The Impact of Thermal Plumes on properties of the Sherwood Sandstone Aquifer

UKRI Natural Environment Research Council

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Justification

- The global community has to face a just transition towards sustainable energy due to the exponential rise in greenhouse gas emissions and resulting Climate Change impacts.
- In the Special Report (SR15) issued by the International Panel on Climate Change (IPCC) in 2018, geothermal energy is listed as one of the forms of renewable energy that can aid in our just transition and green growth.
- SR15 details specific climate action mitigation methods. The action relevant to this research is adopting low-emission innovations utilising heat pumps and district heat & cooling (SR15, 2018).
- In Northern Ireland, the heating sector represents 50% of the final energy consumption (DfE NI, 2019).
- The city of Belfast in Northern Ireland characterises the highest demand for heating and cooling energy in the country, peaking at > 10500kW/km2 (DfE, 2010).

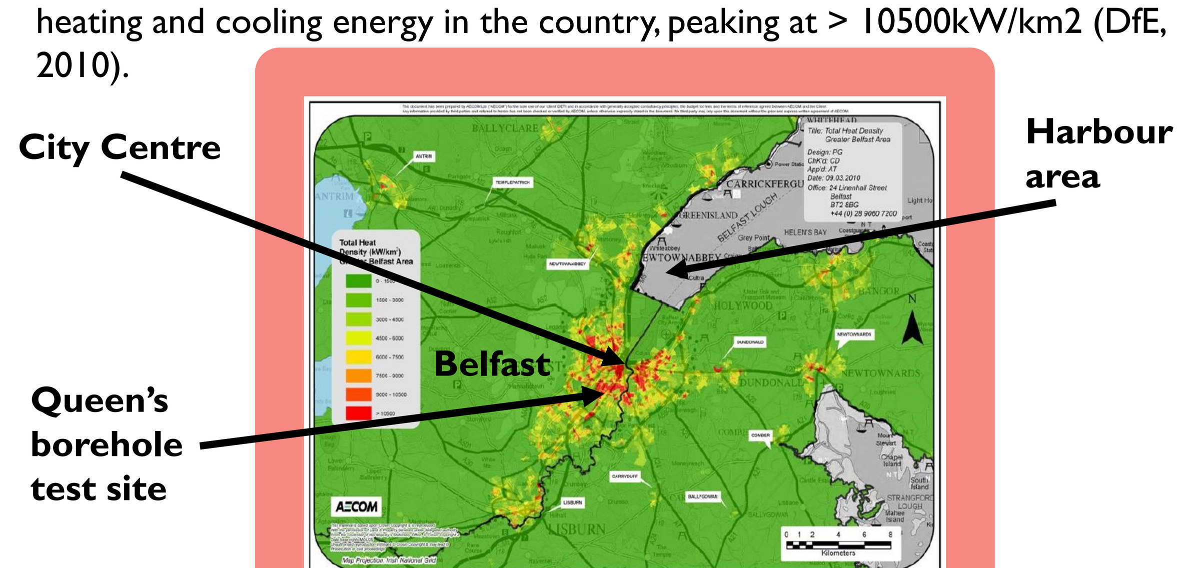

Figure 1: Heat Density Map for Belfast (DfE, 2010)

- Current renewable heat energy figures are not available for Northern Ireland, with minimal development since the last figure was issued in 2010 of 1.7% (DfE, 2010).
- There is significant opportunity for improvement through adopting low-emission innovations in the heating and cooling energy sector with a focus on Belfast.
- The geology of Belfast presents the opportunity to do so using geothermal energy in the form of aquifer thermal energy storage (ATES).

Geological Background

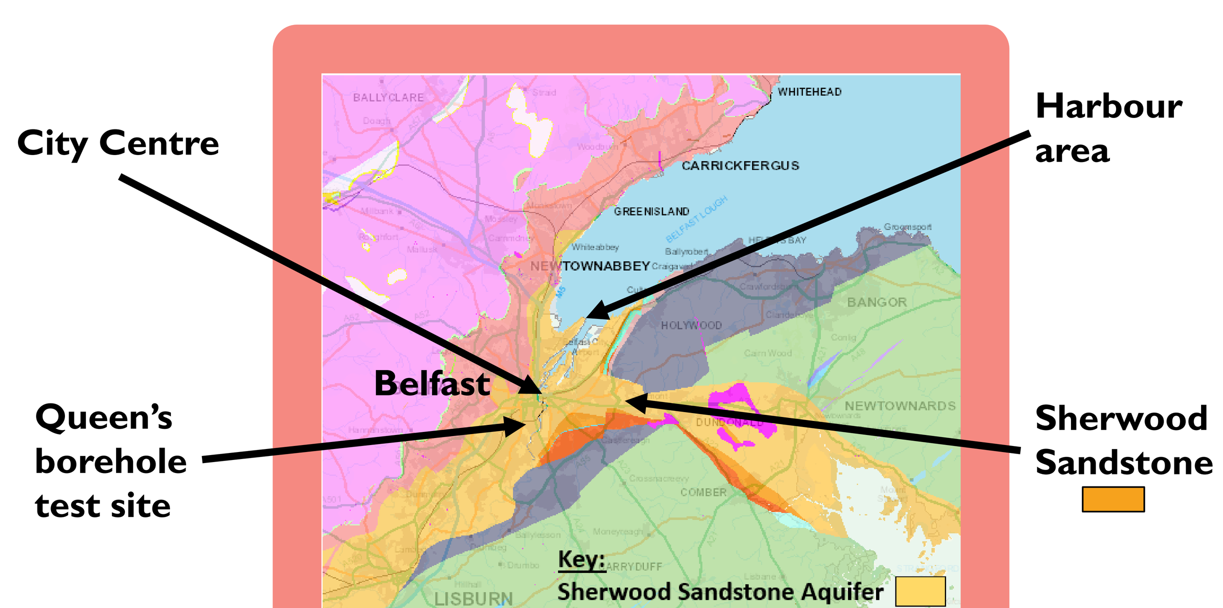

Figure 2: Bedrock map of Belfast (Geoindex, 2021)

- The geology of Northern Ireland has a high degree of variation. Hydro geologically, there are multiple aquifers across the country that represent an opportunity for groundwater development in the form of ATES.
- The most prolific aquifer is the Triassic Sherwood Sandstone (SWS) located in the Belfast area that has a long history as a source of ground water (Fig.2).
- The aquifer is now only used for private consumption and two small scale geothermal energy cooling schemes but represents a significant opportunity for sustainable ATES development.
- The SWS was identified in a 1980 UK Energy Storage project as having a definite need for an ATES experiment recharging the aquifer with source water at a known temperature for a fixed period via a central borehole, storing it for the same period and then re-extracting it.
- This research project will conduct a similar experiment and subsequent numerical model development.

What is Aquifer Thermal Energy Storage (ATES)?

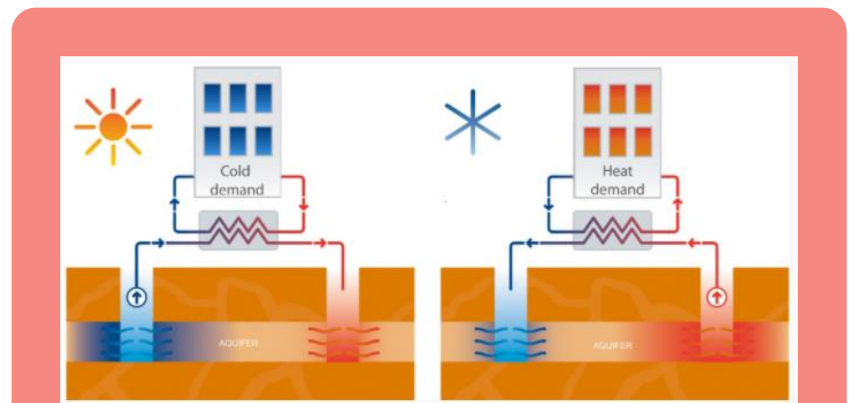

Figure 3: ATES system illustration (IF Technology, 2021)

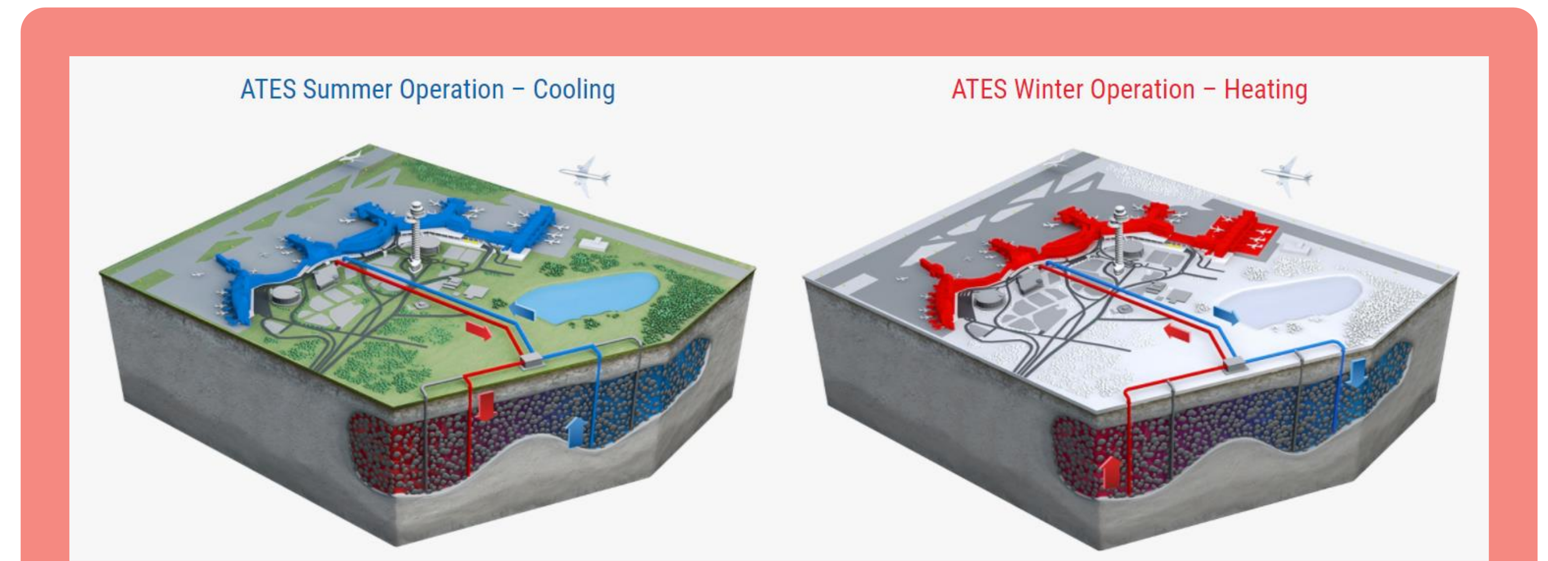

Figure 4: Airport example of ATES development in seasonal modes of heating and cooling

- The key challenge of increasing the share of renewables in the heating and cooling sector is attributed to the seasonal offset between thermal energy demand and supply, with standard open-loop geothermal systems only functioning in one mode of either heating or cooling.
- ATES offers a solution to this mismatch by storing heat and cold temporarily in the subsurface in an aquifer in the form of groundwater via groups of dedicated boreholes (Fig.3).
- The system is capable of large energy storage capacities and is therefore most suitable for largescale applications, e.g. the airport in Fig. 4.
- ATES applications require the presence of an aquifer, suitable hydrogeological conditions, such as a low groundwater flow, high permeabilities, adequate aquifer heterogeneities and geochemical conditions that prevent clogging and corrosion of wells.
- System design therefore requires complex pre-investigation to ensure efficient operation.

Borehole Test Site

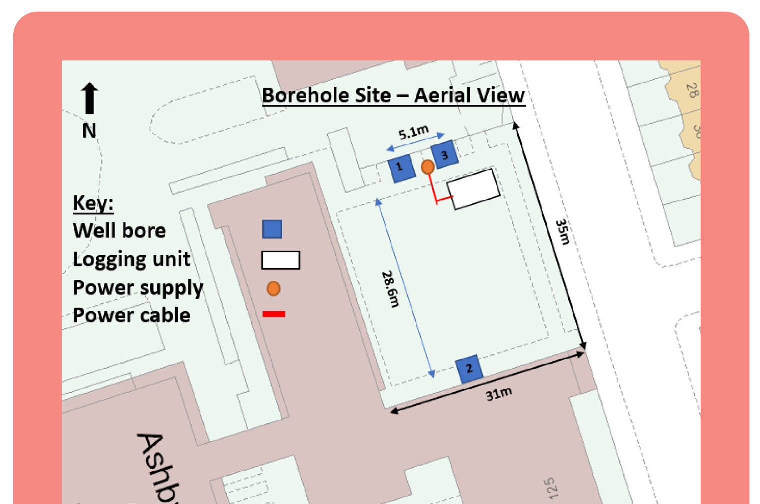

Figure 5: Queens's University Borehole Test Site

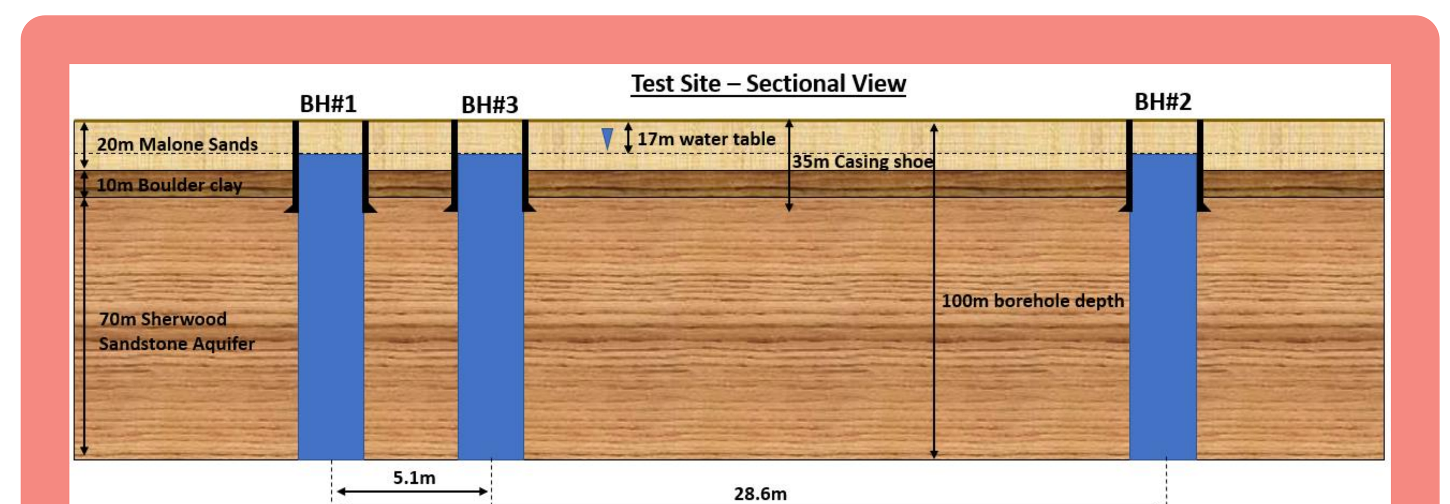

Figure 6: Queen's University Boreholes Test Site Sectional View

- Queen's University have three test wells drilled on campus into the Sherwood Sandstone aquifer to a depth of 100m that will be used for the purposes of this research (Fig. 5 Aerial View and Fig.6 Sectional View above).
- The total depth of the Sherwood is not known in this location but is up to 300m thick in the Lagan Valley basin.
- Local geology is 2-3m of fill deposit, 20m of Malone Sands (fine-medium coarse, well sorted, orange/red colour with occasional beds of gravel clasts), 10m of Lower Boulder Clay (clay/ till deposit, dark brown/ red with various clasts), 70m of Sherwood Sandstone (cream/ red/ brown, fine-medium grain, weathered at top, becoming fresher at depth). Natural water table is at 17m.

Methodology Considerations

- The thermal plumes discharged into the "warm well" of an ATES system are not only likely to reduce aquifer porosities and permeabilities by facilitating inorganic precipitation and secondary mineralisation but also by promoting microbial activity within the aquifer, with the additional biomass adding to the reduction of aquifer porosities.
- This in turn may affect the overall efficiency and sustainability of the duplet borewell installation and reduce the sustainable yield of the groundwater body for other nearby water supplies.
- The thermal storage performance of the ATES system and heat transport around the wells are likely to be impacted by existing aquifer heterogeneity due to preferential flow paths.
- The thermal storage performance of the ATES system and heat transport around the wells are also likely to be impacted in the long term by the "warm well" due to points mentioned in the first consideration.
- The influence of thermal plume temperature ranges on thermal storage performance and aquifer hydraulic properties requires long term borehole site investigation and numerical modelling.

Research Questions

I. What will the impacts be on the hydraulic properties of the Sherwood Sandstone aquifer as a result of storing the thermal plumes in 'warm wells?
II. How does variation in temperature of the thermal plume alter the impacts observed on the Sherwood Sandstone aquifer hydraulic properties?
III. What is the thermal storage performance of the Sherwood Sandstone aquifer in the test area?
IV. How is the thermal storage performance impacted by variation in thermal plume temperature?
V. What impact does the Sherwood Sandstone aquifer heterogeneity have on thermal storage performance?
VI. How can ATES be integrated into the future energy matrix for Northern Ireland?

Research Update

- In-situ geophysical characterisation completed, including Bore hole Magnetic Resonance (BMR).
- Aquifer transmissivity properties analysed from previous pumping and injection test data.
- Gov dpts DfE and DAERA consulted on future ATES projects in NI based on research outcomes.
- Initial FeFlow model constructed to analyse thermal plume propagation based on in-situ data (Fig. 7).
- Future of Geothermal Energy in Conference held with 320 attendees.

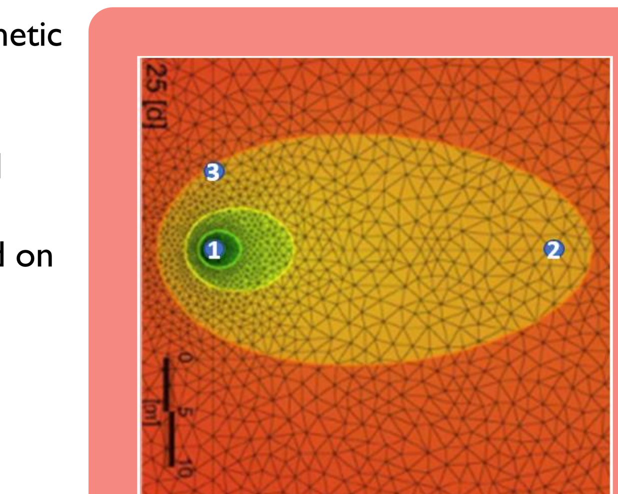

Figure 7: Initial Fe Flow modelling

Planned Methodology

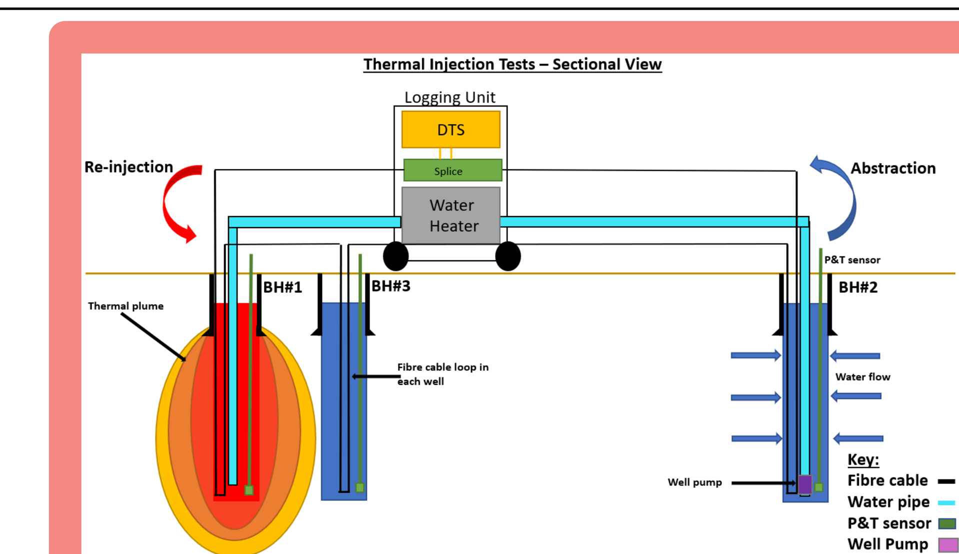

Figure 8: Thermal Injection testing Section View

- Experimental long-term thermal injection testing and wellbore monitoring at varying temperatures as illustrated in Fig. 8.
- Down hole temperature monitoring using multi-mode fibre optical cable as part of a distributed temperature sensing system (DTS).
- Monitoring of aquifer properties with geophysical logging and BMR.
- Collected monitoring data will be integrated into numerical heat transport models using FeFlow and LeapFrog.
- Recommendations concluded for next steps of ATES development in NI.

Future ATES Integration

- The Department for Economy are currently drafting a new Northern Ireland Energy Strategy to 2050 & the Department for Agriculture, Environment and Rural Affairs are currently drafting a Climate Change Act for Northern Ireland.
- The aim of this research is to feed into the strategies of both these documents as a future low-emission renewable energy in the heating and cooling energy sector.
- Additional options for ATES integration into the energy matrix include; storage of waste heat from hydrogen production/ wastewater treatment to then supply this heat energy into a social housing district heating scheme or districting eating style poly tunnel project.

Acknowledgements

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References

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