ANNEX 6

EASTGATE GEOTHERMAL

BOREHOLE

INTERIM REPORT

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SUMMARY

The Eastgate Geothermal Exploration Borehole has wholly vindicated the hydrogeological concepts upon which it was proposed. A very encouraging increase in groundwater temperature with increasing depth has been found, significantly exceeding the geothermal gradient previously reported from the nearby Rookhope Borehole. A bottom hole temperature (at 1000m) of around 48^{o}C is anticipated (subject to geophysical logging after borehole completion), and if this borehole (or another nearby) were sunk to a typical "production" depth of about 1800m, the bottom-hole temperature would be expected to be around 78^{o}C. By any standards, therefore, the Eastgate prospecting programme has been a great success, revealing the presence of a geothermal resource at least as promising as the best ever previously identified in the UK. In the process of reaching this finding, much valuable geological information has been collected, which sheds further light on the geological history of the area (thus contributing to the store of knowledge which underpins the North Pennines' status as a European Geopark).

The borehole is currently able to supply water at 26 ^{o}C. This could provide warm water for potential direct use on site, such as for space heating of new buildings by means of pipes embedded in a floor slab. The composition, temperature and flow are also likely to prove consistent with a "hot springs" development, where low volumes of warm saline water are typically used. The overall feasibility of this option would require resolution of a number of further issues, including:

i. the sustainable flow of water at 26^{o}C or higher;

ii. the compatibility of the water chemistry with spa water requirements (and the possible need for some pre-treatment before such use);

iii. establishment of a suitable disposal pathway for spent waters.

By drilling a second deeper borehole, a more flexible resources is likely to be obtainable, potentially providing low-cost space heating and hot water for a large number of domestic and commercial premises. In this second option, the current exploration borehole could be retained for re-injection of spent waters, avoiding the need to consider disposal to surface waters.

These two options are not mutually exclusive: the direct use of water from the exploration borehole could proceed while the drilling of a deeper borehole got underway. Both options could eventually run in series, with hot water first supplying building heat, then being used in the spa before re-injection back into the ground. Although both options will require the use of electrical power to pump water out of the borehole, the power needed is relatively modest in relation to the sources of renewable energy (hydroelectric and wind) that have been identified nearby.

1. INTRODUCTION

This report provides interim results from the Eastgate geothermal drilling project. It has been jointly written by PB Power and the University of Newcastle.

The report is divided into five sections, including this introduction.

- Section 2 outlines drilling progress to date.
- Section 3 summarises the provisional results.
- Section 4 describes the timetable for completion of the project.
- Section 5 outlines the options and next steps to exploit the geothermal resource.

This interim report will be followed by a more detailed final report once the project has been completed.

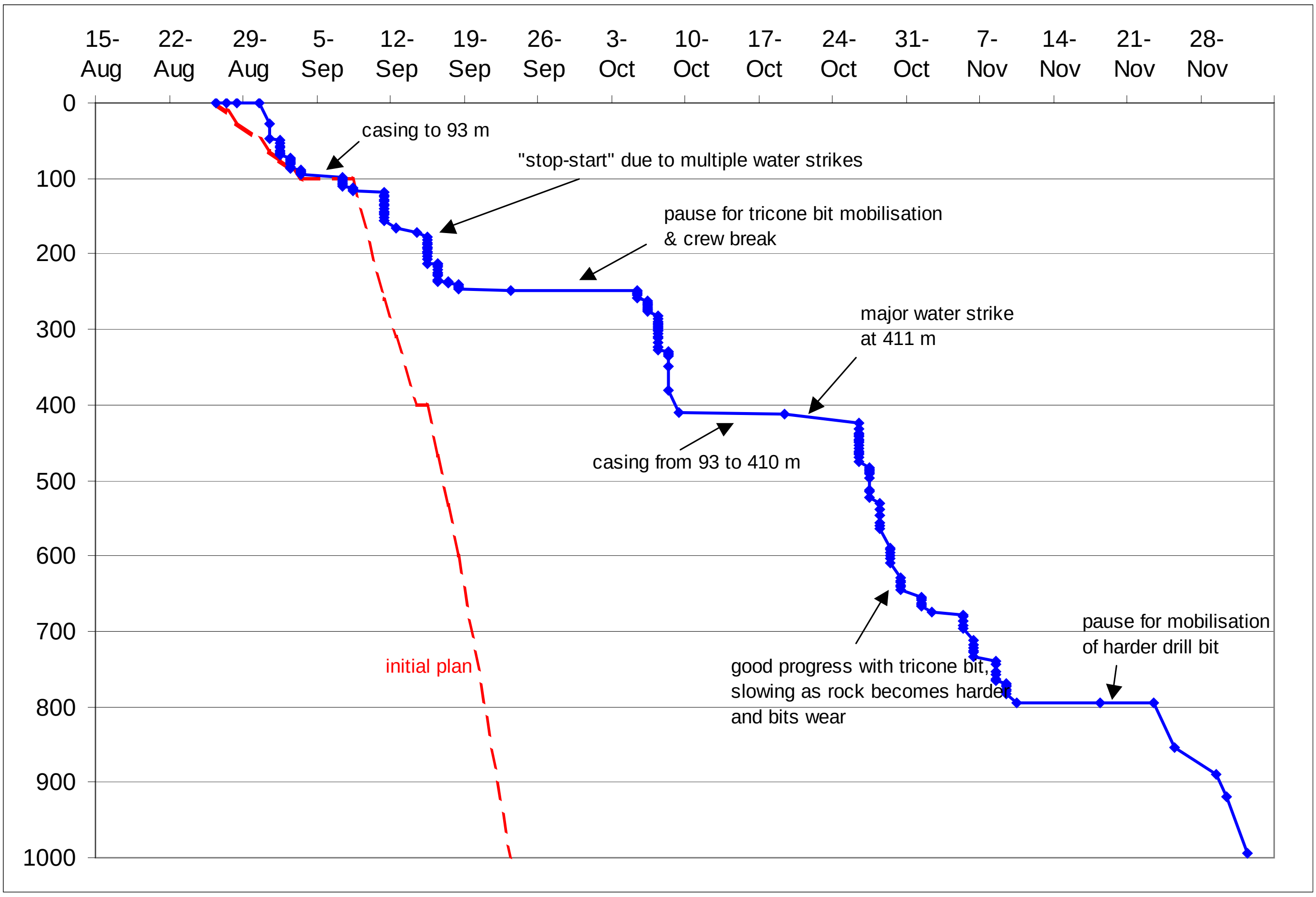
2. DRILLING PROGRESS TO DATE

The borehole was completed on December 2nd at a depth of 995 metres. It has been constructed in 3 phases:

1. From surface to 93 metres, cased and cemented with a final diameter of $13^3/_8$ inches.
2. From 93 to 410 metres, cased and cemented with a final diameter of $9^5/_8$ inches;
3. From 410 to 995 metres, without casing and with a diameter of $8^1/_2$ inches.

Progress has been slower than initially planned, as shown in Figure 2.1 below. There have been two reasons for this. Firstly, bad weather in August delayed the preparation of the drilling site. Secondly, significant volumes of water have been encountered throughout the drilling of the borehole. These volumes have been slowed the rate of drilling, and eventually required the use of a slower drilling technique (tri-cone bit versus the original down-the-hole hammer).

Figure 2.1: Progress of Eastgate borehole



3. RESULTS

3.1 Geology and groundwater

Progress in drilling the borehole has been compared with knowledge gained from the 808 metre (m) deep Rookhope Borehole, which intersected the Weardale Granite at around -50m OD (OD represents height relative to sea level). The Eastgate Borehole intersected the granite at 273.5m depth (-13.5m OD, or some 37m higher than at Rookhope), finding an unexpectedly thin weathered mantle. As the hole has progressed through the granite, its character has changed from a green, altered, granite (possibly a consequence of metasomatism associated with its proximity to the Slitt Vein) to a fresh grey-white rock resembling a typical Cornish or Scottish granite of similar age.

The hole started in the Slitt Vein itself, and has intercepted notable masses of vein material (quartz-dominated, but with notable fluorite above the Whin Sill) at various depths. Sparry calcite was associated with some veinlets encountered within the upper reaches of the granite. Below about 600m in the granite, there were few showings of vein mineralization until 888.5m, when red vein quartz with abundant fine-grained pyrite was encountered. Subsequently, at about 913m depth (where the granite was once again displaying a greenish tinge) approximately one metre of further vein material was traversed, comprising first white quartz, then black quartz (the latter colour possibly being due to sulphide inclusions) together with minor pyrite. These are the deepest provings of hydrothermal mineralization found to date in this major orefield.

Unusually high rates of groundwater ingress to the borehole were experienced while traversing the Carboniferous sequence. Indeed, at times the water yield of this one borehole exceeded the former total water make of the entire Cambokeels Mine (1.6 million litres per day)! As was noted in Section 2, this exceptionally heavy water make necessitated time-consuming changes in drilling techniques.

The casing that was grouted-in to eliminate shallow-sourced groundwaters (see Section 2) was emplaced in accordance with hydrogeological considerations. The first casing was designed to eliminate all water makes above the Whin Sill, on the grounds that the Sill itself is usually a poor aquifer which would be unlikely to yield further major water makes. In the event, this presumption was confounded: two major feeders were encountered within the Whin Sill, no doubt reflecting the presence of splay fractures associated with the Slitt Vein. These renewed feeders brought the water make back to previous levels (> 60 m^3/hr). The second run of casing (toe at 403 metres, which was 130m into the granite) effectively eliminated all shallower feeders. When drilling recommenced the hole was initially dry. However, counter to all expectations of the permeability of even highly fractured granite, a major open fissure[1] which was pierced at 411m depth gave rise to a new water strike (far more saline than the shallower waters) on the order of 50 – 60 m^3/hr – a truly astonishing water yield in a granite at such depth! Although smaller fissures have been encountered subsequently, the water make from the 411m feeder has dominated the overall water make of the borehole during the rest of the drilling programme.

Measurements of electrical conductivity (a good proxy measure of the salinity of the water intercepted by the borehole) and temperature (obviously a useful indicator of geothermal conditions) have been made continuously during drilling and are summarised in Figures 3.1

[1] When this fissure was hit, the bit dropped suddenly by 0.5m, and the drill-string pressure gauge jumped from a few bars pressure to 23 bar (at 411m), and then off the scale (> 30 bar) when the bit landed at 411.5m.

and 3.2[2]. Because the water yield from the 411m feeder has dominated the overall water make of the borehole during the rest of the drilling programme, the temperature of the water entering the hole at that particular depth has swamped the temperature and chemical signals associated with deeper waters. Geophysical logging after completion of the hole should reveal more about true variations in temperature and conductivity with depth.

Samples of water from the hole have been taken at frequent intervals, and have been analysed for a range of major and trace elements (see Table 3.1). Chemical results indicate that most of the water encountered in the borehole is a mixture of shallow-sourced, low-salinity ground waters with much more saline waters coming from a deep source. In accordance with this interpretation, the deeper samples are more dominated by the deep-source saline component. The maximum salinity so far encountered is equivalent to about 5% NaCl. The cation content of the deep waters is dominated by sodium and calcium, and the dominant anion is chloride. The trace elements indicative of deep origins include strontium, lithium and barium.

The Eastgate borehole waters are similar to the saline feeder encountered in Cambokeels mine when it was operational, indicating that the borehole has intersected the same “hydrothermal plumbing system” as the portion of the vein formerly encountered in the mine. The Eastgate waters are about one third of the salinity of those currently exploited in Southampton (Table 3.1).

3.2 Geothermal potential

In terms of geothermal potential, the borehole has thus far demonstrated a very encouraging rise in groundwater temperature with increasing depth (Figure 3.1). At the time of writing, however, the true geothermal gradient signal still unclear due to recirculation of excess water make within the borehole, which induces mixing of waters from different depths. However, from the data already available it is clear that the geothermal gradient is certainly in excess of that found in the Rookhope borehole (which was ~ 3^oC / 100m, itself somewhat in excess of the UK average of about 2.5^oC / 100m). Indeed at times the geothermal gradient seems to be approaching the maximum value of about 6.25^oC / 100m as measured in Frazer’s Hush Mine prior to closure. Geophysical logging of settled water column one week or so after drilling ends is expected to give the best indication of the actual gradient. In the meantime, using a conservative estimate of the geothermal gradient in this borehole of around 3.8^oC / 100m, the anticipated bottom-hole temperature at 1000m can be expected to be on the order of 48^oC. Were the borehole deepened to the same depth as the production

[2] It is important to note that the on-site measurements of electrical conductivity are over-estimated at depths greater than 400m. However, the onsite measurements remain valuable, since correlation of these with more accurate lab data will allow re-scaling of the on-site data for further use.

Figure 3.1. Observed temperature

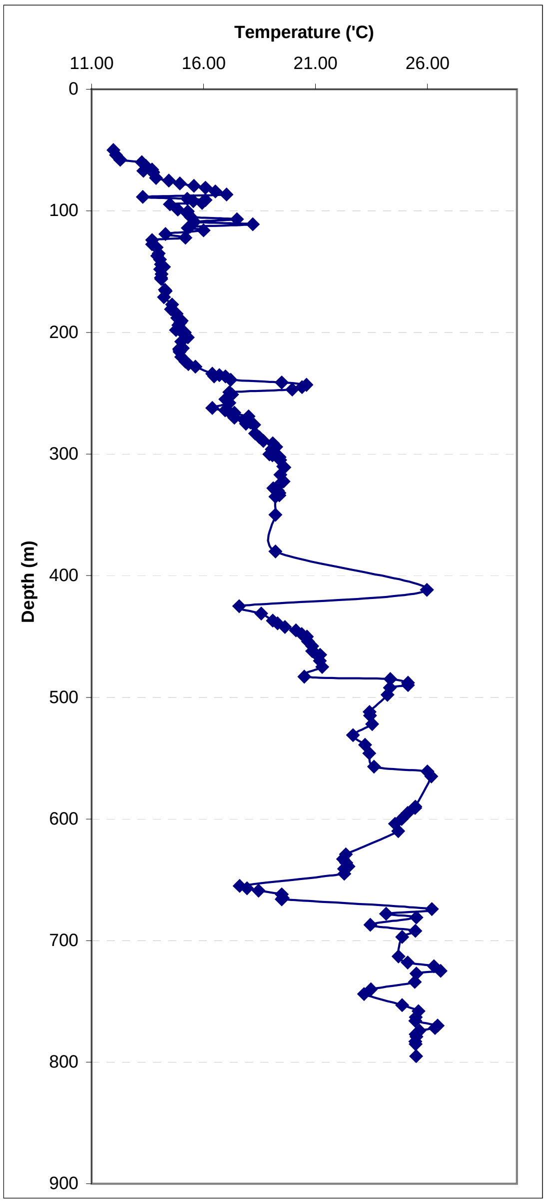
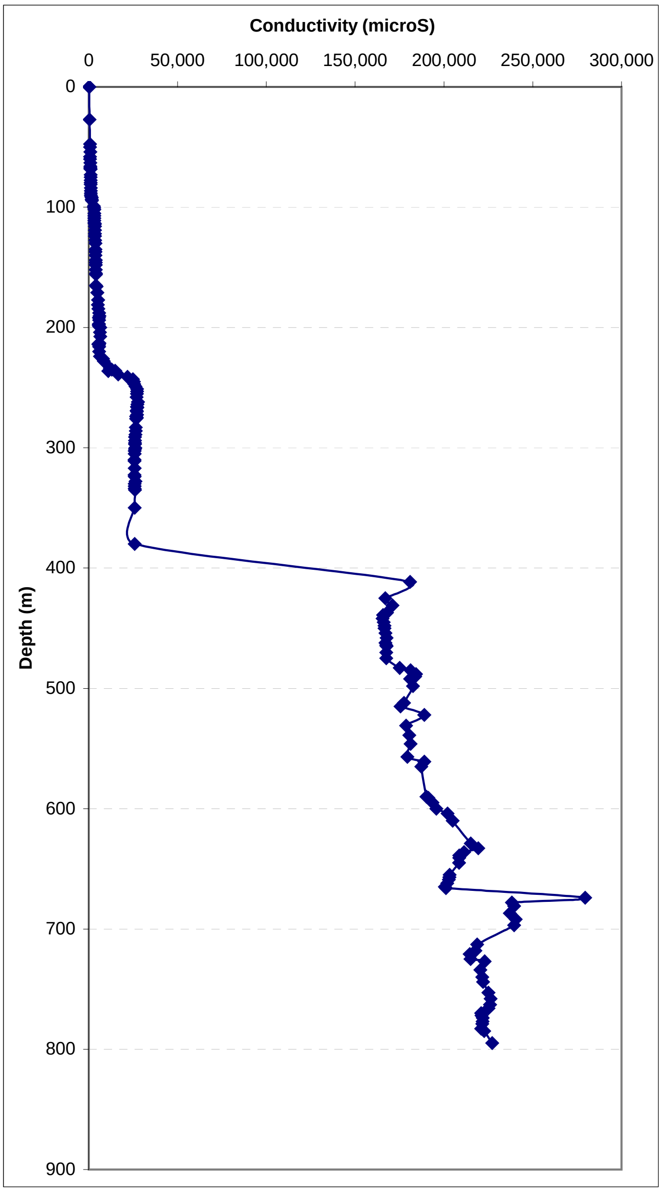


Figure 3.2. Observed electrical conductivity



geothermal well in Southampton (i.e. 1800m) one would anticipate a comparable bottom-hole temperature of about 78^{o}C. By any standards, therefore, the Eastgate prospecting programme has been a great success, revealing the presence of a geothermal resource at least as promising as the best ever previously identified in the UK.

Key engineering issues arising from the findings to date essentially amount to coupled questions over water quantity and water temperature. For certain applications, the large quantity of water at 26^{o}C already encountered has clear potential as a resource. However, there are good grounds to expect that an even greater resource might be associated with a lesser quantity of water at greater depth, were the 411m feeder to be completely sealed out of the borehole. These issues are considered further in Section 5 below.

Table 3.1 Summary of chemical data from deep borehole water samples and other sources

		Cambokeels 1988	*Eastgate 2004*				*Southampton geothermal well (for comparison)*
Sample		CK88/1	E11	E20	E22	E26	
		mine discharge	borehole sample	borehole sample	borehole sample	borehole sample	
Depth	metres		152	300	411.5	674	1725
Temperature	C		14.1	18.9	26	26.2	76
Flow	m^3/day	1600					1700
Conductivity on sample	μS/cm		3900	26150	181000	279600	
pH			7.8	6.9	6.2	6.4	6
Conductivity (lab)	μS/cm		3867	16030	65400	66800	
Alkalinity	mg/l as CaCO3		240	126	60	54	62
Nitrate	mg/l		<5	<5	<5	<5	
Chloride	mg/l	24600	826	5906	28750	28560	75900
Sulphate	mg/l		399	290	48.5	47.8	1230
Bromide	mg/l					140	91
Ammonia	mg/l				11		36
Calcium	mg/l	5236	231	1066	5285	5250	4240
Magnesium	mg/l	121	8.4	20.4	72.4	73.1	752
Sodium	mg/l	7345	521	2243	9630	9790	41300
Potassium	mg/l	340.0	44.1	140	631	656	705
Iron	mg/l	0.73	0	0.4	0.4	0	4.1
Manganese	mg/l		0.6	1.6	0	0	1.26
Zinc	mg/l		<0.1	<0.1	<0.1	<0.1	
Copper	mg/l		<0.1	<0.1	<0.1	<0.1	
Lead	mg/l		<0.2	<0.2	<0.2	<0.2	
Lithium	mg/l	70.5	3.8	20.5	90.6	93.5	31
Silicon	mg/l		6	4	6	3	15
Strontium	mg/l		8.7	61.8	343	353	134
Barium	mg/l				12.9	13.3	0.52
Total dissolved solids		37713	2049	9754	44881	44980	124440

4 PROGRAMME TO COMPLETION

Remaining activities on the project, and their expected dates for completion, are shown in table 4.1 below.

Table 4.1: timetable for project completion

Activity	***Expected completion***
Testing programme	December 10th
Site demobilisation	December 17th
Final technical presentation to Task Force	December 14th
Site restoration	December 22nd
Final technical report to Task Force (with copy to Environment Agency and British Geological Survey – condition of drilling consent)	early January 2005
Final project close-out report to Task Force	January 2005 (depending on final invoicing from Foraco)

The final site condition is to be agreed with Lafarge. It may be desirable both for the tenant farmer and for future access to leave the drilling platform and access road in place, and this is the current proposal from the project team. Note that removal of these features is part of Foraco's contract, should it be required.

Costs invoiced to date by Foraco have been in line with the budget agreed in the contract. Project delays, however, have resulted in some extra costs being incurred by Foraco (although savings have been made in other areas). While it can be argued that the sources of delay were foreseeable by Foraco, and thus their responsibility, we consider that they have been a good contractor and have worked conscientiously to overcome difficulties and ensure the project's success. We therefore consider it appropriate to allow some compensation of the extra costs out of the savings made. Total cost will remain within the agreed maximum price.

5 TECHNOLOGY OPTIONS

The project has proven the existence of a geothermal water resource at the Lafarge site, as described in Section 3. At this stage, there are two options for the exploitation of this resource as part of a redevelopment of the site. These are discussed below.

5.1 Option A

Using the existing borehole as it stands: "Warm water, low volume"

The existing borehole could supply warm water for use on site. This water would then require disposal, possibly after treatment, into the River Wear. For this reason it is likely that only low volumes of water could be used, in order to allow sufficient dilution in the river. Use for space heating in new buildings in "ground-source heat" mode (by means of pipes embedded in a floor slab) would be feasible using the water at the present average temperature of 26^{o}C.

The composition, temperature and flow could also suit a use for a "hot springs" development, where low volumes of warm saline water are typically used.

Feasibility of this option will depend on the following uncertainties being satisfactorily resolved:

- Available warm water flow

  The major feeder at 410 metres depth supplies water at 26°C. This temperature is typical of swimming pools, although at the cooler end of the temperature range used for spas and hot springs. If warmer water were required, it would be possible (with further funding) to temporarily seal off the 411m feeder using inflatable packers, to allow direct testing of the temperature and volume of warmer water from deeper sources.

- Composition

  Further work will be necessary to determine the suitability for bathing purposes of the waters already encountered (including any pre-treatment that might be needed to remove specifications, such as barium), and to evaluate treatment requirements prior to disposal.

- Water disposal

  A route for water disposal needs to be established. The salinity of the water is such that disposal into the river during dry periods would need to be at low levels to encounter sufficient dilution. Acceptable dilution levels would need to be agreed with the EA as part of the discharge consenting process. If treatment of the water prior to disposal is required, technologies to do this need to be identified.

- Sustainable abstraction rate

  Pumping of water from the borehole will require an abstraction licence from the EA. Test pumping data will required to support any licence application, and to demonstrate the sustainable rate of water extraction.

All equipment used will need to have appropriate corrosion resistance to handle the salinity of the water.

5.2 Option B

Deepening the existing borehole or drilling a further production borehole: "Hot water, high volume"

Greater volumes of water, at higher (and therefore more useful) temperatures could be made available by deepening the existing borehole or drilling a further production borehole. The second option would be preferable, as it would allow the existing exploration borehole to be used for re-injection of water, removing disposal as a limitation on usable water volume. Any second borehole should be need to be designed to be drilled to a greater depth, thus accessing a higher temperature resource. For example, the geothermal gradient predicts a temperature of 70°C at 1525 metres depth, which would allow a wide range of space heating uses (e.g. as used in the Southampton district heating system).

The key uncertainties with this option are:

- Water sources at greater depth

  There is no guarantee that more water will be found at greater depths. Results to date, however, suggest that significant water sources exist at many levels in and around the Slitt Vein structure, so that it would be reasonable to expect to find fairly prolific sources of hot water at greater depth.

- Water re-injection

  Injection of water into boreholes is always more difficult than pumping it out, mainly because of the limited scope for raising head before the well overflows. A reasonable amount of head room exists in the exploration borehole, but some testing of the capacity of the hole to receive water will be needed.

5.3 A hybrid approach

Options A and B are not mutually exclusive. Option A could be used as a first stage, while Option B is developed. Both options could eventually run in series, with hot water first supplying building heat, then being used in the spa before re-injection back into the ground.

5.4 Energy balances

The heat extracted using either option depends on the use to which the water is put, as well as on the volume and temperature available from the borehole(s). For Option A, useful heat extracted is likely to be a few hundred kilowatts, while for Option B several megawatts could be available.

Both options will require the use of electrical power to pump water out of the borehole. The power required depends on the water volume pumped and the head lift against which pumping would need to be sustained. Neither of these values can be absolutely confirmed at present, but using a realistic example of 10 litres per second of water pumped from a depth of 250 metres (almost certainly a very pessimistic assumption, given the current standing-water level in the borehole), the power needed would only be of the order of 25 kW. This could be readily supplied by renewable electricity from the hydroelectric or wind power projects proposed elsewhere on the Lafarge site.

5.5 Next steps

Definitive conclusions and next steps will be presented in our final report on the project. At this stage, we consider that the immediate next steps are those required to confirm the feasibility of Option A, namely:

- Conduct a pumping test both with and without the 411 metre feeder, to establish the sustainable pumping rate and temperature.
- Establish bathing suitability and disposal options from the detailed water composition.
- Identify technology options for water treatment.