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Gravity changes in the Tauhara sector of the Wairakei–Tauhara geothermal field, New Zealand

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ABSTRACT

Five microgravity surveys, done between 1972 and 2006, show that in the northern part of the Tauhara geothermal field there were large gravity decreases prior to 1985 associated with the expansion of steam zones resulting from pressure drawdown caused by fluid extraction at Wairakei. Since 1985 there have been gravity increases of up to 240 μgal in the northern part of Tauhara, corresponding to a mass increase of about 20 Mt. The gravity increases are centred near the unused deep well TH4, and are inferred to result mainly from resaturation of a deep steam zone due to a downflow of water in the well. We suggest that the water entered the well from a confined groundwater aquifer at a known casing break at 393 m depth and exited in the region of slotted casing at about 900–1000 m depth causing displacement of single-phase liquid upwards into the overlying steam zone. The average downflow rate is estimated to be about 110 t/h (30 kg/s); however, no downhole measurements in the well have been possible due to casing breaks. Simple modelling of the gravity data suggests the region of resaturation had the form of a cone of impression 150–250 m high and extending laterally for 1–2 km. Since 1985, gravity changes in the central and southern parts of the Tauhara field have been less than 50 μgal, indicating little net mass loss (<2 Mt), and hence little effect in this area from the continuing production at Wairakei. The subsidence centred near Crown Road has been attributed to compaction of a thin, elliptical lens of porous, thermally-altered volcanic deposits at shallow depth as a result of a water level decline in the near-surface, steam-heated groundwater aquifer. Gravity data (1994 onwards) at a point near the centre of the subsidence bowl show that, despite ground subsidence of about 0.55 m, there have been no significant gravity changes. One explanation for the absence of gravity changes is that the water lost from the near-surface aquifer has drained downwards increasing the saturation in part of a deeper, partly saturated layer.

1. Introduction

The Wairakei–Tauhara geothermal system is comprised of two sectors: Wairakei in the northwest and Tauhara in the southeast (Fig. 1); hereafter referred to as Wairakei field and Tauhara field, respectively. Several deep exploration wells (TH1–TH4) were drilled in the northern part of the Tauhara field during the 1960s. No significant production from these wells occurred until 2006 when geothermal fluid production of about 5 kt/day was taken from TH2 and TH6 (drilled late 2006; total depth 1010 m) for industrial use.

Pressure data from the Tauhara wells show that there was pressure drawdown up until 1980, indicating a hydrological connection with the producing Wairakei field. The deep pressure drawdown also appears to have induced ground subsidence at Tauhara of up to 100 mm/yr (Fig. 2), localised in subsidence bowls[1] near Rakaunui Road and Spa Hotel in the northern part of Tauhara field (Allis et al., 2001). A third bowl started to form in the late 1990s near Crown Road in the central part of the field, but this may not be caused by deep pressure drawdown (Bromley and Currie, 2003).

Allis et al. (1989) noted that in the northern part of the Tauhara field (northern Tauhara) there has been significant reservoir pressure drawdown, and chemical or thermal changes in the surface features, since the early 1960s, while in the southern part (southern Tauhara) no major changes have been detected in the surface manifestations. This led them to suggest that there had been no pressure drawdown in the southern part, and that a separate geothermal upflow existed in southern Tauhara.

Pressure measurements in the deep exploration wells at Tauhara indicate that by the early 1980s a steam zone, about 50 m thick, had formed in the northern part of the field (Allis, 1983). By the late 1990s, three steam zones had been identified in this area: (a) A shallow steam zone at about 280–350 mRL (metres with respect to sea level) in parts of the Oruanui Formation (Fig. 3), which hosts groundwater aquifers. This zone feeds surface thermal features such as the hydrothermal explosion craters at the Taupo Pony Club, adjacent to Broadlands Road (Fig. 1); (b) An intermediate steam

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[1] The term "bowl" is used here to denote an area of significantly greater subsidence rate; it does not imply that this area is circular in shape, or that it has vertical sides.

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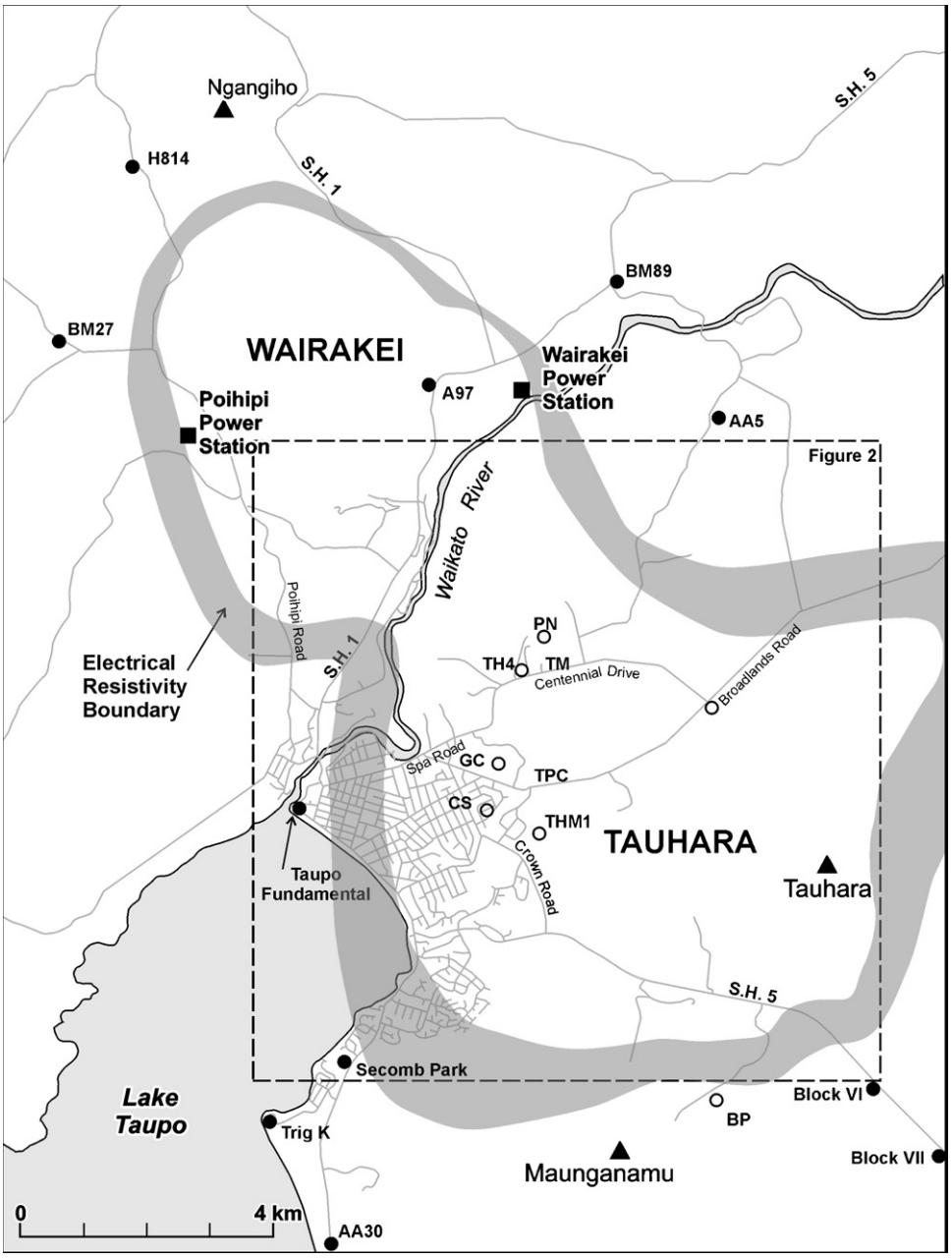

Fig. 1. Map showing location and extent of the Wairakei and Tauhara sectors of the Wairakei–Tauhara field. Black dots: location of gravity measurements outside the field used to check if there have been gravity changes at the Taupo Fundamental base station. Open circles show locations of groundwater level monitor bores: GC, Golf Course; PN, Plant Nursery; CS, Cumberland Street; BP, Bonshaw Park. Other localities: TM, Tenon Mill; TPC, Taupo Pony Club thermal area. Lines correspond to main and local roads.

zone lying at about 50–150 mRL, in parts of the middle unit (Huka-2) of the Huka Falls Formation (Fig. 3); (c) A deep steam zone in the upper part of the Waiora Formation that lies beneath the lowest unit (Huka-1) of the Huka Falls Formation. This zone has been estimated to be about 150 m thick with the top at about −100 mRL (Menzies and Lawless, 2000).

2. Previous gravity data

Repeat gravity measurements have been made in the Wairakei field since the early 1960s (Hunt, 1995). At the beginning there were widespread gravity decreases (up to −500 μgal) associated with mass depletion related to the formation and extension of steam and two-phase zones. However, since the 1970s there have been mainly positive gravity changes in Wairakei field associated with a rise in the deep liquid level resulting from resaturation of the lower parts of the two-phase zone.

Except at benchmark AA8 near well TH2 (Fig. 2) in northern Tauhara, no repeat gravity measurements were made in the field during the 1960s. Measurements were made at benchmark BM53 (Fig. 2) in 1971, and at this and several other benchmarks in northern Tauhara in the early 1980s, as part of the Wairakei surveys. These measurements show that between 1971 and 1985 there were gravity decreases associated with the early geothermal reservoir pressure drawdown.

If there had been pressure drawdown in southern Tauhara then it is expected that there would have been mass changes there, and repeat measurements would have shown that there had been gravity decreases which might have been of similar magnitude to those observed at AA8 and BM53. However, the first survey measuring gravity changes in the central part of Tauhara field was not made