Report on extended test pumping at Lanchester Wines Abbotsford Road site

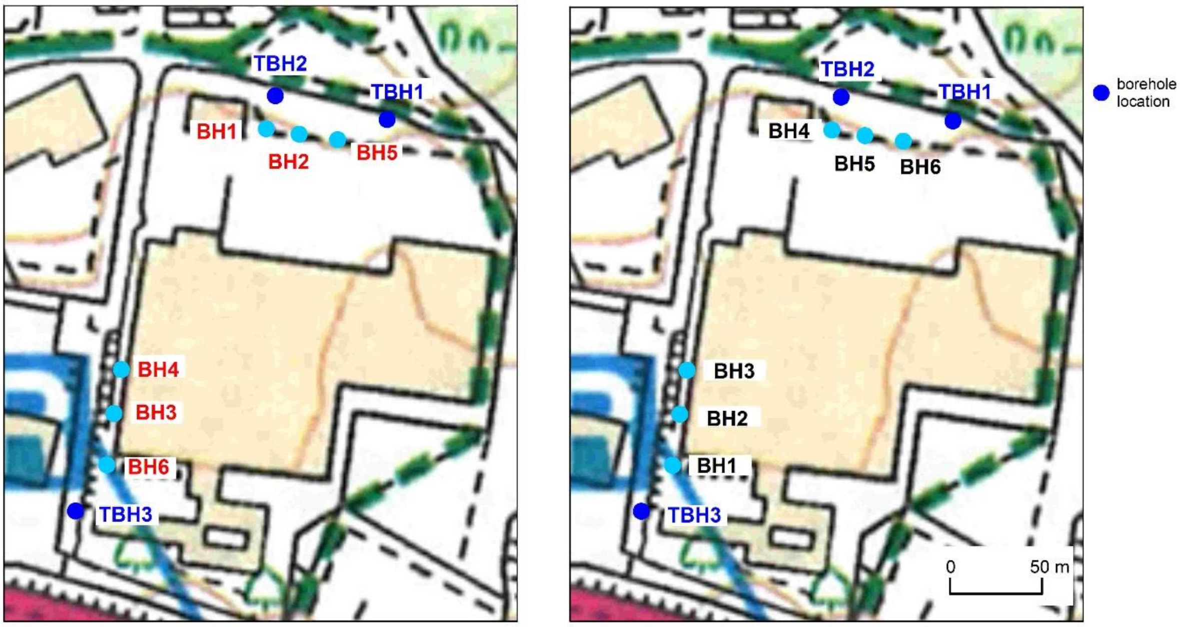
This note describes the extended test pumping of boreholes at the Lanchester Wines Abbotsford Road site at Gateshead carried out in December 2017. Its purpose is to provide further information requested by the Environment Agency in the context of the Lanchester Wines application for an Environmental Permit for a groundwater source heat pump heating system at the site. The work is reported by LWRC in their role as hydrogeological consultants.

The note covers background site and equipment issues, the purpose and details of the 2017 test pumping, the monitored aquifer response and water quality information. It then addresses the question of degree of impact of the testing on the nearby Lanchester Wines Nest Road site and the likely impact in the wider area.

1. Background

The system uses six boreholes, three to abstract water and three to recharge used water back into the ground. The naming system for the boreholes at the Abbotsford Road site was changed on 3rd April 2017 by the installers of the electronic building management system (BMS). For clarity the original and the revised borehole names are shown in Figure 1. All references to boreholes made below use the new nomenclature unless specifically mentioned otherwise.

Abstraction borehole BH1 is 117 metres deep, BH2 is 110 metres deep and BH3 is 123 metres deep. All the abstraction bores have 20 metres of 508 mm diameter casing grouted at the top and the finished borehole diameter is 480 mm. Injection borehole BH4 is 156 metres deep, BH5 is 155



Old borehole names up to 3 April 2017

New borehole names post 3 April 2017

Figure 1: Locations and nomenclature of boreholes at Abbotsford Road up to April 2017 (old bore names) and after April 2017 (new bore names)

metres deep and BH6 is 155 metres deep. All the injection boreholes have 20 metres of 508 mm diameter casing grouted at the top of the bore and all are finished at 480 mm diameter. In BH4 the drillers record described 2.5 metres of broken ground associated with a coal seam at a depth of 150 metres near the base of the hole.

The idea of carrying out an extended test of the open loop groundwater source heat pump heating system at the Abbotsford Road site followed from an initial operational test of the system carried out over a period of two days in June 2016. That test was the first time the abstraction and injection borehole and heating system as a whole had been used and it confirmed that the groundwater source heat pump heating system worked as intended. Groundwater was abstracted from three boreholes located on the south western part of the site (BH3, BH2 and BH1), passed through a heat exchanger designed to extract 6°C of heat and the used water was recharged at a lower temperature back into the same aquifer via three injection boreholes (BH4, BH5 and BH6) located on the northern part of the site. A note on this test was provided to the Agency in 2017.

The extended testing was originally planned to begin in November or early December 2016 but was delayed whilst work on the borehole wellheads and other civil works were completed and whilst submersible pumps, control equipment and power cables were procured and installed. Further delays to starting the test occurred due to problems with the electronic monitoring, flow metering and control system (BMS). It was also necessary to bring forward the procurement and to install three mechanical flow meters in the absence of a reliable measured combined flow volume being available from the electronic MagFlow meter. The mechanical flow meters allowed flow from the individual abstraction boreholes to be measured.

By July 2017 it appeared that the system was ready and the extended test could begin and so the system was started on 10th July 2017. It quickly became clear that the combined abstraction rate from the three boreholes was only around 16 litre/sec which was much less than had been recorded during the June 2016 system test. Various attempts were made to increase the pumping rate such as increasing the power output to the submersible pumps using the inverter controls but the maximum flow rate remained less than 18 litre/sec with most flow coming from BH2. The pumps were left running at this rate until 26th July in order to obtain useful hydrological information and to allow water samples to be taken to check the water quality from the abstraction bores. In the meantime further enquiries were made to the original pump suppliers, pump installers and other contractors involved regarding the original specification and installation of the submersible pumps.

It was noted that equilibrium drawdown in the abstraction boreholes and equilibrium recharge levels in the injection boreholes were reached quickly at this pumping rate and that the heat pump, compressors and heating system in general worked as expected. In fact the heat pump system had to be shut down because the warehouse became too hot. The pumping and recharge water levels in the boreholes appeared to be consistent with what would have been expected at those flow rates given the hydraulic characteristics seen during the June 2016 testing.

Given the poor submersible pump performance and the anomalies in the electronic monitoring data it was clear that further checks and remedial action had to be undertaken. Midland Pumps Ltd, a specialist pump supplier and installer, was called in to examine the plantroom pipework arrangements and to carry out pump winding resistance and insulation resistance tests on the submersible pumps. In its report of 4th September 2017 Midland concluded that the plant design and construction was of good standard but that the submersible pump motors and/or cables in boreholes BH3 and BH1 had little or no electrical resistance and that there was reduced insulation resistance in BH2 borehole pump. The pumps were, therefore, likely to be damaged and needed to be taken out of the borehole to be examined and repaired or replaced. In addition, Midland Pumps pointed out that Grundfos recommend that where submersible pumps are controlled by an inverter sine wave electrical power filters should be fitted in order to regulate the current supply to the submersible pumps. In the course of these checks it was discovered that the MagFlow electronic flow meter needed earthing plates fitted.

As a result of these investigations orders were placed in September 2017 with the original pump installers, Borehole Engineering Ltd, to return to site and remove and examine all the submersible pumps and repair/replace them where necessary and report on findings. Earthing plates for the MagFlow meter were also ordered as well as sine wave filters.

The submersible pumps, rising mains and control cables were lifted out of the boreholes and checked between 11th September and 27th September and a number of problems with the pump installation were identified which explained the poor performance of the pumps revealed in July 2017. It was found, for example, that the pump in BH2 was incorrectly installed. It should have been installed in BH3, that the power cable to the pump in BH3 was damaged and was allowing water to gain access to exposed unsheathed conducting wire within the cable bundle and that the acrylic potted connection between the power cable and the pump motor cable in BH1 had been incorrectly made and had allowed water ingress into the power supply cable. The submersible pumps and motors themselves appeared undamaged. Consequently, a new power cable was fitted to the pump to be placed in BH3. A new 75 mm diameter dip pipe of Boode well screen specification in straight screwed sections was also installed for taking manual water level measurements. The dip pipe was attached to the rising main and this together with low level control electrodes and level/temperature dataloggers was placed in BH3 with the pump. A new cable junction was formed between the power supply cable and cable fitted to the submersible pump motor and placed in BH2 and a new Boode manual dip pipe and other fittings were also installed here as in BH3. In BH1 the damaged power cable was replaced and a new cable fitted to the submersible pump. The pump, cable and control electrodes together with a Boode specification manual dip tube were replaced in the borehole.

The installation of the sine wave filters commenced on 10th November 2017 and was completed by 16th November. Borehole Engineering then connected and ran each submersible pump for up to two hours to check that the pump rotation was correct and to confirm the yield and that the pumps were working satisfactorily as specified. BH1 and BH2 checks were carried out on the 15th and 16th November. During the reinstallation work the pumping rates used over the hour or two that was needed to check the pumps were higher than the rates the bores had been pumped at in June 2016, ie about 48 litre/sec in total compared to 40 litre/sec in 2016.

On the 17th November BH2 and BH3 pumps were run in tandem to check that the extended test pumping rate of up to 41 litre/sec could be achieved. In fact the pumping rate used was much higher, up to 50 litre/sec. A sudden build up of pressure in the borehole discharge pipework occurred so the test was stopped. It was initially suspected that the pressure build up might be due to the backing up of discharge water in the injection pipework downstream of the heat exchanger and this might be due in turn to the constant pressure valves on the discharge lines. Professional advice from the installer of the constant pressure valves that had been fitted on the injection pipes was sought. It was discovered during further checks on 27th November that the cause of pressure build up was in fact the blocking of the fine mesh filter basket on the water intake to the heat exchanger. The mesh filter contained silt from the geological formation and also plastic shavings that had clearly come originally from the black pvc pipework used in the plant room and there was also debris from the blue pvc borehole liner/screen that had fallen into the bore presumably when the top of the screen had been damaged/sawn during the original installation work. The damage to the top of the blue pvc borehole liner had only become visible when the steel cover flange plate on BH2 was removed. The fine mesh filter-strainer is located in the plant room between the borehole submersible pumps and the heat exchanger. Once identified as the problem the filter mesh was pressure cleaned and further pumping of BH2 and BH3 in tandem was carried out but initially and inadvertently this was at a combined rate of perhaps 50 to 55 litre/sec from the two boreholes. This certainly had the effect of drawing further silt into the filter. Eventually by adjusting the combined flow rate to around 34 litre/sec the problem of filter blocking was eliminated.

Following the conclusion of this work it was intended to begin the extended test pumping in early December 2017. Further problems with the electronic BMS and with the gas fired electrical power generator meant a number of interruptions occurred and that a relatively clear and continuous period of pumping proved to be possible only between 19th and 27th of December 2017. However, borehole monitoring data from the period 1st December 2017 to 1st January 2018 do provide additional hydrogeological insight into the aquifer response to pumping and injection and so these data are included in Figures 2 and 3.

2. Extended test pumping 1st to 31st December 2017

2.1 Purpose of the test

Although the June 2016 system test had been successful the short duration of its operation meant that there was some uncertainty as to whether the yield from the abstraction boreholes could be sustained for longer pumping periods and under operational use. Following discussion with the Environment Agency on these points a Section 32 application was made to the Agency to carry out an extended test pumping exercise of the system for a period of between one and six months in order to clarify whether equilibrium drawdown conditions could be achieved in the abstraction and injection boreholes and in order to find out how the pumping and injection system would perform under operational conditions. The initial part of the extended test was intended to establish whether the required borehole water abstraction and injection rates could be sustained and the second part of the extended testing was intended to clarify how the system and aquifer would respond to being used operationally.

The Section 32 consent envisaged that the abstraction boreholes would be pumped at a combined rate of up to 41 litre/sec until an equilibrium state was reached in water levels in both the abstraction and injection boreholes. Frequent water level monitoring in all six production boreholes together with frequent measurement of flow rate was required.

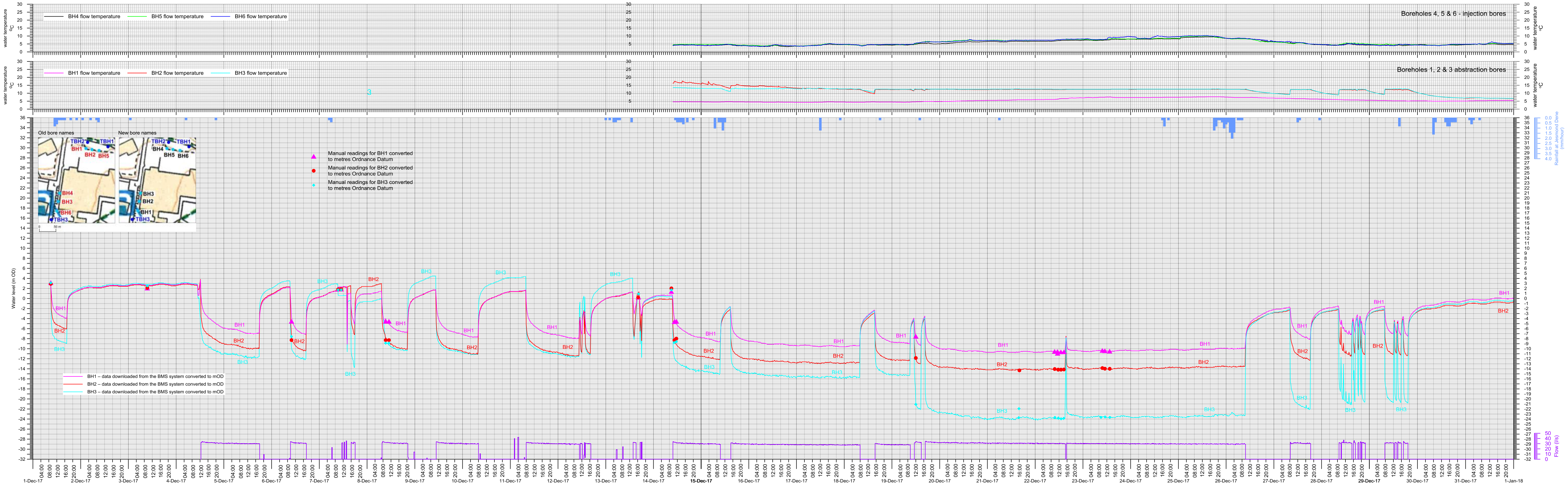


Figure 2: Water level monitoring results for the abstraction boreholes at Abbotsford Road

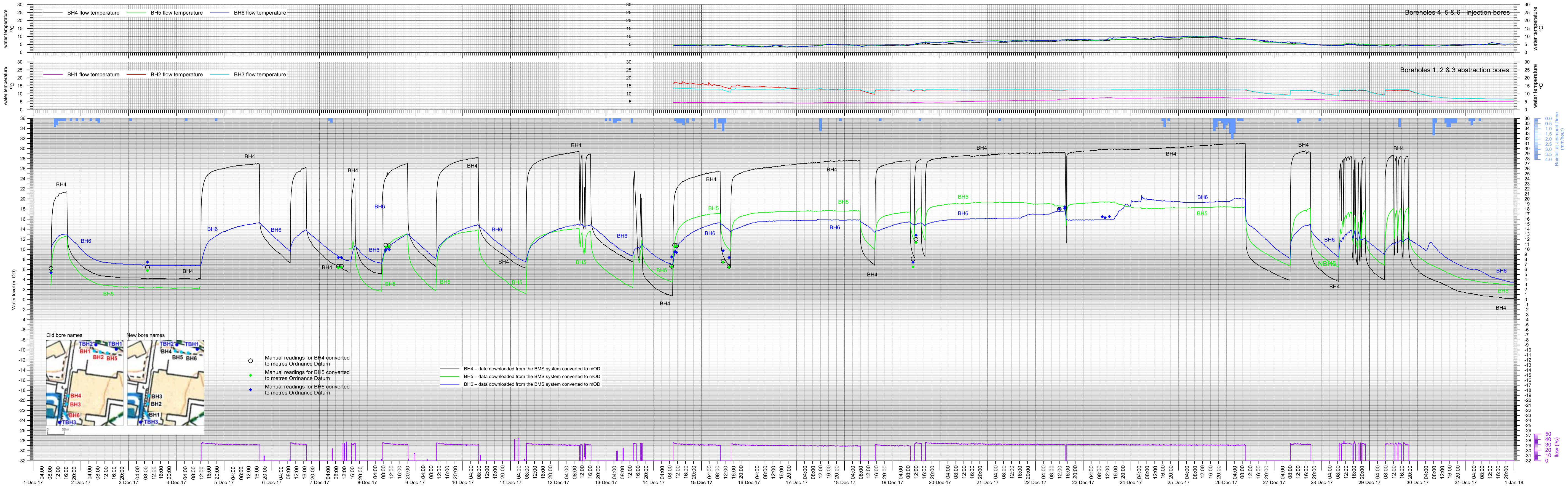


Figure 3: Water level monitoring results for the injection boreholes at Abbotsford Road

2.2 Monitoring

Impress Sensor dataloggers were installed in each abstraction and injection borehole at the Abbotsford Road site at depths of 70 or 80 metres below ground level. Readings were taken at 15 minute intervals by the loggers and the data stored in the BMS system memory. Water level monitoring results from these dataloggers for the period 1st to 31st December 2017 are plotted in Figures 2 and 3. To simplify management of the test only boreholes BH2 and BH3 were pumped during December 2017 but all the injection bores were in use. A continuous record of the combined flow rate from the abstraction boreholes measured by the MagFlow electronic flow meter is shown in Figure 2 and Figure 3. The MagFlow meter is located in the plant room before the heat exchanger on the single inflow pipe which carries the combined flow from the three abstraction boreholes. Water temperature data measured by the dataloggers in both the abstraction and injection boreholes are also shown in the figures.

The combined abstraction rate from the two pumped boreholes seen at the beginning or at the recommencement of pumping according to the MagFlow meter record was around 35 litre/sec but this decreased gradually to 30 litre/sec, generally after about two days of pumping. Manual readings of flow were taken from the mechanical flow meters measuring the output from BH3 and BH2 on the 22nd December after the borehole pumps had been in continuous operation for about two days and these gave a mean flow value of 30 litre/sec which was identical to the BMS MagFlow meter readings for the same period.

Anomalies had been noted in the BMS water level and temperature data in early December and on 13th – 14th December the installers of the BMS system, Syntech, returned to site and adjusted and reset the system. Accordingly, corrections have been made to the water level record prior to 13 December. The water level records from 1st to 31st December were also adjusted to tie in with the manual water level readings where possible, particularly with manual readings taken on 21st to 23rd December when additional LWRC staff were on hand to double check the water level dip readings.

2.3 Aquifer response to pumping

In general the water levels monitored in the abstraction boreholes BH3, BH2 and BH1 during December 2017 (shown in Figure 2) exhibit a consistent and classic aquifer drawdown and recovery curve response to the start of pumping and to the cessation of pumping. In detail the response varies according to the rate of pumping and duration of pumping. For example, during the period 1st December to 13th December 2017 water level drawdown measured in BH3 was about 16 metres and in BH2 about 13 metres. Following the adjustments to the BMS settings carried out on 13th December when the pumps had been switched off, it appears that the pumping rate may have been increased in BH3 when the pumps were switched on again because the water level drawdown in this borehole upon resumption of pumping increased from about 13 metres recorded prior to 13th December to about 20 metres after the 13th whilst drawdown in BH2 remained virtually unchanged. A similar change happened on 19th December after another short break in pumping. Prior to 08:00 on 19th December the combined pumping rate was around 29 litre/sec. After 08:00 on the 19th pumping stopped on two occasions during the day for about 2 hours on each occasion. When the pumps started again at around 17:00 on 19th December the combined pumping rate from BH3 and BH2 was around 35 litre/sec. This gradually fell back to around 32 litre/sec over the next 71 hours (up to 15:30 on the 22nd December). At 15:30 the pumps were turned off again for about half an hour in order to top up the coolant level in the gas powered electricity generator.

Following the short shutdown at around 15:30 on 22nd December, pumping resumed from BH3 and BH2 at a combined rate of 30 litre/sec and pumping water levels in the abstraction boreholes quickly returned to similar levels as before switch off. The combined pumping rate remained at 30 litre/sec over the next 90 hours of pumping (between the 23rd and the 26th December) but it is apparent that there was a small recovery of about half a metre in pumped water levels in BH3 and BH2 during this period. From the monitoring data it is clear that both the abstraction boreholes in use reached an equilibrium drawdown condition after about 30 hours of pumping.

2.4 Groundwater temperature response to pumping

Groundwater temperatures measured in the abstraction boreholes varied between 6°C and 13°C according to the BMS record. Temperature data recorded by the BMS prior to the adjustments made on the 13th and 14th December are considered to be unreliable and have therefore not been plotted.

Looking at the temperature record for the period 14th to 31st December it is a noticeable feature in the record that the pumped water temperature increased more or less immediately in BH3 and BH2 when the pumps were switched on and reached a plateau at around 12°C whilst pumping was in progress and then fell back to about 7°C over a period of about a day and a half after pumping stopped in both BH3 and BH2. This suggests that there is significant stratification in the Coal Measure aquifers and that upon pumping relatively warmer probably deeper groundwater is drawn in.

The groundwater temperatures shown in the record post 14th December are consistent with the groundwater temperature data measured at Nest Road which indicate that groundwater temperature there is about 12.1C° and that it varies only slightly by about 0.1°C over the year.

2.5 Aquifer response to injecting used water into BH4, BH5 and BH6

Figure 3 shows datalogger water levels measured in the injection boreholes BH4, BH5 and BH6. The BMS record has been adjusted to take account of different settings for offsets and datums used pre and post 13th December and has also been adjusted to tie in with the manual water level readings where possible.

The rate at which water is recharged into the injection boreholes is controlled by gate valves. The gate valve settings on the injection boreholes were arrived at by trial and error when the system was set up in December 2016. These valves had deliberately been left untouched and as they were originally set up. According to information supplied by the person who set up the gate valves at that time this meant that most of the recharge water went into BH4 with less flow being directed into BH5 and a much smaller flow into BH6. This explains the greater rise in water level seen in BH4 compared to the BH5 and BH6.

Looking at the three injection boreholes it is clear that equilibrium recharge levels were reached in BH5 and BH6 in about 34 hours. In BH4 it took between 56 and 72 hours to reach equilibrium with the water level in BH4 rising to about 31 m OD from a rest water level of around 5 m OD. This increase in water level can be compared to the rise in water level seen in trial borehole TBH2 located about twenty metres away to the north of BH4. Here water level rose from a rest water level of about 5 m OD to an equilibrium recharge water level of about 10 m OD. The large rise in water level elevation seen in BH4 therefore is probably related to turbulence within the injection borehole itself and the higher rate of water input into this borehole.

There was no indication to the north of the Abbotsford Road site and downslope of the injection boreholes of any groundwater seepage or risings occurring at ground level. Given the evidence of water levels measured in TBH2 this would be unlikely.

2.6 Water quality

Water sampling during step and constant rate test pumping carried out at injection BH4 in April 2016 indicated that the groundwater there was brackish to saline and was very reducing with elevated manganese (1.2 to 3.1 mg/l), high COD, an absence of oxidised nitrogen and the presence of 2 to 4 mg/l of ammoniacal nitrogen. There were indications that as pumping continued during the two days of testing that salinity increased with chloride reaching 1860 mg/l (10% of sea water concentration) but that the water became less reducing as pumping continued (manganese and ammonium fell). Groundwater at the reinjection location as indicated in BH4 could be characterised as sodium chloride type water. Total suspended solids were quite low decreasing to 2 – 4 mg/l during the constant rate test. The water chemistry results are shown in Table 1.

With regard to the abstraction boreholes location, here the water as shown by sampling at BH1 had lower concentrations of manganese and ammoniacal nitrogen and in addition nitrate was detected (0.4 – 2.5 mg/l as NO_3) indicating less reducing conditions. Groundwater was significantly less saline at BH1 than BH6 with electrical conductivity measured at 1000 – 2000 µS/cm and chloride concentrations of 170 to 200 mg/l. There was no indication that salinity increased during pumping. At the abstraction boreholes location the water could be characterised, therefore, as Na-Ca-HCO_3-Cl groundwater type. The sulphate to chloride ratio of 0.3 to 0.45 was greater than sea water (0.1) suggesting a geological source for the sulphate possibly from pyrite. Iron concentrations were low and suspended solids less than 2 mg/l.

Because of the differences in water quality between the abstraction and reinjection locations it is important that during the abstraction – heat exchange – reinjection process sudden changes in pressure, contact with atmospheric oxygen (or other oxidizing agents) and changes in pH are avoided in order to eliminate or reduce precipitation of redox and pH sensitive elements in the water such as iron and manganese. To avoid large pressure changes constant pressure valves are installed on the three injection pipes to maintain a constant positive pressure in the discharge pipelines. As far as possible air entrainment or degassing in the water supply and discharge pipes has been eliminated by this and other means. To minimise the risk of oxidisation of manganese and iron and the risk of entraining air bubbles in the injected water the submersible pumps are located well below pumping water level in the abstraction bores and the discharge pipes were placed well below rest water level on the reinjection bores.

Groundwater from BH1 contains dissolved manganese at concentrations of 150 – 250 µg/l which could precipitate as black manganese oxide if exposed to oxygen. However it is known that

Borehole		Old BH5 (New BH6)			Old BH6 (New BH1)				Old BH5 (New BH6)		Old BH6 (New BH1)		Old BH3 (New BH2)			Old BH4 (New BH3)			Old BH6 (New BH1)			New BH1	New BH2	New BH3
		Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 4	CRT	CRT	CRT	CRT												
Date		23/02/2016	23/02/2016	23/02/2016	16/02/2016	16/02/2016	16/02/2016	16/02/2016	24/02/2016	25/02/2016	17/02/2016	18/02/2016	01/06/2016	02/06/2016	03/06/2016	01/06/2016	02/06/2016	03/06/2016	01/06/2016	02/06/2016	03/06/2016	27/07/2017	27/07/2017	27/07/2017
Time		10:30	12:50	15:30	10:35	12:15	13:55	15:35	09:10	08:30	09:10	08:50												
Inorganics																								
Conductivity @ 20 deg.C	mS/cm	2.44	3.12	4.81	1.05	1.16	1.2	1.14	3.37	5.52	1.12	1.26	1.28	1.33	1.33	1.84	1.8	1.77	1.37	1.37	1.4	1.41	1.4	1.42
Nitrite as NO2	mg/l	-	-	-	<0.05	0.068	0.051	<0.05	<0.05	<0.05	<0.05	<0.05											-	
pH	pH Units	7.33	7.42	7.58	7.87	7.97	7.89	7.61	7.69	7.59	7.75	7.68	7.9	7.85	7.94	7.85	7.85	7.74	7.94	7.96	8.03	7.73	7.68	7.69
Sulphate	mg/l	147	121	81	96.5	93.2	93.3	87.4	40.3	63.5	103	84.7	98.9	99.7	101	71	70.1	70	54.7	55.8	58.6	134	139	133
Chloride	mg/l	-	-	-	171	194	189	187	962	1860	167	205	199	196	195	397	403	380	258	250	273	234	235	233
COD, unfiltered	mg/l	36.4	71	72.2	7.6	7.86	10.4	11	21.2	67.8	<7	<7	7.19	9.68	<7	15.7	13.8	14.1	7.41	10.9	12.8	12.4	17.5	<7
Nitrite as N	mg/l	<0.0152	<0.0152	<0.0152	-	-	-	-	-	-	-	-	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152	<0.0152
Nitrogen, Total	mg/l	3.4	2.78	2.65	1.15	1.05	<1	1.04	2.83	2.14	1.13	1.13										1.01	1.04	1.07
Ammoniacal Nitrogen as NH3	mg/l	4.04	3.23	3.12	0.961	1.16	1.13	1.17	3.26	2.33	0.917	1.17	1.2	1.28	1.24	1.19	1.32	1.17	1.22	1.12	1.24	0.984	1.18	0.996
Nitrate as NO3	mg/l	-	-	-	2.11	1.04	0.457	<0.3	<0.3	<0.3	2.45	0.422	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3		-	
Nitrate as N	mg/l	<0.0677	<0.0677	<0.0677	-	-	-	-	-	-	-	-	<0.0677	<0.0677	<0.0677	<0.0677	<0.0677	<0.0677	<0.0677	<0.0677	<0.0677	<0.067	<0.0677	<0.0677
Alkalinity, Total as CaCO3	mg/l	155	705	370	310	320	325	330	350	340	300	340	350	350	355	320	330	320	320	325	330	360	320	340
Suspended solids, Total	mg/l	46	122	69	<2	2	<2	<2	2.5	4	<2	<2	<2	<2	<2	2	<2	<2	<2	<2	<2	14	<2	<2
Filtered (Dissolved) Metals																								
Calcium (diss.filt)	mg/l	163	180	234	84.5	86.4	89.1	88.3	196	298	83.5	86.5	88.8	90.1	88.9	107	108	101	91.7	93.5	88	110	107	103
Sodium (diss.filt)	mg/l	277	368	589	96.7	113	112	109	507	944	89.7	115	127	129	134	196	196	189	129	132	120	147	143	140
Magnesium (diss.filt)	mg/l	52.5	71.4	76.3	31.7	32.1	33.3	33	58.1	102	32.1	32.3	34.2	35.1	35.3	44.1	44.1	41	34.4	34.9	35.4	45.2	44.7	44.2
Potassium (diss.filt)	mg/l	21.9	21.6	26.5	13.4	14.5	15.1	15.6	29.7	32.8	13.5	17	15.3	15.7	15.8	16.3	16.4	15.9	15.7	15.9	18.1	16.9	16.6	16.2
Iron (diss.filt)	mg/l	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019										0.276	0.354	0.239
Manganese (diss.filt)	µg/l	3120	2880	2080	208	173	177	157	1230	1290	233	114										159	161	156
Zinc (diss.filt)	µg/l	26.1	9.12	9.02	33.2	18.1	11.5	12	13.7	12.4	15	7.15	<4.1	3.13	6.19	12.6	12.4	9.26	11.5	9.93	6.7	39.9	8.02	16.5
Aluminium (diss.filt)	µg/l																					8.3	<2	<2
Aluminium (tot.unfilt)	µg/l																					<50	<50	<50
Manganese (tot.unfilt)	µg/l																					184	175	156
Iron (tot.unfilt)	mg/l																					6.7	0.189	0.233
Semi-Volatile Organic Compounds (SVOCs)																								
1,2,4-Trichlorobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
1,2-Dichlorobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
1,3-Dichlorobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
1,4-Dichlorobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,4,5-Trichlorophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,4,6-Trichlorophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,4-Dichlorophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,4-Dimethylphenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,4-Dinitrotoluene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2,6-Dinitrotoluene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Chloronaphthalene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Chlorophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Methylnaphthalene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Methylphenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Nitroaniline (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
2-Nitrophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
3-Nitroaniline (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Bromophenylphenylether (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Chloro-3-methylphenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Chloroaniline (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Chlorophenylphenylether (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Methylphenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Nitroaniline (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
4-Nitrophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Azobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Acenaphthylene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1

"Old" refers to nomenclature prior to 3 April 2017 and "new" refers to borehole names after 3 April 2017

Table 1 continued overleaf

Table 1: Hydro chemical data from pumping boreholes at Abbotsford Road

Borehole		Old BH5 (New BH6)			Old BH6 (New BH1)				Old BH5 (New BH6)		Old BH6 (New BH1)		Old BH3 (New BH2)			Old BH4 (New BH3)			Old BH6 (New BH1)			New BH1	New BH2	New BH3
		Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 4	CRT	CRT	CRT	CRT												
Date		23/02/2016	23/02/2016	23/02/2016	16/02/2016	16/02/2016	16/02/2016	16/02/2016	24/02/2016	25/02/2016	17/02/2016	18/02/2016	01/06/2016	02/06/2016	03/06/2016	01/06/2016	02/06/2016	03/06/2016	01/06/2016	02/06/2016	03/06/2016	27/07/2017	27/07/2017	27/07/2017
Time		10:30	12:50	15:30	10:35	12:15	13:55	15:35	09:10	08:30	09:10	08:50												
Acenaphthene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Anthracene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
bis(2-Chloroethyl)ether (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
bis(2-Chloroethoxy)methane (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
bis(2-Ethylhexyl) phthalate (aq)	µg/l	<2	<2	<2	<2	<2	<2	<2	<12	<12	<2	<2										<1	<1	<1
Butylbenzyl phthalate (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Benzo(a)anthracene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Benzo(b)fluoranthene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Benzo(k)fluoranthene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Benzo(a)pyrene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Benzo(g,h,i)perylene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Carbazole (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Chrysene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Dibenzofuran (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
n-Dibutyl phthalate (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Diethyl phthalate (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Dibenzo(a,h)anthracene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Dimethyl phthalate (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
n-Dioctyl phthalate (aq)	µg/l	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5										<1	<1	<1
Fluoranthene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Fluorene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Hexachlorobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Hexachlorobutadiene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Pentachlorophenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Phenol (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
n-Nitroso-n-dipropylamine (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Hexachloroethane (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Nitrobenzene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Naphthalene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Isophorone (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Hexachlorocyclopentadiene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Phenanthrene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Indeno(1,2,3-cd)pyrene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1
Pyrene (aq)	µg/l	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1										<1	<1	<1

Table 1: continued

manganese does not oxidise as readily as iron and typically requires a higher pH than seen in the abstraction boreholes.

The June 2016 sample results from the abstraction boreholes are very similar to the analyses of samples obtained a year later in July 2017. Iron and manganese concentrations are stable between February 2016 and July 2017, suspended solids are very low, sodium slightly higher and dissolved iron low. These figures are encouraging vis a vis the running of the heat pump system. It was not possible to take pumped samples from the injection boreholes for obvious reasons. Figure 4 shows a Piper diagram of all the results and this supports the assessment made above: the near river borehole water quality is saline/brackish and it appears that historically mixing with fresher water has occurred further inland as seen in the hydrochemistry of the abstraction boreholes.

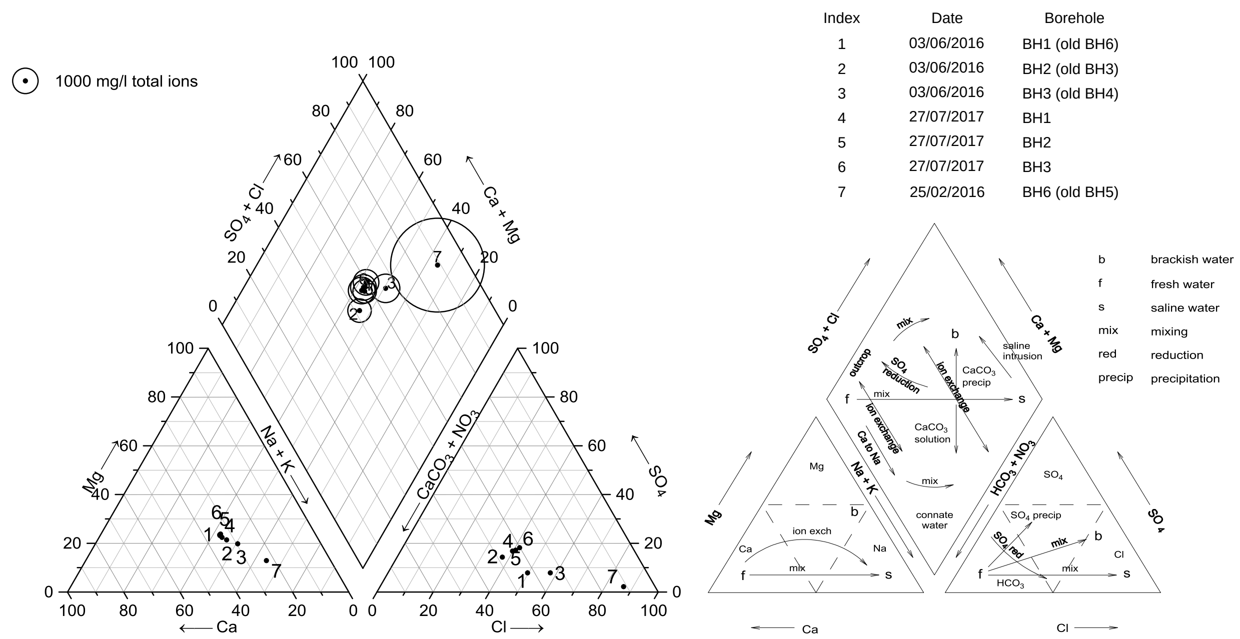


Figure 4: Piper diagram of water chemistry from pumped samples from boreholes at the Lanchester Wines Abbotsford Road site taken in 2016 and 2017

2.7 Impact of activities at the Abbotsford Road site on the Lanchester Wines Nest Road site

Concern has been expressed by the Environment Agency that groundwater resources in the Felling area of Gateshead may be limited and that installing a groundwater source heat pump heating system at the Lanchester Wines Abbotsford Road site and at the Nest Road site could have a negative impact on groundwater levels and groundwater quality in the area.

Looking at the hydrogeological background, both sites are similar being underlain to a great depth by the Middle Coal Measures which comprise aquiferous sandstones interbedded with shales, siltstones and coal. At the Abbotsford Road location the main worked coal seams were the Three-Quarters and High Main located at 72 metres and 151 metres respectively below ground level. The Nest Road site is located over the former Felling pit and here the most important coal seam worked was the High Main situated at approximately 117 metres below ground level. No evidence of penetration of open mine galleries was found during the drilling and construction of boreholes at either site although there was some suspicion of former coal workings being present at depth in BH4 at

Abbotsford Road. The main difference between the two sites is the presence of a glacial buried channel at the Nest Road site and the fact that the Nest Road site is closer to the River Tyne.

Figure 5 compares water levels measured at borehole 4 at Nest Road with groundwater levels at the Abbotsford Road site for the period 1st to 31st December 2017. The Nest Road data were measured by a datalogger that was placed in borehole 4 in June 2017. For comparison, water levels measured at the Abbotsford Road abstraction and injection boreholes are also shown. Overall the Nest Road groundwater level hydrograph shows a gradual rise from about 4.5 m OD to 5 m OD during December 2017. Superimposed on this trend is a diurnal tidal rise and fall of 6 – 12 cm in amplitude.

Comparing the Nest Road data with that from Abbotsford Road there is no evidence of any changes in water levels at Nest Road that can be associated with pumping or injection activity at the Abbotsford Road site.

3. General hydrogeology of the Felling – Gateshead area

3.1 Background

Four groundwater level monitoring sites are maintained by the Environment Agency in the Newcastle – Gateshead area. The locations of these boreholes are shown on Figure 6 and the monitoring data from the Agency boreholes are graphed and shown in Figure 7.

The Environment Agency records begin between the years 1994 and 1997. Looking at the records for the whole period shown in Figure 7 there is a clear similarity in groundwater level response in the general area as shown in the records from three of the boreholes over the past 20 years, namely Tyneside House 1, Tyneside House 2 and Birtley. All three show a strong rising trend in groundwater levels between 1997 and 2017 presumably due to the cessation of coal mining since the 1980s mines closures and reduction of active dewatering of mines in the area. Groundwater levels rose from around -30 metres OD to about +3 metres OD. it is noticeable that groundwater recovery took place in a series of steps which were almost annual in frequency of occurrence with a sharp possibly seasonal rise in water level being followed by a smaller fall in level. By January 2011 groundwater levels at the three bores had risen to an elevation of around zero metres OD. The stepwise rise and fall pattern seen in the recovery of groundwater could have been driven by seasonal rainfall recharge processes but it might also be related to the sequential rewatering of old mine workings which are likely to have been grouped together spatially and situated at discrete elevations below ground level. Alternatively the stepwise recovery might be associated with managed dewatering by the Coal Authority to control the rate of recovery in groundwater level by selectively pumping at different locations. Since January 2011 the recovery in groundwater levels at the three sites has been much more gradual and from 2013 the rising trend has evened out, settling at around the +3 m OD mark over the area between the Tyne and Birtley.

The fourth borehole, Walker, shows a different groundwater hydrograph response to the other three boreholes even taking into account that the Walker monitoring data consist of manual readings at monthly intervals rather than a continuous record of hourly data. The Walker record does not show the large stepwise quasi seasonal or annual stepwise fluctuations that can be seen in the other three boreholes. However, the overall groundwater level trend at Walker since 1998 is still upwards with groundwater level rising from -5 m OD measured in 1998 to +3 m OD in 2017.

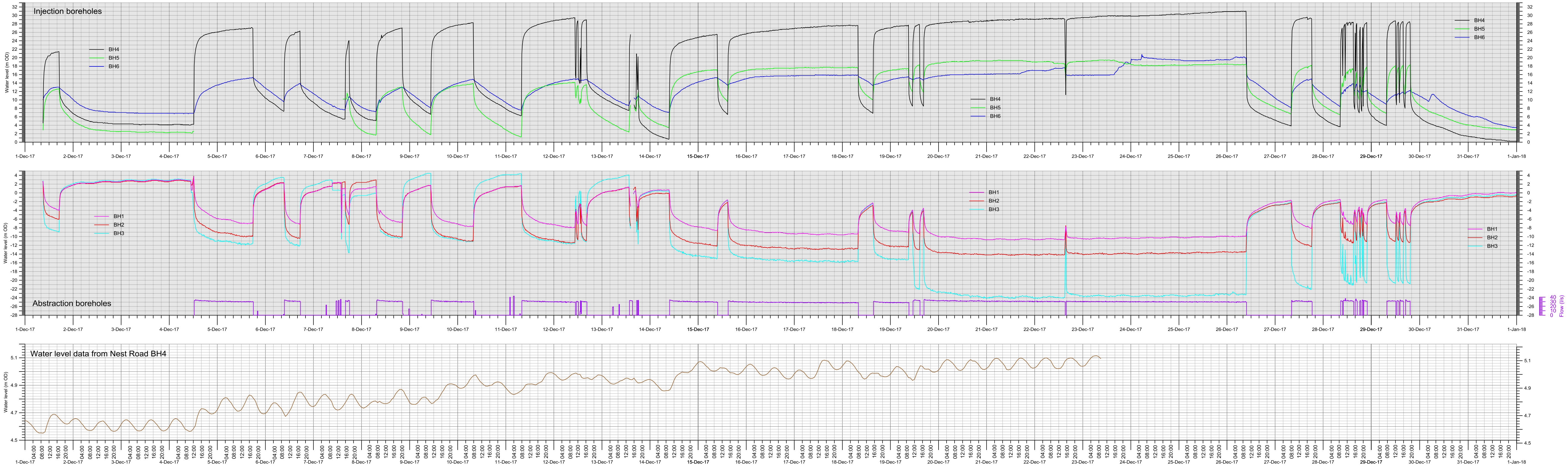


Figure 5: Comparison of Nest Road monitoring data with abstraction and injection boreholes at Abbotsford Road

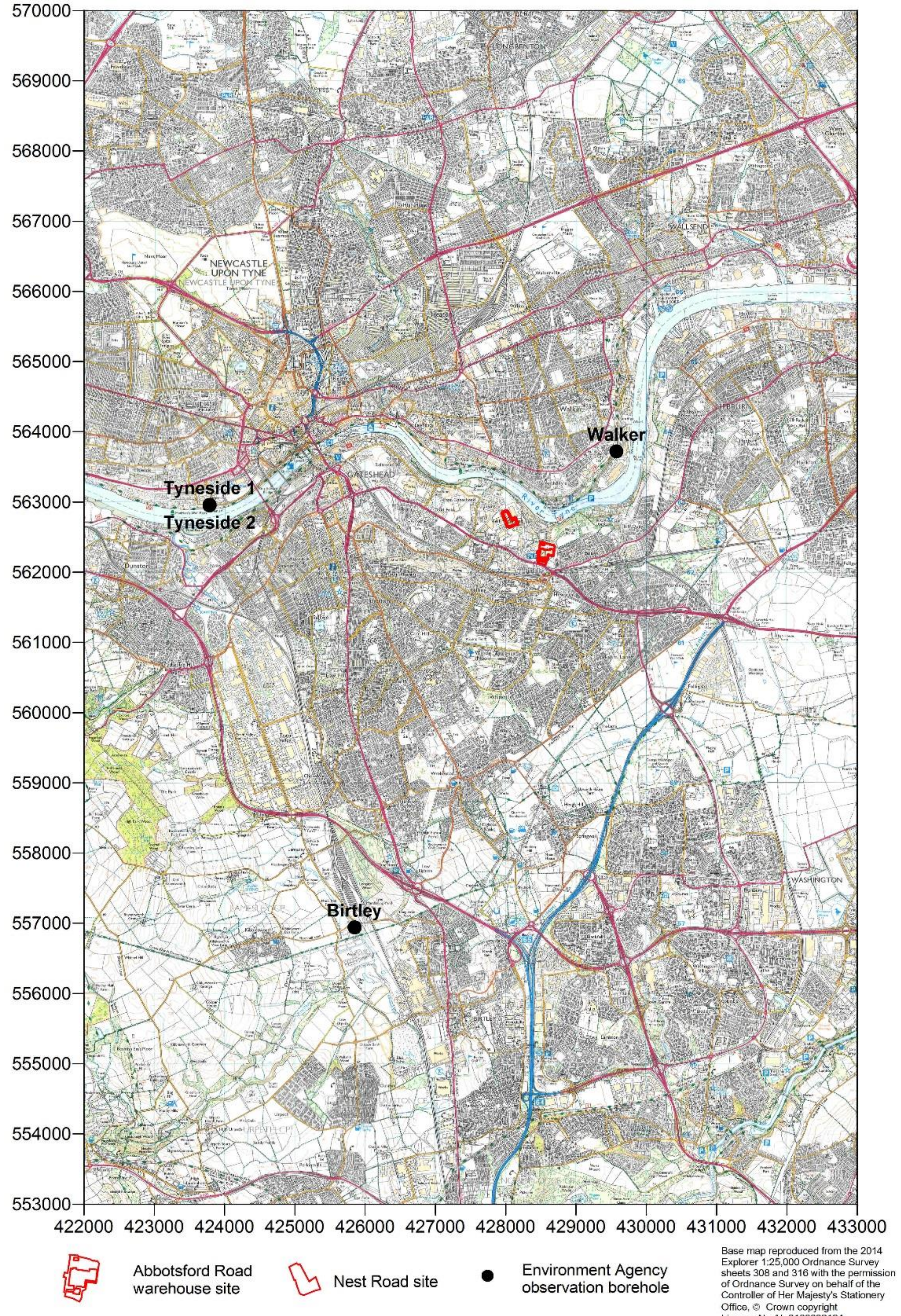


Figure 6: Locations of Environment Agency observation boreholes

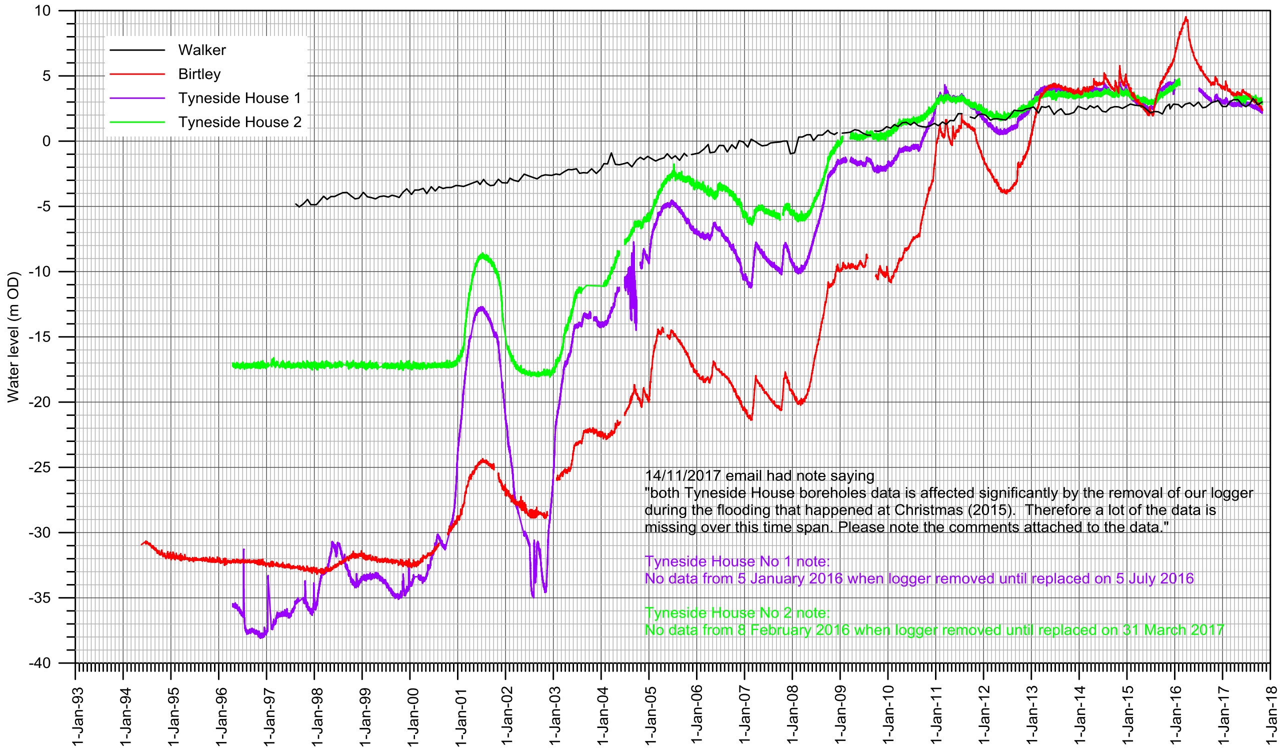


Figure 7: Environment Agency observation borehole water levels

3.2 Nest Road and Abbotsford Road groundwater monitoring

Comparing the datalogger results from borehole 4 at Nest Road for the period May to December 2017 to the Environment Agency monitoring data in Figure 8 the Nest Road data show that a peak in groundwater level occurred in June to July 2017. This was followed by a decline in the hydrograph to a low point in November 2017 possibly followed by a flattening of the hydrograph which could signal the beginning of seasonal recovery. The Nest Road record shows most similarity to the Tyneside House 2 record. There is a clear tidal effect seen in the records for Tyneside House 1 and 2 and for Nest Road with noticeably less tidal efficiency evident in the Nest Road borehole. The daily tidal effect varies: at Nest Road it is small, about 5 cm at neaps increasing to 10 cm at springs, at Tyneside House 1 it is 10 cm at neaps and 20 cm at springs and at Tyneside House 2 it is 30 cm and 40 cm. There is no tidal effect in the Birtley record.

The inference from the above is that until a few years ago it is likely that there was significant induced groundwater flow inland into this area from the River Tyne, perhaps from the coast or from connate water drawn into the dewatered zone from the deep water bearing formations. Induced recharge from the south of fresher groundwater or from rainfall recharge would have resulted in mixing of groundwaters in this area. There is a degree of hydraulic connection in the riparian zone between the River Tyne and the aquifers in the Coal Measures but the river/aquifer hydraulic connection is unlikely to be good given the small range of the tidal effects seen in all the boreholes compared to the tidal range of 2 metres (neaps) to 4 metres (springs) of the River Tyne at Newcastle. The smallest tidal influence among the sites shown in Figure 8 is seen in the record for borehole 4 at Nest Road. This could be due to the influence of a buried channel traversing the site which contains coarser sand and gravel deposits that are likely to have a higher storativity than the surrounding Coal Measures strata or it could be due simply to silt and mud sealing the bed of the Tyne.

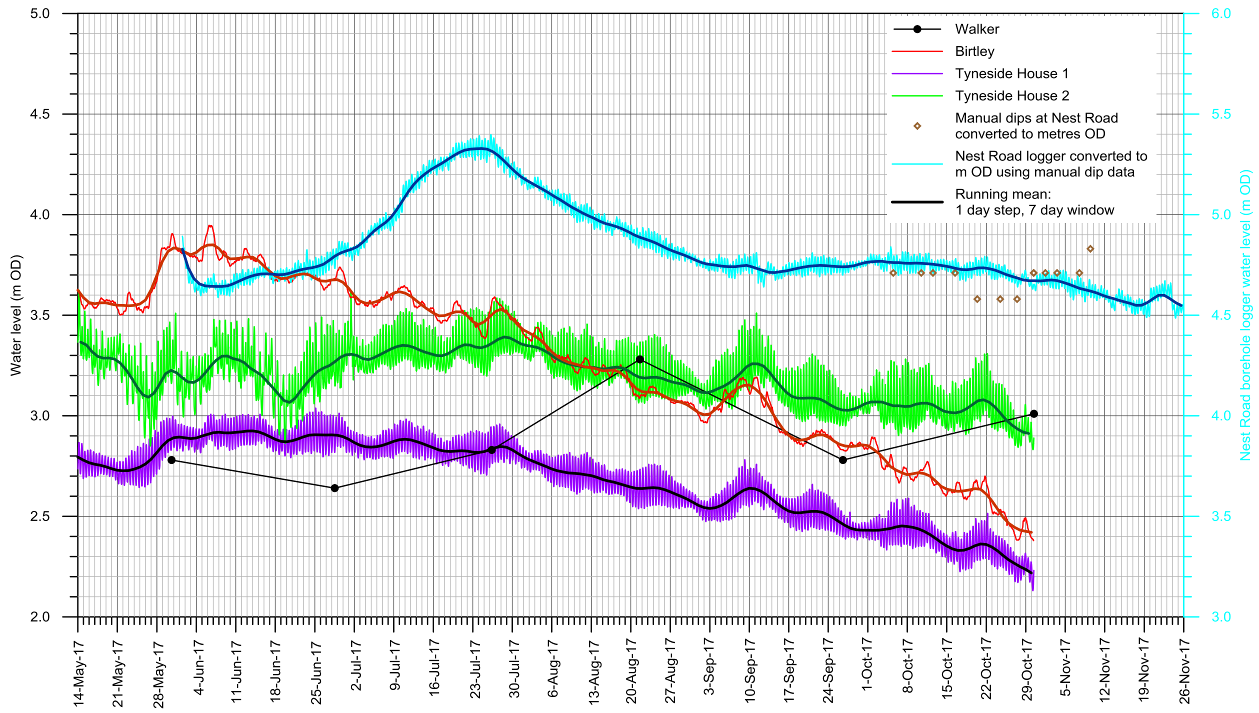


Figure 8: Environment Agency observation bore and Nest Road water levels from May to December 2017

Looking specifically at the Nest Road record since May 2017 in Figure 8 it appears that the rise and fall in water levels seen in the Nest Road data has some similarity to the Tyneside House 2 record. The general trend in groundwater elevation since July 2017 has been downward in Tyneside House 1 and Tyneside House 2 (about half a metre). At Nest Road borehole 4 the fall has been around three quarters of a metre. There appears to be a seasonal decline in groundwater levels from July 2017. This decline is repeated in the other two monitoring boreholes with the most pronounced seasonal decline seen in the Birtley record which shows a fall of about 1.2 metres in water level since July 2017.

Although the Coal Measure aquifers in this area are very stratified it is clear from the Environment Agency's regional monitoring and from monitoring at the Lanchester Wines sites that winter rainfall recharge can be quite rapid. In the case of BH6 at Abbotsford Road rainfall recharge from individual rainfall events can be seen suggesting good vertical hydraulic connections can exist within the Coal Measures.

Regional groundwater recovery is likely to continue at a much reduced rate and could eventually restore groundwater flow towards the River Tyne. However, experience from other historically overabstracted aquifers where groundwater levels have recovered indicates that groundwater quality will remain relatively poor in the Gateshead area even after full recovery of groundwater levels has occurred.

3.3 Impact of the Abbotsford Road groundwater source heat pump system

Historical groundwater control in the area has been characterised by pumping to dewater the Coal Measures for mining purposes followed by a reduction or cessation of pumping and a slow recovery in groundwater levels over the past 30 years. It is not yet apparent how far the recovery has to progress but there may still be a small depression in groundwater levels in the south of the area near Birtley which could be sufficient to create some southward groundwater movement from the River Tyne into the Coal Measure aquifers.

The installation and operation of the Abbotsford Road groundwater source heat pump heating system is unlikely to have a significant effect in this scenario. The overall groundwater flow pattern that appears to exist at the moment which is variable in terms of dominant flow direction but is generally from north to south at low gradient in the area between the abstraction and injection wells would remain if the Abbotsford Road scheme is permitted. However, the effect of recharging water into boreholes BH4, BH5 and BH6 will be to create a hydraulic barrier preventing the movement of saline water from the river southwards. A local groundwater flow cell will be created at the Abbotsford Road site as illustrated in Figure 9 and this would move the saline water interface north nearer to the river.

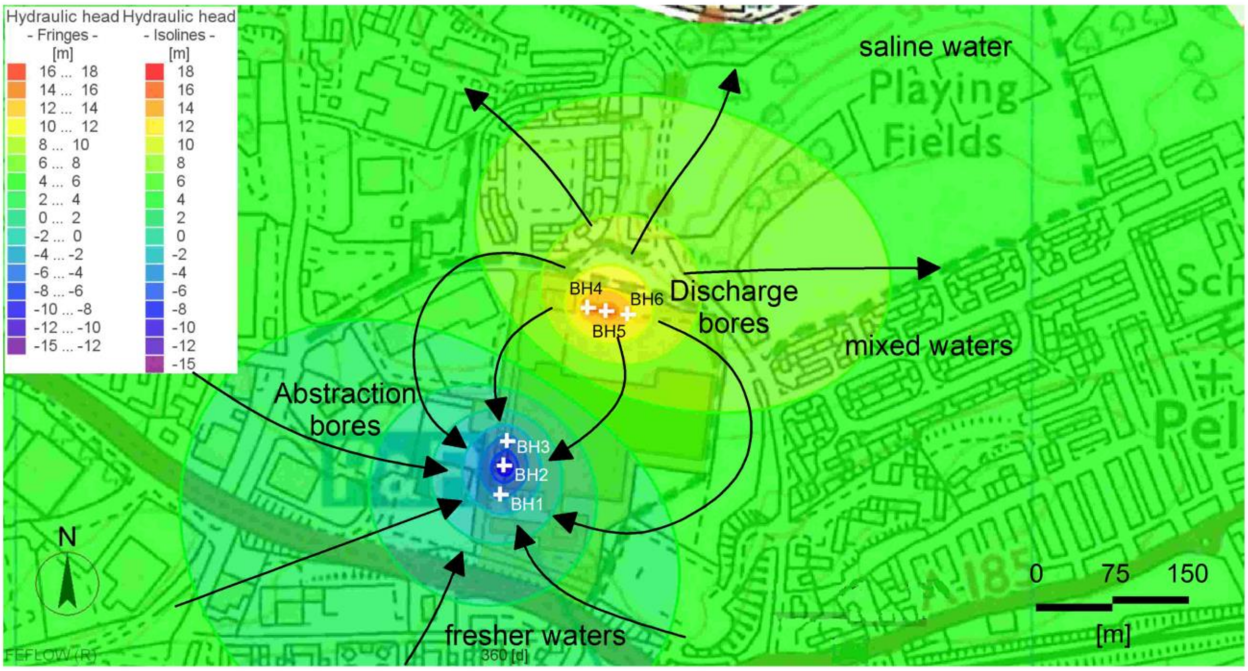


Figure 9: Modelled hydraulic head and direction of groundwater flow (arrows) during the winter months of GSHP system operation showing a groundwater flow cell produced by the operation of the system

Given that the scheme would create an abstraction – injection wellfield an equilibrium groundwater flow pattern would be expected to be established in the vicinity of the Abbotsford Road site as a result of the pumping and recharge activities related to the heat pump system.

In general significant change in groundwater quality due to the operation of the scheme, given the history of the area and the evidence of long term groundwater recovery, is unlikely. The scheme may, in fact, have a positive effect on groundwater quality as described above.

LWRC
23 January 2018