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Shallow Groundwater Temperatures and the Urban Heat Island Effect:

The First U.K. City-wide Geothermal Map to Support Development of Ground Source Heating Systems Strategy

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1. Introduction

U.K. Government aims to reduce greenhouse gas emissions by 80% by 2050 (Climate Change Act, 2008). Ground source heating systems could contribute to the U.K.'s energy future but uptake has been slow due to a lack of case studies. The aim of this work was to produce the 1st U.K. city-wide heat map to support the development of ground source heating. We also sought to describe groundwater temperature variation with lithology & estimate the available thermal energy beneath the city.

The coastal city of Cardiff, Wales, U.K., has a shallow superficial aquifer in gravels over Mercia Mudstone. Some of the gravels are locally confined by clays. In 1999 Cardiff Bay was impounded forming a freshwater lake (Cardiff Bay Barrage). The Cardiff Bay Barrage Act, 1993, had a requirement for groundwater monitoring & a city-wide borehole network was installed. We used 168 of these boreholes to measure groundwater temperatures in a shallow urban aquifer.

2. Methodology

- OTT® loggers in 6 boreholes recording temperatures at 30min intervals provided time series data for 2 years (2012-2014)
- Initial fieldwork in Spring 2014 (coldest time for groundwater)
- 167 groundwater monitoring boreholes up to 20m deep + 1 deep borehole
- In-Situ® Rugged Temperature, Level & Conductivity Meter (TLC) used to record temperatures every 1m from top to base
- Weather, soil & river temperature data also obtained
- 35 boreholes in a range of geology & land use re-profiled in Autumn 2014 (warmest time for groundwater) to characterise seasonal changes & define the 'zone of seasonal fluctuation'

Fig. 1. Borehole temperature profiling using a TLC Meter

Fig. 2. TLC Meter measuring borehole temperature

Fig. 3. On site at one of the boreholes

3. Analysis

- Dry or very shallow boreholes & anomalous data removed leaving 121 profiles
- Data for 1st metre of water excluded from analysis to remove atmospheric temperature effects
- Average temperature for each borehole (excluding 1st metre) calculated
- Average temperatures contoured in Surfer® 10
- Contour plot overlaid on basemap to produce 2D thermal resource map (Fig. 4)
- 3D GOCAD® model of sub-city heat created from whole borehole temperature profiles (Fig. 5)
- Borehole logs coded with lithology to characterise temperature variation with lithology (Fig. 6)

4. Results

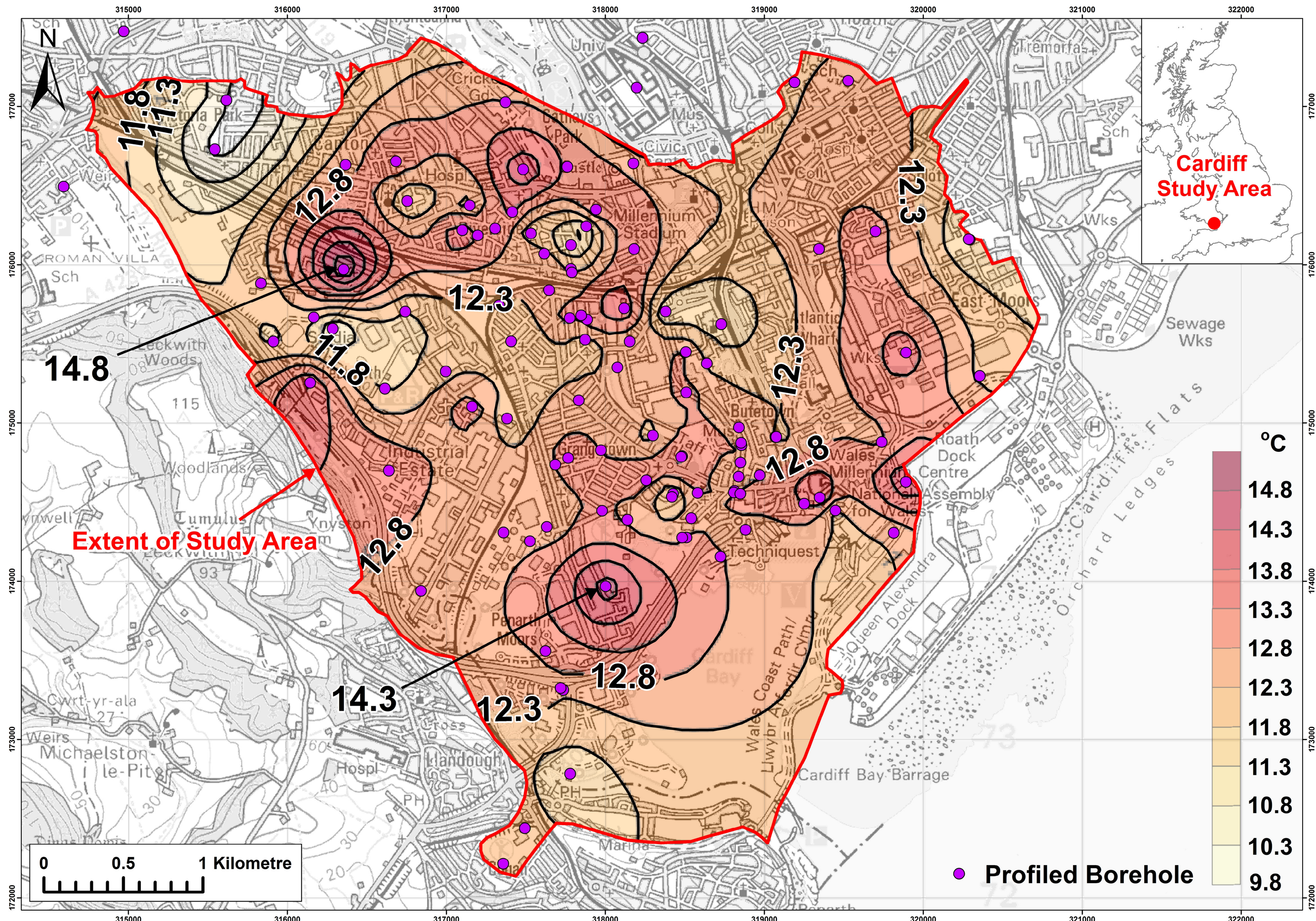

Fig. 4. Thermal resource map. Map shows average groundwater temperature across the city. Darker colours show warmer groundwater. Contains Ordnance Survey data © Crown Copyright & database rights 2014.

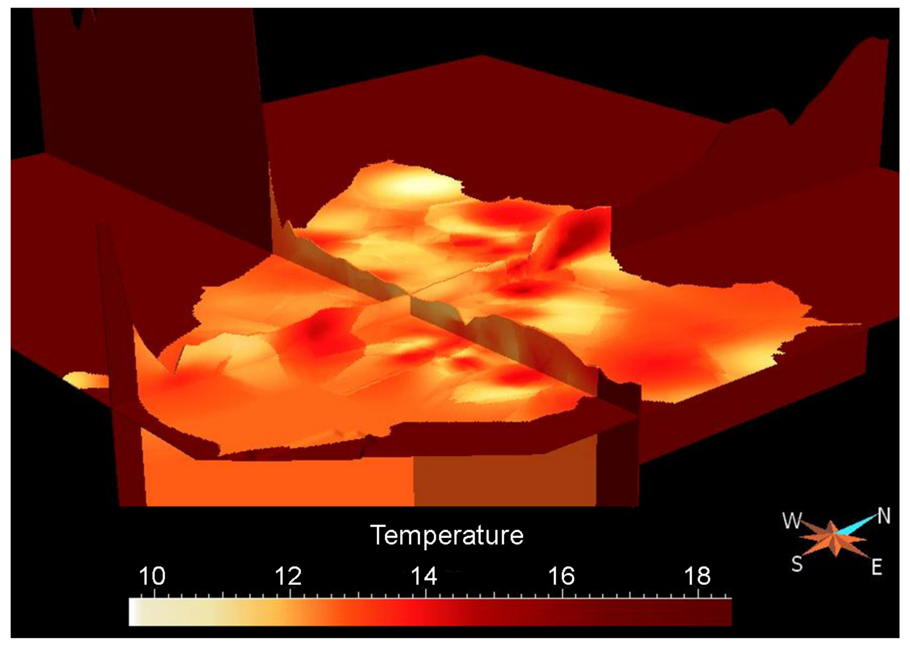

Fig. 5. Vertically exaggerated 3D model of Cardiff's groundwater temperatures showing temperature variability across the city's subsurface

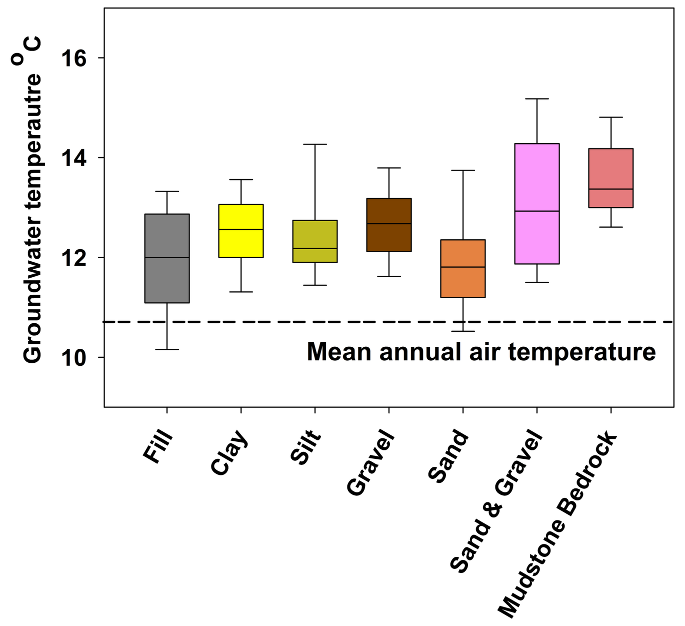

Fig. 6. Groundwater temperature ranges for each lithology

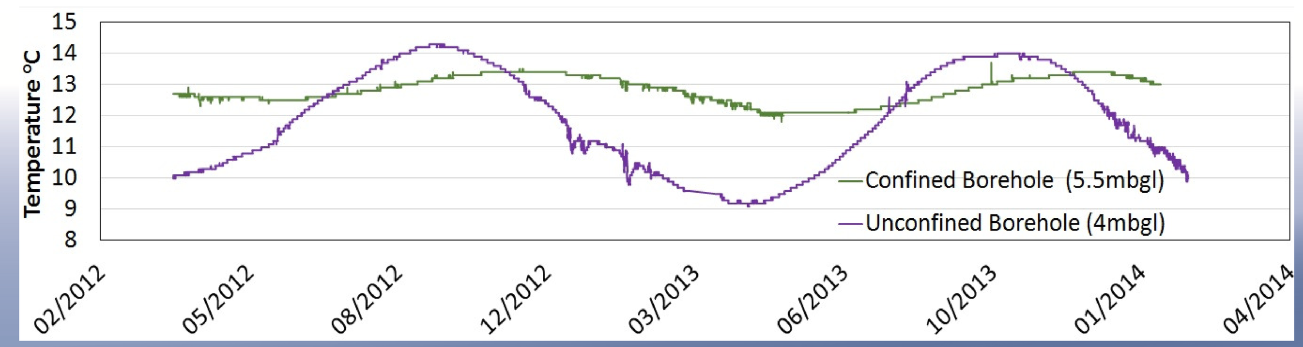

Fig. 7. OTT® logger data shows groundwater temperature variation for 2 years in gravel for a confined & an unconfined borehole

5. Future Work

- In situ monitoring of 40+ boreholes in different geology & land use, capturing seasonal change
- Groundwater pumping tests to assess sustainable yields & heat recharge
- Development of mobile ground source heat pump testing system
- Chemical analysis of groundwater quality to support system design
- Monitor a SuDS scheme before & after construction to assess impacts of reduced infiltration
- Development of 3D geological & hydrogeological model
- Identify heat sources in urban aquifers & the relationship between temperature & geology

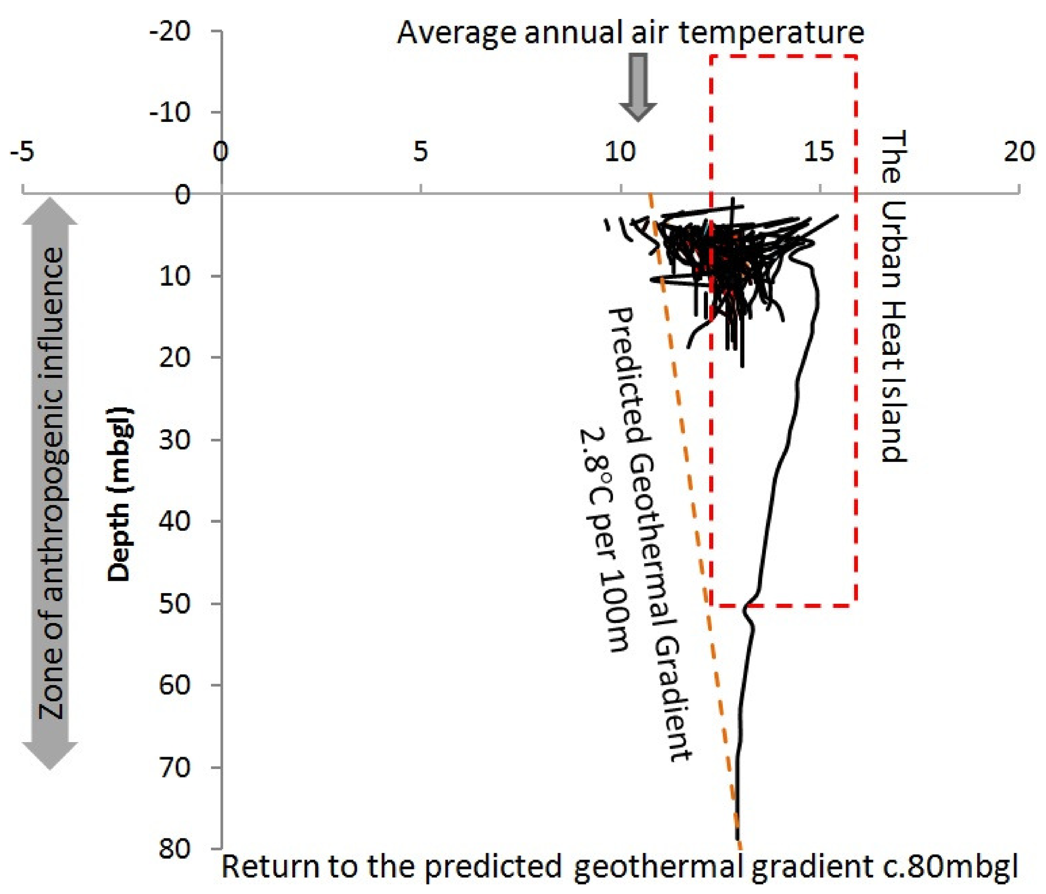

Fig. 8. Borehole temperature profiles generally above predicted geothermal gradient (Busby et al, 2011). Black lines show temperature profiles of boreholes.

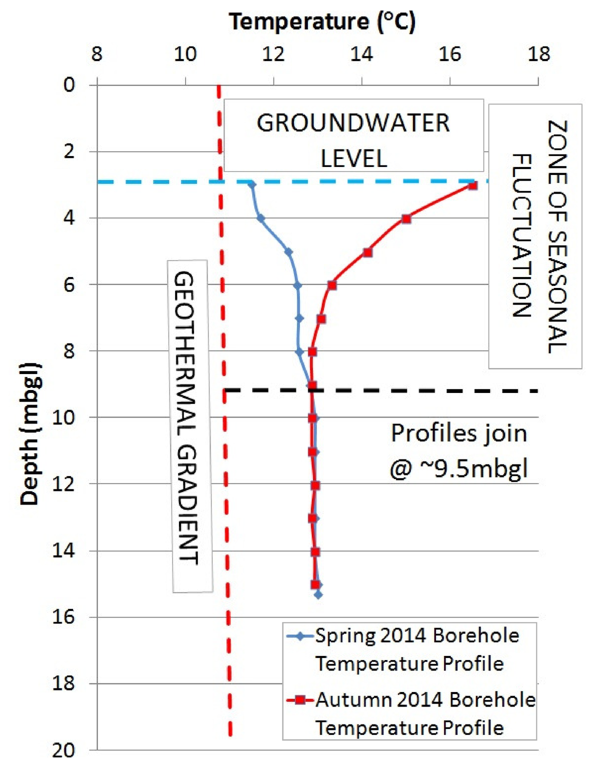

Fig. 9. Spring & Autumn temperature profiles for a typical borehole. Point where the profiles meet defines the zone of seasonal fluctuation

6. Key Findings

- Average spring groundwater temperature for 0-20mbgl = 12.4℃
- 90% of data above U.K. mean groundwater temperature (11.3℃)
- Max. groundwater temperature = 16.1℃ (above mean annual air temperature (10.8℃))
- Warmer than the predicted regional geothermal gradient (2.8℃/km)
- Temperatures above the predicted geothermal gradient seen 80mbgl - urban heat island effect deeper than thought? (Fig. 8)
- Warmer temperatures in city centre (13.8-14.6℃), cooler in surrounding areas (10.1-11.3℃)
- Temperature variation smaller in confined (1.1-1.9℃) than unconfined (3.2-6.6℃) aquifer
- 'Zone of seasonal fluctuation' ends at a mean depth of 9.5mbgl (7.1-15.5mbgl) (Fig. 9)
- Potential heat sources - land use, subsurface infrastructure, microbes, variability of aquifer, water rock interaction & deeper geothermal water
- Existing dewater scheme could supply c.4.8GW/year of energy
- Knowledge could inform design strategy & regulation, & reduce installation & running costs

References: Busby, J., Kingdom, A. & Williams, J. 2011. The Measured Shallow Temperature Field in Britain. Quarterly Journal of Engineering Geology & Hydrogeology, 44, 373-387

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