal out the upper superficial sequence. Onward drilling in the underlying bedrock was to be undertaken to a depth of up to 200m (final depth to be reviewed depending on conditions encountered) and a 40mm single U closed loop was to be installed and grouted in.

10.3 EB5 BOREHOLE DRILL LOG / SUMMARY OF GEOLOGICAL CONDITIONS AND BOREHOLE COMPLETION

The completed borehole log is provided at Appendix A. The borehole construction details are summarised in **Table 8** below:

Table 8 Summary details of EB5 Borehole

Borehole ID	Completion date	Elevation mAOD	Top of casing mAOD	Total depth	Casing depth	Borehole diameter	Casing diameter
EB5	13/2/25 (drilling)	32.262	31.531	118m	22m	275mm	275mm
					27m	225mm	225mm
						190mm	
						160mm	

The upper made-ground/soils/subsoils at the EB5 borehole location were excavated to 1.9 m using a tracked excavator, and a concrete ring with biscuit/manhole cover set in. This provided a well chamber to assist with drill setup and water/mud flush management.

Drilling started on 07/01/25 and progressed using symmetrix to install 275mm casing to 22mbgl to stabilise the upper section of the borehole. Drill returns at 22mbgl were indicating that the borehole was still in the superficial deposits sequence. With uncertainty over depth to bedrock and based upon concerns raised by the drillers regarding ability to progress 275mm steel further with possible excessive pressure being put on casing welds (casing sections were welded together on site as drilling advanced) it was decided to install a second string of 225mm steel casing. This was installed and then advanced to 27mbgl. During this drilling phase bedrock was encountered at 22.5mbgl.

An attempt was made to recover the 225mm casing with the intention, given the relatively short distance to bedrock, to extend the 275mm casing. However, the 225mm casing was firmly embedded in the bedrock at 27mbgl and could not be pulled.

Drilling progressed from 27mbgl to 45mbgl with 190mm DTHH. Dolerite was encountered down to 33mbgl with red mudstone below this. From 45mbgl drilling was undertaken using water flush. At the end of each drilling day the borehole was flushed for 45 mins and the 3 x 3m rods removed to leave the drill string raised above hole base overnight.

The mud make-up during drilling comprised water with bentonite added during later phases of the drilling.

Drilling rates varied in the Permian bedrock sequence with rates in the lower part of the borehole at 6m/hr down to 3m/hr.

Sediment was observed to build up at the base of the borehole overnight to different degrees. This became more noticeable from ~76mbgl where 6m of sediment collected overnight. To attempt to improve the situation, drilling additives (bentonite) were added to the water flush.

Drilling progressed with mud flush to a final depth of 118mbgl on 13/02/25. The rate of drilling penetration gradually slowed as the borehole deepened.

On 14/02/25 a 40mm single U closed loop with grout pipe was installed using a loop reel to full depth (including 1m long weight at base). Prior to install the loop was water filled.

The borehole was grouted using Geotherm-X GR grout. An initial phase of grouting was undertaken on the afternoon of 17/02/24. Indications towards the end of the grouting on 17/02/25 were that grout had come up from the base of the borehole to ~ 60mbgl. Checking of the grout level with a dip meter in the borehole on the subsequent days confirmed that there was no grout above 50m. A second grouting operation was undertaken on 25/02/25. Prior to this starting 20mm pVC gun barrel was installed into the borehole to act as a new grout pipe. The original grout pipe that ran to the base of the borehole was now sealed owing to the grout in the base of the borehole. At 57mbgl resistance was encountered and the pipe forced down slightly to gather a sample. The pipe was recovered from the borehole and the samples from the base of the pipe indicated that grout was present to 57m in the borehole. The tremmie / grout pipe was re-installed and grouting re-started. On 26/02/25 the borehole was tested again using the same method and the level of grout was determined to be at ~9mbgl. Topping up of the grout occurred on 27/2/25 and grout returned to surface.

The borehole steel casing was cut down to below the chamber cover and a cover fitted. This can be accessed via a manhole on the concrete chamber cover.

10.4 EB5 SAMPLE COLLECTION AND BOREHOLE TESTING

Drill cuttings were collected during drilling from the air flush and mud flush arisings. Samples were taken to the GSNI core store after the works for further inspection and long term storage.

10.5 EB5 GEOPHYSICAL LOGGING

No geophysical logging of this borehole was undertaken.

10.6 EB5 ISSUES ARISING PRE/DURING WORKS AND HOW ADDRESSED / LESSONS LEARNED

Following on from the issues at EB1 works were scheduled to ensure everything was in place to install the loop shortly after the final depth had been reached.

Prior to grouting, insufficient research on the exact required grout mix (product:water) was undertaken with the roles of the supervising engineer and the drilling contractor supplying the grout not adequately defined for this element of the works.

For such activities it is clear that a step-by-step procedure for grout mixing and application should be agreed in advance and that the grout mix required should be confirmed with the grout product provider. This grout mix will vary according to the product being used and the thermal properties being aimed for. Having spoken to the Belgium stockist for the grout and the UK supplier, it became apparent that there is currently no guidance available to support drilling operators. In the absence of such a guide there can be uncertainty and a risk of drillers applying previous experience when grouting rather than the bespoke mix ratio required for some thermally enhanced grouts. To assist with overcoming this, we would encourage the development of a short, simplified guide for installers and the makeup of trial batches of grout several days prior to commencing the grouting. This will assist with establishing how the grout is likely to behave once placed in the borehole.

11.0 SUMMARY OF GEOLOGICAL CONDITIONS ENCOUNTERED V GEOLOGICAL MAPPING

11.1 SUMMARY OF ENCOUNTERED GEOLOGY

A summary of the drilled boreholes can be found below in Table 9.

Table 9 Summary of borehole details.

Label	Easting	Northing	Depth	IGR	Achieved Objective
STRAT	340455	374094	303m	J4045574094	Stratigraphic Sequence established, core recovery, geophysical logging of borehole
EB1	340436	374092	148m	J4043674092	Geological conditions verified. Single U closed loop install (failed)
EB2	340505	374262	110.4m	J4050574262	Geological and Hydrogeological Conditions established.!
EB3	340127	374480	46m	J4012774480	Geological and Hydrogeological Conditions established, borehole geophysical logging completed, hydrogeological testing.
EB5	340448	374378	118m	J4044874378	Single U closed loop installed, Thermal Response Test completed.

Table 10 below summarises the encountered geology at each investigation borehole. A description of the encountered geology at the Stormont site is as follows:

- Superficial Glacial Deposits: Silt and Sands dominated with gravel and cobbles/boulders in places
- Sherwood Sandstone: Reddish brown silty SAND, weathered.
- Permian Bedrock: Mudstone, Sandstone, Breccia
- Greywacke: Grey, brittle, indurated Sandstone

- Intrusive dykes/sills: Speckled white and grey DOLERITE, minor calcite.

Table 10 Summary of the Geology within the Stormont Estate

Borehole	Encountered Geology depths (mbgl)				Igneous Intrusions mbgl	Sherwood sst thickness (m)
	Superficials	Sherwood Sandstone	Permian	Greywacke		
STRAT	0 - 34.5	34.5 - 58.2	58.2 - 288.9	- 288.9 - 302.6	148.15-149.12 163.5-169.63	23.7
EB1	0 - 34.5	34.5 - 58.2	58.2 - 148	- -	None	23.7
EB2	0 - 28	28 - 36.6	36.6 - 110.4	- -	None	8.6
EB3	0 - 12.9	12.9 - 16.8	16.8 - 46	-	16.8 - 38.6 40.3-42.2 (in mudstone)	3.9
EB5	0 - 28	-	33 - 118	-	28-33	-

11.2 MAPPED GEOLOGY VS ENCOUNTERED GEOLOGY

Overall, the borehole investigations largely corroborate the expected geological sequence as presented in the literature and mapping, particularly regarding the presence of superficial glacial deposits and the presence of the Sherwood Sandstone overlying Permian strata.

The investigation however did reveal that the thickness of the Sherwood Sandstone is considerably less than anticipated and compared to thicknesses observed in boreholes to the west and east of the Stormont Estate. It also indicated the site to be significantly influenced by igneous intrusions (dolerite) with 3 of the

5 drill locations encountering these conditions (and likelihood, if EB1 had been drilled deeper, it would have encountered intrusions as found at the very nearby deeper STRAT borehole).

As such limitations in the thickness and integrity of the Sherwood Sandstone observed during the investigation, are indicative that the aquifer is not as extensive in the Stormont Estate area as initially anticipated and as found to the west and east of the site.

Permian bedrock is observed beneath the Sherwood Sandstone in all boreholes. At the STRAT borehole a total thickness of ~230.7m of Permian deposits above basement greywacke was confirmed.

As such the exploratory drilling has been essential in developing the understanding the complexity of the local geological and hydrogeological setting across the Stormont Estate. The data gathered has been used to inform decisions around the most suitable shallow geothermal system to be implemented at the site, should this be taken forward.

12.0 NOISE MONITORING

As part of the works at the STRAT borehole, noise monitoring was completed to allow reference baseline data for drilling works to be gathered as part of the demonstrator works programme. It is intended that this information will assist in the planning and risk assessment of other similar geothermal projects. It was found that there is a general absence of noise data for drilling rigs used as part of shallow geothermal projects. It was also noted that the rig manufacturers rarely test or publish data on the noise level of individual drilling rigs. This demonstrator project seeks to overcome this by making the noise monitoring data publicly available.

Monitoring was undertaken using a Rion NL52 Sound Level Meter, located ~17m from the drill location.

Monitoring took place between 14/5/24 and 24/5/24, with the adjacent drilling works at the STRAT borehole location occurring between 14/5/24 and 27/5/24. Noise sources included the drilling rig operation, generator and the mud circulation system. A summary of the noise result is presented in Table 11.

Table 11 Results of Source Noise Survey

Monitoring Date and Time	Day	L _{Aeq,T} (dB)	L _{Amax,T} (dB)	L _{Amin,T} (dB)	L _{A10,T} (dB)	L _{A90,T} (dB)
14/05/24 13:30 – 18:05	Tuesday	66.0	101.7	58.2	64.2	62.2
15/05/24 08:00 – 15:30	Wednesday	63.7	83.7	53.3	64.7	61.8
15/05/24 16:30 – 18:55	Wednesday	63.9	88.4	58.5	64.7	62.7
16/05/24 07:20 – 18:10	Thursday	66.6	90.5	24.8	66.9	64.2
17/05/24 07:05 – 16:10	Friday	66.8	94.6	46.9	66.2	63.4
20/05/24 08:10 – 18:30	Monday	65.7	96.3	52.6	64.4	61.1
21/05/24 07:45 – 18:15	Tuesday	67.3	90.8	43.9	67.7	64.3
22/05/24 07:45 – 18:45	Wednesday	67.9	92.3	50.4	68.5	66.2
23/05/24 07:45 – 18:30	Thursday	68.4	92.1	49.1	69.1	66.7
24/05/24 07:40 – 16:30	Friday	68.5	102.7	47.9	68.2	65.4

Values are sound pressure levels in dB

Further detail on the monitoring undertaken and data collected is reported in *Tetra Tech 2024 Borehole Noise Monitoring Report*.

13.0 VIBRATION MONITORING

Due to the proximity of the STRAT/EB1 and EB2 drilling sites to a Grade B+ listed building (Dundonald House) it was a condition of the planning permission that vibration monitoring be undertaken. This also provided the opportunity to gather reference baseline data as part of the demonstrator works programme. It is intended that this information will be informative for other similar projects.

Unattended vibration measurements were obtained using one Omnidots SWARM Vibration meter. The instrument measured Peak Particle Velocity (PPV) at a scanning duration of 2 seconds.

A traffic light system based on the above British Standards was considered appropriate for assessing risk as presented in Table 12.

Table 12 Continuous Vibration Level Criteria at Dundonald House- Building Damage

Monitoring Levels	Time Period	Vibration Limit at Monitoring Location Peak Particle Velocity (PPV) (mm/s)
Red (at this level all works to cease immediately, investigate cause of exceedance, use alternative methods where appropriate)	00:00 – 23:59	>10.0 (>30 Seconds)
Amber (continual monitoring and investigation of alternative methods where appropriate)		1.1-9.9
Green (no action required)		<1.0

As stipulated in the Vibration Method Statement the threshold limit for the drilling works was set at >10.0mm/s (>30 secs).

The monitoring indicated no exceedances of the red threshold limit. Occasional short-lived measurements were observed in the amber range which were regarded as most likely due to heavy rainfall events (including where the location of the monitor was initially being affected by water running of building roof) or unrelated activities (nearly all of the amber readings occurred outside of when drilling works were occurring).

The monitoring undertaken is reported in:

Tetra Tech 2024 Dundonald House- Vibration Monitoring Report 1 May/June 2024

Tetra Tech 2024 Dundonald House- Vibration Monitoring Report 2 Aug/Sept 2024

Tetra Tech 2024 Dundonald House- Vibration Monitoring Report 3 Sept/Oct 2024

Tetra Tech 2024 Dundonald House- Vibration Monitoring Report 4 Oct/Nov/Dec 2024

APPENDIX A: BOREHOLE GEOLOGICAL / CONSTRUCTION LOGS

APPENDIX B STRATIGRAPHY BOREHOLE CORE PHOTOLOG

APPENDIX C: GEOPHYSICAL LOGGING REPORTS INCLUDING LIST OF DIGITAL OUTPUT/DATASETS

Geophysical Logs	Digital Dataset
STRAT Borehole	Strat_BMR.csv
	Strat_Comp_Final.las
	Strat_Comp_Final_Lower.las
	Strat_Composite.csv
	Strat_Discontinuities.csv
	Strat_Image_Final.dlis
EB2 Borehole	EB2_Composite.csv
	EB2_Composite.las
	EB2_Fluid.csv
	EB2_Fluid.las
	EB2_Image.dlis
EB3 Borehole	EB3_Composite.csv
	EB3_Composite.las
	EB3_Fluid.csv
	EB3_Fluid.las
	EB3_Image.dlis

APPENDIX D GEOTHERMAL DEMONSTRATOR PROJECT SPECIFICATION