Monitoring Groundwater Temperatures in a Shallow Urban Aquifer Before, During and After Installation of a Ground Source Heat System in Cardiff, U.K.

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1. Introduction

Following studies into groundwater temperatures within a shallow urban aquifer in the coastal U.K. city of Cardiff, a map was produced showing the distribution of subsurface heat (Fig. 1). Groundwater temperatures in the top 20mbgl were found to be up to 4°C warmer than predicted by the U.K. average geothermal gradient in over 90% of the sampled sites, possibly elevated by the Urban Heat Island Effect.

After initial baseline temperature mapping had established a potential thermal resource for shallow, open-loop ground source heat pump (GSHP) systems, a GSHP was installed to examine the sustainability of the resource at a selected test site. A groundwater temperature monitoring network was set up to characterise baseline groundwater temperatures & monitor any impacts of the first open-loop GSHP in the city, which began operating in October 2015.

2. Heat Mapping

- Groundwater temperature profiled downhole at 1m depth intervals in 168 boreholes across the city using an In-Situ® Rugged Temperature, Level & Conductivity Meter
- Temperatures contoured to make a heat map (Fig. 1)
- Map aimed at planners & regulators for use in assessing the use of GSHPs
- Groundwater temperatures were higher than the U.K. average
- Warmer groundwater temperatures observed in the city compared with the surrounding area

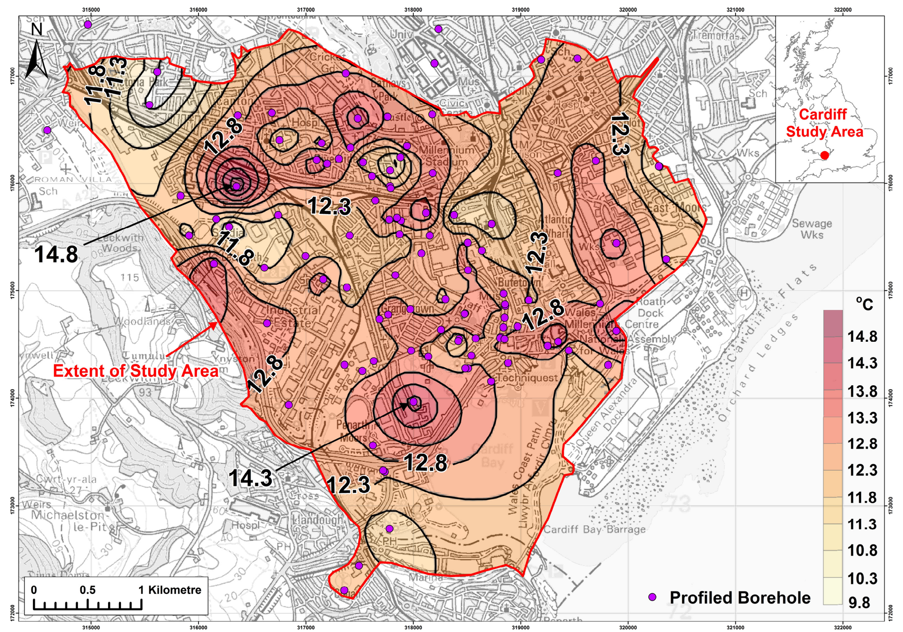
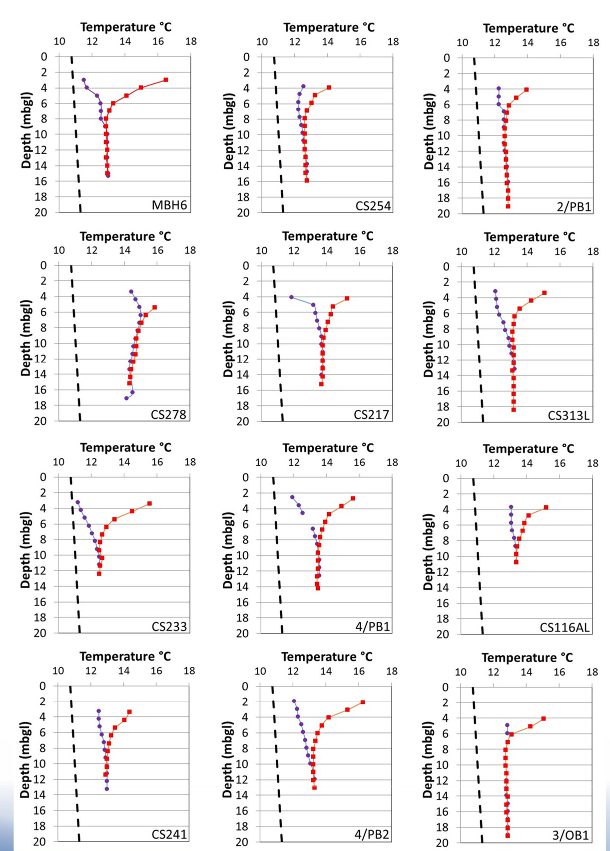


Fig. 1. Heat map shows average groundwater temperature across the city. Contains Ordnance Survey data © Crown Copyright & database rights 2016.

3. Zone of Seasonal Fluctuation



- Initial study in Spring with repeat profiling at a subset of boreholes in Autumn to define the depth of the Zone of Seasonal Fluctuation (mean depth of 9.5mbgl but varies between 7.1-15.5mbgl) (Fig. 2)
- Temperatures elevated above the U.K. average geothermal gradient extended to 70mbgl in the only two deep boreholes (>50m) in the study
- Average Spring groundwater temperatures of 12.4°C (max. 16.1°C) give potential for GSHP in shallow urban aquifers warmed by the Urban Heat Island Effect

Fig. 2. Spring & Autumn downhole borehole temperature profiles for a subset of measured boreholes. Depth of the Zone of Seasonal Fluctuation is indicated where profiles join. Dashed line is the U.K. average geothermal gradient (Busby, *et al.*, 2011)

4. Monitoring Network

Thermally enhanced shallow aquifers lessen installation & operation costs of GSHPs by reducing required drilling depths & pumped head of water. Heat maps offer a tool for optimal planning of GSHPs. To prove resource sustainability & aid planning of GSHPs to avoid system interaction, groundwater temperature monitoring before & after installation of a GSHP was undertaken.

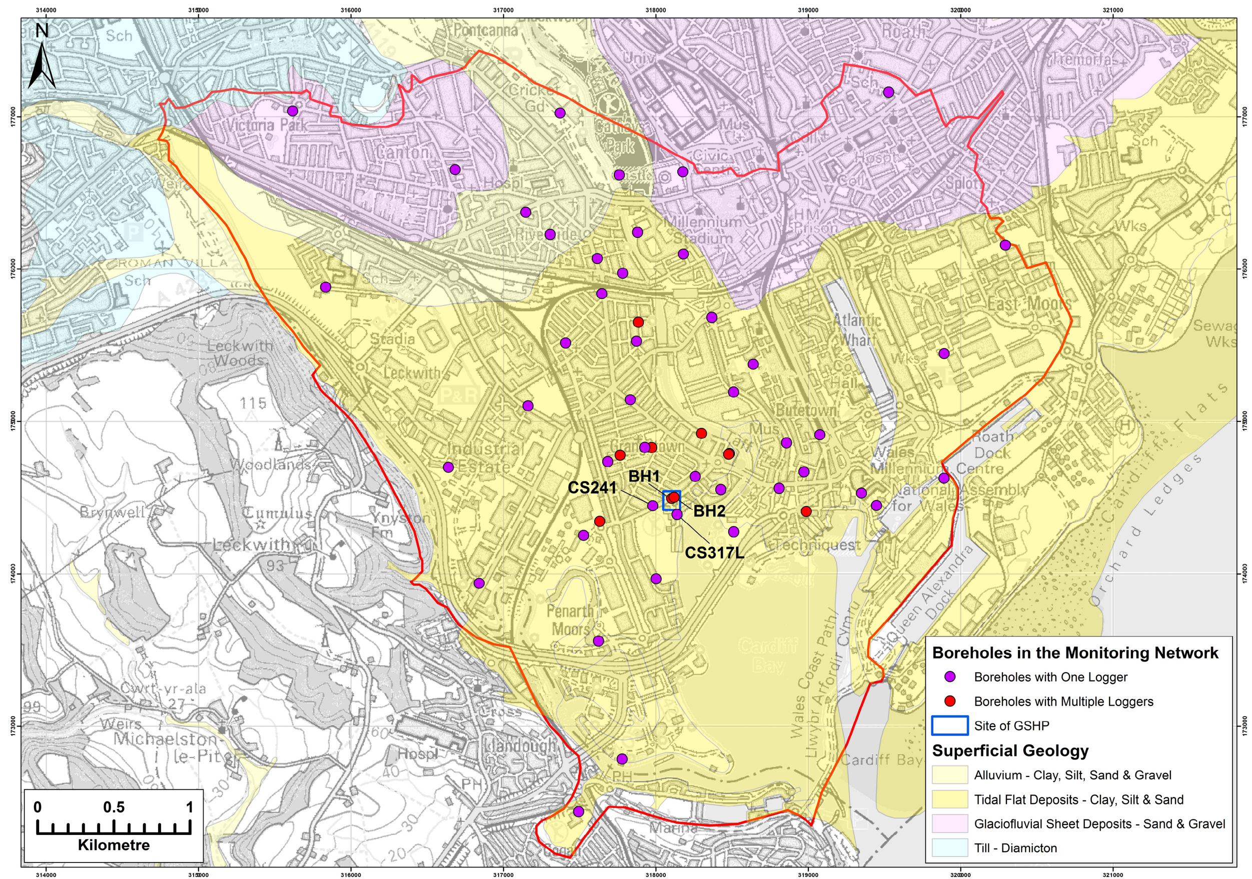


Fig. 3. Temperature monitoring network. Map shows the locations of *in situ* temperature loggers. Contains Ordnance Survey data © Crown Copyright & database rights 2016.

- 97 *in situ* groundwater temperature loggers installed at discrete depths in 60 boreholes across the city recording temperature every 30mins since June 2015 (Fig. 3)
- Loggers installed up & down gradient of the GSHP
- Majority of loggers installed below the Zone of Seasonal Fluctuation
- Some boreholes fitted with multiple loggers at different depth, including in the near surface
- Multiple loggers at 1.3m intervals in the GSHP boreholes
- Six telemetered boreholes (including GSHP boreholes)
- Air, soil, river, bay & GSHP plant room temperatures also recorded

5. Time Series Data

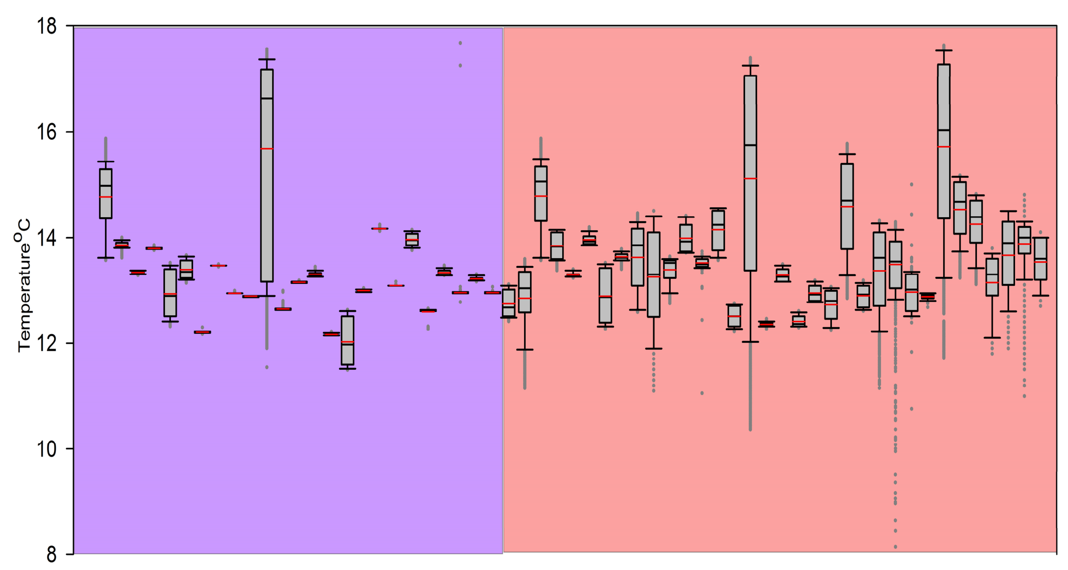


Fig. 4. Logger temperature variation during first 7 months (Jun15-Jan16). Purple - logger below the mean Zone of Seasonal Fluctuation (9.5mbgl), red - loggers within it

- Max. temp. variation = 9.81°C
- Min. temp. variation = 0.03°C
- Minimal temperature variation below Zone of Seasonal Fluctuation
- Base of Zone of Seasonal Fluctuation varies spatially
- Amount of seasonal fluctuation varies
- Lag time between air temperatures & groundwater temperatures varies at different boreholes

6. Monitoring Data from the Ground Source Heat Pump

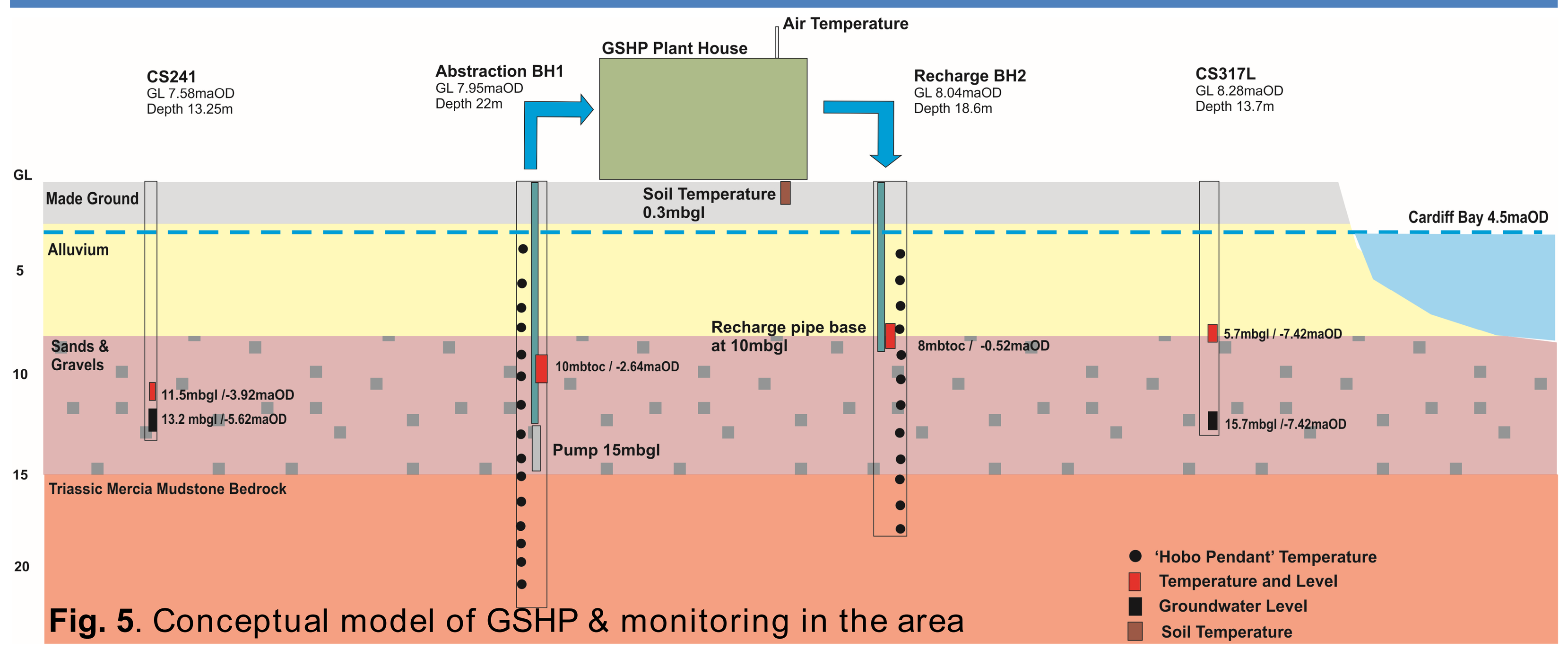


Fig. 5. Conceptual model of GSHP & monitoring in the area

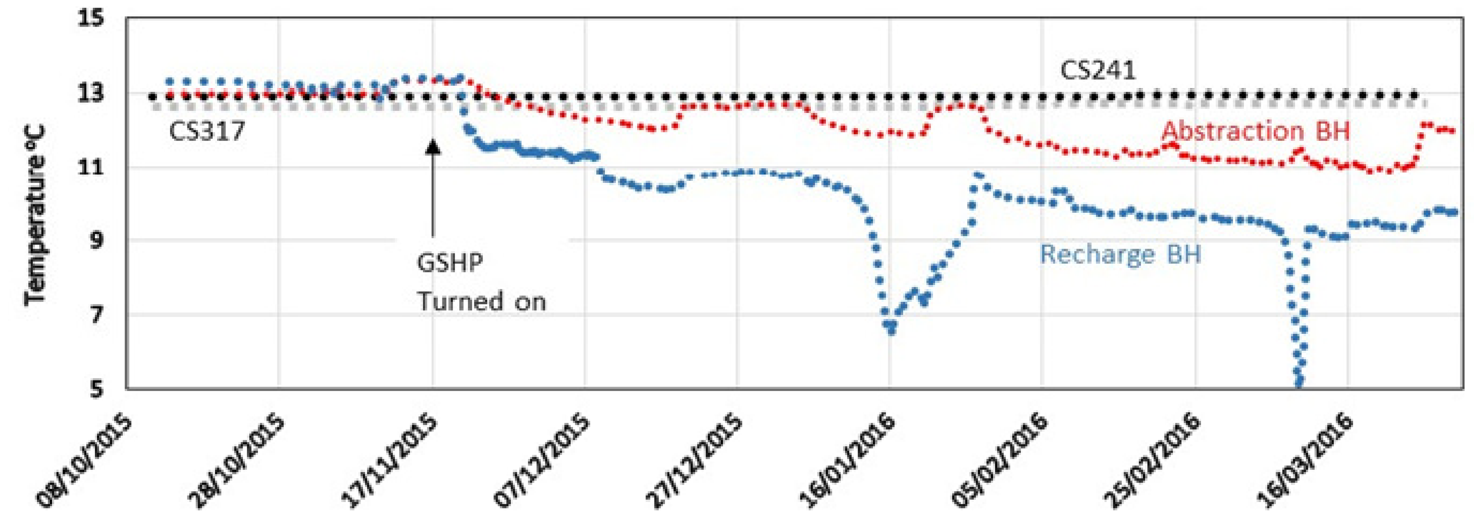


Fig. 6. Groundwater temperatures at abstraction, discharge & 2 nearby monitoring boreholes

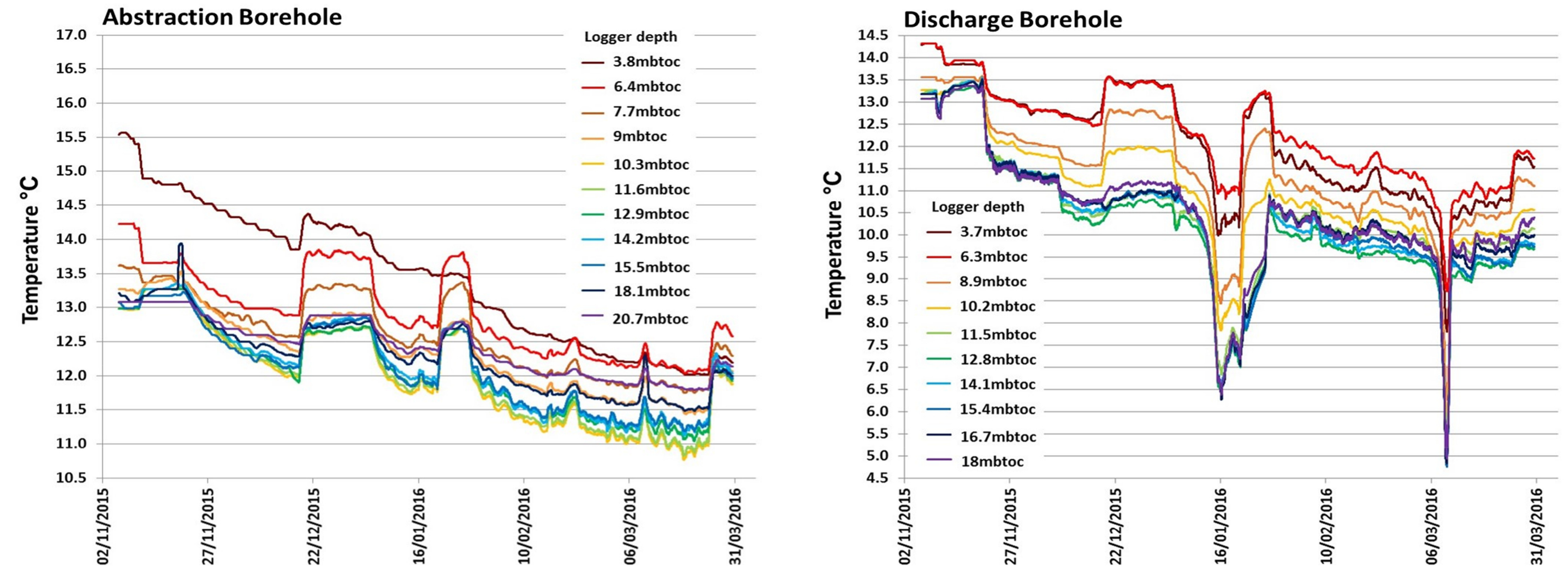


Fig. 7. Groundwater temperature at various depths in the abstraction & discharge boreholes

7. Key Findings

- No change from baseline temperatures detected in monitoring boreholes near the GSHP
- Abstraction & discharge boreholes show similar temperature profiles, both having warmer temperatures at the top & base of the borehole & cooler at the centre (c.11mbtoc)
- Coolest temperatures in each borehole seen at locations of discharge pipe & abstraction pump, where cooler waters may be drawn in from the surrounding aquifer
- Temperatures reduced with average ΔT of 2°C. Temperatures rebound when pump is off
- Max. baseline temperature variation in the target aquifer below the Zone of Seasonal Fluctuation = 0.03°C. Temperature stability in this zone makes it suitable for GSHPs
- Temperatures vary with depth in GSHP boreholes so the location of monitoring loggers used for system regulation & permitting is critical

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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