Practical methods of minimizing or mitigating environmental effects from integrated geothermal developments; recent examples from New Zealand

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Abstract

Monitoring of the environmental effects of geothermal resource utilisation in New Zealand has confirmed the benefits of appropriate management in terms of production and reinjection strategies. Such strategies can minimise, reverse or mitigate the effects on surface thermal activity. This applies to direct use of low enthalpy resources as well as integrated use of high enthalpy resources. At Rotokawa, a strategy of deep production and total shallow reinjection for an integrated steam turbine/binary power plant has resulted in a gradual enhancement of several chloride springs, with no significant detrimental effects. At Wairakei, less than 50% of the waste hot water is reinjected, but several users are able to take advantage of the separated hot water in a way that mitigates for the historic loss of geysers at Wairakei Valley. These include tourist facilities based on a geothermally-heated prawn farm, and hot stream restoration with an artificial geyser/silica terrace that was developed by local Maori. At Mokai, several years of production history from a binary/steam turbine, with shallow reinjection of brine and steam condensate, has not caused any significant environment effects on surface thermal features. At Rotorua, management of extraction and reinjection from numerous domestic bores has achieved a significant recovery in hot spring and geyser activity. Users of many other hot spring areas in New Zealand are also managed by application of regulatory control through policies and plans under the Resource Management Act. These plans are presently undergoing a process of industry-wide review and improvement, by addressing changes in the philosophy of environmental management.

Keywords: *New Zealand, environmental, Rotokawa, Wairakei, Rotorua, Mokai.*

1 Introduction

New Zealand, like Iceland, is a country that has pioneered the sustainable use of its indigenous geothermal resources, reducing the need to burn hydrocarbons, and thereby reducing CO_2 emissions. With declining natural gas reserves, N.Z. energy planners are increasingly looking to fill the gap in future energy supplies by increased geothermal utilisation, as a renewable energy source, rather than using coal. A key factor in achieving this goal is the management of environmental effects, through appropriate regulation. More practical methods of minimizing or mitigating such effects are needed, along with more integrated or “cascaded” uses, and examples of more-efficient and economic direct geothermal energy use, to encourage greater uptake of geothermal technology. Examples of such methods from recent geothermal developments in New Zealand (summarised in Thain and Dunstall, 2000) are given in this paper, together with a discussion of appropriate and practical geothermal system management policies.

2 Rotokawa

An integrated steam turbine and binary power plant at Rotokawa, with an installed capacity of about 25 MWe has been operating successfully since July 1997, utilizing 2 production and 3 reinjection wells. Confidence in the resource performance led to an increase in December 2002 of 5 MWe, and plans for a second stage (nominally 30 MWe) are well advanced. A strategy of deep production (1500-2500 m) and shallow injection (300-600 m) was adopted for the first stage based on limited vertical connection between these aquifers. Over 5 years, 20 Mtonnes has been produced. Full reinjection is practised, including steam condensate, but excluding non-condensable gases. Gravity and pressure monitoring has shown that the injection aquifer (originally 2-phase) has been re-saturating within a few hundred meters of the injection wells, and pressures have risen by a few bars. Production wells have shown no significant changes in enthalpy or output, although RK9 was shut down after problems in 2002-3 associated with casing damage. Deep pressures have declined by at least 12 bars.

Environmental monitoring, established under conditions associated with the original resource consent, has included gases (H_2S, Hg), groundwater, and surface thermal features. Over the 5 years, there have been no significant changes in gas emissions or ground water levels. Groundwater chemical monitoring has shown a gradual rise in chloride concentration of up to 5% per year. Average chloride flux, through surface discharges into the Parariki Stream, has also increased by about 8% per year, but remains within the wide range of natural fluctuations (+/-50%) caused by rainfall on Lake Rotokawa, the source of the stream. In December 2001, a new high-chloride discharging spring (“Ed’s spring”) appeared from an area of near-boiling hot pools about 300m southeast of the power station. This feature now has occasional periods of vigorous boiling and eruption, discharges about 2 l/s, deposits sinter, and is evolving an associated thermophilic ecosystem. Although its chemistry is distinctly different from that of the reinjected fluid, precluding the possibility of a direct fluid connection, the small pressure rise that stimulated its activity is probably related to increased pressures in the underlying injection aquifer. It is therefore considered an indirect effect of development, and an enhancement to the thermal feature environment at Rotokawa.

3 Mokai

At Mokai, a nominal 57 MWe integrated power plant (steam turbine and binary), began commercial operation in February 2000. Full reinjection (excluding gases) is also practised here, with production from 4 deep wells and injection into 2 shallow wells. Changes in the reservoir pressures have generally been as expected, and there has been no indication of premature reinjection returns or unexpected chemical changes. Improvements in direct use include a large glasshouse-heating project currently under construction.

A comprehensive environmental monitoring programme covering springs, streams, and groundwater, has shown no significant post-production changes to water chemistry due to abstraction or injection of fluids at Mokai. Temperatures and water levels in groundwater monitor bores have also shown no changes that could be attributed to reservoir pressure drawdown or reinjection returns. Monitored ecosystems, consisting of rare thermal ferns and aquatic invertebrates associated with hot spring discharges, have not been affected. A small increase in thermal activity was observed in March 2000 associated with a line of existing thermal craters near the reinjection area. These craters contain steam-heated mud pools. The increase in steam activity was local, and did not directly include reinjected chloride fluid, but may have been related to a local pressure increase in the underlying aquifer. A nearby hot spring used for bathing was not affected. Within a year, the expanded area of steam-heated ground was populated by thermally tolerant plants such as club mosses, leading to an overall enhancement of the local thermal ecosystem. The only adverse effect was the cost of re-fencing the thermal area to keep out stock.

4 Wairakei

Wairakei Power Station has been producing about 160 MWe for 45 years. Contact Energy is presently applying for renewal of Resource Consents to maintain full production for a further 25 years. In recent years, changes have included the purchase by Contact of the nearby 55 MWe Poihipi Road Power Station. This generates, from steam wells, a load-following output averaging 24 MWe (limited by Consents since 1997, to avoid interference). Historically, all the separated liquid at Wairakei was discharged into the Waikato River, but since 1997, 30-50% (about 13MT/yr) has been reinjected. This has caused a small (2 bar) pressure rise in the production area, and future plans are to reinject more fluid outside the resistivity boundary of the field to avoid premature cooling. A 15 MWe binary plant proposal to extract more energy from 130^{o}C reinjection fluids is currently undergoing detailed commercial consideration. Small quantities of steam are provided to Wairakei businesses for direct heating purposes. These include the Geotherm Exports orchid glasshouse at Poihipi, the Wairakei Resort Hotel (7.45 kT/yr), and Century Resources /IGNS offices. Increased direct use of waste hot water for tourist facilities has also been achieved at the nearby Prawn Farm (0.71 MT/yr) and the Wairakei Terraces (1.46 MT/yr), where new artificial silica terraces, a geyser, and alum pools have been constructed. The adjacent Te Kiri O Hinekai thermal stream, with its historic “Honeymoon Pool”, has been re-established by diverting hot water from the main Wairakei drain. In conjunction with a Maori ‘living village’ and animal park, this is now a popular tourist facility. “Craters of the Moon” (Karapiti) is another very popular Wairakei Tourist Park facility, freely accessible to the public and maintained by the Department of Conservation. This steam-heated thermal area expanded dramatically during the early days of Wairakei pressure drawdown, when boiling created more upwardly-mobile steam. The heat output increased 10 fold, from 40 MW in 1952, and then settled to a relatively stable 200 MW. Ongoing intermittent hydrothermal eruptions (about 1/yr) are an exciting reminder of the natural transience of these steam-heated features. All these environmental and amenity benefits are considered to partially mitigate for historic adverse effects, such as the loss of geysers at Wairakei Geyser Valley and Spa Park (Taupo), when reservoir pressures initially declined in the 1960s. Other environmental effects at Wairakei have included gradual subsidence (broad bowls up to 15m deep beneath the Wairakei Stream, and 3m at Spa Hotel, Taupo), and local drainage of groundwater aquifers in the Eastern Borefield (1980s) and Alum Lakes area (since 1997). These effects have been due to a steady decline (by over 60%) in the shallow steam zone pressures, which has caused drainage of some overlying compressible mudstones, and induced down-flows of groundwater through local fractures. The main consequences have included remedial adjustments to fixed structures such as pipelines, drains and transmission lines to accommodate strain accumulation, and some cooling and dilution of deep production fluids by down-flowing acidic groundwater.

5 Rotorua

Records of thermal feature changes at Rotorua go back more than 150 years. They have demonstrated a high degree of natural variability in geyser and hot spring discharges (Scott and Cody, 2000). Exploitation of the thermal aquifer beneath the city started in the 1920s but greatly expanded between 1967 and 1986. Natural surface activity declined noticeably from the 1970s, and despite the previous evidence for natural variability, this decline was attributed to pressure drawdown from excessive fluid extraction. To counteract this, the government implemented in 1987 a control program that included closures of many wells (within 1.5 km of the centre of Whakarewarewa thermal area), and punitive royalty charges with provisions to encourage reinjection. These measures have been very successful in reversing the decline. Aquifer water levels have risen by 2-3 m, and many thermal features have been rejuvenated. Spring discharge flows have increased, and geysers have resumed stronger or longer duration eruptions. The pressure rise has also stimulated some recent hydrothermal eruptions in Kuirau Park, including a dormant vent that had previously been buried and built upon.

6 Regulatory control through geothermal plans

The environmental management of geothermal resources in New Zealand is administered by Regional Councils under the Resource Management Act. The Councils have formulated geothermal policies and plans, and, in the case of Waikato Region, these are presently under review. The definition and use of terms in these documents can be a source of debate and confusion. Examples, in connection with thermal features, are: “significant”, “sinter deposition”, “protection/preservation”, “natural/artificial”, “interference”, and “reversible /recoverable”. In connection with resource use, issues such as “renewable/sustainable utilisation” and “adverse/beneficial effects” also cause concern. The following comments on these issues are intended to provide useful and practical guidance for managing such environmental concerns.

6.1 Significant or sinter depositing features

It is usually accepted that there will be *some* risk of losses of individual features in systems identified for development. The purpose of ranking surface geothermal features in a region is to identify, for protection, geothermal systems exhibiting “outstanding” features that could be seriously affected by resource utilisation, and to ensure that a representative range of features is protected. However, it is inappropriate to apply the term “significant” to *all* identified natural geothermal features. Some thermal areas are many square kilometres in size, containing dispersed weak steam vents and large portions of non-thermal ground. Application of rules to such features could place undue constraints on the owners of these properties.

The term “sinter depositing” can also be used inappropriately with regard to a means of classifying or ranking thermal features. It apparently provides a means of visually identifying springs that could be susceptible to deep reservoir pressure drawdown associated with fluid extraction. Highly mineralised hot springs and geysers, feeding from deep reservoir fluids, often do deposit large quantities of silica sinter. However, the term “sinter” covers a wide range of deposits that form in springs (e.g. amorphous silica, travertine, calcite) and these are not all diagnostic of a direct plumbing connection between the spring and a high temperature geothermal reservoir. Sinters can also form from acidic steam-heated groundwater, which is not directly connected to deep reservoir liquid. Indeed, deep pressure drawdown is likely to enhance such features through additional upward steam flow. Therefore, the term “sinter depositing” should not be used to rank features for protection on the basis of resilience or rarity, because the term is simply not a useful discriminator and hot spring “sinters”, in the broadest definition of the term, are relatively common.

6.2 Protection/preservation

Management plans are sometimes premised by an underlying simplistic assumption that protection of natural geothermal features from change is, a) achievable, and b) guaranteed by excluding large-scale resource utilisation. However, observations show that nearly all geothermal features vary naturally (cyclically, randomly or intermittently) over timescales that can range from minutes to decades. It is not possible to guarantee their *preservation* in terms of maintaining a constant discharge temperature, flowrate or heatflow. Furthermore, recent experience (e.g. at Rotokawa and Mokai) has demonstrated that large-scale resource development does not necessarily result in loss of surface geothermal features. Indeed, with innovative resource management strategies (e.g. shallow injection, when appropriate) discharge from thermal features of many types can often be enhanced rather than reduced. The principal aim of geothermal management plans and policies should be to encourage efficient integrated use, while protecting the *diversity* of thermal features in the region (rather than specific individual features). This can be achieved (as proposed in the Waikato Region) by designating several geothermal systems to remain undeveloped (except for tourism facilities), as a kind of environmental insurance policy. However, properly managed development of all other geothermal resources for sustainable energy utilisation should be facilitated, with reasonable conditions imposed, in a balanced manner. Conditions should encourage enhancement of *any* type of surface thermal feature, by way of mitigation for unavoidable and adverse changes to other thermal features. This replicates the sort of variation behaviour that occurs naturally. Geysers and fumaroles, for example, are both naturally transient features. So newly created steam vents compensate for the loss of chloride springs, or vice-versa.

An issue commonly faced by direct users of low enthalpy resources is the “buffer zone” distance from significant thermal features, and other users, that a new user should respect in order to avoid interference effects. A distance of 20 m is considered reasonable in New Zealand for relatively small amounts of fluid extraction and injection (<1 kg/s). There should also be some regulatory incentive for the use of down-hole heat exchangers or ground-source heat pumps, rather than direct fluid extraction, because of the relative benefit to the environment, in that pressure interference is no longer an issue.

6.3 Natural/artificial

A common misperception regarding geothermal features is to regard them in ‘black-and-white’ terms as being either natural or artificial. This can lead to a pedantic application of rules designed to preserve natural features and discourage artificial features. In fact, there is a continuum of natural to human influences on thermal features (that is, many ‘shades-of- grey’). At one end of the spectrum, for example, the artificial geyser and silica terrace at Wairakei Terraces, which uses water from the reinjection pipeline, is indisputably *man-made.* The Lady Knox “geyser” at Waiotapu is *artificial,* in the sense of being stimulated daily by soap to erupt through a hidden pipe (installed in 1906), but has a very natural appearance and is highly valued. The “Healy 2 Bore” at Tokaanu is another example of a geysering spring, sinter-cone and terraces, with an associated highly valued ecosystem, that has evolved over 50 years from an abandoned bore. Although it was initially created by *human activity,* it now appears totally natural. The “Craters of the Moon” thermal area at Wairakei has always existed as a natural feature, but the intensity of thermal activity increased dramatically in response to Wairakei pressure drawdown, so it has been *indirectly affected* by human activity. The same could be said of existing geysers and discharging hot springs at Orakei-Korako that are *indirectly* supported by raised groundwater levels in response to the artificial filling of Lake Ohakuri in 1961. Several hydrothermal eruptions at Kuirau Park, Rotorua, were stimulated by pressure recovery related to the bore closure programme. These examples illustrate the point that rules need to be made flexible enough to cater for a wide spectrum of scenarios when considering the desirability of human influences on geothermal features.

6.4 Reversible/recoverable development effects

Many of the past assumptions of the likely effects from *new*, large-scale geothermal energy developments are outdated. The modern philosophy is to develop new fields in stages, big enough to create measurable effects on the resource, but not big enough to create large irreversible effects on surface thermal features or resource sustainability. Stages are typically about 5 years in duration, and up to 2 times the previous level of utilisation. Monitoring, and predictions based on regularly updated reservoir models, provides confidence of the probable effects (out to about 50 years) for each stage. Hence the risks are minimised for the regulator, the owner, the developer, and the investor. Historically, of the 7 geothermal fields developed for power generation in N.Z., only 2 of the earlier developments have directly resulted in significant loss of surface geothermal features. At Rotorua, a change of bore management policy to raise pressure has caused a significant recovery of geysers and springs. This demonstrates that such features *can* be recovered, and are not necessarily lost irretrievably when pressures decline.

6.5 Sustainable/renewable

An issue for sustainable utilisation is the duration of “reasonably foreseeable use” (eg 1-4 generations, or 25-100 years). Most reservoir modellers would not be confident about predicting geothermal reservoir behaviour beyond about 50 years, and this is probably a reasonable period to choose. Within that time, it is expected that technological advances will have provided access to far greater heat resources deeper within the earths crust. Furthermore, a long-term strategy of cyclic use of existing geothermal reservoirs would have the advantage of encouraging natural recharge of fluids and heat during a “fallow” period of recovery in between periods of heat extraction. Thus the concepts of renewable and sustainable geothermal energy use can be upheld whilst undertaking cyclic extraction of heat by drawing down reservoir pressure. This is analogous to hydroelectric lake storage management, but on a longer scale.

7 Conclusions

When considering the induced effects of geothermal development on the environment, a balanced view is to weigh up the adverse effects against the beneficial effects to determine a net effect that may be mitigated for. Examples of beneficial effects that are often overlooked include: subsidence induced wetlands; thermal ecosystems associated with increased areas of steam-heated ground and surface-disposal of hot water; and reduced gas emissions relative to fossil fuel alternatives. Geothermal plans should recognize the modern approach to utilisation of new resources, by allowing staged development of all but a few “protected” systems, in a manner that minimizes risk, and allows for recovery by adjustments to field management. Optimum size increments should be established by considering the resource knowledge acquired during each stage. Monitoring can provide early warning of adverse effects, and remedial measures can be implemented. If adverse effects on thermal features occur, they can often be reversed by locally managing the subsurface pressures.

8 References

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