EARTH ENERGY SYSTEMS: ENVIRONMENTAL EFFECTS OF DIRECT USE OF GEOTHERMAL ENERGY RESOURCES

Ian K. G. Boothroyd[1], Nat Wilson[1]

[1]Golder Associates (New Zealand) Ltd., Auckland, New Zealand.

iboothroyd@golder.co.nz

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ABSTRACT

The use of Earth Energy Systems (EES) is meeting increasing interest as form of direct use for providing energy and heating for smaller distribution circuits. In this paper we review the potential impacts of direct geothermal energy use on the environment and environmental matters relevant to human health. Three main categories of environmental and human health concerns related to EES are identified: thermogeological; geological and hydrogeological; and water quality and quantity concerns. Particular focus is given to groundwater ecology and water quality. The sustainability of direct use of EES is also considered, and specific attention is given to ecological sustainability and thermal ecological impacts. Consideration for the development of regulations for the implementation of direct use of EES is also discussed.

1. INTRODUCTION

Increasing social, environmental and political concerns over the threat of climate change as a result of anthropogenic greenhouse gas emission has driven a move to alternative technologies. Development of above ground sources of energy such as wind, solar, hydrological and tidal has either increased dramatically over the past decade or technology is advancing at a rate that makes exploitation of these natural resources more cost-effective. The development of deep below ground high temperature geothermal resources has also been growing in recent years.

The use of shallow groundwater thermal resources has emerged as a sustainable option for heating and cooling in industry and local networks. Ground source heat pumps have become increasingly popular for this purpose. Two essential forms of ground source heat pumps have been developed: pumps connected to below-ground heat exchangers (closed loop) or fed directly by groundwater from a well or bore (open loop).

Lund et al. (2011) provided an estimate of the worldwide installed thermal power for direct utilization (as at the end of 2009) and found an almost 72% increase in direct use since 2005; representing 48,493MWt. He also found that the distribution of thermal energy used by category is approximately 47.2% for ground-source heat pumps, 25.8% for bathing and swimming (including balneology), 14.9% for space heating (of which 85% is for district heating), 5.5% for greenhouses and open ground heating; and the remainder for industrial process heating, aquaculture pond and raceway heating, agricultural drying and for other uses.

Environmental and human health concerns related to EES fall into three main categories: thermogeological; geological and hydrogeological; and water quality and quantity concerns.

2. SHALLOW GROUNDWATER SYSTEMS

The earth is a huge energy storage device that absorbs the sun’s energy in the form of clean, renewable energy. Shallow geothermal systems are those where the underground in the first approximately 100 m is well suited for supply and storage of thermal energy as the climatic temperature change over the seasons is generally reduced to a steady temperature at 10-20 m depth and with further depth temperatures are increasing according to the geothermal gradient (average 3°C for each 100 m of depth) (Sanner 2001).

Direct use of shallow geothermal systems (or geoexchange systems) uses the Earth’s energy storage capability to heat and cool buildings, and to provide hot water. Direct use systems take this heat during the heating season and return it during the cooling season. The heat island effect of urban areas results in an elevation of the groundwater temperature under areas of urban development (Allen et al. 2003). The availability of an extensive gravel aquifer beneath a city can add to the very positive impact on the attractiveness of geothermal energy systems (Allen et al. 2003).

3. GEOLOGICAL EFFECTS

3.1 Thermogeological

Extracting heat from a borehole heat exchanger decreases the temperature of a zone around the borehole. Increasing temperature of the ground can also lead to consolidation and creep settlement in unconsolidated soils or to thermal expansion of rocks (especially clay and marl with 3-layer-clay minerals; and Anhydrite). Severe damage might be caused by rocks which swell under the presence of water. This damage starts very slowly, but is difficult to prevent once commenced.

3.2 Hydrogeological

The main hydrogeological risks related to the drilling of boreholes are the accidental connecting of different aquifers or connecting aquifers to the earth’s surface; and drilling into artesian aquifers. For shallow geothermal drilling it is beneficial if aquifers are not connected to the surface. Similarly it is essential that aquifers at different depths are not connected to each other. Connecting aquifers can result in the potential mixing of waters and contamination of potable water supplies.

4. ENVIRONMENTAL EFFECTS

4.1 Temperature

Underground hydrogeochemical and biological processes are dependent on the prevailing environment and will depend on, but not limited to, sediment characteristics, inground flora and fauna, organic matter content and temperature. Typically in shallow groundwaters, groundwater temperature is 1-2 ^{0}C higher than the mean surface water temperature and is influenced by such factors as the recharge of groundwater.

Several directives consider temperature increase as a form of pollution. The RMA limits increases in temperature to ±3 ^{0}C; while the EU Water Framework Directive states that the deterioration of the chemical and ecological status of surface water and groundwater must be prevented.

In a study of several countries, Haehnlein et al. (2010) found that regulations for heating and cooling the groundwater with open geothermal systems, varied between 15 and 25 ^{0}C for maximum temperatures and 2 and 5 ^{0}C for minimum temperatures. The allowed temperature difference between undisturbed and influenced groundwater temperature varies from 3 ^{0}C (e.g. Switzerland) to 11 ^{0}C (France). There were no absolute temperature limits for heating and cooling of groundwater for closed geothermal systems.

The most important potential adverse impacts associated with heat are thermal interference or thermal sustainability, ecological impacts and geotechnical impacts.

4.2 Water quality

The discharge of heated groundwater can influence geochemical parameters of groundwater. The reinjection of heated groundwater can lead to carbonate precipitation, increased dissolution of silicate minerals, the mobilization of organic compounds from sediments, and to decreasing groundwater oxygen saturation (Brielmann 2009).

For open-loop systems, water is usually disposed to a surface water body or returned to an aquifer. Where the discharge is to surface water, and where the rise is above certain critical limits, it may affect aquatic species and their function, promote the growth of parasites of fish, and result in the invasion of non-indigenous species. Likewise, discharge of warm water to aquifers may reduce the permeability of gases. In porous medium and fractured rocks, the relative permeability of the liquid phase (water) decreases when the gas proportion increases.

Open-loop groundwater systems present the highest risk to groundwater contamination of all EES because there is a need to dispose the cooled or heated water. Discharge may be to surface waters, an aquifer or sewer. Unless permitted by a regional plan, a discharge to surface or groundwater may require resource consent and some consideration of effects on the environment.

Contamination of groundwater by drilling into a contaminated zone may occur. Leakages from closed systems (horizontal or vertical loops) where fluid escapes from inside the pipes can contaminate groundwater.

4.3 Microbial flora

Changes in the microbiological communities in soils can potentially occur as a consequence of heat rejected to the ground and groundwater by EES. Brielmann (2009) concluded that aquifer thermal energy discharge can affect aquifer bacteria, but was not the only factor affecting the groundwater flora. They also concluded that a more relevant factor was surface water infiltration through the soil. As the exchange of water through the hypoheic zone is known to undergo seasonal dynamics and result in patterns of physic-chemical conditions, nutrients and organic matter, Brielmann et al. (2009) also concluded that aquifer thermal energy discharge is unlikely to pose a threat to ecosystem functioning and drinking water protection in uncontaminated shallow aquifers.

4.4 Fauna

Studies on the effects of thermal energy discharge on groundwater fauna are very limited. Although much less abundant than microorganisms, the groundwater is often highly specialised (Scarsbrook et al. 2007). Groundwater fauna often exists only at low temperatures and often patchy in distribution. Brielmann et al. (2009) also studied the effects of thermal energy discharge on the fauna of shallow groundwater ecosystems and found that although faunal abundance showed no relation to impacted groundwater temperatures resulting from groundwater use, faunal diversity decreased with temperature.

4.5 Other

Depending on the refrigerant used in the system, leakage over the lifecycle of a heat pump could impact the environment. Although EES systems reduce energy consumption, some refrigerants are considered to contribute to global warming.

5. CONCLUDING REMARKS

Rybach (2003) considered that, in principle, the environmental impacts of direct use are the same as with power generation, but the degree to which utilization affects the environment is proportional to its scale; as the various phases of direct utilizations are on a smaller scale and the fluid extracted is considerably less than in power generation, the environmental effects of direct uses are correspondingly smaller.

Haehnlein et al. (2010) concluded that in many countries, the use of shallow geothermal energy is not so significant in comparison to other renewable energy resources. Thus, there is little or no experience with such shallow geothermal systems, and therefore there is no perceived environmental effects and thus no need for regulations. Additional legal restrictions might also be considered as unwanted barriers that could decelerate the development of such shallow geothermal systems.

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