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A scoping study into shallow thermogeological resources beneath Glasgow and the surrounding area

Clean Coal and Renewables Team

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BRITISH GEOLOGICAL SURVEY

CLEAN COAL AND RENEWABLES TEAM

INTERNAL REPORT OR/09/008

A scoping study into shallow thermogeological resources beneath Glasgow and the surrounding area

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1 Introduction

This report describes the results of an initial scoping study into the shallow thermogeological resource beneath Glasgow and the surrounding area, and the potential for further investigations into this issue.

1.1 DEFINITIONS

In this report, **shallow** refers to depths up to about 200 m. However, the very shallow thermogeological resource (less than approximately 2 m depth) is not considered here.

The **thermogeological resource** is so termed to distinguish it from the **geothermal resource**. In reality and in theory, both are the same thing. One standard definition of **geothermal energy** is that it refers to the part of the earth's heat that can be recovered and exploited by humans. In practise, geothermal energy is widely used to refer to higher temperature energy, above approximately 40°C, which is usually obtainable only in areas of high magmatic activity or at depths of approximately 1 km and below. It includes **geothermal power**, which is generally used to mean the generation of electricity by steam-driven turbines powered by geothermally heated water at more than 100°C. It also includes direct space heating and heating of domestic water supply by geothermally heated water, which is typically between 40 and 100°C (Downing and Gray 1986).

Thermogeology is a term that has been coined to refer to low temperature (usually less than about 30°C) heat energy that occurs at shallow depths (i.e. less than about 200 m) (Banks 2008). Thermogeology is the study of **ground source heat**, which occurs ubiquitously in the shallow subsurface. Ground source heat – the heat stored naturally in rocks – is derived primarily from solar energy, with only a small component (if any) of genuine geothermal energy, which derives from heat fluxes in the deep subsurface (Banks et al. 2003, Banks 2008).

The term thermogeology is used in this report as a useful one for distinguishing between shallow, lower temperature heat useful for domestic space heating and hot water, by means of ground source heat pumps, and deeper, higher temperature heat that may be useful for large scale direct space heating and hot water and potentially electricity generation.

Ground source heat pumps are an established technology for extracting thermal energy from the ground. Heat from soil, sediment, rock or water at depth in the ground is collected and extracted by the heat pump, which raises its temperature to a level that is usable for space heating and heating domestic hot water. The collector system involves either a **horizontal loop** of pipes, normally set at less than 2 m depth in the ground, or a **vertical loop**, installed in a borehole that is typically drilled to a maximum of 100 m depth. All horizontal loop and most vertical loop systems are **closed loop**, in which the piping is filled with a liquid (usually of antifreeze solution) and sealed. The liquid is continuously circulated in the loop of piping, absorbing heat from the surrounding sediment, rock or water which is then extracted by the heat pump. **Open loop** systems abstract water from underground, extract the heat from the water, and discharge the water, either to waste or more usually back into the ground.

The water abstracted for use in ground source heat pump systems can be natural **groundwater** (flowing in un-mined aquifers, both bedrock and superficial) or it can be **minewater** (groundwater that has discharged underground into mined voids and which may later reach the ground surface).

1.2 GROUND SOURCE HEATING IN THE UK

Ground source heat pumps first began to be seen in the UK in the early 1980s (BERR 2009), but large scale interest in their use only took off around 2003 (Banks 2008). There is as yet no registration or licensing requirement for ground source heat pumps, and therefore no accurate information on how many have been installed and where. Licensing is required for groundwater abstraction, which is a feature of open loop systems, which tend to be the largest ground source heat systems, and so it should be possible to collect information on these systems through the databases of the Environment Agency and SEPA. However, the most recent information available from SEPA's CLAS database (in 2008) does not show any abstractions for heat pump use in Scotland. Clarification has been sought from SEPA as to whether and how open loop ground source heat pump systems are licensed.

Based on available information, most of the ground source heat pumps already installed in the UK are thought to be small closed loop systems installed in individual houses. The Department for Business Enterprise and Regulatory Reform (BERR) estimated that some 3000 ground source heat pumps had been installed in single family homes between 1992 and 2008 (BERR 2009). BERR also estimated at the start of 2009 that around 250 ground source heat pumps are installed in the UK every year, increasingly including larger – usually open loop – systems in larger residential, commercial and public buildings (BERR 2009). Virtually all of these open loop systems make use of natural groundwater. Two UK schemes are known of that use minewater, and these will be discussed in more detail below.

BERR (2009) state that there are 1550 large industrial estates in the UK where it has been estimated that heat pump systems could be installed, with an average size of 800 kilowatts of thermal power (BERR do not specify where this estimate is from or whether this refers specifically to *ground* source heat pumps – e.g. as opposed to air or surface water source heat pumps).

As background, there is only one geothermal (i.e. high temperature) heating system in operation in the UK, in Southampton. This is often referred to as a geothermal power plant (e.g. BERR 2009, Wikipedia 2009). However, this is misleading, as the system does not use geothermal heat to generate electricity, which is the usual accepted meaning of geothermal power (Section 1.1). Rather, it abstracts water at a temperature of about 75°C, from a borehole nearly 1.8 km deep, to heat a district heating system with a size of <=1.4 megawatts (Manning et al. 2007, Downing and Gray 1986). There have been a number of past studies into the potential for further geothermal (high temperature) energy (power and/or heating) plants in the UK, including BGS's major *Investigation of the Geothermal Potential of the UK* (various reports covering different regions). Downing and Gray (1986) provided an overview. The only other UK site where geothermal investigations have developed as far as drilling is at Weardale, where a 1 km deep borehole provided water at about 45°C (Manning et al. 2007).

1.3 MINEWATER VERSUS GROUNDWATER AS A THERMOGEOLOGICAL RESOURCE

Virtually all geological units in the UK have the capacity to store sufficient heat to support the use of small-scale (closed loop) ground source heat pumps for space heating. Across almost all of the UK, groundwater (and therefore subsurface) temperatures, at typical abstraction depths of up to around 100 m, tend to be between 10 and 12°C, and to be essentially stable throughout the year. The only exceptions are likely to be at higher altitudes, where in shallower (less than ~20 m depth) groundwater flow systems, groundwater temperatures are lower, to a minimum of around 5°C for groundwater in shallow localised aquifers, e.g. at the top of the Cairngorms.

However, large scale ground source heat pump systems – those serving more than a single home – are almost always open loop systems. These systems generally require high abstraction rates, often in excess of 20 litres/second (l/s), either from one borehole or from a wellfield of several.

This is in the upper range of potential yields from Scottish aquifers. For example, the Carboniferous sedimentary aquifers in the Midland Valley, in their natural, undisturbed state, are thought to generally form moderately productive aquifers, capable of providing borehole yields that are normally in the range 5 to 15 l/s (MacDonald et al. 2004, Robins 1990, Ball 1999). The potential of open loop systems in un-mined aquifers therefore depends largely on the potential yield of the borehole – the aquifer productivity – and only secondarily on the thermal properties of the geological units.

Where mining has increased the void space in aquifer rocks, often across large volumes of rock, the permeability and therefore the productivity of the aquifer is often massively increased. Transmissivity estimates for mined rock are hard to come by, and none are known for the Carboniferous in Scotland, but there are many records of boreholes intercepting mine workings in Glasgow and the surrounding area which were pumped at yields of more than 30 l/s, and at least one of a dewatering borehole pumped at more than 150 l/s. One of the last remaining dewatering boreholes in Scottish mines (not in the Clyde Basin) abstracts constantly at an estimated rate of at least 300 l/s, possibly up to 600 l/s. Abandoned, sometimes collapsed, and flooded workings have a huge surface area and subsurface (flooded) volume that could provide a significant heat exchange area across the rock-water interface (Banks et al. 2003, PB Power 2004). This and the associated potential high abstraction rates, make them of interest for large open loop ground source heat pump systems (Banks et al. 2003).

2 Minewater as a heat source in the UK

2.1 EXISTING SCHEMES

There are only two known current schemes in the UK that use minewater as a source of heat. Both are in Scotland: one at Shettleston in east Glasgow and one in Lumphinnans in Fife. Both were at least partly designed by John Gilbert Architects (http://www.johngilbert.co.uk/).

2.1.1 Shettleston, Glasgow

This open loop ground source heat scheme was completed in 1999 and serves 16 new-build dwellings (two storey houses and two/three storey flats). The heating system is based on mine water from flooded coal mine workings in the Ell Seam beneath the site, which is abstracted via a borehole approximately 100 m deep. It is not clear if the flooded workings are also at 100 m depth. Mine water at 12°C is circulated through a water-to-water heat pump, heating water to 55°C which is output to an insulated thermal storage tank with 10 m^3 volume. The hot water in this tank is supplemented by a side loop to 36 m^2 of solar collector panels which gives additional energy gain to the thermal tank, mostly in the afternoon: from the available details, however, it doesn't seem that these solar panels provide a large proportion of the supplied heat. From the thermal store, water is distributed to hot water central heating radiators and through closed exchanger coils to domestic hot water storage cylinders (which are fitted with electric immersion heaters to further boost water temperature if necessary). The total annual heating and hot water cost per dwelling is £90-£100 (Banks et al. 2003, Banks et al. 2008).

Waste water from the system is discharged below the water table via a shallower re-injection borehole, at 3°C (Banks et al. 2008). I haven't been able to find any information on the depth of the re-injection borehole or the rest water level in this or the abstraction borehole.

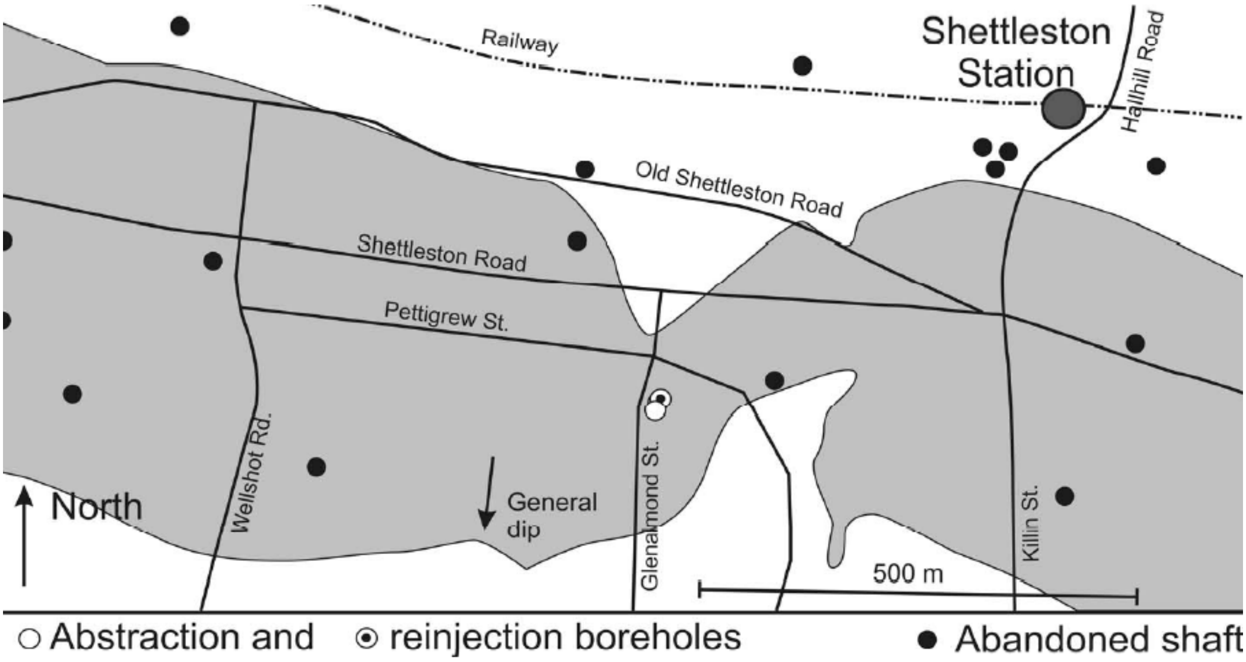

Figure 1 Map illustrating workings in the Ell Coal Seam below the Shettleston ground source heat scheme in east Glasgow, with sites of abandoned shafts and the abstraction and reinjection boreholes of the scheme also marked (Diagram from Banks et al. 2008 / Holymoor Consultancy)

2.1.2 Lumphinnans, Fife

This open loop ground source heat scheme was retro-fitted to a 1950s apartment block of 18 dwellings, and completed in 2000/01. Mine water is pumped from flooded coal mine workings in the Jersey / Diamond seam beneath the site via a 172 m deep borehole. It isn't clear if the flooded workings are also at 172 m depth. The temperature of the pumped mine water is variously reported as 12°C (Banks et al. 2008) or 14.5°C (Banks et al. 2003). It is circulated through a water-to-water heat pump, heating water to 55°C which is output to a thermal storage tank. This feeds domestic hot water (which also includes supplementary immersion heaters) and central heating systems (Banks et al. 2003, Banks et al. 2008).

Waste water at 3°C is returned to a permeable stratum above the flooded workings from which water is abstracted (it isn't clear how far above), via a shallower re-injection borehole some 100 m away from the abstraction borehole (Banks et al. 2003).

Summary chemistry of the abstracted mine water is reported by Banks et al. (2008) (Table 1).

Table 1 Lumphinnans mine water chemistry (from Banks et al. 2008)

Parameter	Value
pH	6.16
Eh (mV)	+ 29
Alkalinity (meq/L)	6.5
Sulphate (mg/L)	1339
Chloride (mg/L)	20.3
Calcium (mg/L)	315
Magnesium (mg/L)	224
Sodium (mg/L)	15.6
Potassium (mg/L)	21.6
Iron (mg/L)	57.9
Manganese (mg/L)	3

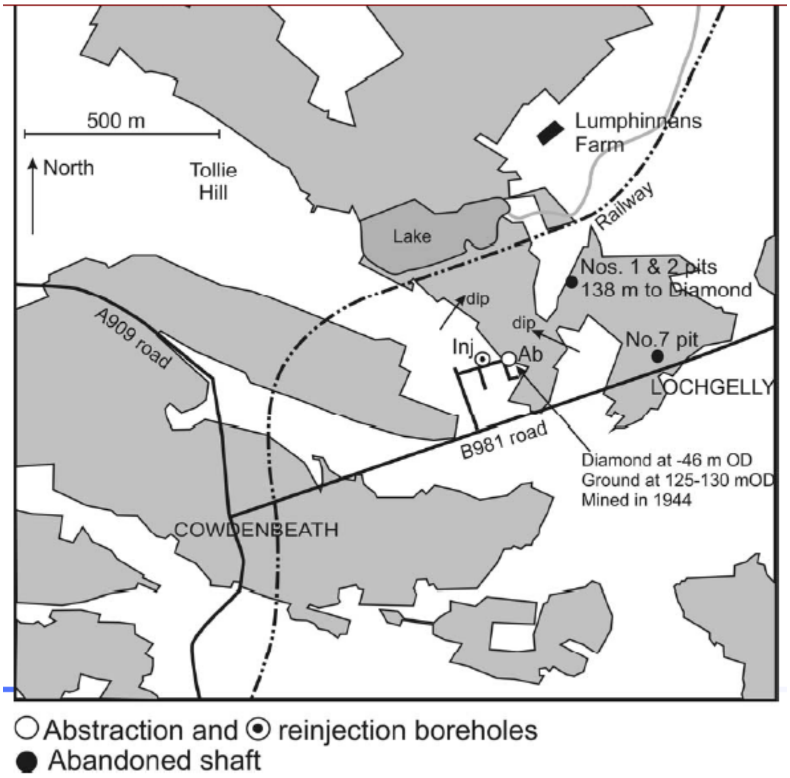

Figure 2 Map illustrating workings in the Diamond / Jersey coal seam beneath the Lumphinnans ground source heat scheme in Fife, with sites of abandoned shafts and the abstraction and reinjection boreholes of the scheme also marked (Diagram from Banks et al. 2008 / Holymoor Consultancy)

2.2 PREVIOUS STUDIES

Two relatively large studies have been done into the potential for using mine water for heating in the UK, one in Scotland and one in England and Wales.

2.2.1 The Scottish National Minewater Potential Study and the Shawfair Minewater Project

The Scottish study was done by PB Power (Energy Services Division) for Midlothian Council (PB Power 2004). The report states that the study was based on existing geothermal surveys, although it doesn't reference these. Although the title of the report is the *Shawfair Minewater Project*, the subtitle (*Scottish National Minewater Potential Study)* and the report content make it clear that this study considered the potential for minewater heating at Shawfair in the context of the potential across the Central Belt of Scotland.

Both the specific potential at Shawfair (Section 2.2.1.1) and the wider potential (Section 2.2.1.2) are summarised here.

2.2.1.1 THE SHAWFAIR MINEWATER PROJECT

Shawfair is the name of a planned new town to be built largely on the site of the former Monktonhall colliery in Midlothian, southeast of Edinburgh (although as of January 2009 its future development is uncertain). It overlies substantial former coal mine workings. Early in the development plans for Shawfair there was considerable interest in the use of minewater and heat pump technology to supply a community heating scheme (e.g. Banks et al. 2003, PB Power 2004, Malolepszy et al. 2005, McLoughlin 2006). The PB Power feasibility study on the resource potential, energy demand and technological options for the site concluded that there was potential for such a scheme, and a successful grant application to the EC was made in 2003 with £3.5 million being awarded. However, further funding applications by Midlothian Council from UK and Scottish government sources (McLoughlin 2006) failed when the business case for the minewater heating scheme could not be successfully concluded, and the plans for using minewater at Shawfair have been abandoned (Minewater Project 2009).

The Coal Authority has an ongoing commitment to pumping minewater from Monktonhall to control mine water levels (Coal Authority pers.comm.). Monktonhall Colliery originally had an 11 km^2 footprint accessed by two 1000 m deep shafts. The temperature at 1000 m depth is some 25°C and the feasibility studies suggested that sustainable pumping of mine water at 16°C would be possible (Banks et al. 2003).[1] A heat pump could raise this temperature to between 40 and 60°C. Waste mine water exiting the heat pumps at around 8°C could be re-injected to the mine periphery and/or at a level below the abstraction point in a nearby shaft, or could be discharged at surface to reed bed water treatment facilities, or used for other purposes, such as cooling or grey water (Banks et al. 2003, PB Power 2004). Other options could have been the separate abstraction of shallower, cooler water for use in cooling installations, leading potentially to seasonal manipulation of the mine water and thermal energy storage in the flooded mine workings (Banks et al. 2003). The studies raised concerns about mine water quality, specifically the high iron content, and its potential corrosive and encrustation effects on heat exchangers (Banks et al. 2003).

2.2.1.2 THE SCOTTISH NATIONAL MINEWATER POTENTIAL STUDY

The *Scottish National Minewater Potential Study* (PB Power 2003) reviewed rebounding water level monitoring data, provided by the Coal Authority and their consultants, IMC Consulting Engineers Ltd, for closed coal mines in Scotland in order to estimate the potential thermal resource available from the old mine workings. The monitoring data were originally collected to ascertain the rates and influence of rebounding water levels in the mines, not for the purpose of estimating available thermal energy (PB Power 2004). Most of this study concentrated on the heat demand and economic cost of mine water heating schemes: only approximately 16 out of 153 pages deal with the technical potential of mine water for heating.

The report identifies more than 60 underground coal mine locations in Scotland and categorises them as follows (PB Power 2004):

1. Sites with a pumping system already installed to manage groundwater levels and discharge.
2. Sites with a known discharge by gravity and natural flows.
3. All other sites where drilling and deep pump installations would be needed to create a mine water circulation system.

The report states that the deepest mine workings have virgin rock temperatures of about 37 to 40°C, and that the water in the deepest parts of the mines may well be close to the maximum rock temperatures, but that near to shafts, natural convection systems will destroy the thermal convection (PB Power 2004). It is not clear if this agrees with other reports that the water temperature at approximately 1 km depth (e.g. in Monktonhall) is approximately 25°C (Banks et al. 2003), or with other data collected recently by BGS (see footnote below and Section 3.1). However, the remainder of the report assumes that the mixed water temperature delivered to heat

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[1] There appears to be little available data on mine water or groundwater temperatures in Scotland to indicate whether this reported temperature of 25°C at 1000 m depth is typical. Other BGS work has shown pumped minewater temperatures – probably from significantly shallower depths than 1000 m – of approximately 12 to 19°C. A single temperature measurement of natural groundwater from approximately 1000 m depth in an un-mined coal seam in the Central Belt gave 15°C.

pumps is not more than 13°C, which is typically equivalent to water abstracted through boreholes or shafts (i.e. categories 1 and 3, above) from 100 m depth (PB Power 2004). This is acknowledged as probably a conservative estimate. No thermal data are available for Category 2 (gravity) discharges, but it is assumed that temperatures will be lower than pumped discharges, possibly around 10°C (PB Power). This is supported by a single temperature measurement of gravity minewater drainage taken during a separate BGS project into groundwater chemistry (Baseline Scotland), which was 9.8°C.

Estimates of the potential flow rate of minewater from the mines were made based on records of the numbers of men known to be employed underground during mine operation. Additional information was obtained on mine size and interconnectivity, although the report doesn't make clear how detailed this information was compared to what may potentially be available, nor how it was used in the estimate of minewater flow rate.

Estimates of heat resource were then made from estimates of the flow rate of minewater. The conversion factor for the Monktonhall site was 16.75 litres/second (l/s) minewater flow per 1000 kWth (kilowatt thermal) (PB Power 2004). It isn't clear if the same factor was used for all the examined mines in the study.

Issues related to mine water chemistry, solids content and corrosion / precipitation potential were not considered in detail, but most potential problems of this nature were assumed to be treatable given available technology (PB Power 2004).

The report provides maps of identified collieries, pumping sites and/or gravity discharges in Scottish coalfields, and information on the pumping and/or discharge flow rates from each. Most of the larger sites and flows are in the east side of central Scotland, but smaller schemes are present throughout former coal mining areas (PB Power 2004). The report recommends that category 1 and 2 sites should be developed first, because the mine water resources have already been proved and the risks are therefore lower.

The study then combines these assessments / estimates of mine water flow with a detailed assessment of the heat demand and economic costs of developing heating schemes at each of the identified abandoned mine sites. Based on this, it provides a list of the ten preferred sites for developing mine water heating schemes in Scotland (Table 2), with the thermal resource interpreted from the estimated flow rates. The total estimated heat capacity of the ten sites is 83 MW. It is noted that the economic ranking of sites varies depending on the technology option selected and the discount rate applied; that sites where there is little or no current heat demand are not ranked highly (e.g. Monktonhall); and that more detailed evaluation may show that the two smallest sites in this list would prove to be less economically viable than some of the larger ones (PB Power 2004). Most of these too are in the east of the central belt; only two (including one of the smallest) are in the general Glasgow area (in Motherwell).

Table 2 The ten preferred abandoned Scottish coal mines for mine water heating schemes (from PB Power 2004)

Postcode	Site	Mine water Thermal Resource (kW)[1]
EH19	Lady Victoria	9450
EH22	Lingerwood	1890
EH47	Polkemmet	9450
EH51	Kinneil	11340
FK10	Manor Powis	7560
KA9	Auchincruive	5670
KY1	Seafield	11340
KY12	Blairhall, Bogside and Valleyfield	17010
ML2	Overtown	1890
ML7	Kingshill No 1 and 3	7560

2.2.2 A high level study into mine water potential in England and Wales

A similar study to that carried out for Scotland by PB Power was carried out for England and Wales by the Sustainable Development Centre's Low Carbon Technology Team (Wiltshire and Burzynski 2008). The aim was to prioritise the most promising sites for mine water heating schemes for future detailed investigation. The study carried out the following steps to assess the mine water heating potential (Wiltshire and Burzynski 2008):

- Identified locations of abandoned coal mines, from Coal Authority data.
- Estimated minewater heat resource in identified coal mines, based on the number of men recorded as working underground, in terms of mine water flow rates and interpreted heat capacity.
- Identified mine water parameters (where possible).
- Identified locations of mine water discharges and their characteristics (where possible).

GIS analysis was then carried out to map the locations of mines with attribute data on mine water, and to compare with local heat energy demand.

The heat capacity was estimated using a conversion factor of 26.5 l/s minewater flow per 1000 kW (kilowatt) (Wiltshire and Burzynski 2008) – a more conservative estimate than that used by PB Power in the Scottish study (which was 16.75 l/s per 1000 kW; see above).

About 1717 coal mines in England and Wales were analysed; of these, some 1400 abandoned mines were identified and mapped. There was sufficient information to estimate the size and potential heat capacity of some 320 to 340 of these. A total of 196 mine water pumping sites and discharges were identified at 49 locations. Of these, the 25 largest had estimated mine water flow rates of more than 26 l/s, and associated estimated heat output potential above 1 MW. The total potential capacity of these mine water discharges is 89 MW. This assumed a temperature drop of 9°C and a heat output potential of 37.8 kW per 1 l/s of water flow. For the 320 to 340 total number of coal mines for which the size was estimated, the total estimated heat capacity was 1983 MW (Wiltshire and Burzynski 2008).

3 Minewater as a resource in Glasgow and the surrounding area

3.1 CURRENT KNOWLEDGE

A recent summary of the current understanding of groundwater in Glasgow and the wider Clyde Basin, including the known impacts of mining on local hydrogeology is given in Ó Dochartaigh (2009).

The locations of boreholes encountering mine workings at shallow (less than 30 m) and deep (greater than 30 m) levels, and the locations of the mouths of abandoned mines and adits are shown on the Glasgow Environmental Geology series of maps (Institute of Geological Sciences/Forsyth 1983). It is not yet known how many of these are still accessible, and there have been no recent hydrogeological investigations of them.

During the heyday of mining in the area, groundwater abstraction for mine dewatering was extensive, but there is little concrete information on the volumes of groundwater pumped from mines during dewatering operations. BGS hold some Coal Authority records showing the volume of water pumped from named mined seams, but these don't generally show if water was pumped out of the mine altogether or whether it was pumped from one part of the mine to another. This risk of 'double accounting' means it's impossible to calculate the total volume abstracted. Also, the records generally don't specify when pumping from each mine finally stopped.

An initial estimate of the volume of minewater pumped in the Clyde Basin area was made by identifying mine dewatering boreholes from BGS and cross-referencing with BGS-held records from the Coal Authority to identify which mine each borehole was abstracting from. It was assumed that mine dewatering was stopped at the time of the last seam closing, which is recorded in Coal Authority records. The volume of minewater pumped from each borehole is shown according to the decade it is assumed that mine water dewatering ceased (Ó Dochartaigh et al. 2007). The total estimated volume of groundwater pumped from mines in the lower Clyde catchment alone (largely the greater Glasgow and Lanarkshire areas) around 1950 was 215 Ml/d (Ó Dochartaigh et al 2007). Robins (1990) states that the peak of mine water abstraction was likely to have been in the early 1960s, and Harrison (1982) suggests the total abstraction then from coal mines in the Carboniferous of the Midland Valley could have been 640 Ml/d. Another estimate put the volume of groundwater pumped from both deep and opencast coal mines in Scotland (all of which were in Carboniferous aquifers in the Midland Valley) in 1980, long after the peak of mining activity, at 258 Ml/d (Robins 1990).

There are no widespread reported problems caused by rising groundwater levels in Glasgow, but the lack of modern records of groundwater levels means that current groundwater levels in the bedrock aquifer are largely unknown. Acid mine water discharge is also not currently a known problem in the Glasgow city area, and investigations at a number of sites showed good quality groundwater in abandoned mine workings (GCC, pers. comm.). Parts of former mine workings have been infilled, which may cause diversions in groundwater flow, leading to groundwater discharge and/or chemical degradation in unexpected places.

Limited other information of relevance to minewater as a resource in the Midland Valley is available from a separate BGS project investigating natural groundwater chemistry in aquifers across Scotland (Baseline Scotland). In autumn 2008 new groundwater samples were collected from boreholes abstracting from Carboniferous sedimentary aquifers across the Midland Valley. Most of these boreholes were not impacted by mining, but some are likely to be at least partly impacted, in that they are believed to intersect mine workings at depth. Four samples were collected of minewater either pumped or flowing under gravity from abandoned mine workings. Accurate temperature measurements were made of at least 22 of these groundwater samples, including the four minewaters. However, none were in the immediate Glasgow area. The temperature data appear to support some of the information from the Scotland minewater potential study (PB Power 2004). Two of the measured pumped minewater temperatures in the Baseline Scotland project were 11.7 and 14.5°C, similar to the typical temperature of natural groundwater from Carboniferous aquifers in the Midland Valley. The third, at 19.2°C, appears to be anomalous. The single measured temperature of a gravity minewater flow was 9.8°C.

The Coal Authority has a database of discharges from abandoned mines in Scotland, which at the moment I have permission to use on the Baseline Scotland project. Only one of these recorded discharges is in Glasgow: on the outskirts in Swinton, by Coatbridge.

There are likely to be more technical details available for the existing minewater heating schemes at Lumphinnans and particularly Shettleston. For example, a student at Newcastle University – A. Fraga Pumar – recently carried out a project based at Shettleston, in collaboration with the Coal Authority, although a Coal Authority hydrogeologist knew of few details (Ian Watson, pers.comm). A source for these may be Dave Banks (Holymoor Consultancy).

3.2 QUESTIONS AND PROPOSALS FOR RESEARCH

3.2.1 Some questions to steer research

- What can we discover about the heat resource that would add value for developers / planners?
  - How do we predict heat resource? – using a factor to from minewater flow rates? From actual temperatures?
  - What about the sustainability of the heat resource – depends both on water flow (i.e. recharge, transmissivity etc) and heat.
  - Can we tell ground source heat potential for a single site – and would this be useful?
  - Can we work out the heat potential for whole city areas – a regional overview – and how useful would this be? What data inputs are needed?
- The most practical thing we can probably do is better understand the minewater system in order to make predictions about how it behaves: i.e., answer the following questions:
  - How much minewater is there, how fast is it flowing and how sustainable are the flows (what's the natural recharge rate)?
  - Where are the mine workings and what condition are they in: access locations, adjacent workings (laterally and vertically), void volumes, degree of flooding? What's the interconnectivity of adjacent mine pools (laterally and vertically) by natural and induced (subsidence) fracture systems?
  - What is the temperature of minewater insitu (via shafts / boreholes) and in outflows? Does it vary spatially / temporally / with depth? What's the in situ heat exchange in flooded mine workings? How do we better understand the thermal response of minewaters?
  - What's the quality of minewater? Once used, would waste water need to be treated before discharge?
  - Could existing gravity drainage of mines be used? Or would boreholes need to be drilled into workings (or could we use existing shafts)?
  - What are the geological hazards associated with minewater heating schemes? E.g. mine collapse; changing minewater chemistry.
- What kind of predictions can we make for minewater behaviour related to abstraction for heat schemes?
  - What volume/percentage of the groundwater and/or minewaters can be abstracted and returned annually without affecting long term heat transfer?
  - Can we predict if there'll be thermal breakthrough from returning cold water to mines? Generally, how much information can be obtained by thermal modelling and what data requirements are there?
  - Does BGS have the inhouse skills to carry out any required thermal modelling, and if not, which organisations do?
- What data are already available that we can collate and interpret? E.g.:
  - 3D models of coal seams.
  - Mine (abandonment) plans.
  - Groundwater levels in bedrock and mine workings in Glasgow and the surrounding area. Are they rising/falling?
  - Minewater discharges and accessible shafts/boreholes into mine workings in Glasgow and the surrounding area. The Coal Authority has what's probably the most comprehensive database, but it has no data for any flows in Glasgow; anecdotal information from Glasgow City Council also suggests there aren't any significant flows.
  - Minewater temperatures. The Coal Authority may have some information, but there's unlikely to be much.

    - Minewater quality. The Coal Authority is likely to have quite a lot of information, including long term monitoring data, for selected sites – probably none in the Clyde Basin, though – but may not have much, if any, for most minewater discharge sites.

- We probably need to learn more about the technical issues of how groundwater quality can affect the engineering of heating schemes, e.g. related to corrosion and clogging. Corrosion – in particular due to high concentrations of ions such as sulphate – is of particular concern related to minewater schemes, as minewaters can have particularly elevated concentrations of sulphate and related ions. Banks et al. (2003, 2008) state that most potential water quality problems can be prevented by sealing and controlling pressure conditions in the pumping and heat exchange circuits, and thereby preventing degassing of CO_2 and consequent chemical changes and mineral precipitation in the abstracted water.
- What about storing heat from the surface in minewater systems (‘artificial heat storage and recovery’)? Could it be done or would the heat be lost? Can we model this?
- What information will be needed to effectively manage and develop policy surrounding minewater heating schemes, and what can we provide? This is likely to be particularly relevant to managing multiple heat schemes. Other issues surrounding ground source heat pump management may be more relevant to non-minewater schemes, e.g. leakage of antifreeze solutions from closed loop systems.
- Can we contribute to the debate about accredited standards for ground source heat pump schemes?
- How much do we need to be aware of the economic issues: e.g. installation costs (high; a barrier) versus running costs (low, a driver).

3.2.2 Proposals for further research

1. **Minewater modelling.** To produce as detailed a model as possible of minewater characteristics for a specific area or mine. This would be at a more detailed level than was possible by the first approximation method used in the Scottish National Minewater Potential study (PB Power 2004). It would include if possible: minewater locations (based on the most detailed possible maps/3D models of coal seams/abandoned workings), volumes, flow rates, flow directions, minewater-groundwater interaction; discharge locations, temperature, and minewater chemistry, and how these vary with space and time. This model would provide a better understanding of the minewater system that could be used to predict possible minewater behaviour under conditions of potential future abstraction and re-injection of minewater for heating schemes.

   The current geological information (including 3D geological modelling) for the Glasgow area includes coal seams with information on where they have been worked, at varying levels of detail, depending on available data. In most cases this is the lateral extent of the base of worked coal seams, with variable amounts of borehole point data constraining the depth of the workings. Where coal seams have been modelled in 3D, these data have been used to produce surfaces of the base of the worked seams. In the Clyde Gateway area data have been collated on all major coal seams down to a depth of ~500 m. There is limited information on the type of workings (e.g. stoop and room or open) and on areas which have been filled with waste or other fill. There is virtually no information on where workings (particularly open workings) have subsequently collapsed. Using this information, however, potentially combined with additional more detailed information from the Coal Authority, we are likely to be able to produce at least a first approximation of the extent (lateral and vertical) of mine workings and the connections between them, and the likely void volume and minewater flow directions. This will be the basis of a conceptual model, attributed with numerical data, of minewater presence and behaviour.

By end March 2008 we will have a first approximation groundwater recharge model for the Glasgow area, incorporating direct rainfall recharge and indirect recharge from rivers, water mains and sewers. This could be applied to the conceptual model of minewater in order to help estimate the long term sustainability of the system.

2. **Thermal estimates/modelling.** To estimate the thermal resources of the trial modelled minewater system. We may be able to use measurements of actual minewater temperature data, or we may have to use generic conversion factors between minewater flows and thermal potential, as was done in the PB Power study (2004). We may also be able to develop thermal modelling based on the minewater model, to investigate the sustainability of the heat resource over time. The data requirements for this will need to be discussed in detail.
3. **Data collection.** To collect basic data, particularly on minewater temperature and minewater flows from adits. However, there is limited potential to do this in the Glasgow area, as the available information so far shows few if any minewater discharges here. The main source of information on the location of known minewater discharges, and more widely of still-accessible mine shafts or boreholes, is likely to be Glasgow City Council. Where discharges from mine adits can be identified on the ground – there are quite a few across the Central Belt, although not in Glasgow – estimates of flow rates could be made. Where shafts or boreholes into mine workings are still accessible, we could carry out sampling and testing (including test pumping), but there are unlikely to be many, if any, available in Glasgow.
4. **A tool for developers and planners.** Ultimately what we may want to produce is a tool for developers and planners of minewater heating schemes. This is likely to mean considering the following questions; some of these may be at least partly answered by the activities in 1-3 above.
    - Developers – what do they need to know to develop new schemes? E.g. where the mine workings are; how much water can be abstracted /returned and at what depths; how hot the water is likely to be and how variable; how sustainable the water flow will be; how sustainable the heat will be; what depth should they re-inject at?
    - Planners – what do they need to know? E.g. what the heat resource is on a city-wide scale; how to estimate this (minewater volume & flow; recharge; minewater-groundwater interaction; minewater temperature; recharge temperature?); what kind of interference (water / heat) would there be with multiple schemes; what is the long term sustainability (and how to estimate this – water / heat flow)?

3.2.3 Potential partners

The Coal Authority may have an interest in the wider scale thermal potential of minewaters. I've had brief discussions recently with Ian Watson, a Coal Authority hydrogeologist, on minewaters generally in the Central Belt. There may be potential to engage him or others in the Coal Authority about the thermal resource.

Glasgow City Council are likely to hold much of the available information and knowledge about mine workings, accessible mine openings and any minewater discharges in Glasgow.

Dave Banks of Holymoor Consultancy has done much to publicise ground source heat as a resource in the UK, and has been involved with much of the relevant UK work related to minewater thermal resources.

Newcastle University, particularly Paul Younger, have done much work on mine-related hydrogeology in the UK, including Scotland.

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Appendix 1 Some UK players in the ground source heat field

The following is a list and some brief details of some of the main organisations and individuals thought to be currently actively involved in ground source heat schemes in the UK. It is not comprehensive, and is based only on internet searches.

Table 3 Some of the main UK players in the ground source heat field

Name	Brief details
Ground Source Heat Pump Association (GSHPA)	http://www.gshp.org.uk/. An umbrella organisation launched in 2006 (before this was the Ground Source Heat Pump Club). It has some 80 members, and a council currently comprised of 15 of these member organisations. Many of the members are listed below in this table.
The UK Heat Pump Network	http://www.heatpumpnet.org.uk/. Established in 1999 by DETR and the DTI, it's a focus for training and information exchange and disseminating information.
Holymoor Consultancy Ltd	http://www.holymoor.co.uk. Run by David Banks, who has been involved in ground source heat schemes in the UK for at least 10 years. Recently published a textbook *An Introduction to Thermogeology: ground source heating and cooling* (Banks 2008).
John Gilbert Architects	http://www.johngilbert.co.uk/. Were involved in the design of the only two known mine water heating schemes in the UK.
Coal Authority	http://www.coal.gov.uk/. Regulates the licensing of coal mines and any activities which impact on any of the CA's coal interests. Have a mine water remediation programme. Have hydrogeologist(s) and work closely in Scotland with consultants Integrated Water Services (http://www.integrated-water.co.uk/).
IMC Group Consulting Ltd	Coal Authority consultants
Geothermal International	http://www.geoheat.co.uk/. Commercial company installing ground source heating and cooling systems.
Geowarmth Heat Pumps	http://www.geowarmth.co.uk/home.htm. Commercial company installing ground source heating and cooling systems.
Ice Energy	http://www.iceenergy.co.uk/. Commercial company installing ground source heating and cooling systems.
Jackson Geothermal	http://www.jacksongeothermal.co.uk/. Commercial company installing ground source heating and cooling systems.
Danfoss Heat Pumps UK	http://www.ecoheatpumps.co.uk. Commercial company installing ground source heating and cooling systems.
Earth Energy	http://www.earthenergy.co.uk/. Commercial company installing ground source heating and cooling systems.
BGS	GeoReports.