Geothermal Water Use: Requirements and Potential Effects

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Geothermal projects require access to water during development and operation. Some current geothermal exploration and development activity is in areas of low water supply potential and/or high water demand.

The National Water Commission contracted Hot Dry Rocks and RPS Aquaterra to consider water use implications relating specifically to the geothermal industry. This extended abstract provides a summary of water requirements by various geothermal operations, and potential effects on water resources.

Keywords: Water Use, Engineered Geothermal Systems, Hot Sedimentary Aquifers, Low Enthalpy Systems, Ground Source Heat Pumps

Introduction

The Intergovernmental Agreement on a National Water Initiative (NWI) was signed at the 25 June 2004 Council of Australian Governments meeting. Through the NWI, the Commonwealth and State governments have agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water. The National Water Commission (NWC) commissioned Hot Dry Rocks (HDR) and RPS Aquaterra (RPS) to provide some insight into how to address the water planning, management and use implications relating to the geothermal industry (RPS Aquaterra & Hot Dry Rocks, 2011).

Geothermal Energy Potential

In essence, the geothermal energy potential in Australia can be best viewed as a continuum between high enthalpy, deeply buried resources (3,000–5,000 m) suitable for large-scale commercial electricity generation (Engineered Geothermal Systems, EGS, and Hot Sedimentary Aquifers, HSA), through to low enthalpy, shallow resources, suitable for small-scale Low Enthalpy Aquifer (LEA) (direct use heating and industrial processes), Ground Source Heat Pumps (GSHP) and Aquifer Thermal Energy Storage (ATES) applications (Figure 1).

EGS and HSA: Water planning issues

Pressure management of the subsurface reservoir is of critical importance to EGS and HSA projects. EGS projects will always require circulation of an introduced working fluid through the engineered reservoir to convey heat energy to the surface as well as to maintain reservoir pressure and inhibit

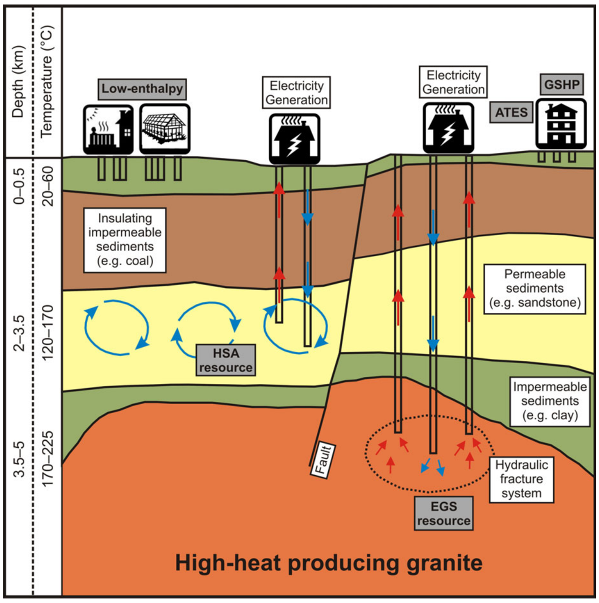

Figure 1: Geothermal energy applications in Australia (modified after Ayling, 2007).

fracture closure. HSA developments use in situ working fluids to maintain reservoir pressures and permeability. In both instances, an inability to maintain and manage reservoir pressures and the efficient circulation of the working fluid will ultimately lead to a decreased operational lifespan of the project. From the geothermal operator's viewpoint, it would be ill-advised to introduce fluids with varying hydrogeochemical properties into the reservoir system as this may well lead to complications with precipitation and scaling of the reservoir and/or bore network. Regulators would also have similar concerns and would be unlikely to allow re-injection that may substantially affect the pressure characteristics and/or the water quality of a valued resource.

It is for these reasons that most, if not all, EGS and HSA projects in the planning and development stages within Australia are designed to be closed-loop systems, with very low consumptive use during scheme operation. Any fluid produced from the production well is reinjected to the same subsurface aquifer (or engineered reservoir in the case of EGS projects).

Water demand is highest in geothermal projects where the volumes of in situ fluids contained within the formations are inadequate to stimulate and operate an engineered underground reservoir. Water consumption for EGS should be controlled by using closed-loop systems (i.e. re-injecting to the same hydrogeological unit), nonevaporative cooling (for electrical power generation plants) and general aquifer pressure management.

EGS and HSA: Exploration stage

The general progression of an exploration program in Australia includes the following steps:

1. Desktop geothermal systems assessment (GSA) (Cooper & Beardsmore, 2008).
2. Shallow ‘heat flow’ drilling.
3. Deep ‘appraisal’ drilling.

Once a GSA of an area has been completed, several areas of interest are typically identified. A drilling program is designed for a series of shallow ‘heat flow’ bores to obtain objective data on local heat flow and other geological information of the area.

Cordon & Driscoll (2008) cite two exploration companies that provided details of water usage from their respective shallow ‘heat flow’ drilling programs in South Australia, estimating 50–85 kL for a single shallow bore. Whilst these companies were exploring in sparsely populated parts of South Australia, they both faced logistical and environmental issues with sourcing the water. By working with the local community and government, the companies were able to minimise real and perceived environmental impacts of the drilling program.

Once a company has achieved a level of confidence in defining its geothermal resource, deep drilling is planned to appraise the reservoir characteristics—typically to a depth of 3,000–5,000 m. This marks the beginning of the development stage. Drilling costs dictate that the first deep exploration well is converted into either an injection well or production well (drilling one well to 3,000–5,000 m is widely anticipated to cost A$12m–A$15m).

Cordon & Driscoll (2008) cite Petratherm’s plan to drill two wells at its Paralana project to a depth of approximately 4,000 m. Four local water bores were being drilled at the project site to meet drilling requirements. Whilst the water bores were targeting shallow, non-prescribed aquifers rather than the deeper prescribed artesian water, Petratherm still required a permit for the construction of a bore.

EGS and HSA: Development stage

Water use in the development stage of an EGS project includes such activities as sumps for drilling fluids, hydraulic permeability tests, fracture stimulation of the reservoir section to develop the underground heat exchanger, tracer tests and circulation tests, and reservoir charging with working fluid. Cordon & Driscoll (2008) comprehensively reviewed water requirements and volumes utilising technical data from Mil-Tech UK Ltd (2006) to predict the development stage as requiring a total of about 280,000 m^3 (280 ML) of water per EGS ‘module’. This is based on the assumption that an EGS module consists of one injector (1st well) and two producers (2nd and 3rd well) of 8.5” open-hole diameter. EGS bores are typically drilled to a depth of 3,000–5,000 m with an assumed separation between bores of about 600 m.

HSA projects require substantially less water since they do not require fracture stimulation or reservoir charging. Cordon & Driscoll (2008) estimated approximately 2,000 m^3 (2 ML) of water for each of the HSA deep bores to be drilled.

EGS and HSA: Operational stage

As there are only a handful of operational EGS plants in the world, and none yet in Australia, conventional geothermal projects are generally used in comparison to provide an estimate of water usage for the production phase of EGS and HSA energy projects. In a typical, successful conventional geothermal reservoir, individual production wells can produce 5 MW or more of net electric power through a combination of high temperatures and high flow. Minor volumes of water are required for periodic maintenance activities during operation of a conventional geothermal system.

The production and/or reinjection capacity from an individual well tends to decrease with time, depending on a number of variables including changes within the reservoir, rates of chemical deposition and mechanical conditions of the well. To restore or regain some of the capacity, well maintenance/rehabilitation is undertaken with a work-over drilling rig, as this is much cheaper and shorter (typically one week) than drilling a new well. Acid cleaning is another rehabilitation method that involves injecting an acid solution into the production or reinjection zone for a short period of time (hours) to dissolve any build-up of scaling products within the formation around the well.

The primary use of water in power plants is cooling, although there are other ancillary uses related to power generation. There are a number of different types of cooling systems and the selection of these is based on the type of power plant, geothermal resource chemistry, site meteorological conditions and access to a cooling source such as a river or aquifer.

Controlling EGS water losses

Controlling water losses is an important aspect of developing a geothermal energy project particularly in areas of restricted water availability. Such losses can have significantly negative economic and environmental impacts if not managed. Australian EGS projects are likely to encounter risks associated with water supply in terms of access to water (licences, allocations, etc) and related management of impacts due to pumping. Consider, for example, a hypothetical EGS project consisting of six wells each producing hot water at 100 L/s. If all the water is reinjected with 1% loss per cycle (estimate based on international experience), the project has to make up 6 L/s, or 0.5 ML per day (182 ML/annum), throughout its entire life. While that may not necessarily be a problem, it does imply that a permanent supply of water might be required for many EGS projects.

Water loss mitigation strategies can be employed. In the case of shallow 'heat flow' bores, the main water losses can be attributed to evaporation on the surface of the sumps or water filtrating out of the sumps as very little water is lost down hole. In one drilling project, sumps were resealed which resulted in significant decreases in water loss from 8–16 kL to 2–8 kL in a 24 hour period during drilling (Cordon & Driscoll, 2008).

EGS field projects carried out throughout the world have experienced the impact of water losses through trial production testing. Tester et al. (2006) reports anecdotal details from several R&D projects, summarised below.

Fenton Hill, USA

The reservoir could be circulated in such a manner that the fractured volume did not continue to grow and, thus, water losses were minimised. If water was injected at high enough pressures to maintain high flow rates, the reservoir continued to grow and water losses were high. The fractures were being jacked open under high-injection pressures, causing extension of the fractures and increased permeability. At lower pressures, this did not happen, so the permeability was lower and flow rates much lower.

Rosemanowes, UK

An experimental proppant (sand) was carried into the joints as part of a secondary stimulation using high viscosity gel. Proppants are small-sized particles that are mixed with hydrofracturing fluids to hold fractures open after a hydraulic fracturing treatment (proppant materials are carefully sorted for size and shape, hardness, and chemical resistance to provide an efficient conduit for production of fluid from the reservoir to the wellbore). This stimulation significantly reduced the water losses and impedance, but encouraged short circuiting and lowered the flow temperature in the production borehole.

Ogachi, Japan

Fluid losses within the reservoir were high during injection testing, because the wells were not properly connected. Once connection between wells was improved, fluid loss was reduced.

Low enthalpy geothermal systems: Water planning issues

Direct heat use from low enthalpy aquifers by ground source heat pumps (GSHP) and aquifer thermal energy stabilisation (ATES) schemes have similar water requirements and effects.

The potential impacts on groundwater via utilisation of low enthalpy geothermal systems can be classed as either hydrogeological or thermogeological events. The lack of information from an Australian context of low enthalpy geothermal systems necessitates the use of international examples.

For the current and envisaged scale of development (limited/isolated), the issues discussed below should be manageable within existing arrangements for bore licensing and water allocation planning, provided they are implemented carefully. Should there be an intense concentration of development, then specific water management arrangements may need to be developed (eg. considering the thermal energy balance of an urban aquifer, as well as its water and salt balance).

Hydrogeological impacts

Potential hydrogeological impacts relating to low enthalpy systems can be grouped into drilling-related issues, and water balance and aquifer hydraulic issues. There are three main drilling-related hydrogeological scenarios that may result in adverse impacts from the drilling of low enthalpy geothermal systems (Banks, 2008):

1. Inadvertent penetration of artesian conditions.
2. Drilling through two aquifers, inducing leakage from one to another.
3. Drilling on contaminated land sites, thus resulting in conduits for contaminants to the aquifer.

In regard to aquifer and hydraulic issues, if the scheme is a single bore or open-loop scheme, then there will be discharge to a receiving water body that is either different to the extraction water body, or the extraction/discharge water body itself may be an open-ended system. This can lead to potential impacts on the water body that might be due to temperature or water chemistry.

In a dual/multi-bore or closed-loop scheme (essentially non-consumptive), where water is being re-injected to the aquifer or circulated through closed pipe networks, there will be localised drawdown or mounding of water levels/pressures around wells, which could affect existing users (Banks, 2008).

The re-injection of water can cause increased rates of dissolution where the formation is susceptible (notably carbonate-type formations). For example, Younger (2006) investigated the potential for limestone dissolution as a result of cooling by low enthalpy geothermal schemes. Injection of warm water could also result in the clogging of pore space (Banks, 2008) through dissolution and redeposition. It should be noted that much of this is speculative at this stage, as the research is yet to be undertaken.

Thermogeological impacts

Thermogeologically, the primary constraint on the capacity of an area or location to support low enthalpy geothermal systems is the number of schemes that can be installed without thermal interference between the schemes.

The lack of information from an Australian context of low enthalpy aquifer geothermal systems necessitates the use of international examples. Since 2003, the Spatial Strategy for London requires onsite generation of renewable energy, with GSHPs recognised as such a technology. This has resulted in a major uptake in London of open-loop systems. To begin with these were consumptive (single bore or open-loop), but the majority are now non consumptive (multi-bore or closed-loop).

Though closed-loop, it is recognised that there is now a developing density of schemes that may be affecting the overall temperature of the main chalk aquifer from which the groundwater is being sourced. A study on the regional distribution of ground temperature in the chalk aquifer of London (Headon et al, 2009), indicated that there is potential modification of the subsurface thermal regime as a result of re-injection. Elsewhere, such as in Winnipeg (Canada), research has also been undertaken to try to determine the extent of the merging of thermal plumes in the carbonate aquifer beneath the city (Ferguson & Woodbury, 2005).

This is not to suggest that all centres of growth are now having adverse impacts on the aquifers from which they are sourced. However, Australia has the opportunity to learn from the experiences of those places that have already undergone growth.

Consents to investigate and discharge to the aquifer are the main requirement in the UK for potential installers. As the applications become more complex, it is expected that the granting of future licences will depend on the quality and thoroughness of the supporting assessments (Fry, 2009).

Geothermal power plants and cooling systems

Binary cycle systems are expected to be used to generate electricity for Australian conditions (somewhat lower enthalpy than other international projects).

A binary cycle unit uses a working fluid with a low boiling point and high vapour pressure, heated in the heat exchanger by the geothermal fluid until it boils and changes state to a gas. The binary working fluid is then expanded through a turbine generator where power is generated. The binary working fluid is then condensed back to a liquid in a cooler before being pressurised back to working pressure by a pump.

Many of the power plants in Australia are likely to be located in remote areas away from water sources and in hot climates. A hot climate and a lower enthalpy resource is likely to restrict the use of air-coolers and a lack of water for cooling would result in hybrid cooling systems being the most probable application for binary power plants in Australia.

The amount of cooling water required will vary substantially between plants, being a function of the technologies selected, resource chemistry and local meteorological conditions.

Conclusions

Projections of water requirements in an expanding geothermal sector are primarily restricted to electricity generating developments associated with EGS and HSA, since low enthalpy geothermal systems are generally multi-bore or closed-loop systems that require negligible water for well development or for operations.

The water requirements for EGS and HSA developments are substantially different since HSA operations do not usually require fracture stimulation nor initial fluid charging of the reservoir (i.e. HSA systems make use of the in situ aquifer properties) where EGS uses water for engineering effective circulation of the working fluid.

For an EGS development, the reported average water requirement for drilling and construction of 280,000 m^3 (280 ML) (Cordon & Driscoll, 2008) is based on a three bore configuration (a 'triplet') comprising two production bores and one injection bore. Such a triplet would normally be expected to supply approximately 10 MWe of power—dependent on resource flow rate and temperature characteristics. Thus, an average of 280,000 m^3 (280 ML) of water might be consumed for each 10 MWe EGS development.

For an HSA triplet construction, Cordon & Driscoll (2008) estimated approximately 2,000 m^3 (2 ML) of water for each of the bores to be drilled; thus 6,000 m^3 (6 ML) might be consumed for each 10 MWe HSA development.

The Waterlines report to the National Water Commission by RPS Aquaterra and Hot Dry Rocks (2011) considered a likely range of EGS and HSA systems that may be developed in Australia, and related growth projections. A broad index of water use was devised that could be applied to water planning studies, accounting the development and operational water needs of EGS/HSA, but not for the cooling needs for electrical power plants. It is estimated that 1 GL per annum is required to sustain 40 MW installed capacity (assuming HSA amounts to 25% to 50% of the combined EGS/HSA mix). With allowance for low to high growth into the 2020s, this indicates that water consumption in the order of 30–60 GL per annum may support 1,200–2,400 MW of generating capacity (plus water for cooling the power plants).

References

Ayling, B.F., 2007. Electricity Generation from Geothermal Energy in Australia. Geoscience Australia, Educational Factsheet GA10662, 2pp.

Banks, D., 2008. An Introduction to Thermogeology: Ground Source Heating. Blackwell Publishing. 339pp.

Cooper, G.T. and Beardsmore, G.R., 2008. Geothermal systems assessment: understanding risks in geothermal exploration in Australia. Proceedings of PESA Eastern Australasian Basins Symposium III, Sydney 14–17 September, (2008), 411–420.

Cordon, E. and Driscoll, J.P., 2008. Full Life-Cycle Water Requirements for Deep Geothermal Energy Developments in South Australia. Department of Primary Industries and Resources (South Australia) and the Australian School of Petroleum, 50pp.

Ferguson, G. and Woodbury, A.D., 2005. Thermal sustainability of groundwater-source cooling in Winnipeg, Manitoba. Canadian Geotechnical Journal, 42(5), 1290–1301.

Fry, V., 2009. Lessons from London: Regulation of open loop ground source heat pumps in Central London. Quarterly Journal of Engineering Geology and Hydrogeology, 42, 325–334.

Headon, J., Banks, D., Waters, A.J. and Robinson, V.K. 2009. Regional distribution of ground temperature in the Chalk aquifer of London, UK. Quarterly Journal of Engineering Geology and Hydrogeology, 42, 313–323.

MIL-TECH UK Ltd., 2006. Assessment of water requirement and storage aspects for a development of a deep Hot Dry Rock (HDR) system Olympic Dam, South Australia. Report prepared for Green Rock Energy Ltd., 17pp.

RPS Aquaterra and Hot Dry Rocks, 2011, Geothermal Energy and Water Use, Waterlines report, National Water Commission, Canberra (in press).

Tester et al., 2006. The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, MIT Press, pp. 1-9; 2-29; 4-1–4-52.

Younger, P.L., 2006. Potential pitfalls for water resources of unregulated development of ground source heating resources. Proceedings of the Annual Conference of the Chartered Institute of Water & Environmental Management.