Adding Energy Value to Res

The use of wet restored mineral workings for energy

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Photo courtesy CEMEX

With landfilling being lost as a restoration option, most mineral working restoration plans include a proportion of open water or wetland environment. Such wet restoration may be popular with local residents and environmentalists; and well-planned lake environments create varied and important wetland habitats for many species and recreation facilities for the nearby population. Artificial lakes may also provide a magnet for commercial and residential developments around the edges of the excavation.

While wet restoration may be attractive to third parties, those parties are often unwilling to pay hard cash for the aesthetic value of the restored void. The flooded pit can, therefore, remain economically sterile from the point of view of the minerals operator. Indeed, before transferring ownership for a nominal sum to a wetland trust or local authority, the minerals operator may need to underwrite management costs for a substantial future period.

By their nature many mineral workings are in remote areas and incentives are required to attract developers to the restored sites. It must, therefore, be in the operator's interest to consider any option which adds real economic value to the flooded excavation.

Flooded workings as water and energy resources

It has long been recognized that flooded minerals workings can be regarded as enormous groundwater wells. As such, they can potentially represent sustainable sources of high-quality groundwater. Indeed, gravel pits, such as Heron Lake at Wraysbury, near London, have been test-pumped by water utilities as reserve public water supplies.

What is less well recognized is that any large body of water is also an enormous reservoir of reliable and sustainable environmental heat and coolth. Thus, a flooded quarry represents a very significant energy source. This energy source can be used to attract commercial and residential development. Such businesses increasingly require low-carbon energy sources to overcome planning restrictions and buildings regulations. There exists, therefore, a potential customer base for low-carbon space heating and cooling around restored mineral workings.

The energy locked into a wet restoration can be extracted using a ground-source heat pump (GSHP), which gives the minerals operator or site owner the potential to support a district heating/cooling utility and to convert an environmentally valuable but financially sterile asset into a source of revenue, without impacting on the environmental value.

Heat pumping

Consider, for example, a large flooded gravel pit surrounded by a commercial office development. Such offices typically have a

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significant demand for cooling. Fortunately, the gravel pit contains thousands of cubic metres of groundwater that typically has a constant year-round temperature of 10–11°C (or even lower in some cases). This water is a resource that has economic value: it can be pumped around a network of heat-exchange elements in the building, absorb the building's waste heat and provide air-conditioning.

Natural water is not only a source of coolth, it is also a source of heat. Water at 10°C cannot be directly used for space-heating: a device is needed to 'concentrate' or 'upgrade' the low-temperature environmental heat to useful 'high-temperature' heat. This device is called a heat pump. In simple terms, it is an unobtrusive humming white box that uses a modest quantity of electricity to power a compression-expansion cycle of refrigerant. One side of the heat pump is coupled to the low-temperature source of heat (the water in a wet restoration), while the other side supplies a waterborne or airborne space-heating system with heat at between 35°C and 55°C.

Of course, this is not a free ride: electrical energy is used to pump heat from a low to a high temperature, but the quantity of useful heat delivered can be around four times the amount of electrical energy consumed. In other words, while one quarter of the heat delivered is derived from the electrical energy input, three quarters is free, carbon-neutral heat sucked out of the gravel pit. The concept of ground-source heat pumping (GSHP) has grown dramatically during the past six years in the UK, largely because:

- GSHP can reduce running costs of space heating and cooling compared with conventional systems.
- GSHP can reduce carbon emissions by around 50% compared with the most efficient gas heaters.
- GSHP systems may be eligible for government subsidies and attractive Enhanced Capital Allowances on corporation tax.
- GSHP can ease the path of new developments through the planning process – being classed as renewable energy.

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GSHP can transform what many regard as a scar on the landscape (an abandoned mineral working) into a source of green energy.

How much heat can be obtained?

Because the heat transfer processes in a lake or flooded gravel pit are rather complex, it can be difficult to establish reliable rules of thumb for the amount of heat available. However, Banks[1] and Kavanaugh & Rafferty[2] imply that if a flooded mineral working is more than 3m deep, it is usually possible to install at least 1kW of heating and/or 2kW of cooling capacity for every 100m^2 of lake area. The heat extracted is ultimately replenished by gains in solar or atmospheric energy being absorbed by the lake. In the case of cooling, the 'dumped' heat is lost by additional radiative, convective or evaporative losses from the lake area.

In many cases the amount of heating and cooling available will be superior to the figures quoted above. This will particularly be the case if there is no temperature-sensitive ecology in the lake, or if there is significant surface water or groundwater through flow. Indeed, any water through flow continuously replenishes the lake's heating and cooling resource and each litre per second should add at least 5kW (and maybe up to 25kW) to the available heating/cooling capacity. The exact amount of heating/cooling available from a flux of water depends on:

- — whether a heat pump is used or whether the water is simply used for passive cooling
- — what magnitude of temperature change is environmentally acceptable.

Thus, a gravel pit measuring 100m x 100m (10,000m^2) with 4 litres/s of groundwater through flow should be able to supply at least 100 x 1kW + 4 x 5kW = 120kW of heat (and potentially considerably more). This is enough to support around 17 modern houses. How many 100m x 100m gravel pits do you know, and how many are much bigger than this?

The mathematical model described below (see 'Calculating the resource and the impact') would appear to verify that this rule of thumb estimate is very reasonable and, indeed, may tend to underestimate the true potential resource.

Pie in the sky?

Several GSHP systems based on mineral workings and lakes are operating in the UK at present:

- In Gloucestershire, a 300kW GSHP system based on the water contained in the flooded gravel workings of the Cotswold Water Park has, since 2003, been providing heating and cooling to the visitor centre and reportedly saves 50 tonnes of CO_2 emissions annually, compared with conventional technology.
- In Nottinghamshire, a 5MW (5,000kW) GSHP system supplies a hospital with heating and cooling using the water contained in Kings Mill Reservoir, a large former mill pond.

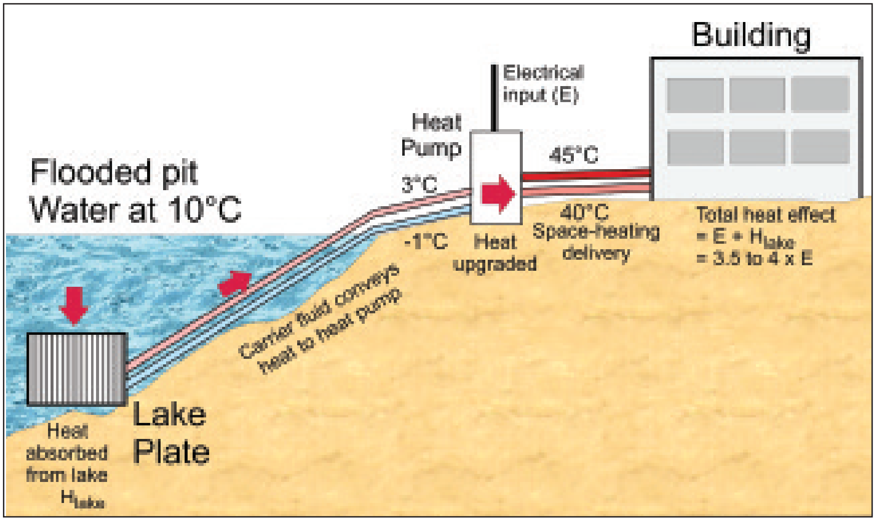


Fig. 1. Conceptual diagram of a closed-loop heat-pump system employing a lake plate

How to do it?

There are two fundamentally different ways of extracting heat from a flooded mineral working. In an open-loop system, water is physically pumped out of the lake via an intake. The water enters a heat exchanger coupled to a heat pump. The heat exchanger 'sucks' heat from the water for use in a building. The resulting cooled water can then be discharged back to the excavation (at some distance from the intake). Such a system is simple and requires relatively few groundworks in the lake itself. The potential drawbacks include:

- — the possibility that the heat exchanger will be fouled by debris entering the intake, or by biofouling
- — the requirement for an abstraction licence/discharge consent to be obtained from the Environment Agency (although this is generally not a problem, as the system does not consume water or add contaminants, but simply changes its temperature)
- — limited efficiency at low water temperatures in winter.

An alternative system which avoids these drawbacks is a so-called closed loop. Here, some form of heat exchanger is placed on the bed of the pit or within the water column. A chilled carrier fluid (typically an anti-freeze solution which allows the system to continue operating even at sub-zero temperatures) is circulated through the heat exchanger. The fluid absorbs heat from the lake water and carries it back to the heat pump. No lake water enters the system (removing the debris/biofouling concern) and no abstraction licence is necessary (no water is removed from the lake). The lake heat exchanger can be an anchored array of coiled polyethylene piping (a lake loop) or a specially constructed stainless steel heat exchanger known as a lake plate (fig. 1).

What about the environmental impact?

The extraction of heat or dumping of waste heat from air-conditioning will change the temperature of the lake. This can, in turn, affect the ecology of the lake. It can also affect the chemistry and the physical stratification of the lake (many lakes have a temperature stratification demarcated by a thermocline). If the guidelines (wattage per square metre) presented above are adhered to, the impact on temperature and ecology should be minimal. Even with larger heat abstraction rates, any impact may still be acceptable.

Conflict with recreational activities should also be minimal, provided that obvious physical conflicts are avoided (snagging of boat anchors, entanglement of scuba-divers in the lake loop etc) by clear demarcation of the heat-exchange area.

A cautionary note on stratification and chemistry

Some lakes and flooded mineral workings are relatively uniform in terms of their chemical and thermal composition. Others may have a very distinct thermal stratigraphy, with a summer thermocline separating a warm top-layer of water from a cold, underlying bottom layer. This may be an advantageous situation if cold water from below the thermocline can be used to provide efficient cooling to a building, with the waste heat from the building being rejected back to the lake above the thermocline.

Occasionally, the lake may be chemically stratified as well as thermally stratified. For example, rotting vegetation may accumulate on the lake bed and create a chemically reducing environment, where oxygen is absent and where the water may contain solutes such as hydrogen sulphide. In contrast, the upper portion of the lake may be oxygenated and support a variety of aquatic life. If waste heat from a building is rejected back to the lower, chemically reduced layer, there is a risk that the water may warm up and become less dense, and that the stratigraphy of the lake may 'overturn', bringing the oxygen-deficient water to the surface, together with its cargo of toxic hydrogen sulphide – a scenario that could have the extreme consequence of fish death. Although this is not a major risk factor in most planned schemes, it would certainly pay to carry out some form of field investigation into the thermal and chemical stratigraphy of the lake.

Calculating the resource and the impact

If it is proposed to use a restored mineral working to support a large heating/cooling scheme, it will usually be necessary to utilize some form of mathematical model to calculate the temperature changes that will result from the extraction or dumping of heat. There may even be implications for the water balance of the lake, as evaporation rates depend on temperature.

The mathematical model will usually need to consider the following components of the heat budget of the lake:

- gains in solar and atmospheric radiation
- reflection of the incoming radiation, due to the lake's albedo
- back radiation of heat from the lake to the atmosphere, the magnitude of which will depend on the lake's temperature
- convective heat exchange with the atmosphere
- evaporative heat loss to the atmosphere
- advection of heat with surface-water or groundwater through flow
- the deliberate technical component (heat extraction or rejection via the heat-exchange system).

Such a model can be constructed in a spreadsheet environment or may be a more complex numerical model.

As a very simple example of how such a model might work, consider a 3m deep lake with an open area of 10,000m^2. There is no surface-water or groundwater through flow. The water temperature is 10°C and the air temperature on a moderately sunny spring day is 13.9°C. The lake will be losing heat to the air by a number of processes, such as evaporation and back radiation, but will also be gaining it from the sun and the atmosphere, such that a quasi-equilibrium may exist.

It turns out that, if the temperature of the lake is lowered (eg by a heat pump coupled to a lake heat exchanger) by 0.5°C, this induces around 130–170kW of net heat exchange from the atmosphere to the lake (in fact, the apparent net heat exchange is due to a lowering of back radiation and evaporative heat loss from the lake). If the temperature is dropped by a full 1°C, the additional heat available for extraction would be at least 240kW. In other words, if 240kW is extracted from the lake under these particular conditions, an average drop of 1°C in the water temperature would be expected and it would be necessary to ask if this is likely to be environmentally acceptable.

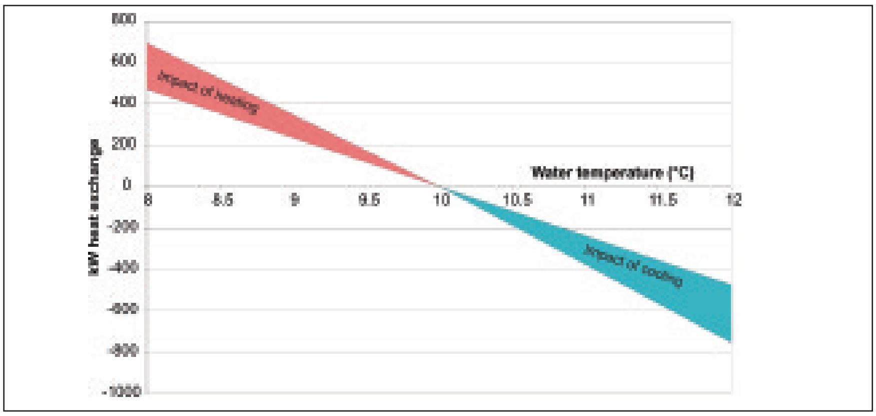
A similar, though opposite, effect is seen for a cooling regime, where the lake temperature rises as heat is added to the lake (see fig. 2).

The above scenario is an example only – behind it lie specific assumptions (eg a given humidity, cloud cover, albedo, wind speed, the fact that it is daytime etc). Both figure 2 and the above example are illustrative and must not be used for design purposes – each lake will have its own conditions and climatic considerations, requiring a site-specific model. They do, however, give an indication of energy availability and the methods used to calculate them.

How much does it cost?

The exact cost of installing a closed-loop heat exchanger (a lake loop or lake plate) in a flooded excavation will, of course, depend on the size of the scheme (the cost per kW typically decreases with increasing size) and the accessibility of the lake bed. However, as a rough guide, the installation of a steel lake plate heat exchanger, ready to be coupled to a lakeside heat pump array, is estimated to cost:
10kW lake plate: Estimated total £10,000 (c. £1,000 per kW)
35kW lake plate: Estimated total £21,000 (c. £600 per kW)
100kW lake plates: Estimated total £50,000 (c. 500 per kW)

Fig. 2. Example of output from a mathematical heat balance model of a lake showing the temperature change corresponding to a given heat extraction (heating) or heat rejection (cooling) in a hypothetical 3m deep lake of 10,000m^2 open area (note: this figure is constructed using specific assumptions regarding cloud cover, air temperature, albedo, sunshine hours, humidity and wind speed. It should not be used as a generic design aid or tool). The envelopes on the response function are defined by algorithms used or recommended by Kavanaugh & Rafferty[3] (upper bound) and Faraldo-Sanchez[2] (lower bound)



It is considered that a pro-rata capital cost of £300 per kW is not unreasonable on large schemes greater than 1MW.

Renewable Heat Incentive

The government has stated that from April 2011, the Renewable Heat Incentive scheme will begin to pay between 6p/kWh for larger schemes and 11p/kWh for smaller schemes. Assuming a heating load on 15 newly built properties of 19,200kWh and an incentive tariff of 7p/kWh, the annual income per household would be £1,344 against an electrical running cost for the heat pumps of about £500 per year.

The financial incentive goes to the owner of the heat pump. Therefore, this benefit could accrue to the developer, the property owner or, via an Energy Supply Company (ESCo), the quarrying company.

The concept in the minerals industry

The minerals industry spends a significant amount of development cost in restoring sites, which are usually delivered back to the landowner or an environmental trust (eg a county wildlife trust) for long-term management. This management costs money and it is not uncommon that the most difficult part of the 'walk-away solution' is agreeing the long-term aftercare costs.

Installation of the necessary means to extract or dump heat to the restoration provides either a long-term potential revenue or makes the site attractive as a commercial development opportunity (as well as an environmental benefit).

By designing the energy system into the restoration and installing it when the pit bottom is easily accessible, the operator leaves an asset, a revenue stream and a site that is worth something both environmentally and financially.

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