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Promoting Beneficial Environmental Effects and Improving Long-Term Utilization Strategies Through IEA-GIA Collaboration

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ABSTRACT

The IEA-GIA provides an opportunity for international collaboration on various aspects of resource development, including environmental issues (Annex 1). Outcomes over the past five years have included a series of workshops, discussion documents, and papers on several topical issues including: protecting and enhancing natural thermal features, minimizing adverse effects from disposal of geothermal fluids and gases, providing policy advice, dealing with induced seismicity, and improving sustainability of geothermal production. With respect to felt induced seismicity, which has been an environmental and social issue associated with EGS projects, particularly in heavily populated areas, a protocol has been prepared on how to deal with the issue pro-actively.

By discussion amongst collaborating Annex 1 members it was agreed that strategies to sustain heat and power generation output by successfully managing geothermal fields in the long term are crucial to the future of geothermal. Over a relatively long term (100 years and beyond), these strategies may involve cycles of utilization to allow recovery of depleted reserves from deeper recharge zones. To achieve continuous geothermal generation, this will require exploration and identification of geothermal systems for backup generation during recovery periods. Also, adaptive management of production and injection, by adjusting rates and locations, will be needed to optimize sustainability and utilization of each system. This requires flexibility and surplus capacity to be built in at an early stage and then maintained throughout the stages of development.

Comparison of international experience showed that successful reservoir management strategies emphasize environmental balance through avoiding, remedying or mitigating adverse effects and promoting beneficial effects, to receive greater community support. In this regard, international experience in developing environmentally-sensitive strategies to promote geothermal production, provides strong role models for future developers.

1. INTRODUCTION

The future of geothermal as a world-wide renewable resource that can make a meaningful contribution to reducing fossil fuel consumption and the effects of global warming from CO_2 emissions, relies, in part, on developing successful long–term strategies to sustainably manage geothermal fields. Resource management will need to prioritize sustainability as well as promote beneficial environmental effects. This may come at a small economic cost in the short term, but will eventually provide substantial long term economic as well as environmental benefits. Utilization over the long term may involve cyclic strategies that consider periods of depletion and recovery. Simulation modeling of the effects of future scenarios will guide strategic decisions with challenges for the modelers including uncertainty that arises from inadequate information on reservoir boundary conditions.

Environmental enhancement strategies are often practical and feasible, but require a holistic case-by-case consideration. Examples include: improved discharges from surface thermal features by targeted fluid injection or extraction at specific aquifers, enhanced thermal habitats, and treatment or injection of discharges.

Collaboration between IEA countries with geothermal interests, sponsor companies and regional associations are collectively participating in the Geothermal Implementing Agreement, facilitating discussion and sharing of international experience with respect to these strategies.

2. DESCRIPTION OF ANNEX 1 TASKS

Geothermal is a relatively benign renewable energy source, with significant advantages over fossil fuels with respect to carbon emissions, but there are some environmental problems associated with its utilization. To further the use of geothermal energy, possible adverse and beneficial environmental effects are identified, and measures devised and adopted to avoid or minimize adverse impacts, while encouraging the benefits. The goals of Annex 1 are: to encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner; to quantify and balance any adverse and beneficial impacts that geothermal energy development may have on the environment, and to identify ways of avoiding, remedying or mitigating adverse effects. Participating countries are: New Zealand, Iceland, USA, Japan, Mexico, Italy, Switzerland, Australia, and EC. The five tasks (a to e) of the Annex are described below.

a. Impacts on Natural Features

Focus of this task is on documenting known impacts of geothermal developments on natural geothermal features such as geysers, hot springs and fumaroles. The aim is to provide a sound historical and international basis on which to devise methods to accurately monitor changes and avoid or mitigate the impacts of development on these geothermal features, which often have significant cultural and economic value.

b. Discharge and Reinjection Problems

This focuses on identifying and determining methods of overcoming the impacts of geothermal developments on other aspects of the environment. This includes the effects of gas emissions from geothermal power plants, effects of toxic chemicals in waste fluid that is discharged both into the ground and into rivers, and effects of ground subsidence. Projects examine the problems associated with disposal of waste geothermal fluids and the effects of CO_2, Hg and H_2S gas emissions, and subsidence.

c. Methods of Impact Mitigation and Environmental Procedures

The objective here is to contribute to the future of geothermal energy utilization by developing an effective, standard environmental analysis process. Field management strategies that result in improved environmental outcomes will be identified and promoted based on operational experience. Successful mitigation schemes that provide developers and regulators with options for compensating unavoidable effects are also identified, documented and promoted.

d. Seismic Risk from Fluid Injection

This addresses the issue of the occurrence of large (felt) induced seismic events, particularly in conjunction with EGS reservoir development, but also in connection with regular geothermal operations. The objective is to investigate these events to obtain a better understanding of why they occur so that they can either be avoided or mitigated. Objectives are to assess and generate an appropriate source parameter model, and test the model in relation to the hydraulic injection history, temperature gradients, stress field and the tectonic/geological background, using stress modeling, rock mechanics and source parameter calculations. Once various mechanisms of the events are understood, the injection process to engineer a geothermal reservoir, and the process of extracting heat over a prolonged period, may be modified to reduce or eliminate the occurrence of large events.

e. Sustainable utilization strategies

The objective here is to collate case histories of models of geothermal developments to see what strategies have worked and to undertake modeling of long term reservoir behavior to select optimum future strategies given different recharge and resource size scenarios. Also, compare environmental gains with economic gains from different sustainable development scenarios; compare different conceptual and hypothetical reservoir model predictions; and investigate (with agreed scenarios) long term reservoir behaviour, recharge factors, recovery times, and optimised cyclic or staged operation strategies.

3. SUSTAINABLE STRATEGIES AND CYCLIC UTILISATION

Improved geothermal energy production can be achieved by properly managing fluid production and injection rates and locations. Total energy yields that are achieved using low extraction rates over long duration cycles may be similar to those achieved with high extraction rates for short duration cycles (Rybach and Mongillo, 2006). The terms ‘renewable’ and ‘sustainable’ are discussed in Axelsson et al (2005). In short, ‘cyclic’ and ‘steady-state’ operations are both sustainable options. Balanced fluid/heat production not exceeding the recharge (natural and induced) can be considered indefinitely sustainable (‘steady-state’). If extraction rates exceed the rate of recharge, however, reservoir depletion will occur, but following termination of production, geothermal resources will undergo asymptotic recovery towards pre-production pressure and temperature states. Practical replenishment (~95% recovery) will usually occur on time scales of the same order as the lifetime of the geothermal production cycle, typically ~50-300 years (Bromley et al., 2006). The optimum level of long-term sustainable production depends on individual geothermal resource characteristics, but also on the technology utilized, which, in turn, influences the characteristics of production and injection fluids. Boundary conditions (especially relative amounts of hot and cold liquid recharge) affect the temperature recovery rates. A delayed response is anticipated along outflow structures relative to up flow structures.

Some examples of successful geothermal developments, where reservoir performance has stabilized during production, are described in an output from IEA-GIA Annex 1 Sustainability Task, (Bromley and Axelsson, 2008). The recovery factors that determine the long term response of these systems to energy extraction are generally dynamic rather than static. Recovery is influenced by an enhanced recharge driven by the strong pressure and temperature gradients initially created by the fluid and heat extraction. Because of this dynamic recovery process, cyclic utilization of geothermal resources is a real option for long-term development strategy, and possibly an economic and sustainable alternative to the strategy of simply limiting extraction to maintain more steady-state reservoir conditions. The cycle durations can be tailored to meet short term demand cycles (if economically justifiable), or can be extended out to periods of the order of 100 years, with resource utilization alternating between geothermal systems in the same region. For this to succeed, standby reserves will need to be explored and allocated for future development.

4. BALANCED ENVIRONMENTAL BENEFITS

In liquid-dominated systems, a consequence of deliberately enhancing hot deep recharge by drawing down reservoir pressure is that reservoir liquids may boil and two-phase conditions may develop in production sectors. Conversely, re-saturation of two-phase conditions may occur in injection sectors. This can affect the relative upflows of hot liquid and steam to the surface. Changes may include a decline in mineralized hot springs and an increase in steam-heated thermal features above production sectors, while the converse may occur above injection sectors. For reservoirs that are steam-dominated, a decline in reservoir pressure will usually reduce the natural upflow of steam to surface features. Other changes induced by subsurface boiling can include transients in steam flow, discharge enthalpies and gas composition of fumaroles. Such changes can have both adverse and beneficial effects on established users of the surface thermal features (such as hot spring resorts, Figure 1), the associated thermal ecosystems, and the developed area around them (e.g. homes and services). Strategies of geothermal environmental management that place an emphasis on achieving balance through controlling adverse effects and promoting beneficial effects tend to receive greater community support. A key objective of the strategies is to devise practical mitigation schemes. An example is shown in Figure 2.

Production and reinjection schemes can be planned with built-in flexibility in order to allow reaction to induced adverse effects, such as reductions in natural spring discharges or increasing subsidence, without compromising the efficient utilization of the resource. Some examples of environmental benefits deriving from adaptive production/injection strategies include: hot stream and thermal feature creation using separated geothermal water, increased steam-heated ground from liquid pressure drawdown, and increased hot spring discharge from shallow injection. Indirect environmental benefits include enhanced thermal ecological habitats where thermal features have increased. Each situation will involve a different set of potential benefits and adverse effects. The key to achieving a successful balance is adaptive resource management. This requires flexibility in terms of pipeline layout, and well configuration. Environmental consents and planning approvals established at the start of a project need to recognize this need for inherent flexibility, in order to achieve better managed optimal outcomes as the geothermal development progresses.

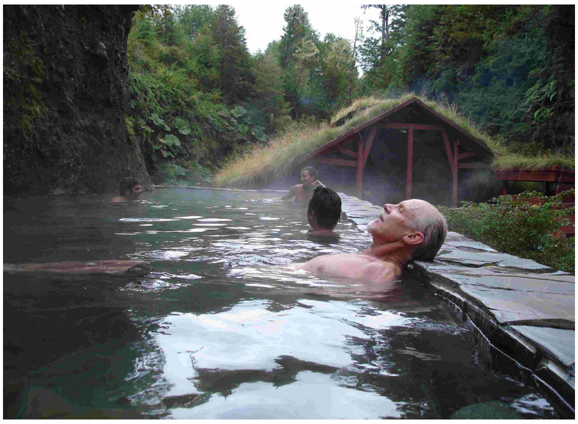

Figure 1: Contemplating environmental benefits at Geometricas Hot Spring in Southern Chile.

Figure 2 . Geyser and silica terrace created artificially at the Wairakei Terraces, New Zealand.

5. RESERVOIR MODELLING AND RESOURCE ASSESSMENT

Despite advances in global geothermal knowledge, there are still many challenges faced by reservoir managers, resource assessors and modelers. One example is whether to rely on resource capacity calculated using stored heat or simulation models. A comparison of Philippines and Icelandic experience by Sarmiento and Bjornsson (2007) suggests that the former suits an aggressive development approach whereas the latter suits a more conservative or risk-averse staged approach, reflecting uncertainties in permeability extent and boundary conditions.

Another issue is choosing the initial boundary and recharge conditions. Are they better constrained by calibrating a natural steady-state flow model, or by subsequent history matching? What effects do conservative boundary assumptions have on long-term performance predictions, calculated recharge and recovery rates? Is pressure stabilisation caused predominantly by storativity from steam cap development, or by gradually enhanced recharge of hot fluid through deep boundaries? When development is incremental, how many years between development steps is appropriate? What is the cost-benefit of drilling non-boundary delineation and monitor wells to improve future capacity predictions? What is the benefit of undertaking tracer tests for gross permeability structure, gravity surveys for mass and saturation changes, and regular chemical monitoring to quantifying injectate returns? Can detailed 3D simulation models of particular injection/production scenarios help solve specific problems with discharge enthalpy, scaling and acid fluid management? Is a multi-variable cross-correlation approach more useful (Horne, 2008)?

These and other issues have been investigated by researchers and reservoir modelers, collaborating under the IEA-GIA umbrella (www.iea-gia.org), and were discussed at an IEA-GIA Sustainability Modeling Workshop in Taupo, New Zealand on 10th November 2008. Annex participants intend to prepare joint publications similar to environmental special issues of ‘Geothermics’ previously compiled through IEA-GIA collaboration (Vol. 29, Nos. 4/5, 2000, and Vol. 34, No. 2, 2005).

6. SUCCESSFUL STRATEGIES

Strategies to successfully manage geothermal fields in the long term are crucial to the future of geothermal as a world-wide renewable resource. Over the next century and beyond, these may involve some form of cyclic utilization to allow recovery of depleted reserves from deeper recharge zones. Adaptive management of production and injection will be needed to maximize longevity. This requires built-in flexibility and surplus capacity to be established and maintained. Strategies of geothermal environmental management should place an emphasis on achieving balance. Successful experience in developing strategies to sustain and expand geothermal production over the past 30 years has provided leadership for other geothermal communities. In the future, the challenge will be to continue to advocate and deploy innovative, environmentally friendly technology.

7. FUTURE PLANS FOR ANNEX 1 ACTIVITIES

The following list is a broad indication of the areas of interest for future collaborative work.

Task A:

Changes in gas and steam emissions from natural features; Distinguishing natural and induced variations in thermal discharges; Modelling causes of groundwater effects from deep pressure change; Methods of ranking thermal features and ecosystems for protection; Classify vulnerability of thermal features to reservoir pressure changes.

Task B:

Cost-effective H_2S and Hg removal from production steam; Geothermal CO_2 capture for horticulture or bottling; CO_2 sequestration by injection or chemical fixing; Arsenic/boron removal from waste water by bio- or chem-processing; Protection of potable water aquifers from outfield reinjection effects; Improved prediction of subsidence and effects avoidance or mitigation.

Task C:

Environmental policy advice; Test the use of targeted injection to rejuvenate failed geysers; Test the use of targeted injection to stop subsidence; Review international geothermal environmental policies and procedures; Review costs of mitigation options for environmental effects.

Task D:

Induced seismicity - determine mechanisms; How to discriminate between EGS-related and natural seismic events; Identifying and characterising attributes typical of induced events (duration, frequency content, dominant frequency); Investigating possible seismic effects during long-term EGS operation (production phase); Long-term thermo-elastic effects (cooling cracks); Will the level of seismicity due to hot fluid production be lower than that during stimulation; Defining how far relevant stress field perturbations can extend from EGS operations; What are the implications of this in terms of safe proximity of stimulated EGS reservoirs to major active faults; Further studies on post shut-in seismicity, that is, why do micro-seismic events continue to occur after suspension of injection; Design downhole EGS operations to minimize ground shaking; Management scheme to involve adjusting volume, rate or temperature of fluid injection; Investigate the nature and degree of dependency of these factors on the local conditions at depth; Predict likelihood of damaging induced earthquakes and devise avoidance or mitigation schemes.

Task E:

Sustainable utilization strategies: Compare simulations of >100 year continuous and periodic (30-50 yr interval) production/injection scenarios; What are the optimum strategies; How rapidly and effectively do geothermal systems recover during breaks after periods of excessive production; What factors are most significant in controlling long-term behavior/capacity; boundary conditions, inflow/recharge, reinjection; How significant and far-reaching are long-term production pressure drawdown and injection cooling effects, i.e. how significant is interference between adjacent geothermal areas; Using case histories, what are the reliability of long term predictions of reservoir behavior using various methods (stored heat, simple analytical models, complex 3D models); What information should be collected at pre-exploitation and early development stages to significantly reduce uncertainties in long-term resource sustainability assessments.

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