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Effects of cycling on domestic GSHPs.

Supporting analysis to EA Technology

Ground loops - testing.

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Domestic GSHPs - effects of cycling

1. Introduction

The Department of Energy and Climate Change (DECC) have commissioned EA Technology to carry out investigations into the effect of cycling on examples of domestic air source heat pumps (ASHPs) and closed loop ground source heat pumps (GSHPs). This follows on from earlier work carried out by EA Technology for DECC on the effect of cycling on ASHPs (Green & Knowles2011). This work is part of a series of activities commissioned by DECC following the EST monitoring trial of domestic ASHPs and GSHPs throughout the United Kingdom (EST 2010, Dunbabin & Wickins2012)

Mimer have been sub-contracted by EA Technology to provide support for the re-commissioning of the GSHPs ground loops, the selection of a suitable GSHP, and supporting analyses of the experimental measurements made by EA Technology of the GSHP behaviour.

2. Background to experimental set-up

The work has been undertaken using one of two identical houses (Figure 1) constructed for test purposes at EA Technology's Capenhurst site in the 1990's. The house fitted with radiators has already been used for earlier work on the effect of cycling on an ASHP. This house happens to have had two closed loop GSHP boreholes installed in 1998 to investigate the potential of heat pumps for active and passive cooling in domestic properties using small heat pumps. Although these boreholes have not been used in the intervening years, it was possible that they could be re-commissioned and used to investigate the behaviour of a modern domestic GSHP in heating mode.

Figure 1: The experimental house.

3. Ground loops

Unfortunately there is only a limited amount of information regarding the exact nature and location of the holes. There are two boreholes, reportedly 60m and 80m deep respectively and 6m apart. They use single 32mm OD, SDR-11, HDPE, U-tubes in each borehole and are reported to have been grouted with bentonite. (This is a naturally occurring, low hydraulic permeability grout, of low thermal conductivity. This was standard practice at the time of installation). The ends of each U-tube are brought back below ground level to the side of the house (in 32mm pipe) where they rise out of the ground and penetrate the inner and outer leaf of the wall to enter the utility room (Figure 2). No information has been found in terms of a driller's log, the diameter of the boreholes, their exact location relative to the house, or the length of the header pipework. They had originally been filled with an antifreeze mixture for frost protection purposes.

Figure 2: The two 32mm GSHP ground loops as they enter the house in parallel.

4. Geology.

In the absence of a driller's log, a limited desktop assessment has been undertaken. A site specific report by Entec for the NDA (Entec2010) suggests that the geology of the site comprises "drift covered hardrock (Sherwood Sandstone)". The 1:50000 BGS Solid Geology map for the area indicates that the geology is Pebble Beds overlying Lower Mottled Sandstone. These are from the Bunter formation and are Triassic. There is no information as to the depth of the overlying drift. Figure 3 shows the relevant extract and associated key from Sheet 108 of the BGS map. (IGS1965)

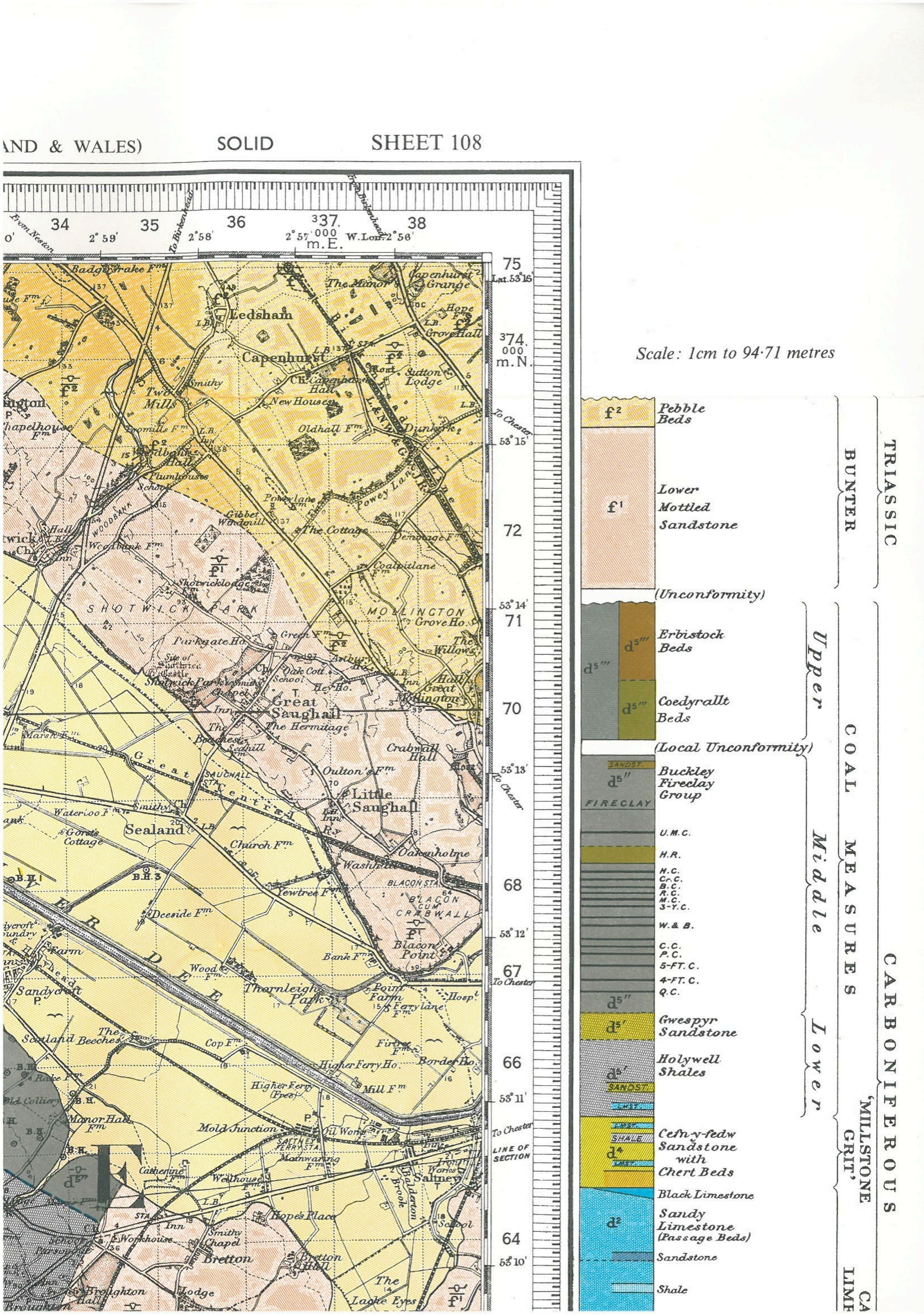

Figure 3: Extract and key from relevant solid geology map of the site. (see top right).

5. Re-commissioning of GSHP loops

EA Technology carried out circulation tests on the loops both individually and combined which indicated that they were free to flow and suitable for use with a new GSHP. Table I shows the recorded flow rates at three different speed settings on the circulation pump, for the individual holes and for the two holes combined. When the new GSHP was connected to the ground loops, the heat pump manufacturer, as part of their commissioning procedure, flushed the two loops and replaced the contents with a new antifreeze mixture.

Table I: Flow characteristics of the Capenhurst borehole loops.

Both loops (parallel)				
pump	flow (m3/h)	l/s	lpm	Q (kW)
1	0.87	0.24	14.5	3.0
2	1.2	0.33	20.0	4.2
3	1.5	0.42	25.0	5.3
80m				
pump				
1	0.71	0.20	11.8	2.5
2	0.945	0.26	15.8	3.3
3	1.105	0.31	18.4	3.9
60m				
pump				
1	0.686	0.19	11.4	2.4
2	0.918	0.26	15.3	3.2
3	1.05	0.29	17.5	3.7

Note: These figures are for flows purely around the ground loops. The final column is the calculated heat output at these flow rates for a temperature drop of 3°C.

6. Thermal testing of boreholes

As part of this work, it had been decided to attempt to obtain a measurement of the ground thermal conductivity. Because there is no direct access to the top of each borehole, and due to the limited information regarding the original drilling of the boreholes, this exercise could only be of limited success. However, because it was relatively straightforward to implement a simplified approach to thermal response testing, this was carried out on each borehole.

Normally a specialist thermal response test (TRT) rig is mobilised to a borehole site, and connected directly to the borehole to be tested. In this instance EA Technology arranged for a 6kW flow boiler to be connected such that heated water could be circulated to any one of the boreholes, whilst recording the response in the ground loop temperature. Instrumentation was provided that recorded the electrical and heat energy injected to the ground loop with time, as well as the temperatures at the input and output of the ground loop header pipework. 50 hour heating tests were conducted on each borehole, with a cool down period in between the two tests.

Figures 4 and 5 show the 50 hour temperature responses for the 80m and 60m boreholes respectively. Whilst both of these curves show the characteristic behaviour expected from a thermal response test, they suffer at later time from external effects that give rise to temperature fluctuations. These do not appear to have been caused by fluctuations in the power input which was very constant. It is likely that they arose due to the fact that it was not possible in this situation to insulate the pipework between the top of the boreholes and the temperature sensors.

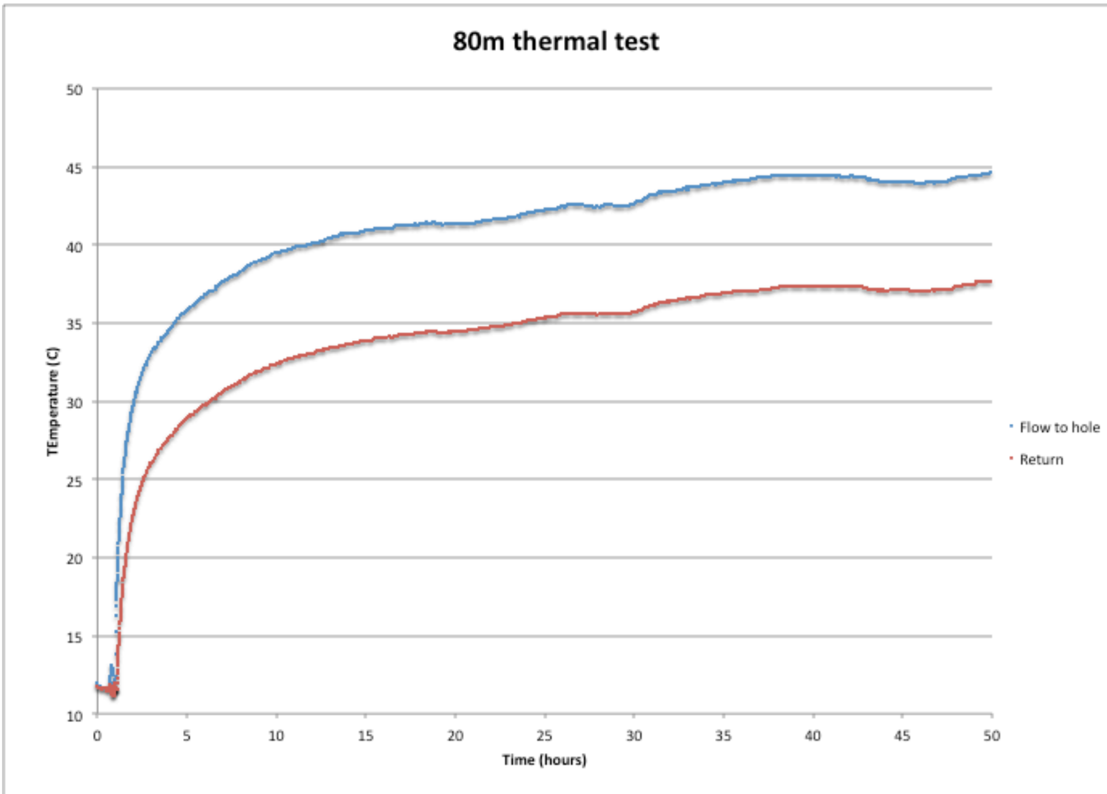

Figure 4: Flow and return temperature profile of 50 hour test on 80m borehole.

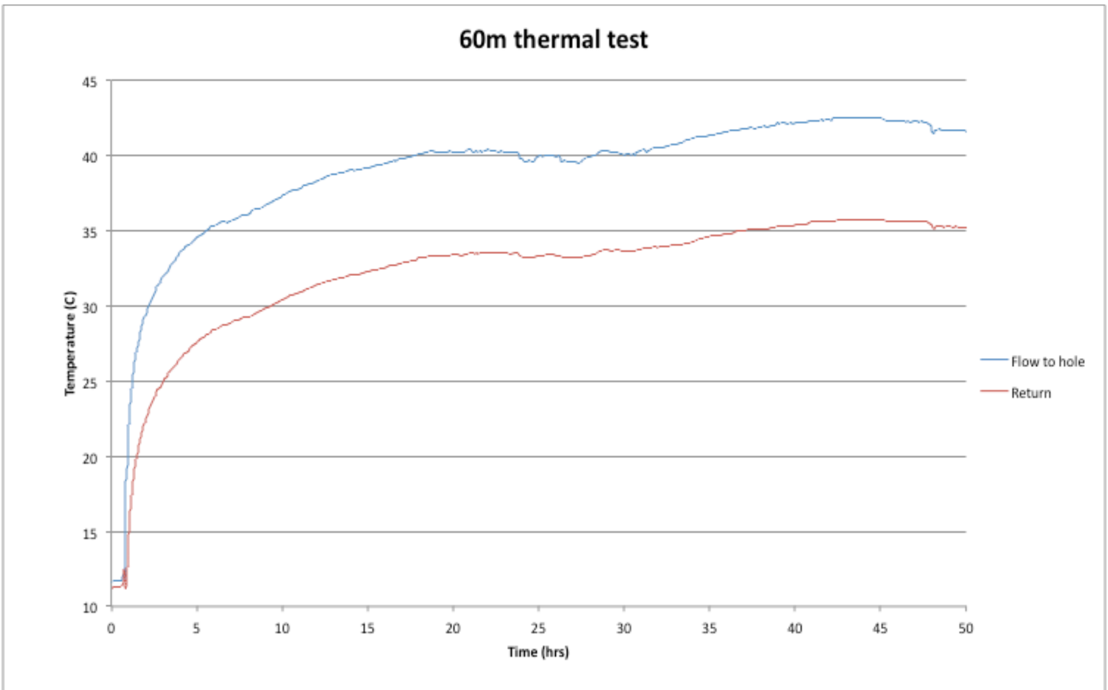

Figure 5: Flow and return temperature profile of 50 hour test on 60m borehole

Figures 6 and 7 show exploded sections of the start of these tests for the 80m and 60m holes respectively. The two useful numbers that can be derived from these figures are the temperature of the ground at the start of the test, and the time for fluid to pass the inlet temperature sensor, circulate through the ground loop and return to the outlet temperature sensor.

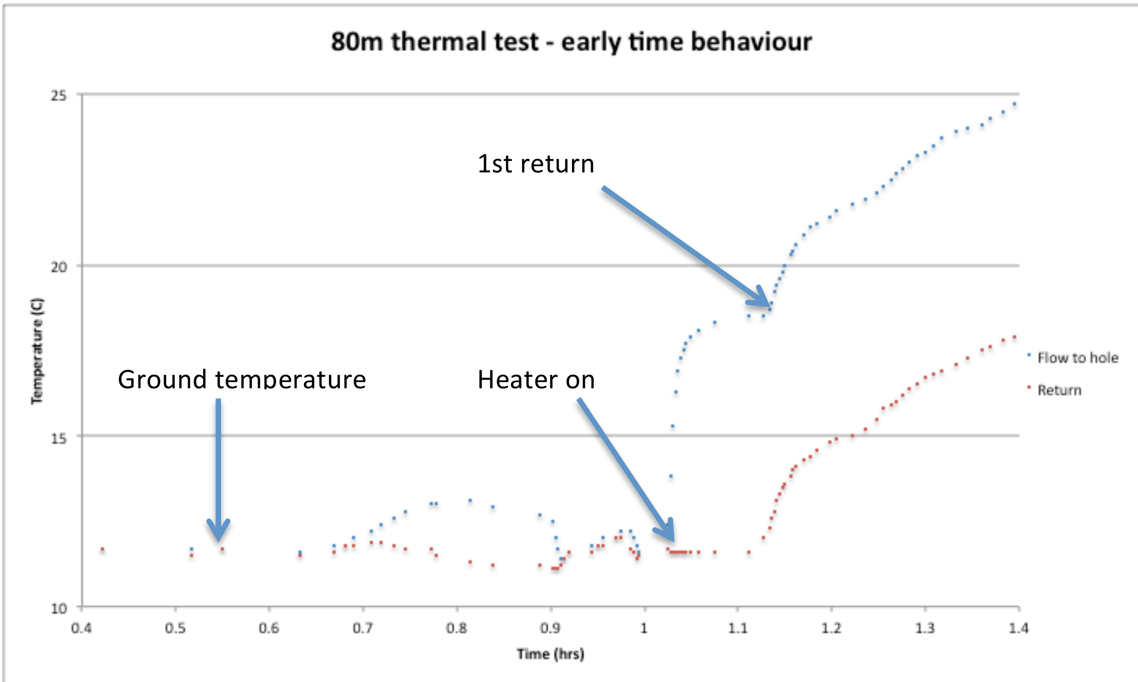

Figure 6: Early time behaviour of 80m thermal test.

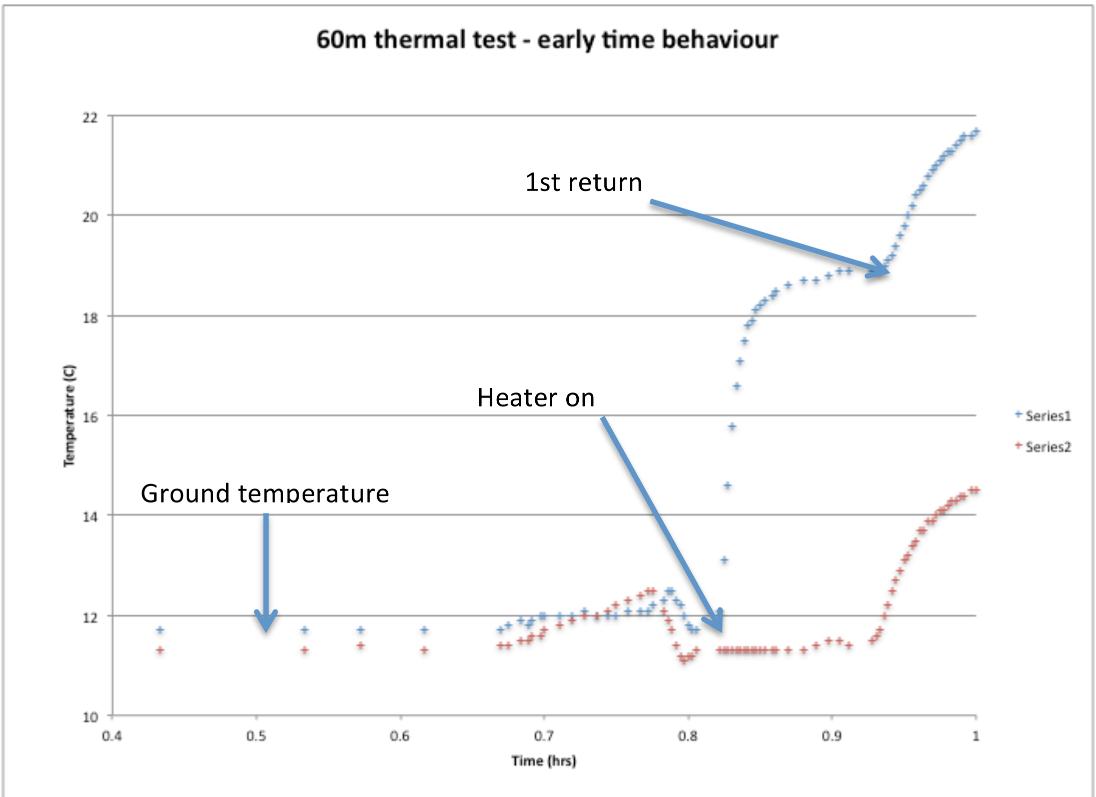

Figure 7: Early time behaviour of 60 m thermal test.

The established method of deriving ground thermal conductivity is to plot the mean of the temperature rise of the circulating borehole fluid against logarithmic time. (eg Banks2008, Chapter 12) From the slope of these plots, particularly at late time, the thermal conductivity can be derived. Figures 8 and 9 show the two logarithmic plots for the 80m and 60m holes respectively. Slopes are shown for both the bulk period of the test and at late time. It is seen that the temperature variations due to ambient effects have a marked influence on the late time shapes of these logarithmic curves.

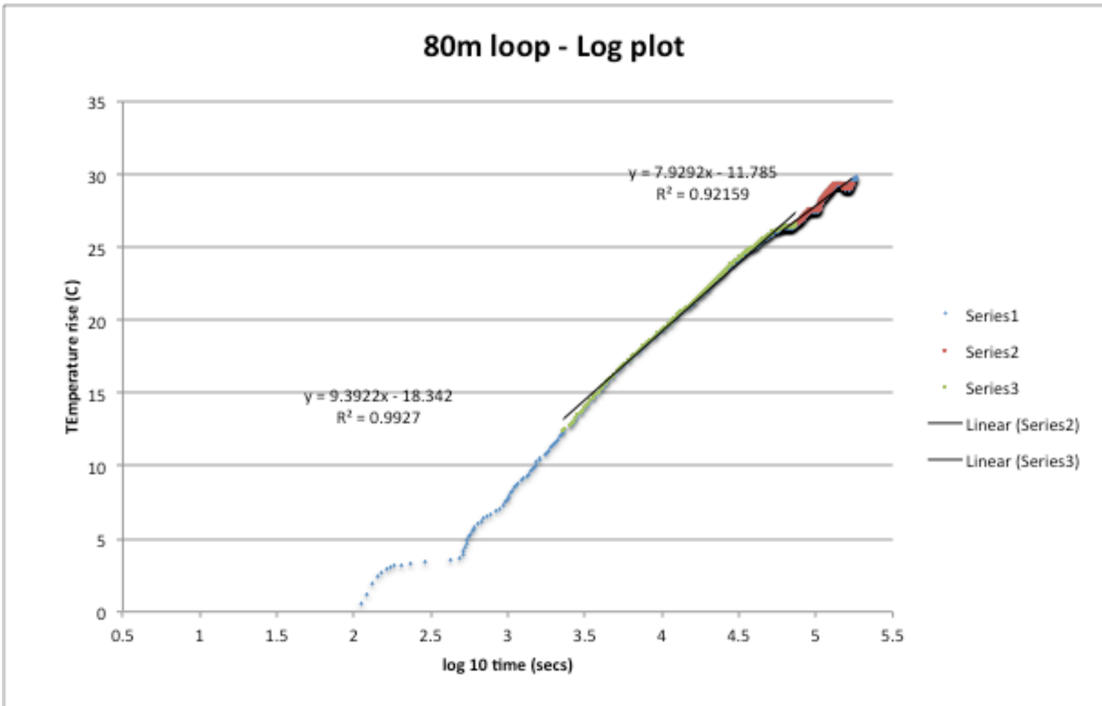

Figure 8: Log plot of temperature increase for 80m test.

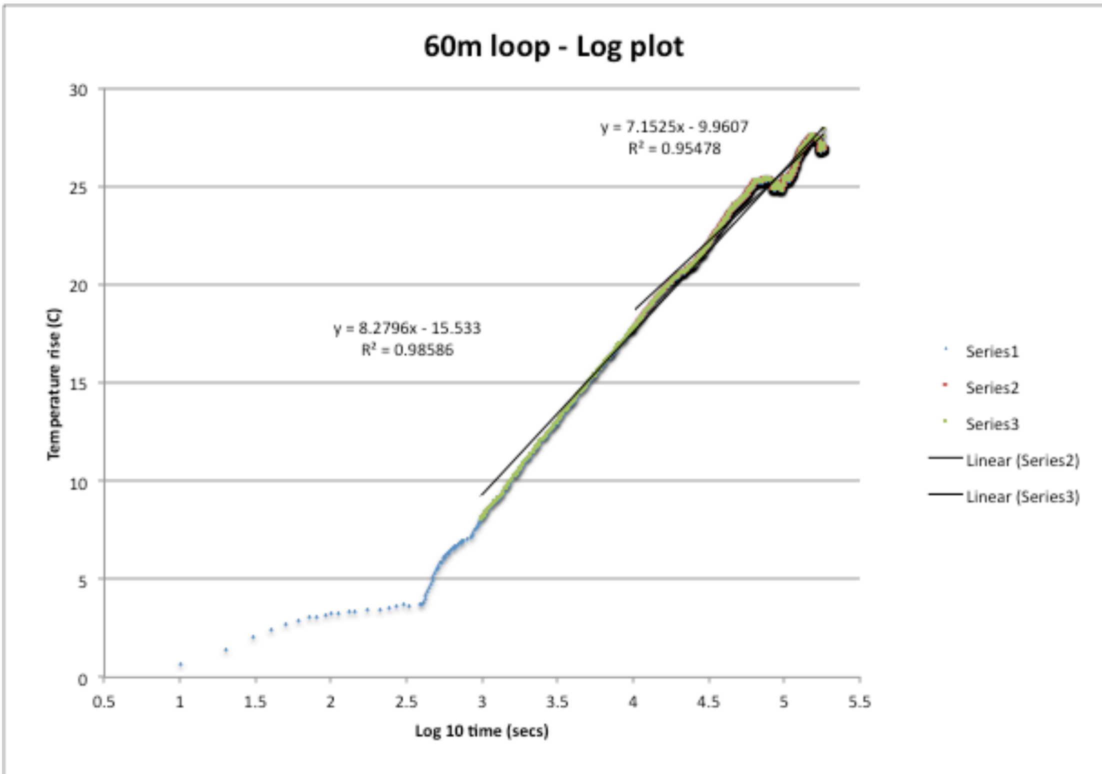

Figure 9: Log plot of temperature increase for 60m test.

Apart from the slope of these lines, the only additional parameter required to determine the thermal conductivity is the heat input per metre of borehole (ie Q/L in W/m). Unfortunately, in this experimental setup we have an uncertainty associated with this parameter. Whilst the measurement of the energy injected into each ground loop is known, the amount of heat "lost" in the header pipework is not known. We can therefore only bracket the conductivity, by assuming a best case, where all of the energy is injected into the borehole loops (only) and a worst case, where a pro-rated amount of energy is lost to the header pipework. Note that we have to accept at face value that the borehole U-tubes are genuinely 80m and 60m long. It was not possible in this situation to "dip" the boreholes to confirm these depths as is common practice with a TRT test, or where the U-tube tails are exposed at surface.

Table II shows the thermal conductivities derived for best and worst case energy rates using the bulk and late time slopes, for the two boreholes.

Table II: Thermal conductivities derived from log plots (W/mK)

	80m	80m	60m	60m
	borehole only	borehole+header	borehole only	borehole+header
Bulk time	1.50	1.34	2.26	1.94
Late time	1.78	1.58	2.62	2.24

Taking the late time slopes only, the range is 1.58 to 2.62 W/mK

For pure sandstone of this age we would have expected a conductivity value in excess of 2 W/mK, and probably in the 2.3 to 2.5 W/mK range (eg Rollin2003). The unknowns here are the extent of the overlying pebble beds, their water content, and the length and nature of the header pipework. The mid-value of the values derived from the late time slopes is 2.1 W/mK. A value of 2.0 W/mK has been used in the simulation work described later.

(Note that the average power input for the "80m" test was 6.130 kW, and 6.170 kW for the "60m" test)

7. Borehole resistance

A parameter that affects the operation of borehole systems is the "borehole resistance". This is a collective resistance reflecting the thermal resistances encountered between the wall of the borehole and the fluid flowing in the U-tubes. The logarithmic plot method can also provide an estimate of this parameter, derived from the intercept of the straight line portion of the plot with the y-axis. The borehole diameter is required for this as well as estimates of the specific heat capacity of the rock, and the rock density. Assuming the following values

Borehole radius: 0.075 m
Specific heat capacity of rock: 860 J/kg.K
Density of rock: 2600 kg/m^3

Table III shows the variation of borehole resistance as per the cases shown in Table II

Table III: Borehole resistance (mK/W) for both holes derived log plots.

	80m	80m	60m	60m
	borehole only	borehole+header	borehole only	borehole+header
Bulk time	0.3	0.34	0.17	0.20
Late time	0.22	0.26	0.13	0.16

The late time values range between 0.13 and 0.26, a significant variation. For the purposes of the subsequent modeling work a mid point value of 0.18 mK/W has been used. This compares with a calculated value of 0.198 mK/W using assumed values for the physical dimensions of the borehole, U-tube and grout. It is a reasonable value for a closed loop borehole with a single U-tube, grouted with bentonite rather than a thermally enhanced grout.

In Figures 10 and 11, the observed mean temperature rise of the borehole fluid has been compared with an analytical model of the borehole. To obtain the matches, and attempt to compensate for the temperature fluctuations, the thermal conductivity and borehole resistance have been manually adjusted. Both cases use a borehole diameter of 140mm. The 80m model is matched using a thermal conductivity of 1.7 W/mK and a borehole resistance of 0.196 mK/W. The 60 metre model matches with values of conductivity of 2.45 W/mK and borehole resistance of 0.13 mK/W. These are wide variations for two boreholes only 6 metres apart, and probably completed using similar diameter boreholes and grout.

The differences can probably be attributed to:

- Limited knowledge of borehole completions - eg diameter, grout content, and actual depth of U-tubes.

- Inability to control heat losses during the thermal test in pipework between borehole and measuring points.

- Possible pre-warming of any portions of common header trench by the 80m test prior to the 60m test.

Given these uncertainties, and combining the various derived values together with the reported geology, and typical borehole resistances from similarly completed boreholes, the subsequent simulation work has been undertaken using a thermal conductivity value of 2.0 W/mK and a borehole resistance value of 0.18W/mK.

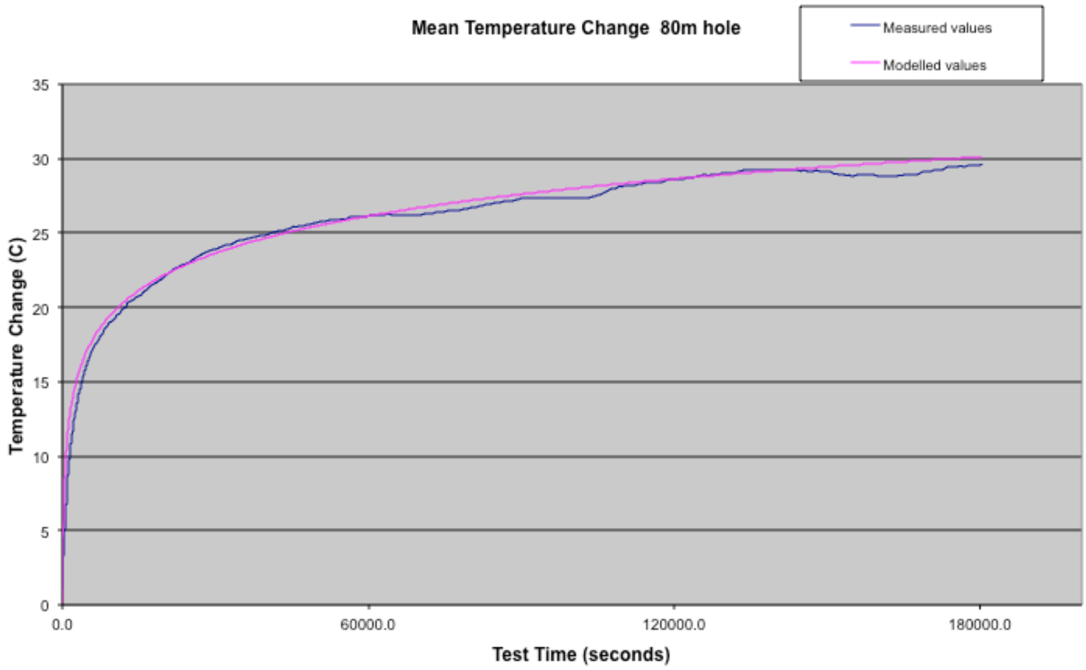

Figure 10: Analytical solution used to match 80m thermal response test.

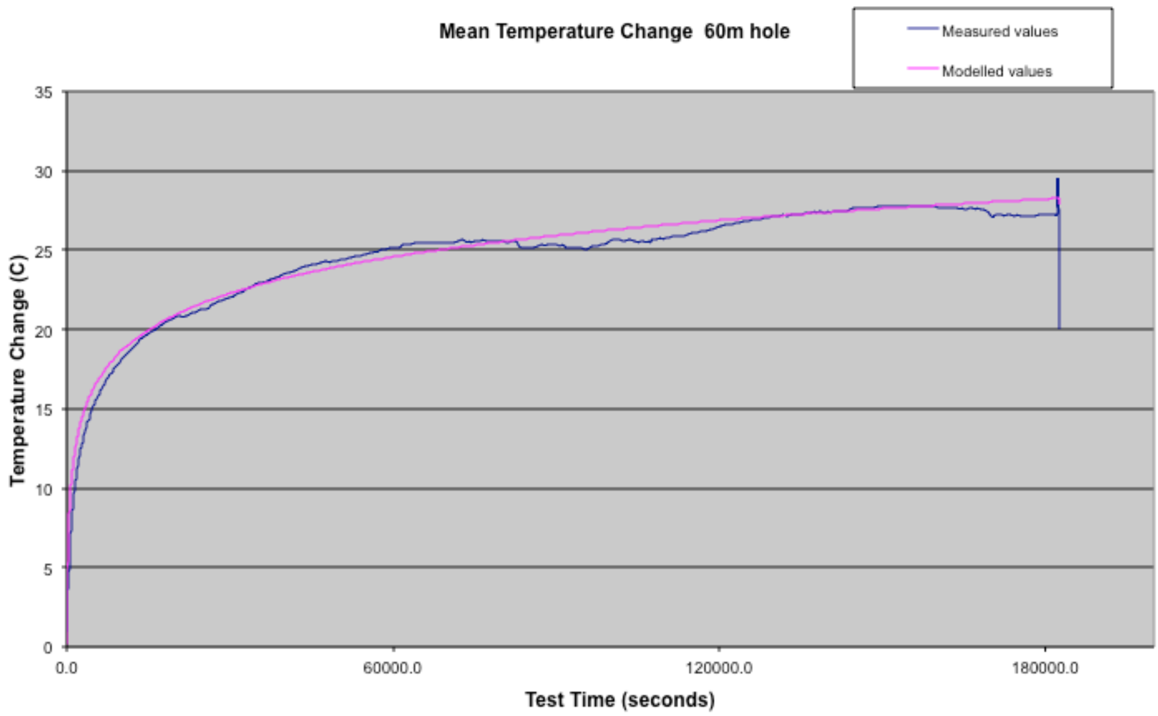

Figure 11: Analytical solution used to match 60m thermal response test.

References

Banks D: An Introduction to Thermogeology: Ground Source Heating and Cooling. Blackwell. ISBN:978-1-4051-7061-1, 2008.

Dunbabin P, Wickins C: Detailed analysis from the first phase of the Energy Savings Trust's heat pump field trial, March 2012, available at: http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/microgeneration/5045-heat-pump-field-trials.pdf

EST 2010: Energy Saving Trust: Getting warmer: a field trial of heat pumps. Sept 2010.

Entec: Strategic Environmental Assessment - Site Specific Baseline, Capenhurst. 21585-02, June 2010.

Green R & Knowles A: “The effect of thermostatic radiator valves on heat pump performance”, EA Technology, June 2011, available at: http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/microgeneration/3531-effect-radiator-valves-heat-pump-perf.pdf

Rollin K E: Assessment of BGS data for ground source heat pump installations in the UK. Internal Report IR/02/196. British Geological Survey, 2003.

IGS1965: Institute of Geological Sciences, Flint, Sheet 108, Solid Edition, 1:50 000 scale. 1965.