SUSTAINING GEOTHERMAL ECOSYSTEMS:

THRESHOLDS OF CHANGE IN GEOTHERMAL ECOSYSTEMS

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Keywords: *Geothermal, Ecosystems, Resilience, Thresholds, Restoration,*

ABSTRACT

New Zealand has a range of geothermally-influenced ecosystems with distinctive ecological features and biotic communities. Retaining resilient geothermal ecosystems is an important goal of many communities and stakeholders, and is reflected in local, regional and national government policy and rules. An understanding of the real and perceived driving forces and pressures contributing to the sustainability of the natural resources of geothermal resources, and the thresholds at which the resource is no longer sustainable are necessary if management goals are to be met. Threshold values are points or zones of change from one ecological condition to another, usually from a natural or anthropogenic change in 'pressure' or 'development'. In this paper we present the results of reviews and investigations that consider threshold values for ecologically sustainable geothermal ecosystems. Particular focus is given to the characteristics of geothermal resources. Threshold values can be used in sustainable planning or as goals for enhancement and restoration.

1. INTRODUCTION

Geothermal resources of New Zealand and elsewhere in the world are coming under increasing pressure particularly as a renewable source of energy, but also for other business initiatives including tourism and food production. Geothermal activity can be associated with volcanic activity, hot crust in tectonically active areas or permeable sedimentary layers at great depth. Ancestral and historical use of thermal springs has been a feature of human development and these resources have been used for bathing, washing and cooking for thousands of years (Axelsson et al. 2005). Geothermal resources have been a feature for tourism since the explorations of the 18th and 19th centuries. Energy production from geothermal resources is a more recent phenomenon and commenced in the first half of the twentieth century; recent spin-offs have been the use of naturally heated water and steam in food production.

Sustainable management, protection and development of the geothermal resources are important if the geothermal features are to be sustained for future economic, recreational and conservation purposes (Boothroyd 2009). Successful management relies on proper understanding of the geothermal system involved, which in turn relies on adequate information on the system (Axelsson et al. 2005). Today, the development of new fields for energy generation generally occurs in stages; sufficient to assess the resource and any effects (Bromley 2005). Thus, sustaining energy production from geothermal resources involves managing energy extraction so as to maximize the resulting benefits, without overexploiting the resource.

In New Zealand, the Resource Management Act 1991 (RMA) is the main legislation governing the sustainable management of natural resources, including geothermal resources. The RMA provides a suite of policy, planning and regulatory instruments to manage the effects of using natural and physical resources (Daysh & Chrisp, 2009). Within this framework, at least for the Waikato region of New Zealand, the management of geothermal systems by the Waikato Regional Council is carried out in a way that aims to ensure that different demands on the regional geothermal resource can be satisfied (Dickie & Luketina, 2005). Accordingly, a series of policies, rules and regulations have been formed for geothermal systems in the region (Luketina & Dickie, 2006).

This paper is a 'thinkpiece' aimed to stimulate debate on the management and development of geothermal resources, especially where surface features and ecosystems are influenced by the characteristics of the geothermal resource. Its focus is on resilience of geothermal ecosystems and the understanding of thresholds that bring about change in ecosystems. The work draws, in part, on the outcomes of a research programme aimed at understanding the ecology, biodiversity, and sustainability of geothermal ecosystems associated with different geothermal systems (e.g., Boothroyd & Browne 2006, Boothroyd et al. 2006, Duggan et al. 2007, Boothroyd & Wilson 2011).

2. SUSTAINABILITY ECOSYSTEMS

2.1 Sustainability of geothermal systems

New Zealand's energy demand has been growing steadily and is forecast to continue to grow and New Zealand must confront two major energy challenges as it meets growing energy demand: respond to the risks of climate change by reducing greenhouse gas emissions caused by the production and use of energy; and deliver clean, secure, affordable energy while treating the environment responsibly.

The Brundtland report in 1987 (World Commission on Environment and Development, 1987) defined sustainable development as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*'.

Axelsson et al. (2005) concluded that sustainability of geothermal energy production has received limited attention, even though the longevity of geothermal production has long been the concern of geothermal operators (Stefansson, 2000; Rybach et al., 2000). Axelsson & Stefansson (2003) consider that the terms *renewable* and *sustainable* are often confused or used interchangeably. Renewable describes a property of the resource, while sustainable applies to how a resource is utilized (Dickie & Luketina 2005).

Focusing on sustainability, Axelsson et al. (2001) proposed a definition for the term sustainable production of geothermal energy from an individual geothermal system as '*For each geothermal system, and for each mode of production, there exists a certain level of maximum energy production, E0, below which it will be possible to maintain constant energy production from the system for a very long time (100-300 years). If the production rate is greater than E0 it cannot be maintained for this length of time. Geothermal energy production below, or equal to E0, is termed sustainable production while production greater than E0 is termed excessive production*'. This definition does not consider economical, environmental, or technological advances relating to the use of geothermal resources.

Although environmental management is a part of the management of geothermal energy production (e.g., reinjection is considered an integral part of any modern, sustainable, environmentally friendly geothermal utilization), less focus has been given to the resilience and sustainability of surface features and especially the living components of geothermal ecosystems.

2.2 Ecosystem services

Ecosystem services are ecosystem functions that bring benefits to people. Ecosystems can be defined as dynamic collections of plants, animals, and microorganisms interacting with each other and their abiotic environment. These benefits (i.e., the ecosystem services) are commonly classified as being one of four types: provisioning, regulating, cultural, or supporting (MA 2005). The MA report defined ecosystem services as: "The direct and indirect contributions of ecosystems to human wellbeing". Geothermal ecosystems, although a more extreme and fragmented environment, contribute services to mankind in much the same way: provision of energy and heat for human and industrial use; cultural, health and meditation services; heat and steam for food preparation; and as a tourism aesthetic service.

2.3 Naturally uncommon ecosystems

Williams et al. (2007) developed a framework for defining the physical environments of historically rare ecosystems (rare prior to human occupation of New Zealand). Such ecosystems are often small, widely dispersed and often lack trees due to the extreme environments. Correspondingly, these ecosystems often exhibit extremes of biodiversity, high national endemism, and may support specialized life forms. 'Rare' ecosystems are defined as those having a total extent less than 0.5% of New Ze4aland's total area. Williams et al. (2007) listed some 72 rare ecosystems including five geothermal systems (Table 1)[1].

[1] Naturally uncommon ecosystems are also listed in Schedule 1 of the proposed National Policy Statement for Biodiversity.

Table 1: Physical environments and vegetation structure of naturally uncommon geothermal ecosystems (from Williams et al. 2007).

Geothermal Ecosystem type	Definition	Vegetation structure	Status
Heated (dry) ground	excessive heat	open land, mossfield, scrub shrubland,	Critically endangered
Hydrothermally altered ground (now cool)	acid soils, toxic elements	open land, shrubland, scrub	Critically endangered
Acid rain systems	acid rain	open land, scrub, treeland, forest	
Fumaroles	superheated steam/acid rain/depression	open land, shrubland	Critically endangered
Geothermal streamsides	Excessive heat/near permanently saturated water	Open land to scrub	Critically endangered

Four of the five naturally uncommon ecosystems are classified as 'critically endangered' by Holdaway et al. (2012). This classification is based on the application of the proposed IUCN Red List criteria for threatened ecosystems (Rodriguex 2011); and ecosystem status is based on 7 quantitative indicators on New Zealand ecological integrity, specifically designed for NZ ecosystems. Several threshold values of decline were established within each indicator (see below).

3. THRESHOLDS OF CHANGE

3.1 What is a threshold?

For the purpose of this paper, thresholds of change are defined as the points where even small changes in environmental conditions will lead to large changes in system state (Suding & Hobbs 2009). There is a growing recognition that threshold models can apply to a broad range of systems, including ecosystems. For example, Andrén (1994) suggested that a dramatic decline in the species richness of birds and mammals occurred below a threshold of 10-30% habitat cover. In urban catchments, the impervious cover model (ICM) highlights the points or zones of change from one ecological condition to another. The influence of increasing impervious surfaces (IC) within catchments (resulting in less infiltration to ground by rainwater) is a well known phenomenon. By almost any measure of stream health, stream ecosystems degrade as imperviousness increases as a percentage of catchment landcover. In a survey of the literature, Schueler et al. (2009) found that 69 % of the global studies investigated confirmed the general findings of ICM. The general predictions of ICM are:

- Stream with <10 % catchment IC: streams function as sensitive streams
- Stream with 10 % - 25 % catchment IC: streams behave as impacted streams
- Stream with 25 % - 60 % catchment IC: degrading of non-supporting of ecosystem function
- Stream with >60 % catchment IC: highly modified

ecosystem function and classified as urban drainage.

As outlined above Holdaway et al. (2012) developed thresholds of decline for ecological integrity indicators applied to naturally uncommon ecosystems in New Zealand. They set threshold values of decline within each indicator of 80% (very severe), 50% (severe) and 30% (moderately severe) (Table 2).

Table 2: Selection of ecological integrity indicators and estimated threshold values used to guide assessments of decline in ecological function (from Holdaway et al. 2012).

Element	Indicator	Severity of decline		
		Very severe	*Severe*	*Moderately severe*
Native dominance	native vegetation cover	≥ 80% decline	≥ 50% decline	≥ 30% decline
	water quality	≥ 80% decline in one or more aspects of water quality	≥ 50% decline in one or more aspects of water quality	≥ 30% decline in one or more aspects of water quality
Species occupancy	composition (plants)	≥ 80% decline in abundance of one or more plant functional types	≥ 50% decline in abundance of one or more plant functional types	≥ 30% decline in abundance of one or more plant functional types
Environmental representation	climate change	Alteration of one or more local climate variables beyond the range usually experienced by the ecosystem	Alteration of one or more local climate variables to the extremes of the range usually experienced by the ecosystem	Alteration of one or more local climate variables within the range usually experienced by the ecosystem

It is notable that these threshold indicators reflect the post-disturbance status of the ecosystems. It is preferable to understand the threshold levels that such systems 'tip' over to changes in system state; early predictions can avoid the decline that is evident in the work of Holdaway et al. (2012).

3.2 Abiotic and biotic thresholds

A framework that can specify ecosystem processes and how these processes can be linked can be valuable in preventing their degradation or as a means to seek to reverse the downward spiral to degradation. King and Hobbs (2006) describe two linked conceptual frameworks towards preventing or restoring degraded ecosystems: structure and function, and abiotic and biotic components. The structural approach focuses on static patterns whereas the functional approach assesses the processes that contribute to the static patterns. For example, typically in the ICM frameworks applied to date the focus has been assessed and managed on the structural approach using static biotic and abiotic measures (Boothroyd 2012).

4. DEVELOPMENT OF POTENTIAL THRESHOLDS FOR GEOTHERMAL ECOSYSTEMS

Geothermal ecosystems are associated with distinctive geophysical and geochemical components, and terrestrial and aquatic ecosystems (Boothroyd 2009) and are distinguished from their cool temperate counterparts by steep gradients in temperature, elevated concentrations of a range of minerals, extreme pH and different habitats. Burns (1997) and Duggan et al. (2007) have related the temperature and other environmental characteristics to the composition and structure of terrestrial thermotolerant vegetation, and aquatic invertebrate communities respectively. Temperature was a strong factor influencing the distribution and composition of the respective biotic communities, although other factors (e.g. habitat and chemical composition of soil and water) were also important. At a landscape level of consideration, the distribution and fragmentation of geothermal ecosystems is a feature of their expression on the earth's surface. These characteristics can provide suitable indicators for the development of thresholds in geothermal ecosystems.

Boothroyd et al. (2006) found that, at the ecosystem level, communities present in geothermal systems primarily reflect the physico-chemical conditions of their particular stream environment. While factors such as temperature, pH, conductivity and dissolved oxygen influence biota in all streams, these appear to be major determinants of biological communities in geothermal streams. At the population level, both macroinvertebrate and algal populations were highly variable between the different systems and sites. Differences within individual streams were generally minimal compared with differences between streams from different geothermal areas. At the molecular level of a single species, preliminary findings by Boothroyd et al. (2006) suggested that there was no difference between larval populations at different spatial scales amongst geothermal ecosystems. Results might vary with different study species or spatial scales.

Current research is investigating further the thresholds at which some aspects of single species and community-level changes might occur in terrestrial and aquatic geothermal ecosystems. However, although the detection and development of thresholds can occur at the community or individual species level, caution must be applied to any derived threshold value and much research and determination of the ecological processes that underlie these patterns must be understood. Single-species seem less problematic than developing thresholds for community-wide responses although the emphasis on ecological research continues at the community-level and may limit the development of threshold values (Luck (2005).

ACKNOWLEDGEMENTS

This paper was developed in part from research funded by FRST Contract CO5X0201.

REFERENCES

Andrén, H. 1994: Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: an overview. Oikos 71: 355-366.

Axelsson, G., Gudmundsson, A., Steingrimsson, B., Palmason, G., Armannsson, H., Tulinius, H., Flovenz, O.G., Bjornsson, S., Stefansson, V.: Sustainable production of geothermal energy: suggested definition. IGA-News, Quarterly No. 43, 1-2 (2001).

Axelsson, G., Stefánsson, V.: Sustainable management of geothermal resources. *International Geothermal Conference, Reykjavík, Iceland*, Paper 075, 40-48 (2003).

Axelsson, G., Stefánsson, V., Björnsson, G., Liu, J.: Sustainable Management of Geothermal Resources and Utilization for 100 – 300 Years. *Proc. World Geothermal Congress 2005*, Antalya, Turkey. (2005).

Boothroyd, I.K.G.: Ecological characteristics and management of geothermal systems of the Taupo Volcanic Zone, New Zealand. *Geothermics* 38: 200-209 (2009).

Boothroyd, I.K.G.: Sustainable catchment management: Thresholds for ecological sustainability. *Proceedings of the Water NZ Stormwater Conference*, Wellington, New Zealand (2012).

Boothroyd, I.K.G., Hay, S., Turner, S.: Uniqueness and diversity of geothermally influenced aquatic ecosystems. In: Proceedings of the 28th New Zealand Geothermal Workshop, Auckland University, Auckland, New Zealand, Paper 216, 6 pp. (2006).

Boothroyd, I.K.G., Browne, G.N.: Invertebrates of geothermally influenced aquatic and terrestrial ecosystems: longitudinal and lateral linkages. In: Proceedings of the 28th New Zealand Geothermal Workshop, Auckland University, Auckland, New Zealand, Paper 212, 4 pp. (2006).

Boothroyd, I.K.G., Wilson, N.: Sustaining geothermal ecosystems: Geochemical influence and restoration of geothermal ecosystems. Proceedings of the 33rd New Zealand Geothermal Workshop, Auckland University, Auckland, New Zealand, Paper 37, 4 pp. (2011).

Bromley, C.: Advances in Environmental Management of Geothermal Developments. *Proc. World Geothermal Congress 2005*, Antalya, Turkey. (2005).

Burns, B.: Vegetation change along a geothermal stress gradient at the Te Kopia steamfield. *Journal of the Royal Society of New Zealand* 27, 279–294 (1997).

Daysh, S., Chrisp, M.: Environmental planning and consenting for Wairakei: 1953–2008. *Geothermics* 38, 192–199 (2009).

Death, R., Barquin, J., Scarsbrook, M.: Biota of cold-water and geothermal springs. In: Harding, J., Mosley, P., Pearson, C., Sorrell, B. (Eds.), *Freshwaters of New Zealand*. New Zealand Hydrological Society and New Zealand Limnological Society, Christchurch, New Zealand, 700 pp. (2004).

Dickie, B.N., Luketina, K.M.: Sustainable management of geothermal resources in the Waikato region, New Zealand. In: *Proc. World Geothermal Congress 2005*, Antalya, Turkey, Paper 303, 9 pp. (2005).

Duggan, I.C., Boothroyd, I.K.G., Speirs, D.: Factors affecting the distribution of stream macroinvertebrates in geothermal areas: Taupo Volcanic Zone, New Zealand. *Hydrobiologia* 592: 235–147 (2007).

Holdaway, R.J., Wiser, S.K,; Williams, P.A.: Status assessment of New Zealand's naturally uncommon ecosystems. *Conservation Biology* 26: 619-629 (2012).

King, E.G.; Hobbs, R.J.: Identifying linkages among conceptual models of ecosystem degradation and restoration: Towards and integrative framework. *Restoration Ecology* 14: 369-378 (2006).

Luck, G.W.: An introduction to ecological thresholds. *Biological Conservation* 124: 299-300 (2005).

Luketina, K.M., Dickie, B.N.: Waikato Regional Council geothermal policy—on the home straight. In: Proceedings of the 28th New Zealand Geothermal Workshop. Auckland University, Auckland, New Zealand, Paper 117, p. 5 pp (2006).

Rodriguez, J. P., Balch, J.K., Rodriguez-Clark. K.M,: Establishing IUCN red list criteria for threatened ecosystems. *Conservation Biology* 25: 21-29 (2011).

Rybach, L., Megel, T., Eugster, W.J.: At what scale are geothermal resources renewable? *Proceedings of the World Geothermal Congress 2000*, Kyushu-Tohoku, Japan, 867-872 (2000).

Schueler, T.R.; Fraley-McNeal, L.; Cappiella, K.: Is impervious cover still important? Review of recent research. *Journal of Hydrologic Engineering* April 2009: 309-315 (2009).

Stefansson, V.: The renewability of geothermal energy. *Proceedings of the World Geothermal Congress 2000*, Kyushu-Tohoku, Japan, pp. 883-888 (2000).

Suding, K. N.; Hobbs, R.J.: Threshold models in restoration and conservation: a developing framework. *Trends in Ecology and Evolution* 24: 271 – 279 (2009).

Williams P.A., Wiser S., Clarkson B., Stanley M.C.: New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework.. *New Zealand Journal of Ecology* 31: 119-128 (2007).