The contribution of geology and groundwater studies to city-scale ground source heat network strategies: A case study from Cardiff, Wales, UK

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1. Introduction

The U.K. Government is seeking to solve the 'Energy Trilemma' of (1) reducing greenhouse gas emissions by 80% by 2050 (UK Climate Change Act, 2008), (2) increase security of supply and (3) reduce cost of home-grown energy. Part of the solution is to develop integrated heat networks that exploit sources of ground and surface water for heating and cooling purposes.

Fig. 1. Aerial view of coastal City of Cardiff which has an urban population of 300,000 and plans to build 40,000 new low-carbon homes. (Photo courtesy of Cardiff City Council)

The City of Cardiff (Fig 1), UK has hosted a 12-month feasibility study which aimed to examine the technical feasibility of extracting low-grade waste heat from a shallow aquifer in superficial deposits. The early-stage heat network concept considers a cluster of shallow open-loop ground source heat pumps connected to mini energy stations (Fig 2). The project included geological and hydrogeological investigations to support concept planning and design, and demonstrate system sustainability to stakeholders and the Environmental Regulator (Natural Resources Wales).

The groundwater level, temperature and chemistry at a GSHP test site in Cardiff is closely monitored (see poster Patton et al 2016, this session).

2. Approach to assessing feasibility and ground conditions

Ground conditions were assessed using a staged investigation approach:

1: **Desk study**; review of geological maps, borehole records and Quaternary stratigraphy
2: **Baseline thermal mapping** across city using existing boreholes (see Patton et al 2016) (Fig 3a)
3: **Drilling and instrumentation** of flow and return boreholes at test site (Fig 4) and monitoring BH's
4: **Logging and Thermal property testing** on core samples (Fig 8 & Fig 9, & Table1)
5: **Creation of 3D geological model** over 14km^2 using >3000 drilling records (Fig 7)
6: **Design and installation of water-to water heat pump** housed in portable unit (Figs 5 & 6)
7: **Heat Flow Modelling** to explore thermal impact scenarios over 10-year period (Fig 3b)

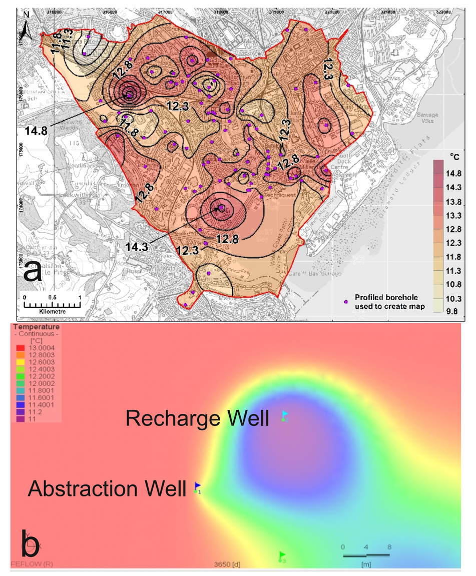

Fig. 3. (a) Baseline temperature map. (b) visualisation of thermal impact on gravel aquifer at test site after 10 years of heat pump operation (FEFLOW).

Fig. 4. Drilling the 18m deep abstraction borehole at the GSHP test site in Cardiff. The water table is 4m below surface.

Fig. 5. Installation of borehole water pump.

Fig. 6. Water-to-water heat pump test rig (2x 11KW units) housed in portable container, located in the school garden.

3. Heat Network Concept

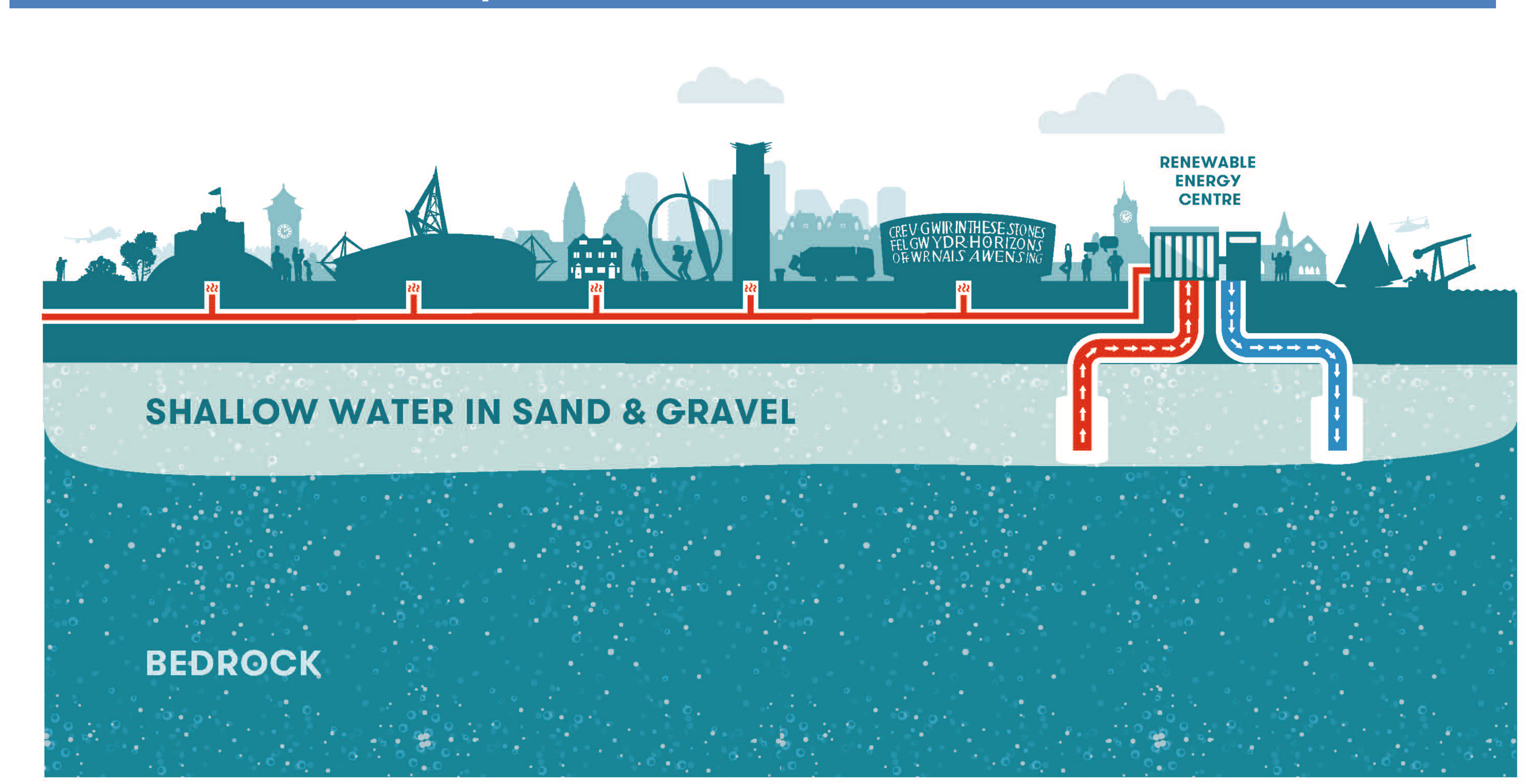

Fig. 2. Early-stage concept (v1.0) for integrating groundwater heat sources with a district heat network in Cardiff utilising a shallow aquifer. The image was designed to help improve public understanding and perception of using Open Loop GSHP technology in an urban setting.

4. Geological Prognosis Tools: 3D Geological Model

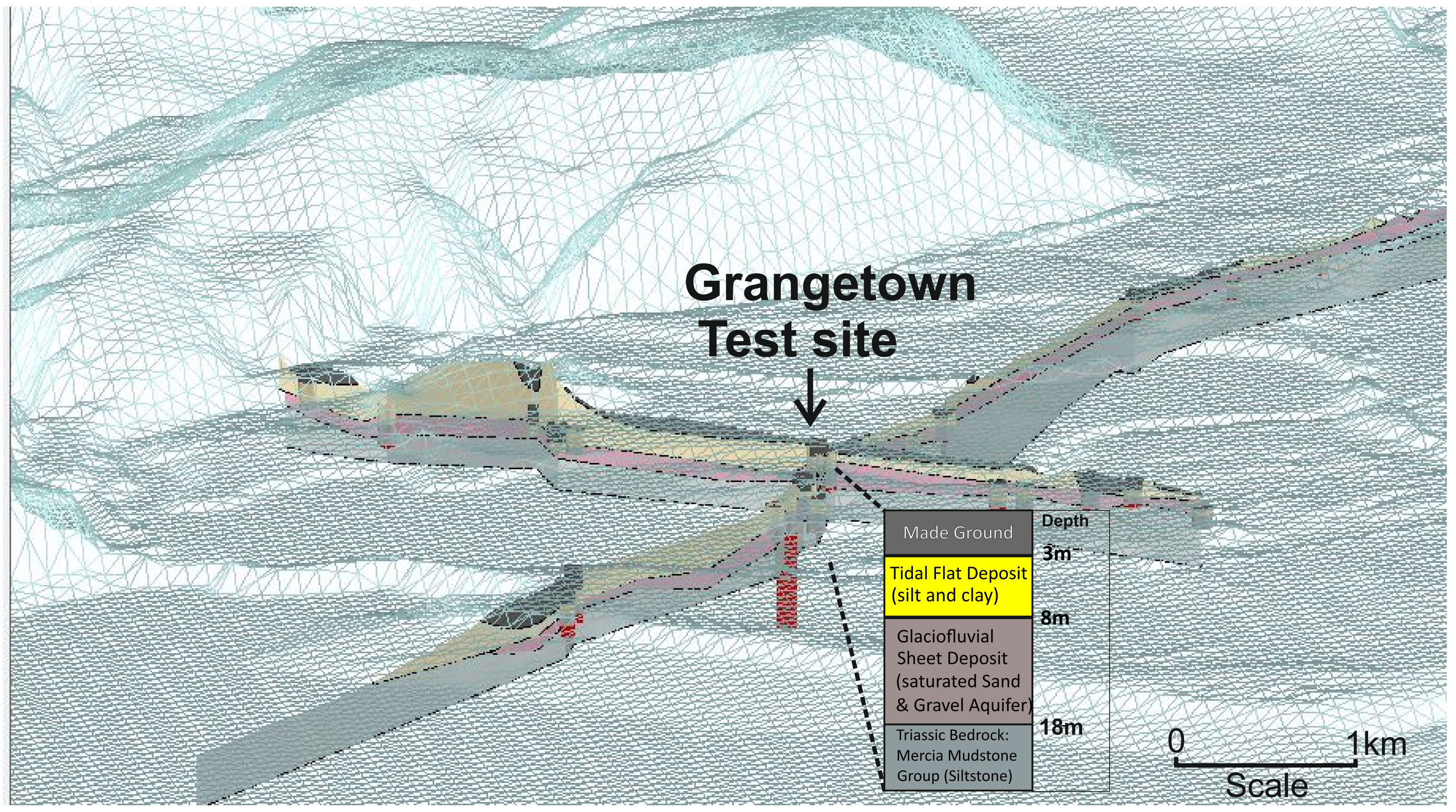

Fig. 7. Extract from the city-scale 3D geological model (1:50,000 scale equivalent), constructed by combining archive data from over 3000 geotechnical borehole log data retrieved from historic site investigations. The improved geological knowledge base enables better early prognosis of ground conditions (geotechnical and geothermal) and is supporting the planning and development of a resilient and sustainable energy strategy for the city. (x5 vertical exaggeration)

5. Physical properties

Physical properties of the aquifer, confining overburden and bedrock influence groundwater conditions, construction costs and thermal recovery. Realistic attribution of process models requires assessment of soil and rock properties. We measured thermal conductivity and diffusivity, density, particle size, Atterberg limits to enhance the BGS's National Physical Properties database.

Table 1. Typical thermal properties of deposits in south Cardiff.

Deposit	Tidal Flat Deposits (organic Clay & Silt)	Mercia Mudstone Group (Red Siltstone)
Thermal Conductivity K W/(m.K)	1.221 (TD -1 probe) 1.027 (SH -1 probe)	1.2 – 1.9 (Weathered – Fresh)
Thermal Diffusivity m^2/d	0.024	0.035 – 0.065 (Weathered – Fresh)

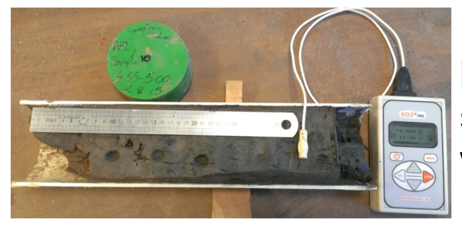

Fig 8. Typical laboratory testing set up with Decagon KD2 PRO probe.

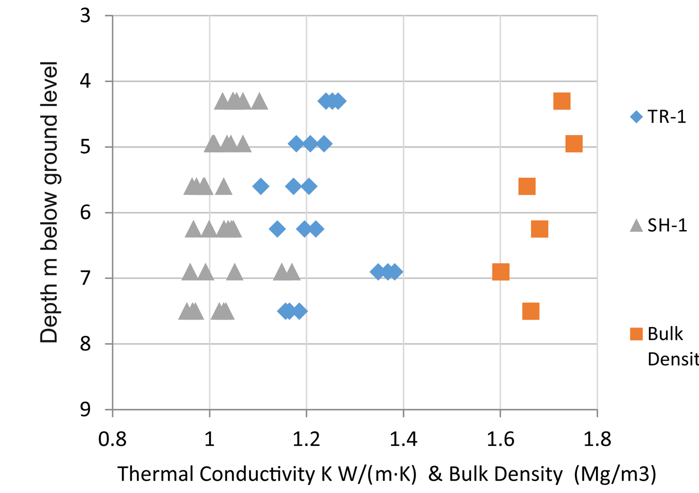

Fig 9. Plot of thermal conductivity and density measurements made on Cardiff Tidal Flat Deposits (organic silts and clays), which confine the gravel aquifer at the test site.

6. Key Findings

- There are many benefits to undertaking geological and groundwater studies early-on
- The geological and groundwater monitoring data supplied by this study is helping inform the regulator and council on impact of the system on the groundwater system. It could also reduce uncertainty in design parameters and reduce installation and running costs for new GSHP's
- Groundwater flow direction is an important consideration for open-loop heat pump configuration
- Groundwater flow direction is probably locally variable, influenced by seasonal rainfall and artificial control of the river and groundwater levels, and Cardiff Bay lagoon
- 11kW heat pump output is enhanced by up to 20% due to the subsurface Urban Heat Island
- Hydrogeological properties of the sand and gravel aquifer varies, reflecting depositional history
- Water volume in shallow gravel aquifer is estimated to be approx 28 M cubic meters
- Monitoring GSHP's provides both customers and regulator some assurance and confidence

7. Future Work

- More extensive borehole drilling, test pumping and data collection
- Site specific 3D groundwater modelling and validation (inter-seasonal storage)
- Investigation of thermal storage potential of waste heat into groundwater
- Consider open water usage – barrage, rivers, docks, lakes, sewers
- Undertake heat demand mapping and energy planning across the city
- More detailed network distribution designs at key locations
- Address utility issues from new heat networks (power demands)
- Business model development – partners, funding, detailed costings
- Explore future heat regulation, and network ownership and governence options

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