Groundwater cooling systems

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Groundwater cooling technology can be incorporated into new-build and existing buildings to improve significantly overall efficiency, thus helping to reduce the environmental impact of building stock. The presence of an existing borehole or water supply can greatly improve the attractiveness of a scheme.

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Groundwater cooling systems

1 Introduction

Maintaining a comfortable temperature inside a building can require a significant amount of energy. Separate heating and cooling systems are often used to maintain the desired air temperature, and the energy required to operate these systems generally comes from electricity, fossil fuels or biomass. Considering that a large proportion of the sun's energy is absorbed by the earth, another option is to use this abundant energy to heat and cool a building.

The ground temperature shows seasonal fluctuations to depths of about 15 m, where the temperature is approximately equal to the mean annual air temperature, which in the UK is 8–11 °C(1). Below this the ground temperature increases at, on average, 2.6 °C per 100 m due to heat flowing from the interior of the earth. Mean temperatures at 100 m depth in the UK vary between about 7 and 15 °C(1,2). Hence, in winter, the ground temperature is higher than the air temperature, whilst in summer it is lower than the air temperature. These temperature differences result in thermal energy potential that can be harnessed to help heat or cool a building. Another thermal characteristic of the ground is that a few metres of surface soil insulate the earth and groundwater below, minimising the amplitude of the variation in soil temperature in comparison with the temperature of the air above the ground.

Groundwater naturally occurs as part of the water cycle and, as it flows through the ground, its temperature tends to that of the ground. In the UK, groundwater is at a uniform temperature of about 12 °C outside of cities, whereas in central London, groundwater temperatures of around 14 °C are reported. Deeper groundwater resources (up to 300 m) are slightly warmer (14–16 °C). In addition to the earth, the groundwater below the surface also provides a source of energy that can be used for heating and cooling a building.

In general, this document can be used as guidance for building services engineers interested in installing groundwater cooling systems. It presents an overview of the major issues affecting the exploitation of groundwater cooling systems.

Section 2 of this publication gives an introduction about groundwater as a resource, how it occurs, its properties and groundwater levels in the UK. Section 3 then presents the design process of using groundwater as a cooling resource by considering initial viability, necessary consents and licences, and test boreholes before looking at the detailed design considerations for elements of the groundwater cooling system. Section 4 compares a groundwater cooling system with a vapour compression cooling system. Appendix A1 presents the necessary forms for requesting a licence from the Environment Agency for water abstraction. Further appendices provide a glossary of terms, a list of useful websites and contacts, and acomparison of groundwater systems installed in London.

1.1 Abbreviations

CAMS	Catchment abstraction management strategies
GSHP	Ground source heat pump
mAOD	Metres above ordnance datum
NRV	Non-return valve
PWL	Pumping water level
SUC	Standard unit charge
SWL	Static water level

2 Groundwater

2.1 How groundwater occurs

When rain falls to the ground, the water does not stop moving. Some of it flows along the surface in streams or lakes, some of it is used by plants, some evaporates and returns to the atmosphere, and some sinks into the ground to become 'groundwater'.

Groundwater is often thought of as an underground river or lake. Only in caves or within lava flows does groundwater occur this way. Instead, groundwater is water that is found underground in cracks and spaces in soil, sand and rocks, see Figure 1(3). The area where water fills these spaces is called the saturated zone. The top of this zone is called the water table. The water table may be only a metre (or less) below the ground's surface or it may be hundreds of metres down. The water table may rise or fall depending on many factors. For example, heavy rains or melting snow may cause the water table to rise, or an extended period of dry weather may cause the water table to fall. Groundwater is stored in, and moves slowly through, layers of soil, sand and rock called aquifers.

Aquifers typically consist of gravel, sand, sandstone, or fractured rock, like limestone and chalk. These materials are permeable because they have large connected spaces that allow water to flow through. Water in aquifers is brought to the surface naturally through a spring or can be discharged into lakes and streams. This water can also be extracted through a well drilled into the aquifer, see Figure 2(4). The water in the well can be brought to the

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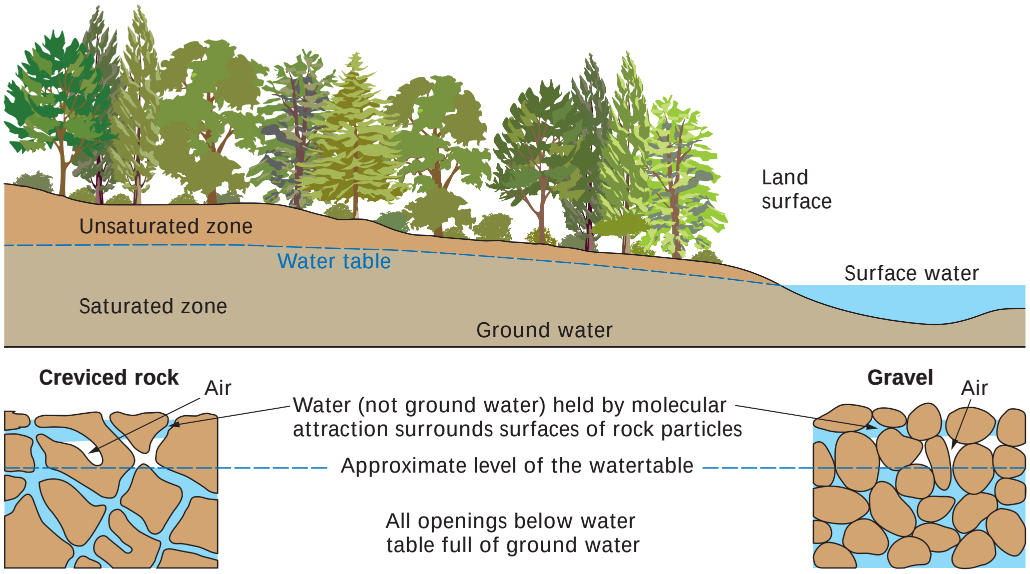

Figure 1 How ground water occurs in rocks$^{(3)}$ (reproduced by permission of the United States Geological Survey)

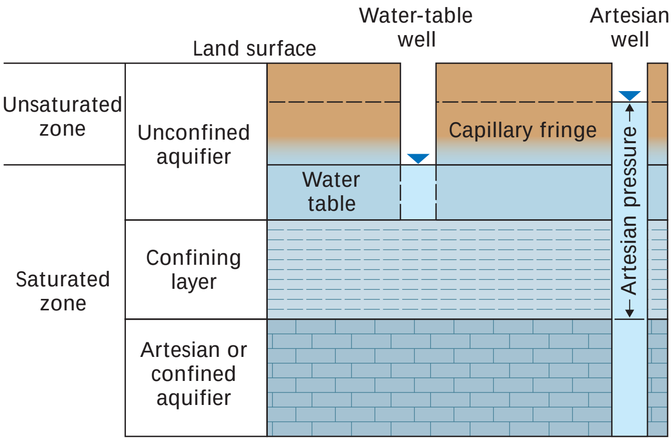

Figure 2 Typical aquifer$^{(4)}$

surface by a pump. Shallow wells may go dry if the water table falls below the bottom of the well. Some wells, called artesian wells, do not need a pump because of natural pressures that force the water up and out of the well. The capillary fringe (or capillary zone) extends from the water table, due to capillary action of the water in the ground, up to the limit of capillary rise of water.

In unconfined aquifers, the groundwater only partially fills the aquifer and the upper surface of the groundwater (the water table) is free to rise or decline. The groundwater is at atmospheric pressure. The height of the water table will be the same as the water level in a well constructed in that unconfined aquifer. The water table typically mimics, in a subdued way, the topography of the land surface above, resulting in a water table with hills, valleys, or flat areas. It is important to note that unconfined aquifers, especially those close to the surface, can be vulnerable to contamination from activities on the land surface.

Confined aquifers may also be referred to as ‘artesian aquifers’. A confined aquifer is sandwiched between confining beds (i.e. layers of impermeable materials, such as clay, which impede the movement of water into and out of the aquifer). Groundwater in these aquifers is under pressure because the confining beds prevent water rising to its natural level. However, because of the pressure, the water level in a well will rise to a level higher than the water level at the top of the aquifer.

2.2 Properties of aquifers

The three important properties of an aquifer are its:

- porosity (the volume of water it holds or stores)
- specific yield (the volume of water it yields, when it drains naturally or is pumped)
- permeability (the rate that water flows through it).

Not all the stored water represented by the porosity can be abstracted for water supply. Part, referred to as the specific retention, is retained in the aquifer against the force of gravity. The proportion that can drain freely represents the specific yield and this is the water that can be abstracted from a well or borehole or which eventually drains from the aquifer at springs. Typical values for the specific yield of sandstone vary between 10 and 30% of the total rock volume$^{(5)}$. In most limestones, it amounts to only 1 or 2%. The specific yield approaches the porosity in aquifers that drain readily, for example coarse sands and gravels, see Figure 3$^{(5)}$.

Groundwater flows very slowly. Typical speeds can be between 1 m/year and 1 m/day, although in very fractured limestones maximum rates are similar to those in rivers$^{(5)}$. The direction of groundwater flow is indicated by the slope of the water table, which is called the ‘hydraulic gradient’. The velocity of the flow of water is proportional

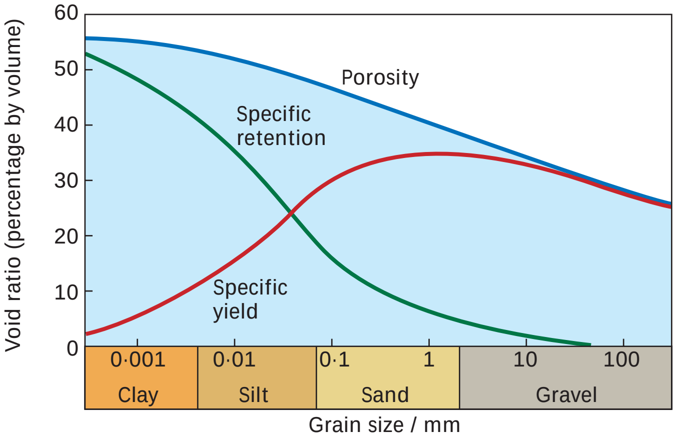

Figure 3 Properties of an aquifer$^{(5)}$

to the hydraulic gradient and a coefficient referred to as the 'hydraulic conductivity', which is dependent upon the interconnectivity of the pore spaces. This relationship is known as Darcy's law and is given as:

$$q = K\, i \tag{1}$$

where q is the volume flow rate per unit cross-sectional area ($\mathrm{m{\cdot}s^{-1}}$), i is the hydraulic gradient (dimensionless) and K is the hydraulic conductivity ($\mathrm{m{\cdot}s^{-1}}$).

The hydraulic conductivity of good aquifers exceeds 30 m/day and for many gravels is 500 m/day. By way of contrast, 10–5 m/day is more usual for un-weathered clay(5).

A more useful practical unit is the transmissivity. This is the product of the hydraulic conductivity and the saturated thickness of the aquifer and represents the ability of the aquifer to transmit water through its entire thickness. The unit used is $\mathrm{m^2}$/day and values for good aquifers exceed 2000 $\mathrm{m^2}$/day(5). Details on the properties of specific aquifers can be found from the British Geological Survey(6,7).

2.3 Chemistry of aquifers

The chemistry of aquifers often represents a significant problem in the design of groundwater systems(2,8). The primary problems related to groundwater chemistry include:

- precipitation of minerals such as calcium carbonate, and iron and manganese oxides, which result in the scaling of heat exchangers and clogging of wells
- corrosion of piping and heat exchangers by ambient and heated groundwater
- bio-fouling of the well intake area
- clogging of the aquifer as a result of precipitation of minerals within the aquifer or the transport of precipitation into the aquifer.

These problems are avoidable if consideration of the potential for geochemistry problems is considered in advance of the system design phase. Further information on the mitigation of these problems is available from Jenne et al(8). It is also appropriate that any proposed scheme uses the skills of a specialist hydrologist to sample the water and provide a report on the quality of the water available. Specialist hydrologists in the UK can be found from the Well Drillers Association (http://welldrillers.org.uk).

2.4 Aquifers and groundwater levels in the UK

Figure 4 shows the major aquifers in England and Wales(9). The most important ones are the chalk, the sandstone and the limestone. The ground properties will affect the productivity of the aquifer. Figure 5 shows the likely productivity of aquifers. Further information on the aquifers of the UK can be found in Downing(5).

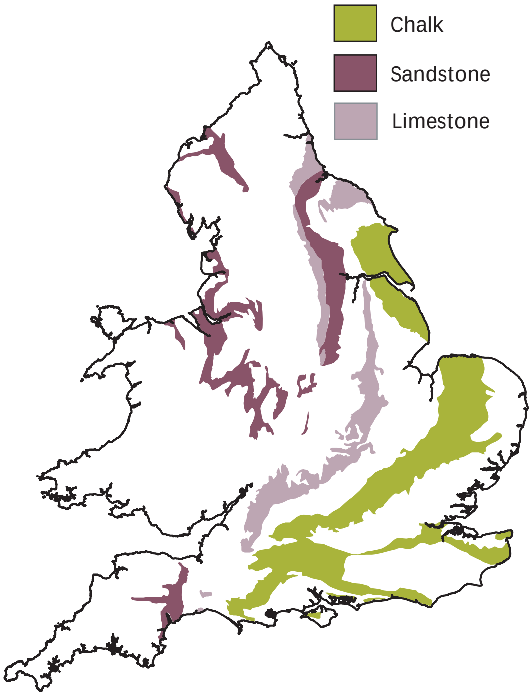

Figure 4 Major aquifers in England and Wales(9) (Crown copyright)

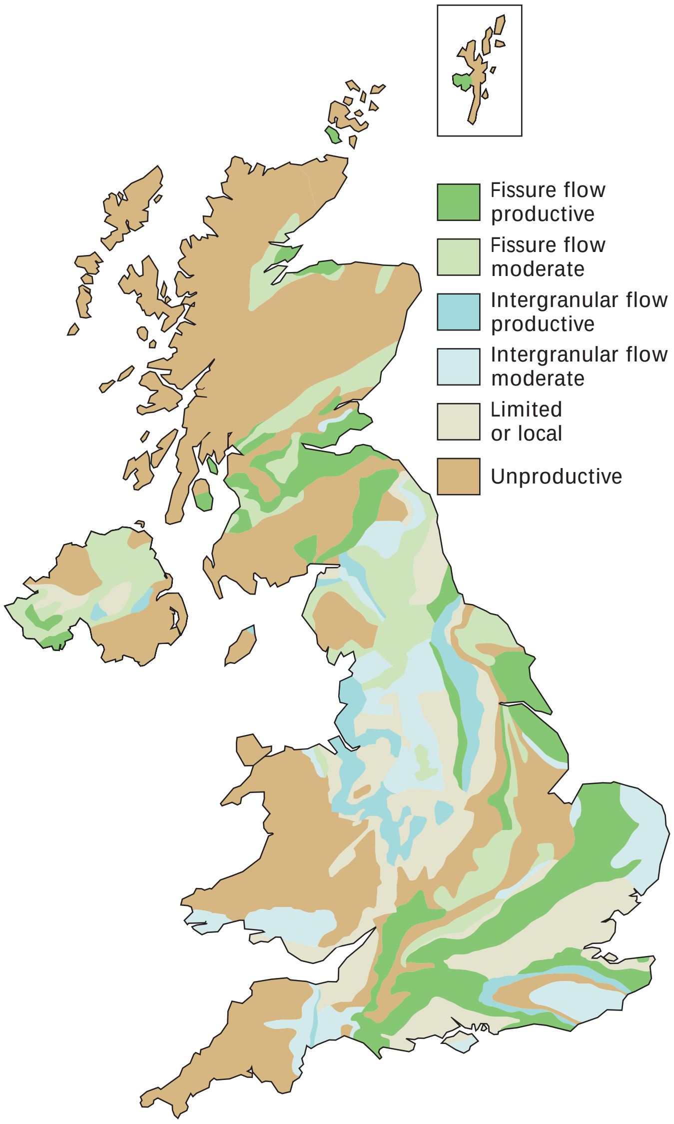

Figure 5 Hydrological map for the UK

Groundwater levels are also indicated by maps. A general map for England and Wales is shown in Figure 6, whereas Figure 7 shows specific contours of groundwater levels in the chalk aquifer beneath London on 1st January 2007. In Figure 7, ‘mAOD’ stands for ‘metres above ordnance datum’. Groundwater levels are important as they will impact on the pumping energy required to abstract the water and therefore may affect the viability of the cooling system.

3 Using groundwater as a cooling resource

3.1 Initial design considerations

3.1.1 Initial viability

Before a groundwater cooling system can be specified there are a number of factors to be considered:

(1) *Availability of suitable aquifer*: groundwater cooling technology can only be applied where there are suitable aquifers. In view of this, it is advisable for a prospective groundwater cooling system owner to firstly obtain a water borehole prognosis report for his or her site from the British Geological Survey (BGS) at a cost of £310 in 2007. The report contains an evaluation of the expected geological sequence and aquifers beneath the site, potential groundwater yields, water levels and groundwater quality. The report also contains map extracts taken from the BGS Digital Geological Map of Great Britain showing various geological layers (artificial (man-made), landslip, superficial and solid (bedrock) geology) and also an index listing of borehole and water well records held in the

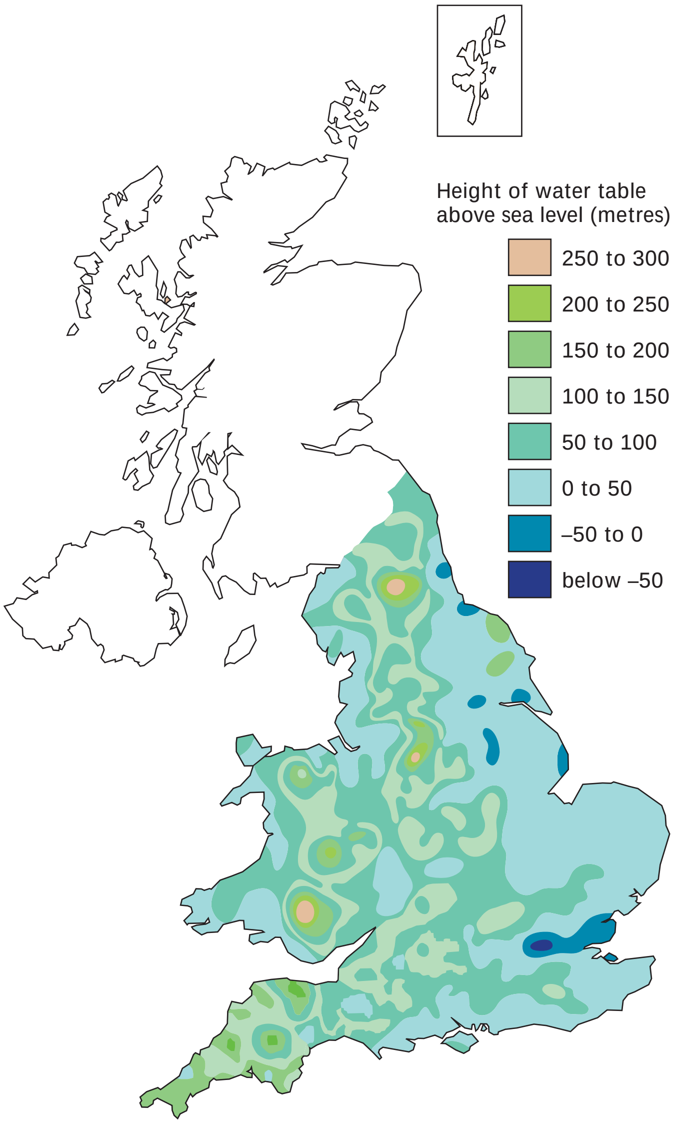

Figure 6 Groundwater levels for England and Wales

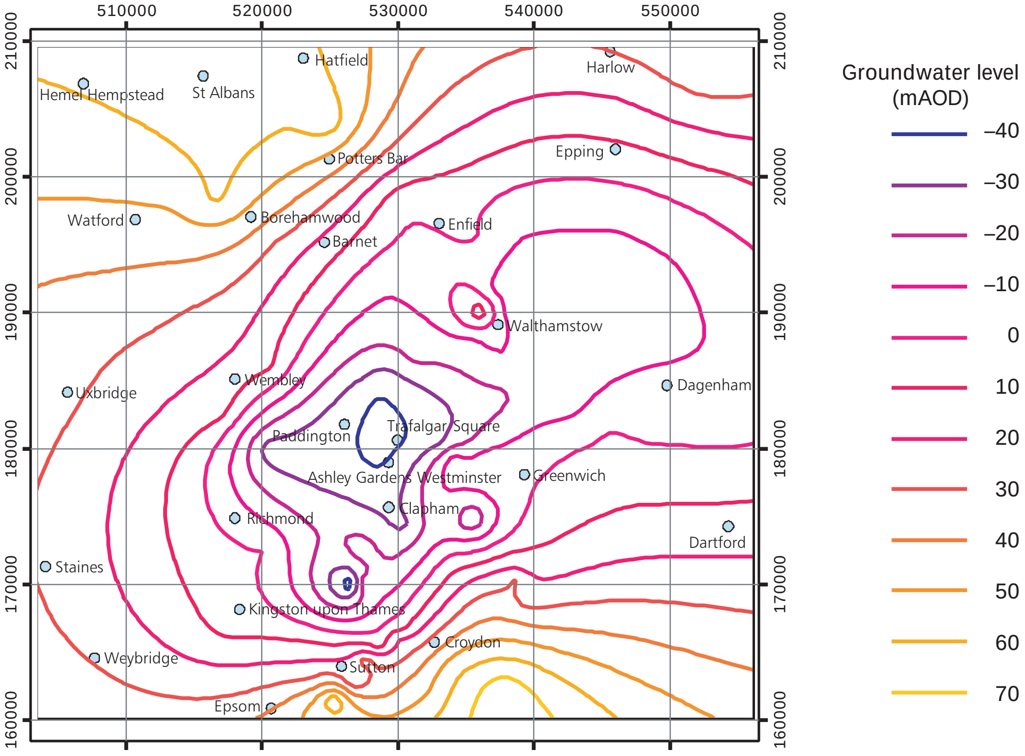

Figure 7 Groundwater levels in the aquifer beneath London[10] (Crown copyright)

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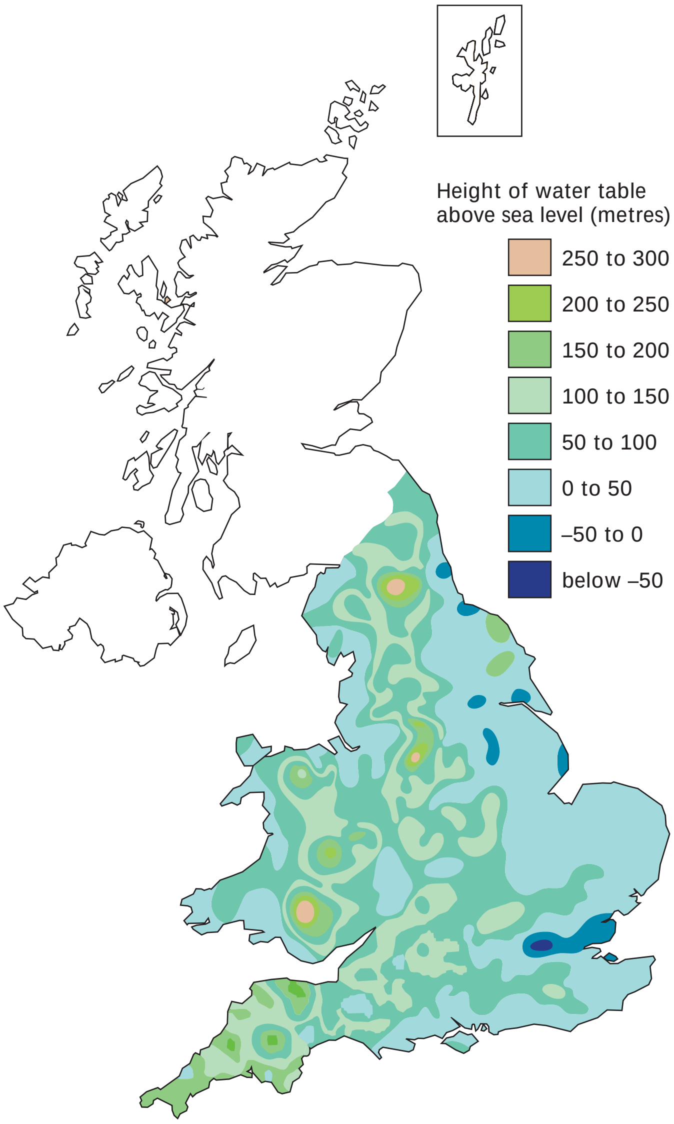

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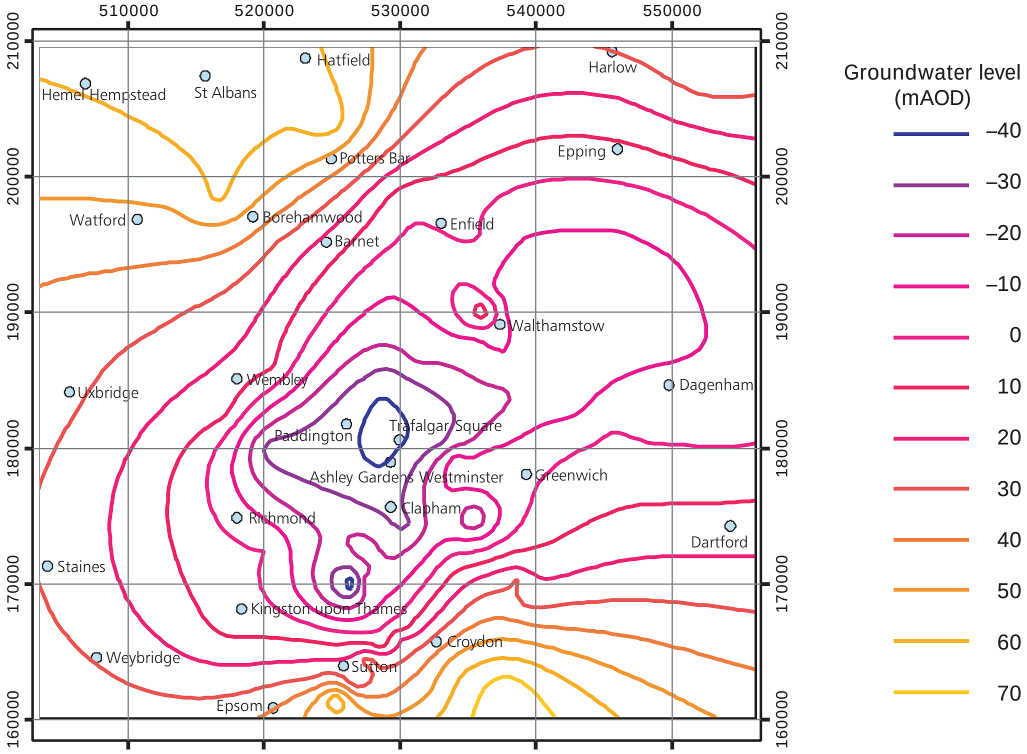


Figure 7 Groundwater levels in the aquifer beneath London[10] (Crown copyright)

National Geoscience Data Centre (NGDC) for the area around the site.

Further information on water borehole prognosis report can be found from BGS website (http://shop.bgs.ac.uk/GeoReports/). The above information will provide an indication as to the practicalities of easily accessing the quantities of water required. Having established that there is a potential groundwater resource, the Environment Agency should be approached for advice on likely restrictions to abstraction and discharge. A specialist borehole drilling company should also be consulted; further information is available from the Well Drillers Association (http://www.welldrillers.org.uk).

(2) *Resource quality*: even if it looks likely that groundwater is available it is important to establish the resource quantity and well flow rate early on. To do this exploratory test as described in section 3.1.3 needs to be undertaken. If it is intended to abstract water, consent to drill and test pump the borehole must be obtained from the Environment Agency. Well flow rate varies depending upon the type and size of well; a good flow rate is 25–50 litre/s per well.

(3) *Distance between groundwater resource and application site*: the use of groundwater resource for cooling must occur near the application site. The reason is primarily economic; although groundwater could be transmitted over moderately long distances, such transmission would not generally be economically viable. Most existing groundwater cooling systems are characterised by transmission distances of less than 1500 m.

(4) *Resource temperature*: the groundwater temperature can restrict the amount of cooling produced by the system. When the groundwater is used directly, its temperature must be lower than the temperature of the air that the system will be required to cool. It is important to test the groundwater for temperature. As stated in section 1, in the UK groundwater is at a uniform temperature of about 12 °C outside of cities, whereas in central London groundwater temperatures of around 14 °C are reported.

(5) *Filtration and sampling*: groundwater in its natural state is generally of excellent quality because rocks etc. act as filters. Particulates such as silt may be filtered, using appropriate gravel or carbon filters, to avoid fouling of heat exchanger surfaces. Surface water may also contain bacteria, albeit in an anaerobic environment. Although the presence of bacteria in a water-cooling scheme will have minimal risk, the water should be sampled for the presence of bacteria, as a precaution.

(6) *Disposal*: implications and costs of disposal need to be considered. The Environment Agency may insist on re-injection or there is likely to be a cost for disposal of water. Re-injection may cause problems if the aquifer is confined.

(7) *Resource life*: the Environment Agency started developing ‘catchment abstraction management strategies’ (CAMS) in April 2001. These strategies provide information on the availability of water and also identify changes needed to the abstraction regime to achieve the sustainable long-term use of water resources. This may result in amending or revoking individual licences or groups of licences. Also, from October 2001, a time limit has been applied to new and amended abstraction licences. This allows the Environment Agency to reassess the impacts of the abstractions on a regular basis and amend the permitted abstraction quantity if necessary. Usually, a time limit is set for 12 years and is linked to the CAMS cycle and common end-date for the CAMS to which the abstraction is subject. It can however be set for 18 years if the licence is granted within 6 years of the CAMS end-date.

3.1.2 Necessary consents and licenses

The responsibility for the strategic management of groundwater resources falls within the remit of the Environment Agency and any groundwater cooling scheme needs to comply with their abstraction rules, some of which are discussed below.

3.1.2.1 Water abstraction

Water abstraction is the removal of water from any sources, either permanently or temporarily, including groundwater (e.g. wells and boreholes) or surface water (rivers, streams, lakes and coastal waters). Abstractions may be ‘one-off’, intermittent, seasonal or continuous. In the UK, the main water abstractors are Statutory Water Supply Undertakers, irrigated agriculture, industry and energy generators.

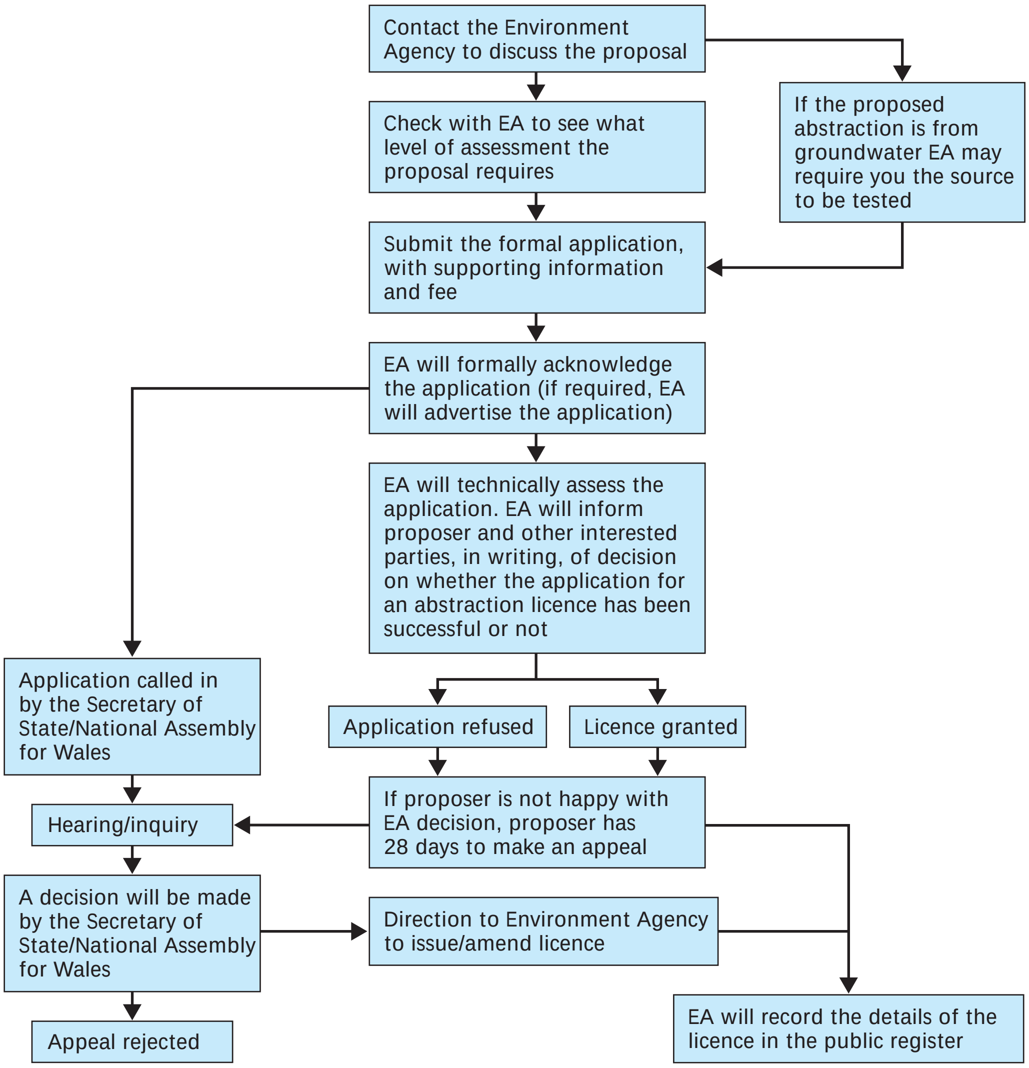
The following issues need to be considered before ground or surface water can be abstracted for cooling purposes in England and Wales:

— An Abstraction Licence from the Environment Agency is needed unless it is an abstraction of not more than 20 cubic metres per day.

— In the case of taking over an existing licensed abstraction, the existing licence holder remains responsible for the charges due on the licence until it is transferred. The onus to complete the transfer is on the existing licence holder but requires the completion of a form that is signed by the existing and new licence holders.

— The amount of water used must be monitored to ensure that the conditions of the abstraction licence are complied with. This will also help to detect abnormal volumes of water being used that might indicate a leak or fault.

Figure 8 shows a flow chart outlining the procedure for obtaining an abstraction licence from the Environment Agency. However, before the Environment Agency can give a view as to whether a licence can be granted, forms WR32 and WR32-GSHP 1 (see Appendix A1) need to be completed. Also, it may be useful to read the guidance contained in Form WR31 (see Appendix A1).



In some cases there are exceptions to this procedure. It is important that the Environment Agency is contacted for advice before contemplating any form of abstraction, reservoir construction or sinking a borehole

Figure 8 Applying for an abstraction or impoundment licence(11) (Crown copyright)

3.1.2.2 Abstraction charges

In order for the Environment Agency to recover its costs incurred through regulating water abstraction there are two types of charge:

— *Application charge*: payable by everyone applying for any licence to abstract or impound water, or for a variation to an existing licence, and is due at the point of application. The application charge is a fixed charge, although it may vary from year to year. The application charge for 2007/08 is £135.

— *Annual subsistence charge*: payable by everyone who holds a licence to abstract or impound water and is due on 1st April of each year or, in the year the consent is authorised, is due on demand. There is a minimum annual subsistence charge of £25.

The annual subsistence charge is calculated by multiplying the following factors together:

— volume (annual licensed volume)

— source (unsupported, supported or tidal)

— season (summer, winter or all year)

— loss (high, medium, low or very low)

— standard unit charge (SUC) (charge for the region in which the abstraction is authorised to be made, see Table 1).

Table 1 Standard unit charges for 2007/08

Region	Standard unit charge / (£/1000 m^3)
Anglian	24.37
Midlands	13.74
Northumbria	24.8
North West	12.71
South West (including Wessex)	19.44
Southern	17.88
Thames	13.05
Yorkshire	10.71
EA Wales	12.85

Further information on water abstraction charges can be obtained from the Environment Agency's 'Business and industry' website (http://www.environment-agency.gov.uk/business/444669/587179/1734110/505764/?lang=_e)(12).

Other costs that may be applicable in a groundwater cooling scheme are those associated with disposal of the groundwater after it has been used for cooling. The local sewage undertaker should be contacted for information on access and charges. Further information on disposal charges to controlled waters can be obtained from the Environment Agency's 'Business and industry' website (http://www.environmentagency.gov.uk/business/444669/587179/1734110/505777/?lang=_e)(13).

3.1.3 Well pumping test

To assess the flow rate a flow test needs to be carried out. In order to carry out a flow test, consent from the Environment Agency is required if an abstraction licence will be needed later, i.e. if it is intended to abstract more than 20 cubic metres per day. A test well needs to be drilled and a properly constructed short-term test will yield information on flow rate. A short-term test should establish flow rate against drawdown. Drawdown should be monitored until stability has occurred, usually for 4–24 hours, although 30-day tests are better.

The short-term tests should be carried out over a range of conditions and should yield information on temperature, pressure, drawdown and recovery. Water level and flow rate need to be stable before flow rate is increased. Tests should produce a productivity curve as shown in Figure 9 and should involve at least three productions rates. the largest production rate being at least the design flow rate needed.

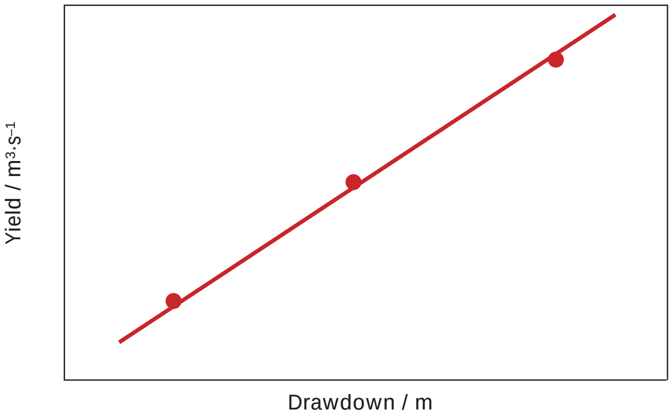


Figure 9 Productivity curve for a typical test well

3.2 Detailed design considerations

3.2.1 Groundwater cooling system

A typical groundwater cooling system can be divided into five sub-systems:

- the production system, including the well bore and associated wellhead equipment
- the transmission and distribution system that transports the geothermal energy from resource site to the user site
- the user system
- the disposal system
- an optional peaking/back-up system.

Figure 10 shows the schematic diagram for a typical groundwater cooling system, as used at Portcullis House, Westminster(14). The system provides about 765 kW of cooling and this has been achieved by extracting groundwater from two boreholes sunk 150 m into a chalk aquifer below the building. The water is extracted at about 14 °C, stored in two 165 000 litre buffer tanks located in the basement, and then pumped through plate heat exchangers connected to cooling coils in air handling units to cool the air down to room temperature. After the water has been used for cooling, some is discharged into a sewer at about 21 °C. The remainder feeds a grey-water system serving toilet cisterns, to reduce the building's demand for refined, potable mains water. It can be seen in Figure 10 that the groundwater is separated from the cooling process with a secondary fluid. This secondary loop is especially necessary when groundwater is particularly corrosive or can cause scaling.

3.2.2 Borehole construction and water well terminology

A borehole is a man-made hole in the ground through which groundwater may flow or be pumped to the surface. It is dug to a depth that penetrates a water-yielding formation to allow water to flow. As shown in Figure 11, a borehole consists of several components(5).

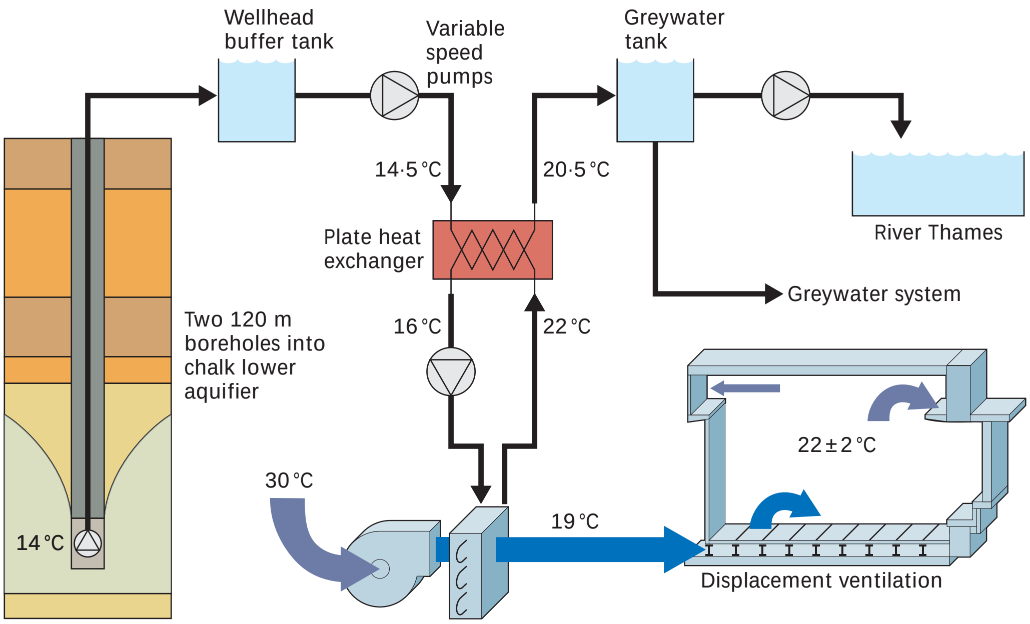


Figure 10 Groundwater cooling system employed at Portcullis House

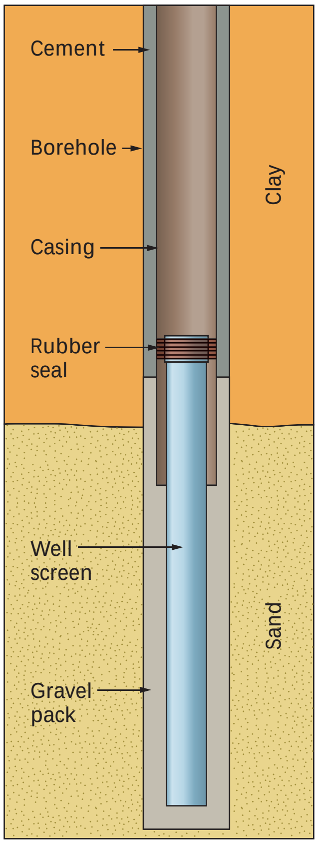


Figure 11 Cross-section through a borehole(5)

Design of boreholes is outside the expertise and responsibility of most design engineers on many groundwater cooling projects. This work is often the subject of a separate contract between the cooling system owner and a hydrogeologist or water well drilling contractor. However, because this well provides the water on which the mechanical system depends, it is advisable for the engineer to be conversant with water well and hydrology terminology.

The Well Drillers Association in the UK has published guidance notes for the construction of boreholes(15). The salient points are:

— At the earliest opportunity obtain a hydrogeological report (geological characteristics and potential suitability) for the proposed borehole location from an organisation such as the British Geological Survey.

— Although no consent to drill and test pump is required for a domestic supply (maximum 20 m^3 per day) it is strongly recommended that contact be made with the Water Resources Manager at the local Environment Agency office prior to any action on site.

— The next stage is likely to involve the services of a specialist drilling consultant, who will undertake exploratory drilling and testing to establish the depth and suitability of the aquifer, water quality and the most appropriate drilling technique. Once enough information has been gathered, the consultant will be able to calculate the groundwater cooling potential and establish the borehole requirements(16).

A variety of methods are used to construct boreholes, depending on the geological conditions and the intended use(17). Borehole construction falls into two general types:

— *Uncased boreholes*: in which the casing extends down the borehole through the upper loose sediment or rocks, but leaving the bottom portion of the borehole uncased. This type of well construction is usually used in hard, fractured rock.

— *Screened boreholes*: in which the casing extends down the borehole through sediment or rock and placing a well screen in the aquifer. This type of well construction is commonly used in unconsolidated sediment, such as sand and gravel(18)

Borehole construction has five or six separate steps. These include: drilling, installing the casing, installing the well screen, installing the filter pack, grouting, well development, and installing a permanent pump(18).

For some wells, known as ‘flowing wells’, a pump may not be needed because the water will flow to the surface due to high hydrostatic pressure. To avoid problems of suspended solids (sand), a gravel pack or screen filter (or both) may be incorporated in the well construction. Proper selection of the screen or gravel pack is based upon sieve analysis of the cutting samples from the drilling process. Sieve analysis should be carried out by a specialist drilling consultant. Some systems also use a surface separator such as a settling tank to allow particulates to drop out of the water. However, surface separation is less desirable since the solids first pass through the pump, which may damage the pump, while the solids will subsequently need to be removed from the settling tank at a later date.

Wells are the foundation of groundwater cooling systems and, as such, it is useful to review certain key terms associated with them, see Figure 12. In any well there will be a water level at which the water stands in the well under non-pumping conditions. This level is indicative of the water table level in unconfined aquifers or the piezometric level (see Appendix A2) in a confined (or artesian) aquifer and is known as the static water level (SWL). When the pump is started, the water level will normally drop to a new, lower level referred to as the pumping water level (PWL). The PWL is a function of the rate at which the well is being pumped; the greater the rate the lower the PWL. The difference between the SWL and the PWL is referred to as the drawdown. Dividing the flow rate by the drawdown (at that flow) produces a value known as the specific capacity with units of litre·s^{-1} per metre drawdown. For example, for a well with an SWL of 15 m that produces 30 litre·s^{-1} at a PWL of 25 m, the drawdown is (25 – 15) = 10 m, and the specific capacity is (30 ÷ 10) = 3 litre·s^{-1} per m drawdown .

Specific capacity is a useful value for indicating the ease with which the aquifer produces water. A high value (e.g. 2.1 litre·s^{-1} per m) would indicate a ‘good’ well, whereas, a value of 0.1 litre·s^{-1} per m would be regarded as ‘poor’(19). For artesian aquifers, specific capacity will be a constant value over a broad range of flows. In water table aquifers, specific capacity will diminish as pumping rates increase.

Key components in the connection of the production well to the system are illustrated in Figure 13. Not shown in this diagram is a pump column check valve, which would be located at the base of the column near the bowl assembly. The check valve maintains the column full of water and in doing so prevents damaging reverse thrust on start-up. Submersible motors are equipped with a thrust

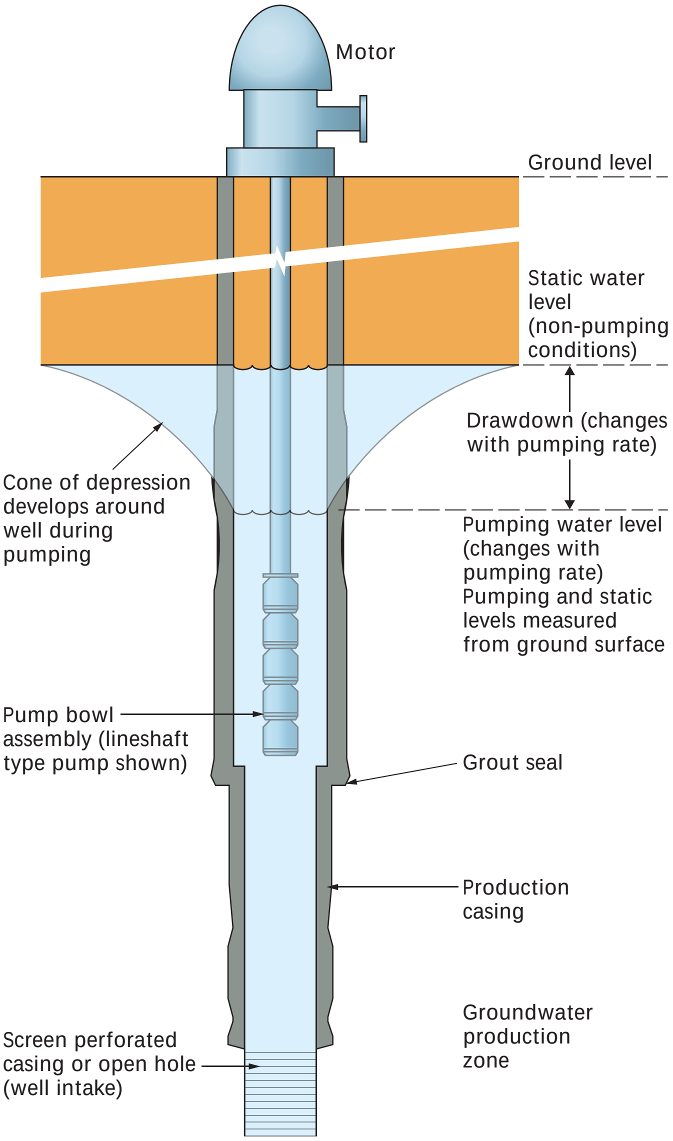


Figure 12 Borehole configuration and terminology(19)

bearing to resist the down thrust developed in normal operation. When starting with an empty column, a pump can exert a temporary up thrust on the motor, which if encountered often can result in premature failure of the motor. To prevent this, submersibles should be equipped with a column check valve.

3.2.3 Borehole pump

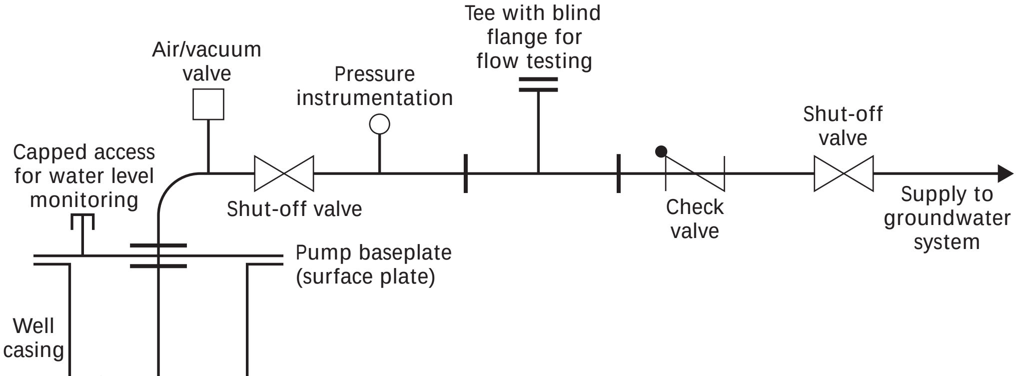
Pumps are either vertical line-shaft or submersible pumps. With a line-shaft pump, the driver is located at ground level and connected to the pump impeller, which is positioned at such a point in the well bore that adequate net positive suction head is available when the pump is operating. Although unlikely with groundwater cooling schemes the reliability of line-shaft pumps is questioned at pumping depths of greater than 240 m(20). The submersible pump is more common in groundwater cooling applications and consists of three primary components: the pump, the drive motor and the motor protector.

For a well pump, the total pump pressure is composed of four primary components:

— lift
— column friction
— surface requirements
— injection pressure (assuming that the water is re-injected to the aquifer).

Lift is the vertical distance that the water must be pumped to reach the surface, i.e. the pumping water level. Column friction is the pressure drop in the borehole pipe. Surface requirements account for the friction losses through piping heat exchangers and controls, etc. The injection pressure requirements are a function of well design, aquifer conditions and water quality. In theory, an injection well penetrating the same aquifer as the production well will experience a water level rise (assuming equal flows) that mirrors the drawdown in the production well. In theory, this ‘drawup’ will encourage the flow of water into the aquifer and no additional pump pressure is required for re-injection. Using the earlier example, an injection well with a 15 m static water level (SWL) would experience a water level rise of 10 m, resulting in surface injection pressure of 10 – 15 = –5 m, i.e. a water level that remains 5 m below the ground surface.

In practice, injection pressure requirements usually exceed the theoretical value. With good quality water, careful drilling, and little sand production, injection pressure will be near the theoretical value. For poor quality water, high sand production, and poor well construction, injection pressure may be 30 to 60% higher than the theoretical value(20).



Notes:
- butterfly valves preferred for shut-off duty
- flange or grooved end piping connections preferred
- check valve either swing type or double disc silent type

Figure 13 Key connection components for a production well(19)

Control of the well pump can be accomplished by various means. In the smallest systems, the water is pumped to a number of pressure tanks arranged in parallel and the water admitted to the system from the tanks. Due to the extensive space requirement for the tanks to accommodate this approach it is not normally employed in large systems. In large systems, typically one of three methods is employed: dual set-point, multiple well (staged pumped), and variable speed.

The dual set-point approach is fairly common in systems with a single production well. Well pump operation is initiated above a given building loop return temperature in the cooling mode, and below a given temperature in the heating mode. Between these two temperatures, the loop 'floats'. In actuality, the loop operates not between two temperatures but between two temperature ranges in order to control cycling of the pump. For example, if the design indicated an optimum loop return temperature of 26.7 °C in the cooling mode, the pump might start at a loop temperature of 28.3 °C and stop at 25 °C. A similar, though smaller, range would exist around the heating mode temperature. The size of the range required around the control temperatures is heavily influenced by cycling limitations on the submersible motor (typically 15 minutes between starts) and the thermal mass of the building loop.

In systems in which multiple wells are required due to aquifer hydrology or redundancy, it is possible to employ a staged groundwater pumping arrangement. This offers somewhat greater control than the single well strategy above but shares the same general approach. Since the pumps are staged, the required controller ranges can be reduced and the issue of system thermal mass is less influential.

Variable speed control of well pumps is the least common of the three strategies. One of the reasons for this is that the primary purpose for using variable speed control, i.e. energy savings, is largely absent in well pump applications. Since a large portion of the well pump head is static head (lift) the nature of the relationship between flow and head is such that savings arising from the use of the drive are substantially less than they would be in a friction head application. Variable speed control, however, offers more accurate control, allows optimisation of the groundwater flow at any load and eliminates any considerations of system thermal mass. When using variable speed control, it is important to obtain confirmation from the system contractor that the motor manufacturer is aware that the product will be used in a variable-speed application. Issues of conductor length (i.e. drive-to-motor), drive switching frequency, critical speeds and motor cooling must be carefully coordinated with and approved by the motor manufacturer to avoid operational problems.

3.2.4 Heat exchanger for groundwater cooling system

3.2.4.1 Plate heat exchanger

The system shown in Figure 10 includes a secondary heat exchanger to prevent circulation of the primary groundwater within the cooling process, normally because the groundwater is either corrosive and/or has high scaling potential. Plate heat exchangers are normally preferred in these applications. This is because they can be constructed with materials that are tolerant to corrosive fluids and can easily be taken apart for cleaning.

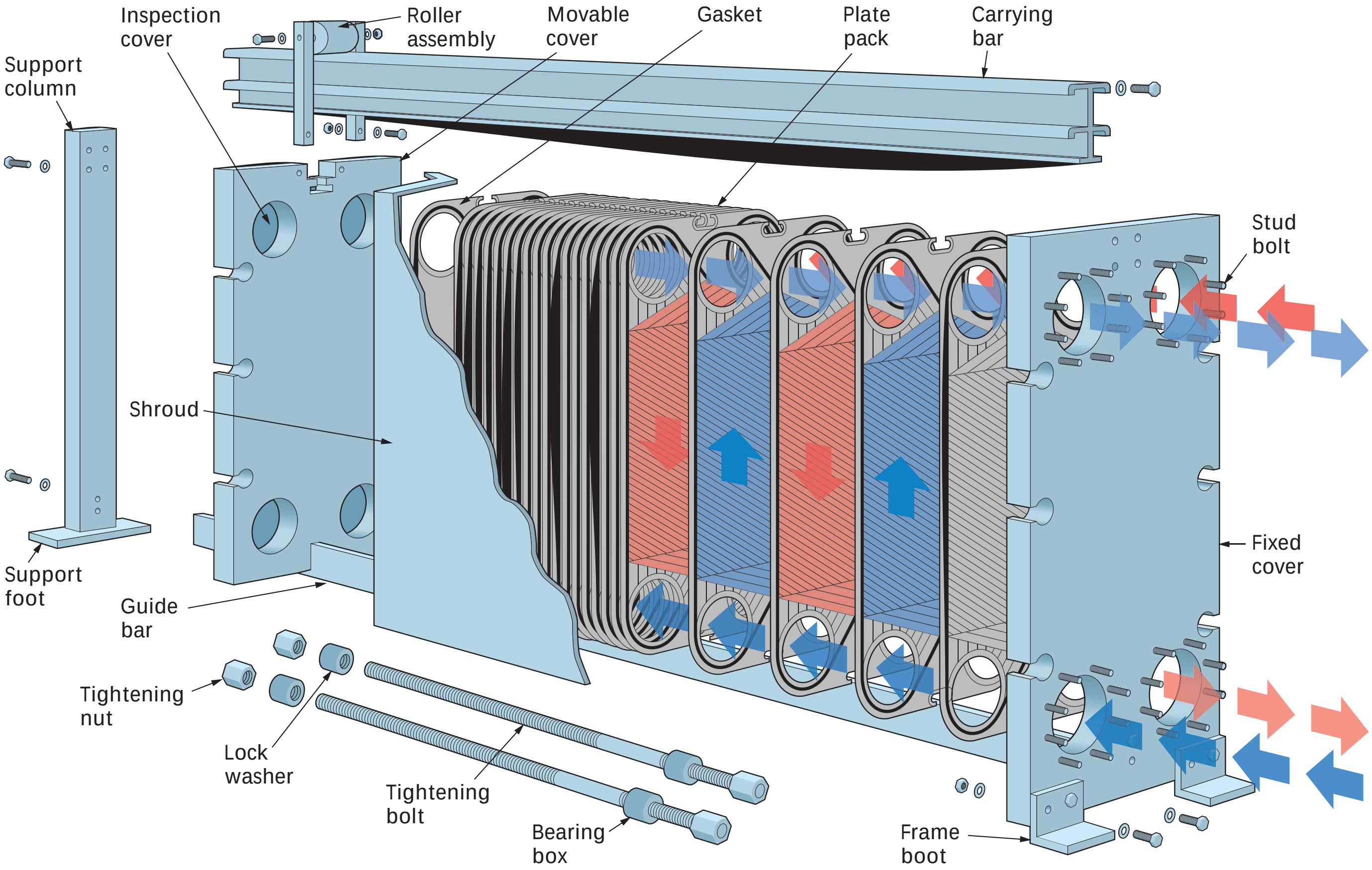


Figure 14 Plate heat exchanger (illustration reproduced by kind permission of Alfa-Laval Ltd.)

The general construction of a plate heat exchanger is shown in Figure 14, from which it can be seen that it consists of a series of parallel plates held firmly together between substantial head frames. The plates are one-piece pressings, frequently of stainless steel, and are spaced by rubber sealing gaskets cemented into a channel around the edge of each plate. Each plate has a number of troughs pressed out at right angles to the direction of flow and arranged so that they interlink with each other to form a channel of constantly changing direction and section. With normal construction the gap between the plates is 1.3–1.5 mm. The primary and secondary liquids flow in alternate spaces and a large surface area can be obtained in a small volume. Also, a high degree of turbulence and high heat transfer coefficients are obtained, even at low flow rates. This can be seen in the example of Portcullis House shown in Figure 10, where the approach temperature between primary and secondary streams is 1.5 K. The high transfer coefficient enables plate heat exchangers to be operated with very small temperature differences, so that a high heat recovery is obtained. A further advantage is that they are easily dismantled for inspection of the plates. The necessity for the long gasket is an inherent weakness but plate heat exchangers have been used successfully up to 423 K and at pressures of 930 kN·m^{-2}(21).

The use of plate heat exchangers is for fluids of similar densities (ρ) and heat capacity rates ($\rho\ C_p$). For air–water heat exchange, finned tube crossflow heat exchangers are preferred as they allow for the large differences in volume flow rates between liquid and gas streams.

3.2.4.2 Fan coil heat exchanger

As shown in Figure 10, this is the final heat exchanger used for reducing the air temperature and humidity using the cooling medium. Typical examples of such heat exchangers are shown in Figures 15 and 16. The basic elements of fan coil heat exchangers are a finned tube coil and a fan section, see Figure 15. The fan section recirculates air continuously from within the perimeter space through the coil, which is supplied with chilled water.

3.2.5 Disposal of water after use

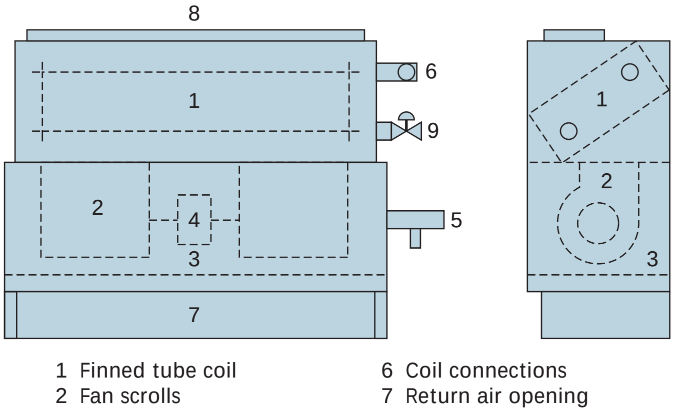
There are two basic options for water disposal from a groundwater cooling system: surface and injection(2). Both options are subject to regulatory oversight and permissions.

Where sites are located near rivers or lakes, it may be possible, subject to obtaining a discharge consent from the Environment Agency, to dispose of the water to surface waters. However, the different temperature of the waste water in relation to the surface water may have an impact on the ecology on the surface waters. It is likely that the Environment Agency will set a limit on the temperature of water that can be discharged. In urban areas, where there is a sewerage network, it may be possible to discharge the waste water stream to a sewer. If the waste water utility is able to accept the water, and its local hydraulic capacity is not exceeded, this can be a viable approach; however, the disposal charges payable to the waste water utility may significantly affect the economics of the system.

In surface disposal, it may be advisable to place a pressure-sustaining valve on the end of the system to maintain the piping full when the pump is not operating. Some designers prefer to simply place a motorised valve at this point in the system and interlock it with the pump (through an end switch). The distance from the building has some influence on the strategy used as the motorised valve requires a control signal and power source, whereas the pilot-operated valve does not.

Injection is more complex and costly but offers the certainty that the groundwater aquifer will not be adversely affected (known as 'aquifer decline') by the operation of the system over the long term since the water is recycled. Also the relative pump energy of the system is less since the system benefits from static recovery. This can be important when analysing the relative coefficient of system performance (COSP) of systems(23).

A typical consumptive system could operate with a COSP up to approximately 10, whereas a system with re-injection could achieve a COSP of approximately 100(24). Key issues are well design and well spacing. In theory, the only difference between a production and an injection well is the direction of flow. In practice, there are some differences in the design depending upon the type of aquifer penetrated. For wells completed in unconsolidated materials, and equipped with a screen, the screen area should be twice that used in the production well. The rule of thumb for injection wells is that the entrance velocity of



1 Finned tube coil
2 Fan scrolls
3 Filter
4 Fan motor
5 Auxiliary condensate pan
6 Coil connections
7 Return air opening
8 Discharge air opening
9 Water control valve

Figure 15 Typical fan coil heat exchanger(22)

Figure 16 Example of a fan coil heat exchanger (courtesy of Searle Manufacturing Co.)

the water through the screen openings (slots) should be limited to 0.013 $m \cdot s^{-1}$ whereas production wells are normally based upon 0.026 $m \cdot s^{-1}$ (19). This does not mean that a large diameter well is required in all cases. The reduced velocity could also be accomplished by screening more of the aquifer, particularly in the case of wells penetrating water table aquifers. For wells completed in fractured rocks, there is often no difference between the injection and production well design. Sealing is an important issue in injection wells; because it is likely that the water level in the well will be higher than the static water level when in operation, it is important that the seal (grout placed between the borehole and the outside of the casing) be carefully placed and that it extends from the top of the aquifer to the ground surface. This prevents the injected water from finding a path up around the outside of the casing to the surface.

Well spacing, or the distance required between the production and injection wells, is an important consideration. It is not necessary that the injection well be sited in such a way as to prevent any flow from the injection to the production well, just that any inter-well flow be sufficiently low that it arrives at the production well at a temperature close to the aquifer temperature. For unconsolidated aquifers, a summary of spacing information is shown in Figure 17(19).

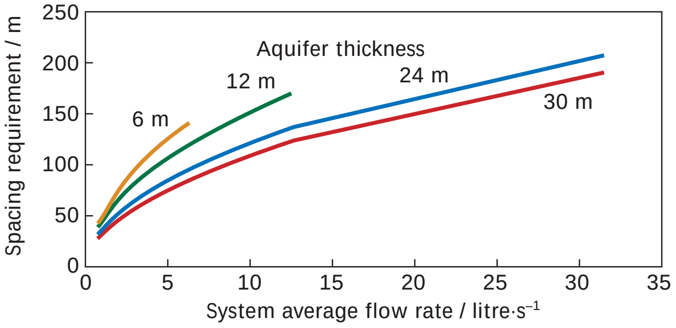


Figure 17 Minimum well spacing requirements(19)

Figure 18 illustrates connection of the system piping to the injection well. Of particular importance is the injection 'dip tube' in the well. Injected fluid should always be released below the static water level in the well so as to minimise the formation of bubbles. Bubbles entering the injection zone can impede water flow, as would an accumulation of particulate. The air release valve also helps to minimise the air in the injection well. The provision for pressure (or water level) monitoring is important in injection wells as a means of monitoring the performance of the well and any accumulation of particulate in the injection interval.

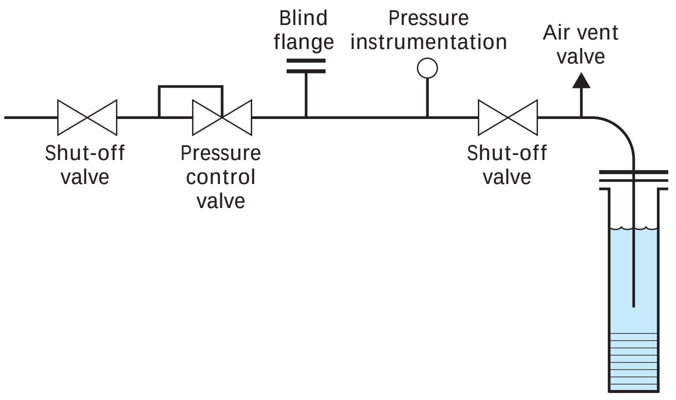


Figure 18 Injection well piping connections(19)

4 Comparison between groundwater and vapour compression cooling

In order to be viable, the groundwater cooling system must compare favourably with a conventional vapour compression system in terms of running cost, energy consumed and CO_2 emissions. The assumptions made and the results are shown in Table 2. The coefficient of system performance (COSP) is the useful cooling divided by the power needed to supply this, including ancillaries. The range of COSP for groundwater depends on pumping power; for deep boreholes with no static recovery, this is high (low COSP), for shallow water sources, or with static recovery, this is low (high COSP). This highlights the advantage of secondary use of clean deep borehole water, which offsets the cost of the static lift.

Table 2 Comparison between groundwater and vapour compression cooling

Characteristic	Groundwater cooling system	Vapour compression refrigeration
Cooling energy output (kW·h)	100	100
$\Delta\theta$ for groundwater (K)	5	N/A
C_p for water (kJ/kg K)	4.2	N/A
Mass of groundwater needed (kg)	17143	N/A
Volume of groundwater needed (m^3)	17.1	N/A
Cost of groundwater at 1.135 pence/m^3 (£)	17.1 × 0.01135 = 0.19	N/A
Nett COSP of cooling system	9.4 to 140.6(24)	2.79(25)
Energy consumption (kW·h)	(100/9.4) to (100/140.6) = 10.64 to 0.71	(100/2.79) = 35.84
Energy cost at £0.08/ kW·h (£)	(10.64 × 0.08) to (0.71 × 0.08) = 0.851 to 0.057	(35.84 × 0.05) = 1.79
Total running cost (£)	1.04 to 0.25	1.79
CO_2 emissions (assuming 0.43 kg CO_2/kW·h) (kg CO_2)	4.58 to 0.31	15.41

Table 2 indicates that the running cost per kW·h of groundwater cooling is between 0.14 and 0.58 of the cost of a vapour compression system. The energy consumption and CO_2 emissions per kW·h of groundwater cooling are around between 3.3 and 50 times lower than that of the vapour compression system. Other annual costs such as maintenance etc. are pertinent; much of the two competing systems are common (air cooling, chilled water circulation etc.), thus the running cost comparison is essentially between borehole and vapour compression water chiller. With time, these costs will become available in the public domain.

Capital cost comparison depends on whether an existing source is being adapted or whether a new borehole must be driven (costing perhaps £144 300 per 600 kW(26)) or a new chiller purchased (budget price £41 000 per 500 kW(27)). Each case requires individual assessment.

the water through the screen openings (slots) should be limited to 0.013 $m{\cdot}s^{-1}$ whereas production wells are normally based upon 0.026 $m{\cdot}s^{-1}$(19). This does not mean that a large diameter well is required in all cases. The reduced velocity could also be accomplished by screening more of the aquifer, particularly in the case of wells penetrating water table aquifers. For wells completed in fractured rocks, there is often no difference between the injection and production well design. Sealing is an important issue in injection wells; because it is likely that the water level in the well will be higher than the static water level when in operation, it is important that the seal (grout placed between the borehole and the outside of the casing) be carefully placed and that it extends from the top of the aquifer to the ground surface. This prevents the injected water from finding a path up around the outside of the casing to the surface.

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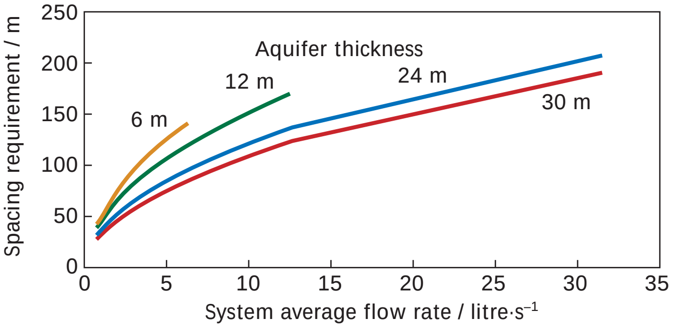

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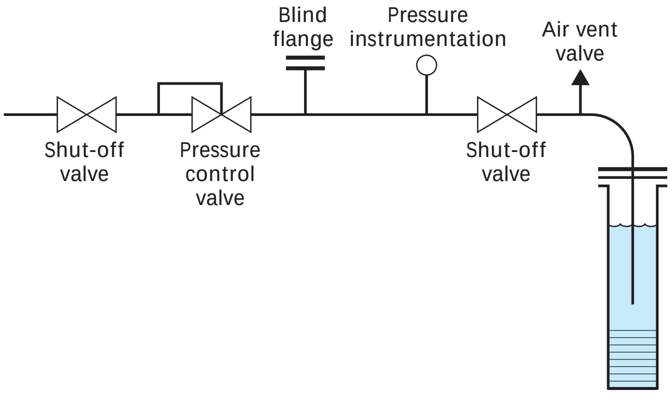

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Energy consumption (kW·h)	(100/9.4) to (100/140.6) = 10.64 to 0.71	(100/2.79) = 35.84
Energy cost at £0.08/ kW·h (£)	(10.64 × 0.08) to (0.71 × 0.08) = 0.851 to 0.057	(35.84 × 0.05) = 1.79
Total running cost (£)	1.04 to 0.25	1.79
CO_2 emissions (assuming 0.43 kg CO_2/kW·h) (kg CO_2)	4.58 to 0.31	15.41

Table 2 indicates that the running cost per kW·h of groundwater cooling is between 0.14 and 0.58 of the cost of a vapour compression system. The energy consumption and CO_2 emissions per kW·h of groundwater cooling are around between 3.3 and 50 times lower than that of the vapour compression system. Other annual costs such as maintenance etc. are pertinent; much of the two competing systems are common (air cooling, chilled water circulation etc.), thus the running cost comparison is essentially between borehole and vapour compression water chiller. With time, these costs will become available in the public domain.

Capital cost comparison depends on whether an existing source is being adapted or whether a new borehole must be driven (costing perhaps £144 300 per 600 kW(26)) or a new chiller purchased (budget price £41 000 per 500 kW(27)). Each case requires individual assessment.

Appendix A1: Environment Agency forms for application for consent

A1.1 Form WR32

Form WR – 32
Water Resources Act 1991 Section 32

ENVIRONMENT AGENCY

APPLICATION FOR CONSENT TO INVESTIGATE A GROUNDWATER SOURCE

This form should be used to apply for consent to construct/extend works to ascertain the presence, quality, quantity of water in underground strata and establish the effect of the proposed abstraction on other wells, boreholes, etc. or any inland waters.

Please read the notes before completing this form. Note especially that **(1) you must supply a clear map (preferably Ordnance Survey, and scale not less than 1:10,000) showing the location of the works you propose; (2) you will have to conduct a water features survey before we issue the consent; (3) in some cases we may require you to provide more information, possibly including an environmental report; (4) the issue of a consent will not necessarily lead to the granting of an abstraction licence.**

FOR ENVIRONMENT AGENCY USE	**Application No.**	**Consent Reference No.**

1. Applicant details

Name of applicant			
Address			
Telephone		Fax	
		Email	
Contact person/ agent/adviser			
Address			
Telephone		Fax	
		Email	

Note: (1) Consents will be issued to the applicant - the person who will be legally bound by any consent granted, we will however, deal with the person you have named as contact/agent/adviser, unless you request otherwise.
(2) This form should be completed when pump and treat schemes are undertaken. If extra space is required please attached additional sheets to this form.
(3) Dewatering activities are currently excluded from the consent process.

courtesy of the Environment Agency

2. Proposal (please tick)

We need to know what you intend to do and why you want the water.

2.1 Do you wish to;	construct new works	
	extend existing works	

2.2 Are your works a;	borehole/well	
	lagoon/seepage reservoir	
	catchpit/spring	
	Other (eg well points)	
	If other, please specify;	
2.3 What will the water be used for?	Agriculture (other than spray irrigation)	
	Spray Irrigation	
	Private Water Supply	
	Public Water Supply	
	Industrial	
	Other	
	If other, please specify;	

2.4 If you have applied for, or hold any other associated permissions, please give reference numbers and brief details (these could include planning permissions, land drainage or discharge consents etc).

3. Proposed rates of abstraction

Annual rate:		cubic metres per year
Max. daily rate		cubic metres per day
Max. hourly rate		cubic metres per hour

courtesy of the Environment Agency

Give brief details and justify your proposed abstraction rates e.g. number of stock, area of crops to be grown, industrial process requirements, if public or private water supply, where it will be used, number of properties supplied etc.

4. Location and construction of works

Site Address:		
Who owns and (if different) who occupies the land where the works will be carried out?		
Name of water bearing strata (e.g. Chalk, Triassic Sandstone etc)		
National Grid Reference(s), preferably eight figure, for each abstraction point. Please also mark clearly on your map.	‘A’	Marked on map as (‘A’, ‘B’, ‘C’ etc.):
	‘B’	
	‘C’	
Specify depth (metres), diameter (millimetres) of well, borehole etc. If seepage reservoir, give dimensions in metres.	Depth (m)	Diameter (mm) or dimensions (m)
	‘A’	‘A’
	‘B’	‘B’
	‘C’	‘C’
Give details of existing or proposed lining (type, depth etc.).	‘A’	
	‘B’	
	‘C’	
Specify proposed construction method;		
Specify details of drilling flush e.g. air, mud and slurry pits		

courtesy of the Environment Agency

5. Development of the source

How do you intend to develop your borehole's yield?	Pumping	☐
	Acidisation	☐
	Other treatments	☐
	Specify any chemicals used;	
How will you dispose of products/waste from this operation?		

6. Discharge of water during test pumping

Where do you plan to discharge during the test? (Mark your discharge point on your map) Please tick one option	Coastal waters of estuary	☐
	Foul Water Sewer	☐
	Surface Water Sewer	☐
	Watercourse (ditch, stream, canal, river)	☐
	Onto or into land (e.g. soakaway)	☐

Application

I/we apply to the Environment Agency for consent to investigate a groundwater source. I/we declare to the best of my knowledge the statements made in the above consent application form, including the map and any accompanying sheets, are true.

Applicant's signature	Print name
Authorised on behalf of	Date

courtesy of the Environment Agency

A1.2 Form WR32-GSHP 1

GSHP proposal information form

Supplement to WR32

Site Name:	Site Location NGR:
Site Address:	
Agent/Consultant:	Agent/Consultant contact details:
On behalf of:	
General description of system:	
Open or closed loop:	Number of abstraction and discharge boreholes:
Proportion of heat requirement to be supplied:	Proposed Delta T:
Net heating / cooling (Annually and over building life cycle):	Abstraction and Discharge rates proposed:
Description of modelling undertaken:	
Environmental Impact Assessment undertaken?	Feasibility Study undertaken?

courtesy of the Environment Agency

Description of Operating Strategy:
Have other sources of renewable energy been identified for this site:
Additional Information:
You can include further information on: Location of the discharge, Nature/origin/temperature/volume/rate of discharge, Design and construction of the discharge outlet, Need for any in-situ monitoring equipment, Need for sampling facilities, Recording and Reporting). Are there any other GSHP systems operating locally?

Please append site maps, methodology statements, and other supporting information when submitting this form.

This form will be used for an initial assessment of your proposal. Giving as much detail as possible will ensure that any delays in the assessment process are minimised. This is an interim form to be used until Environment Agency policy and guidance is formally issued.

courtesy of the Environment Agency

A1.3 Form WR31

FORM WR – 31
Water Resources Act 1991 Section 32

ENVIRONMENT
AGENCY

GROUNDWATER INVESTIGATION

A Guide to Consents Issued Under Section 32 Water Resources Act 1991

Introduction

Groundwater - water in pores, fissures and voids in rocks underground - is a vital natural resource. The Environment Agency has a duty to conserve and manage it, and controls abstraction from it by a licensing system.

Applying for an abstraction licence may be a lengthy and expensive process. So, the law allows investigation work without the need for a full licence. This enables you to find out what water may be available and whether it is suitable for your needs. Instead of a full licence, we issue consents (under Section 32 of the Water Resources Act 1991) which limit abstraction and restrict work to determining:

- The presence of water in underground strata
- The quantity or quality of such water
- The effects of abstracting it on other water sources

Thus, you do not need a full licence, but you must have our consent, for example to drill and test pump a borehole or well, or to excavate and pump a catchpit or a seepage-fed lagoon. **It is an offence to do so without such consent**.

How to apply for a consent

Complete Form WR - 32 ("Application for Consent to Investigate a Groundwater Source"). The applicant, who will be the person to whom we issue the consent, will normally own or occupy the land where the work is to take place. However, the well driller or other contractor will often help complete the form, as it requires certain technical information. We will accept applications signed by the driller, contractor or other agent for the named applicant.

Our job is to make sure your investigations are unlikely to have adverse effects on other water sources and features or the general environment. When we acknowledge your application, we shall therefore require you first to carry out a **SURVEY** of relevant features in the area. This will usually be within a specified radius of the proposed borehole etc. When the expected environmental impacts are likely to be more than negligible, there will also need to be an **environmental appraisal** of your proposals. You will need to produce an appropriate environmental report.

What the consent says

Providing the survey has been properly done, we will normally issue a consent (Form WR - 37). The consent contains several conditions. You must comply with these fully: if not, we may withdraw the consent. We also may withdraw or modify it if the works have effects which we did not anticipate, or if it is otherwise reasonable to do so. Please remember that our overriding duty is to manage all water resources properly.

In particular, the consent will require you to do certain **PUMPING TESTS**. You should also conduct a short test to prove the source yield, ie. how the water level draws down at a given pumping rate and whether the source can produce a supply which is adequate for your needs. The information will help you to select the best abstraction method eg. correct type of pump and the depth at which to set it.

courtesy of the Environment Agency

Major developments and developments close to environmentally sensitive sites will need testing over a longer period to determine the effects of abstraction on existing wells, boreholes, springs, streams and other environmental features in the vicinity. We will advise you what measurements etc. to take during the associated monitoring programme.

Water sampling during test pumping will also show whether the water is of suitable chemical or bacteriological quality for your intended use, or whether it will need treatment. It is your responsibility to ensure that the water abstracted is fit for your particular purpose.

The consent will run for a limited time. It will also specify:

- Permissible dimensions of the works;
- Other required details of construction (eg. casing, grouting);
- Monitoring boreholes (if any) to be sunk;
- Where water should be discharged during test pumping;
- Other special conditions, such as testing only during the summer.

The consent also makes it clear that you must:

- Be concerned about possible pollution from the proposed works (you may need to liaise with our Environment Management staff). This will include the correct disposal of wastes arising from the construction and development of the works;
- Notify us at all key stages in your works programme;
- Inform British Geological Survey (BGS) before starting to sink boreholes which will be deeper than 15 metres (approximately 50 feet);
- To notify the HSE within 30 days of (or any time before) commencement of borehole drilling operations in ‘Coal Mining Areas’.
- Be responsible for all aspects of the works, including any damage that may result;
- Keep clear and accurate records and let both us and BGS have this information
- Allow us (and BGS) access to the site to inspect the works as and when required.

No guarantee of success

Drilling a borehole, developing a well, or excavating a catchpit or seepage-fed lagoon does not guarantee a supply. The yield may not be adequate for your purposes. Abstraction may be difficult due to construction problems within the source, or the quality of the water may be unsuitable and impracticable to treat.

Even if the source does yield well, this does not mean we can grant you an abstraction licence. For example, the test pumping may show that abstraction will have unacceptably adverse effects on other sources or environmental features. **Also, due to water shortages, there may be general restrictions on granting licences in the area. If this is the case, we will inform you at the earliest opportunity, to save you unnecessary expense**.

Take advice before construction/development/drilling

Drilling etc. is expensive. A professional adviser can suggest where best to develop a source or whether it is worth doing so at all. Unless you are fully confident of your plans, we suggest you take such advice. We cannot give it to you ourselves, but may be able to provide a list of names of firms and people who can help.

You must also be sure that the borehole is drilled with correct materials, recognised by the well drilling industry and in compliance with *Well Construction Specification for the Water Industry*[1].

Environmental Report (ER) and planning permission

Although the impact of the Section 32 works will often be negligible, the proposed licensed abstraction that follows may well have environmental effects which we must assess before we can grant a licence. If so, we may need further environmental information, possibly in the form of an environmental report (ER) from you before we can consider your licence application. It is likely that Information derived from your pumping test will form an integral part of the report. It is a good idea to use the time when you are doing the Section 32 works to prepare this.

courtesy of the Environment Agency

Sometimes the Section 32 works, or works related to the licensed abstraction, will require planning permission (possibly involving environmental assessment) from the planning authority. You should check your own Authority's requirements and let us know what they need. We are happy to liaise with them, and you, to avoid unnecessary duplication of effort.

Quality of work and presentation of results

Unless directed otherwise, we will expect you to carry out the works following BS 6316 (1992) *Test Pumping of Water Wells*[2]. It will also be easier, and therefore quicker, for us to process any future licence application if you present and analyse the results from the Section 32 works to a high standard.

Questions?

If you want further information, or have any queries, please contact:

Stephen Barrow
Hydrogeologist
Thames Region, South East Area
Environment Agency
Swift House
Frimley Business Park
Frimley
Surrey GU16 5SQ

Tel 01276 454460

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[1] This is put out as a separate supplement to Civil Engineering Specification for the Water Industry, Second Edition, 1985. Copies available from WRc Plc, Henley Road, Medmenham, Marlow, Bucks SL7 2HD. Tel: (01491) 571531. www.wrcplc.co.uk

[2] Copies available from BSI, 389 Cheswick High Road, London, W4 4AL.. Tel: (020) 89969000. www.bsi-global.com

courtesy of the Environment Agency

Appendix A2: Glossary of terms

Aquifer

A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.

Borehole

A man-made hole in the ground through which groundwater may flow or be pumped to the surface.

Clog

A clog in plumbing is a blockage such as hairballs, grease or other clumping materials. It is generally removed by use of a plunger, plumbing auger or chemical drain cleaner.

Corrosion

The deterioration of essential properties in a material due to reactions with its surroundings. In the most common use of the word, this means a loss of an electron of a metal due to a reaction with water or oxygen. Weakening of iron due to oxidation of the iron atoms is a well-known example of electrochemical corrosion, commonly known as rust. This type of damage usually affects metallic materials, and typically produces oxide(s) and/or salt(s) of the original metal.

Drawdown

The difference between static water level (SWL) and pumping water level (PWL) of an aquifer.

Fouling

Generally defined as the accumulation of unwanted materials on the surfaces of processing equipment, fouling has been recognised as a nearly universal problem in design and operation and affects the operation of equipment in two ways. First, the fouling layer has a low thermal conductivity which increases the resistance to heat transfer and reduces the effectiveness of heat exchangers. Secondly, as deposition occurs, the cross-sectional area is reduced, which causes an increase in pressure drop across the apparatus. The retardation of heat transfer caused by fouling in heat exchangers is the prime reason for the increase in energy use, maintenance, and operational cost.

Groundwater

All water below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

Hydraulic conductivity

This is a measure of the ability of the rock medium to transmit water and its value is different for different rocks. Values of hydraulic conductivity are high for sands and gravels and low for clays.

Hydraulic gradient

The slope of the water table.

Hydrostatic pressure

The pressure at a given depth in a static liquid is a result the weight of the liquid acting on a unit area at that depth plus any pressure acting on the surface of the liquid.

Impeller

A rotor inside a tube or conduit to increase the pressure and flow of a fluid.

Impellers in pumps

A rotating component of a pump, usually made of iron, steel, aluminum or plastic, which transfers energy from the motor that drives the pump to the fluid being pumped by forcing the fluid outwards from the center of rotation.

Landslip

A slide of a large mass of dirt and rock down a mountain or cliff.

Permeability

The rate at which water flows through an aquifer.

Piezometric level

Confined groundwater is usually under pressure because the confining beds prevent water rising to its natural level. If a wall penetrates the confining layer, water will rise to a level known as the piezometric level. If the piezometric level is above ground level, the well discharges as a flowing well, an artesian well, or a spring.

Porosity

The volume of water an aquifer holds or stores.

Precipitation

The formation of a solid in a solution during a chemical reaction. When the chemical reaction occurs, the solid formed is called the precipitate. This can occur when an insoluble substance, the precipitate, is formed in the solution due to a reaction or when the solution has been supersaturated by a compound. In most situations, the solid falls out of the solute phase, and sink to the bottom of the solution; though it will float if it is less dense than the solvent, or form a suspension.

Pumping water level (PWL)

The level to which the water in a well will normally drop when the pump is started.

Saturated thickness

The vertical thickness of the hydrogeologically defined aquifer in which the pore spaces are filled (saturated) with water.

Saturated zone

The area below ground in which all interconnected openings within the geologic medium are completely filled with water.

Sieve analysis

A practice or procedure used to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. It can be used for any type of non-organic or organic granular round materials including sands, clays, granite, feldspars, coal, soil, and a wide range of manufactured powders. It can also be used for grains and seeds.

Specific capacity

The value achieved by dividing flow rate by drawdown.

Specific yield

The volume of water an aquifer yields when it drains naturally or is pumped.

Specific retention

The volume of water retained in an aquifer against the force of gravity.

Static water level (SWL)

The level at which the water stands in a well under non-pumping conditions. This level is indicative of the water table level in unconfined aquifers or the piezometric level in a confined (or artesian) aquifer.

Thermal mass

In the most general sense, this is any mass that absorbs and holds heat. In the architectural sense, it is any mass that absorbs and stores heat during sunny periods when the heat is not desirable in the living space of a building, and then releases the heat during overcast periods or during the night, when the heat is desirable.

Transmissivity

The ability of an aquifer to transmit water through its entire thickness.

Turbulence

In fluid dynamics, turbulence or turbulent flow is a flow regime characterised by chaotic, stochastic property changes. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. Flow that is not turbulent is called laminar flow. The dimensionless Reynolds number characterises whether flow conditions lead to laminar or turbulent flow; e.g. for pipe flow, a Reynolds number above about 2300 means that the flow will be turbulent.

Water table

The surface where the water pressure is equal to atmospheric pressure. It is the upper level of groundwater. Water that is above the water table will drain downwards; a spring forms where the water table meets the surface of the ground. The water table rises and falls in response to rainfall and the rate at which water is extracted, for example for irrigation and industry.

Appendix A3: Useful websites and sources of information

A3.1 Websites

British Drilling Association

The Association aims to improve efficiency in the drilling industry.

— http://www.britishdrillingassociation.co.uk/

British Geological Survey

The Groundwater Systems and Water Quality Programme of the British Geological Survey undertakes both core survey research and commissioned hydrogeological investigations.

— http//www.bgs.ac.uk/

British Geological Survey GeoReports

GeoReports provide an early indication of the condition of the ground, i.e. its geology, hydrogeology and any related hazards (such as subsidence or radon). GeoReports identify what information may already be held for the site in the national geological archive and provide access to expert advice from BGS scientists with knowledge of the local area.

— http://shop.bgs.ac.uk/GeoReports/

British Hydrological Society

The Society aims to promote interest and scholarship in scientific and applied aspects of hydrology and to foster the involvement of its members in national and international activities.

— http://www.hydrology.org.uk/

British Standards Institution

BSI provides standards that represent and support the needs of business and society in the UK and worldwide.

— http://www.bsi-global.com/

British Water

British Water represents the collective interests of the British water and waste water industry at home and overseas.

— http://www.britishwater.co.uk/

Centre for Ecology and Hydrology

The Centre for Ecology and Hydrology is the UK centre of excellence for research in the terrestrial and freshwater environmental sciences.

— http://www.ceh.ac.uk/

Sieve analysis

A practice or procedure used to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. It can be used for any type of non-organic or organic granular round materials including sands, clays, granite, feldspars, coal, soil, and a wide range of manufactured powders. It can also be used for grains and seeds.

Specific capacity

The value achieved by dividing flow rate by drawdown.

Specific yield

The volume of water an aquifer yields when it drains naturally or is pumped.

Specific retention

The volume of water retained in an aquifer against the force of gravity.

Static water level (SWL)

The level at which the water stands in a well under non-pumping conditions. This level is indicative of the water table level in unconfined aquifers or the piezometric level in a confined (or artesian) aquifer.

Thermal mass

In the most general sense, this is any mass that absorbs and holds heat. In the architectural sense, it is any mass that absorbs and stores heat during sunny periods when the heat is not desirable in the living space of a building, and then releases the heat during overcast periods or during the night, when the heat is desirable.

Transmissivity

The ability of an aquifer to transmit water through its entire thickness.

Turbulence

In fluid dynamics, turbulence or turbulent flow is a flow regime characterised by chaotic, stochastic property changes. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and velocity in space and time. Flow that is not turbulent is called laminar flow. The dimensionless Reynolds number characterises whether flow conditions lead to laminar or turbulent flow; e.g. for pipe flow, a Reynolds number above about 2300 means that the flow will be turbulent.

Water table

The surface where the water pressure is equal to atmospheric pressure. It is the upper level of groundwater. Water that is above the water table will drain downwards; a spring forms where the water table meets the surface of the ground. The water table rises and falls in response to rainfall and the rate at which water is extracted, for example for irrigation and industry.

Appendix A3: Useful websites and sources of information

A3.1 Websites

British Drilling Association

The Association aims to improve efficiency in the drilling industry.

— http://www.britishdrillingassociation.co.uk/

British Geological Survey

The Groundwater Systems and Water Quality Programme of the British Geological Survey undertakes both core survey research and commissioned hydrogeological investigations.

— http//www.bgs.ac.uk/

British Geological Survey GeoReports

GeoReports provide an early indication of the condition of the ground, i.e. its geology, hydrogeology and any related hazards (such as subsidence or radon). GeoReports identify what information may already be held for the site in the national geological archive and provide access to expert advice from BGS scientists with knowledge of the local area.

— http://shop.bgs.ac.uk/GeoReports/

British Hydrological Society

The Society aims to promote interest and scholarship in scientific and applied aspects of hydrology and to foster the involvement of its members in national and international activities.

— http://www.hydrology.org.uk/

British Standards Institution

BSI provides standards that represent and support the needs of business and society in the UK and worldwide.

— http://www.bsi-global.com/

British Water

British Water represents the collective interests of the British water and waste water industry at home and overseas.

— http://www.britishwater.co.uk/

Centre for Ecology and Hydrology

The Centre for Ecology and Hydrology is the UK centre of excellence for research in the terrestrial and freshwater environmental sciences.

— http://www.ceh.ac.uk/

Chartered Institution of Water and Environmental Management

An independent multi-disciplinary professional and examining body for scientists, engineers, other environmental professionals, students and those committed to the sustainable management and development of water and the environment.

— http://www.ciwem.org/

Contamlinks

Contamlinks is an information portal for those involved with contaminated land and 'brownfield' redevelopment, such as landowners, developers, regulators, consultants, lawyers and the public.

— http://www.contamlinks.co.uk/

Department of Environment, Food and Rural Affairs

Responsible for all aspects of water policy in England, including water supply and resources, water quality, flood management, the water industry and water conservation.

— http://www.defra.gov.uk/

Environment Agency

The leading public body for protecting and improving the environment in England and Wales. Activities range from influencing Government policy and regulating major industries nationally, through to day-to-day monitoring and clean-up operations at a local level.

— http://www.environment-agency.gov.uk

Environmental and Heritage Service

An agency within the Department of the Environment Northern Ireland which takes the lead in advising on, and implementing, the Government's environmental policy and strategy. It aims to conserve, protect and, where possible, improve the aquatic environment.

— http://www.ehsni.gov.uk/

Environmental Data Services

An independent publisher with a range of on-line products for environmental consultants and managers, policy makers, regulators, lawyers, campaigners and lobbyists worldwide, including the *ENDS Report*.

— http://www.ends.co.uk/

European Commission: Environment: Water

This site provides further information on the different pieces of water legislation (and related policies) in the European Union including the Water Framework Directive, Nitrates Directive and Drinking Water Directive.

— http://ec.europa.eu/environment/water/index_en.htm

Geo-Heat Centre

The Geo-Heat Centre's resources are available to the public, through United States Department of Energy (USDOE) grants. Information developed through first-hand experience with hundreds of projects and through extensive research is provided to individuals, organisations and companies involved in geothermal development.

— http://geoheat.oit.edu/

Geological Society

The aim of the Geological Society's Hydrogeology Group is to advance the study and practice of hydrogeology by holding meetings and encouraging education and research.

— http://www.geolsoc.org.uk/

Groundwater Modellers' Forum

The Groundwater Modellers' Forum provides an opportunity for the UK groundwater modelling community to exchange experience and knowledge on practical and scientific issues; explore methods and agree best practice on groundwater modelling; forge links with academia; and make recommendations on best practice and future R&D work.

— http://www.groundwateruk.org/html/modelling/home.htm

International Association of Hydrogeologists

A scientific and educational organisation whose aims are to promote research into and understanding of the proper management and protection of groundwater for the common good throughout the world.

— http://www.iah.org/

International Groundwater Resources Assessment Centre

The International Groundwater Resources Assessment Centre is a Dutch-based, UNESCO and WMO initiative which aims to contribute to the assessment of the global groundwater resources to encourage and enhance the conjunctive and sustainable utilisation of both groundwater and surface water and elucidate the impact of groundwater on other ecosystems of the Earth.

— http://www.igrac.nl/

National Ground Water Association

A US-based organisation that aims to enhance the skills and credibility of all groundwater professionals, develop and exchange industry knowledge and promote the ground water industry and understanding of groundwater resources.

— http://www.ngwa.org/

Scottish Environment Protection Agency

Responsible for the protection of the Scottish environment including the water environment and have a duty to control discharges to surface water, tidal water to a three mile limit and groundwater.

— http://www.sepa.org.uk/

Soil and Groundwater Technology Association

A non-profit making association of member organisations drawn from UK companies which aims to actively address technical challenges associated with the management of landholdings which are potentially contaminated.

— http://www.sagta.org.uk/

Sustainable Development Commission

The UK Government's independent advisory body on sustainable development.

— http://www.sd-commission.org.uk/

UK Groundwater Forum

The aims of the UK Groundwater Forum are to raise awareness of groundwater and the role it plays in: supporting the environment and in water supply; providing information on groundwater, targeted at specific groups such as decision makers, policy makers and schoolchildren; improving groundwater education in schools by providing educational resources; promoting careers in groundwater-related professions; producing and disseminating information and facilitating discussion on topical groundwater issues within the water and environment community; and providing a means for those in the water and environment community to share information.

— http://www.groundwateruk.org/

Water Services Regulation Authority (OFWAT)

The body responsible for making sure that the regulated water and sewerage companies in England and Wales give a good-quality, efficient service at a fair price.

— http://www.ofwat.gov.uk/

Water Watch

'Water Watch' is a component of the National Hydrological Monitoring Programme (NHMP) which is undertaken jointly by the Centre for Ecology and Hydrology, Wallingford, and the British Geological Survey. It provides monthly reports on hydrological and hydrogeological conditions throughout the UK.

— http://www.ceh.ac.uk/data/nrfa/water_watch.html

WaterUK

Water UK represents UK water and waste water service suppliers at national and European level. Provides links to all water companies.

— http://www.water.org.uk/

Well Drillers Association

The Well Drillers Association acts as a forum for interested parties in the design and construction of water wells and boreholes. Provides a list of companies who can drill water supply boreholes, maintain wells and install pumps.

— http://www.welldrillers.org.uk/

A3.2 Useful contacts

British Standards Institution

British Standards Institution
389 Chiswick High Road
London
W4 4AL

Tel: 020 8996 9001

UK environment agencies:

England and Wales:

Environment Agency
National Customer Contact Centre
PO Box 544
Rotherham
S60 1BY

Tel: 08708 506506

Scotland:

Scottish Environment Protection Agency
SEPA Corporate Office
Erskine Court
Castle Business Park
Stirling
FK9 4TR

Tel: 01786 457700

Northern Ireland:

Environment and Heritage Service
Water Management Unit
17 Antrim Road
Lisburn
BT28 3AL

Tel: 028 9262 3100

Appendix A4: Groundwater systems installed in the London area

Table A4.1 Comparison of groundwater cooling systems in London

Characteristic	Installation					
	Portcullis House	City Hall	Queen's Gallery	Sadler's Well Theatre	Zetter Hotel	Royal Festival Hall
Location	Bridge street Westminster London SW1A 2LW	The Queen's Walk London SE1 2AA	Buckingham Palace Buckingham Palace Road London SW1A 1AA	Rosebery Avenue London EC1R 4TN	86–88 Clerkenwell Road London EC1M 5RJ	Southbank Centre Belvedere Road London SE1 8XX
Year system completed	2001	2001	2002	1998	2004	2006
Buffer tank	2 × 165 000 litres	None	None	None	None	None
Cooling capacity (kW)	765	1000	700	500	47	1200
Number of boreholes	2	2	1	1	1	2
Distance between boreholes (m)	30	50	N/A	N/A	N/A	100
Borehole diameter (mm)	300	200	438	200	200	300
Depth of borehole (m)	150	100	150	200	130	140
Pump set max. rating (kW)	2 × 56	2 × 60	56	30	5	2 × 64
Filtration	Basket strainer	Basket strainer	2 × 400 micron cartridge filters	Basket strainer	Basket strainer	Basket strainer
Water extraction rate (litre/s)	22	30	22	12	1.4	25
Water extract temp. (°C)	13.5	12–14	13.4	11–12	13–14	14
Heat exchanger:						
— type	Plate, 150 × 3	Plate	Plate	Plate	Plate	Plate
— manufacturer	Chem Firm	—	Alfa Laval	—	Alfa Laval	—
— model	—	—	M15-BFM8	—	—	—
Extra use of water	Serving toilet cisterns and pre-wash plates	Toilets, trees	Lake fill in gardens	WCs, hand basins, showers, bottled water for sale	WCs, bottled water for sale	Toilets, cleaning the landscape
Discharge of water used	Sewer	River Thames; sewer if used in grey water	Sewer	Sewer	Sewer	River Thames
Water discharge temp. (°C)	19–21	20–22	22–23	22	22	20
Failures and problems	One pump not working; sand	None as yet	None as yet	None as yet	None as yet	None as yet