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RECHARGE IN WAIRAKEI GEOTHERMAL FIELD FOR 1974-1983

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ABSTRACT

Repeat gravity measurements show that over the whole field there has been no net mass loss (i.e. 100% recharge) for the period 1974-1983; by early 1983 cumulative mass loss from the field was about 1450 x 10^9 kg and cumulative recharge about 1100 x 10^9 kg. However, between 1974 and 1983 a significant net mass loss of about 7 x 10^9 kg occurred in an area west of the main production borefield and an approximately equal net mass gain occurred in the eastern part of the borefield. This is the first time that a significant net mass gain has occurred anywhere in the field since exploitation began. The area in which this gain occurs roughly corresponds to an area in which shallow groundwater levels have dropped by up to 10 m in this period, but is not centred on the area of greatest ground subsidence.

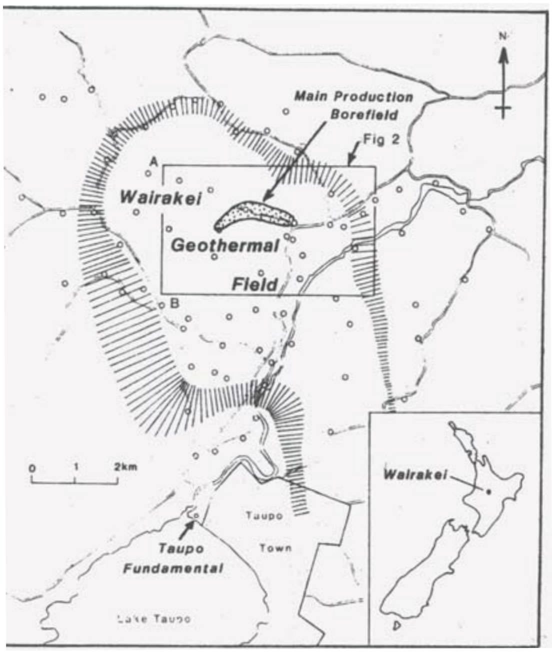

Fig. 1: Location and extent of Wairakei Geothermal Field. The hatched zone indicates the boundaries of the field, at a depth of about 0.5 km, determined from electrical resistivity measurements (G. Risk, pers. comm.). Note that the main production borefield occupies only a small area of the field. Open circles indicate positions of benchmarks used in the gravity survey; some benchmarks in borefield area have been omitted. A and B indicate areas of negative gravity differences referred to in the text.

INTRODUCTION

Repeat gravity surveys have been made in and about Wairakei Geothermal Field (Fig. 1) in 1961, 1962, 1967, 1968, 1971 and 1974 to determine net mass change and the amount of recharge of water into the field. These surveys showed that, during the initial period of exploitation between 1958 and 1962 the annual recharge dropped to about 10%, but subsequently rose and from 1966 to 1974 was about 90% (Hunt, 1970; 1977). This paper gives some preliminary results of a further repeat gravity survey, made in February 1983; full accounts of the methods used and interpretation of the results are in preparation and will be published elsewhere. The time period considered here is December 1974 to February 1983 (approximately 8.3 years); during this time about 490 x 10^9 kg of water (both liquid and gas phases) was drawn from the field to generate electricity.

GRAVITY MEASUREMENTS

The gravity measurements were made on permanent, concrete benchmarks with a LaCoste and Romberg gravity meter (G106). A looping technique was used to minimise instrument drift errors and identify blunders. Gravity values were computed using the methods described by Woodward (1982 a,b); this method differs slightly from that used previously (Hunt, 1975) and has allowed better recognition of tares and blunders - most values computed are within 0.3 μN/kg (0.03 mgal; 30 μgal) of those given previously. All values were computed relative to a base station on Taupo Fundamental benchmark (Fig. 1) situated outside the field.

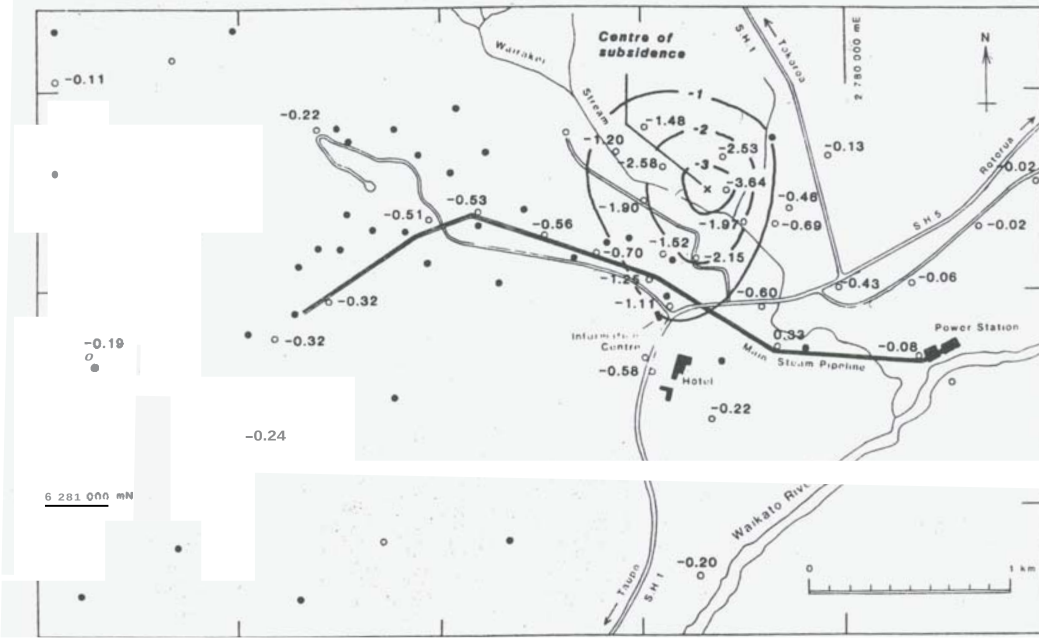

Fig. 2: Elevation changes (m) in and near the main production borefield for the period 1974-1983. open circles indicate benchmarks used in the gravity survey; closed circles indicate shallow ground water level monitoring holes. Note the large ground subsidence (>3 m) north-east of the borefield.

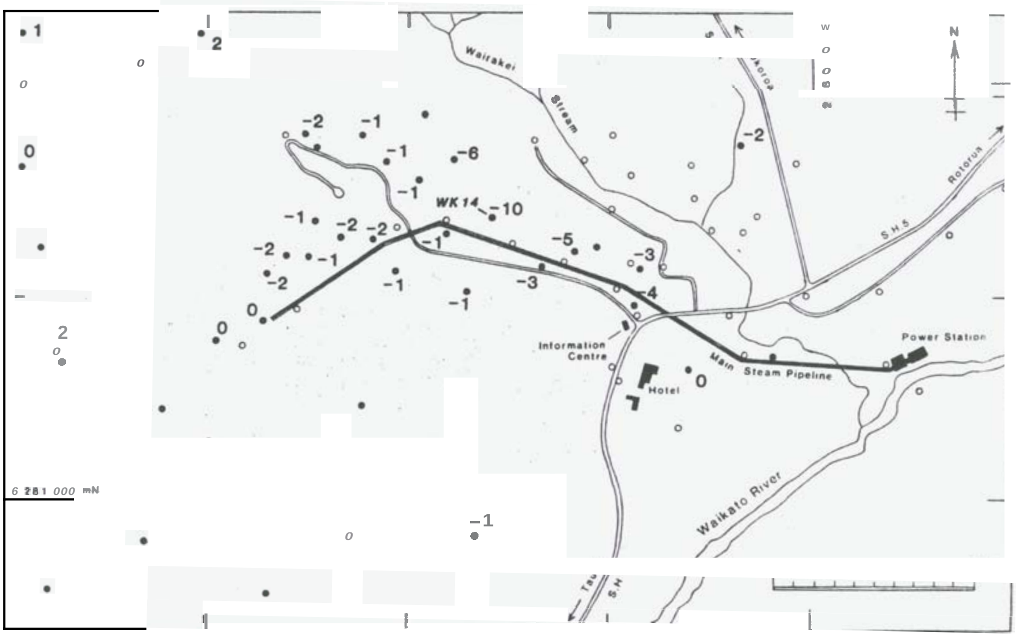

Fig. 3: Groundwater level changes (m) in and near the main production borefield for the period 1974-1983. Symbols as for Fig. 2. Note the large drop (10 m) in groundwater level at bore WK14.

GRAVITY DIFFERENCES

Differences in the value of gravity at a benchmark between surveys may be caused by changes in elevation of the benchmark, and in near-surface groundwater level in addition to net mass changes in the reservoir. Since the aim of the gravity measurements is to determine mass changes in the reservoir, the gravity effects of all other changes must be determined and allowed for.

Considerable ground subsidence has occurred in and about the field (Hatton, 1970; Stilwell, et al. 1975; Allis and Barker, 1982). The amount of subsidence at each benchmark for the period 1974-1983 was determined from levelling data provided by Ministry of Works and Development (Fig. 2) and the corresponding gravity effect calculated using the normal 'free-air' gradient of +3.09 µN/kg per metre of subsidence.

Measurements of the level of the shallow groundwater surface at Wairakei have been made sinc the late 1950's by M.W.D. Prior to 1974 the changes in level have generally been less than 3 m and the gravity effects at the benchmarks used have been considered negligible (<0.3 µN/kg; Hunt, 1975). However, during the period 1974-1983 there have been some larger changes, notably in the north eastern part of the main production borefield (Fig. 3), which require consideration. Assuming the connected porosity of rocks in the groundwater zone is 0.5, on draining there is 50% residual saturation, and the temperature of water at the groundwater level is 100°C, the gravity effect of

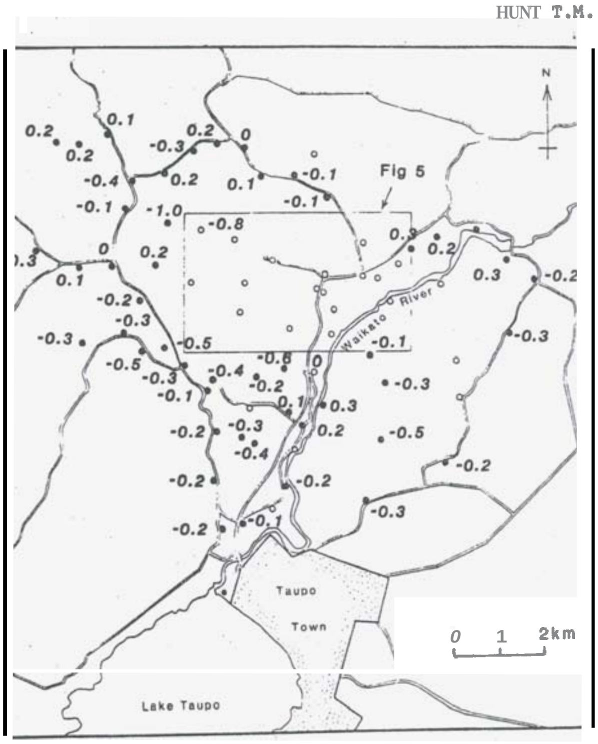

Fig. 4: Corrected gravity differences (µN/kg) at Wairakei Geothermal Field for the period 1974-1983.

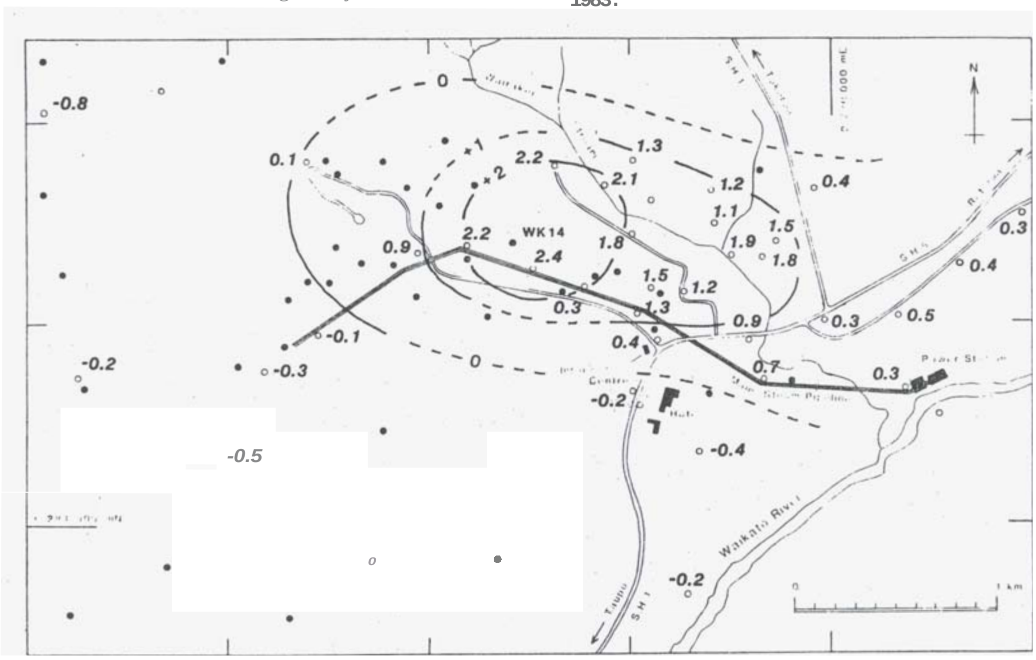

Fig. 5: Corrected gravity differences (µN/kg) in and near the main production borefield for the period 1974-1983. Symbols as for Fig. 2. Note the area of positive gravity differences covering the eastern part of the borefield.

a drop in water level is approximately -0.1 μN/kg per metre drop. Unfortunately there have been few measurements of groundwater level changes outside of the borefield, and so corrections for this effect have been confined mainly to those gravity observations in the borefield.

Other changes which might cause gravity differences include changes in topography, changes in temperature of the groundwater (Allis, 1982), uncertainties in the calibration of the gravity meter, and regional gravity changes. The gravity effects of all these have been investigated, but are considered to be negligible (<0.3 μN/kg).

Gravity differences corrected for the gravity effects of subsidence and changes in groundwater level are called corrected gravity differences.

CORRECTED GRAVITY DIFFERENCES

Corrected gravity differences for the period 1974-1983 are given in Figs 4 and 5.

Values of such differences are generally small (<1 μN/kg) except at same benchmarks in and close to the main production borefield. An estimate of the values caused by errors in measurement, reduction of the data, and other spurious causes can be obtained by examining the differences at benchmarks distant from the borefield. A histogram of the distribution for values of corrected gravity difference at benchmark outside the area covered in Fig. 2, for the period 1974-1983, is shown in Fig. 6. Except for one value of -1 μN/kg, the values range between -0.6 and +0.4 μN/kg and are slightly skewed towards negative values. The pattern is similar to that for the period 1967-1974 (Fig. 6). This suggests that, for the area in and near the borefield, differences of more than +0.4 and less than -0.6 μN/kg are significant, and particularly significant if values at adjacent benchmarks are also outside this range and of the same sign.

DISTRIBUTION OF CORRECTED GRAVITY DIFFERENCES

Significant corrected gravity differences occur in two small and separate areas of the field:

1. An area north-west of the main production borefield (A; Fig. 1), and possibly extending south-west of the field (B; Fig. 2). The differences are negative, indicating a net mass loss, and are up to -1 μN/kg in amplitude.

2. An elongated area covering the eastern part of the main production borefield and the area between it and the Wairakei Stream to the north. The gravity differences are positive indicating a net mass gain, and are up to 2.4 μN/kg in amplitude. This is the first time that significant positive gravity differences have been recorded at Wairakei.

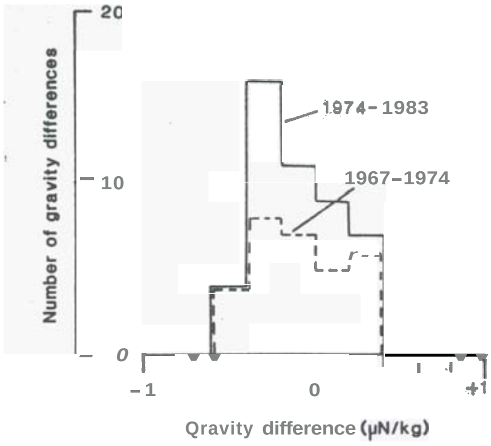

Fig. 6: Histogram showing the frequency distribution of corrected gravity differences at Wairakei for the area outside that covered in Fig. 2. One value of -1.0 μN/kg, for the period 1974-1983, has not been plotted. Note that, apart from this value, all differences lie between +0.4 and -0.6 μN/kg, and that the distribution for 1974-1983 is similar to that for 1967-1974.

MASS CHANGES OVER THE WHOLE FIELD

The integrated sum of the corrected gravity differences (ΣΔgΔs) in each of the above areas is about 3 μN kg^{-1}km^{2} corresponding to a net mass change of about 7 x 10^{9} kg (Hammer, 1945). The net mass loss from the first area approximately balancing the net mass gain in the second; for each area the mass change is less than 2% of the total mass extrated during the period.

The integrated sum of the corrected gravity differences over the whole field is about zero indicating that there has not been any net mass loss from the field and there has been, overall, complete recharge for this period. Cumulative mass loss from the field to early 1983 is about 1450 x 10^{9} kg; and cumulative recharge about 1100 x 10^{9} kg; an overall recharge of about 75% since exploitation began (Fig. 7).

MASS CHANGES WEST OF THE BOREFIELD

Significant negative corrected qravity differences occur north-west of the main production borefield near bores WK 201, 206 and 107 (A; Fig. 1); other negative differences (-0.4 to -0.6 μN/kg amplitude) occur near the junction of Poihipi and Tukairangi Roads (B; Fig. 1). The distribution of these differences is not clearly defined but appears to be similar to that found for the period 1967-1974 (Hunt, 1977), although the amplitudes of the differences are smaller. This suggests that same water continues to be mined from this area, but recharge has increased.

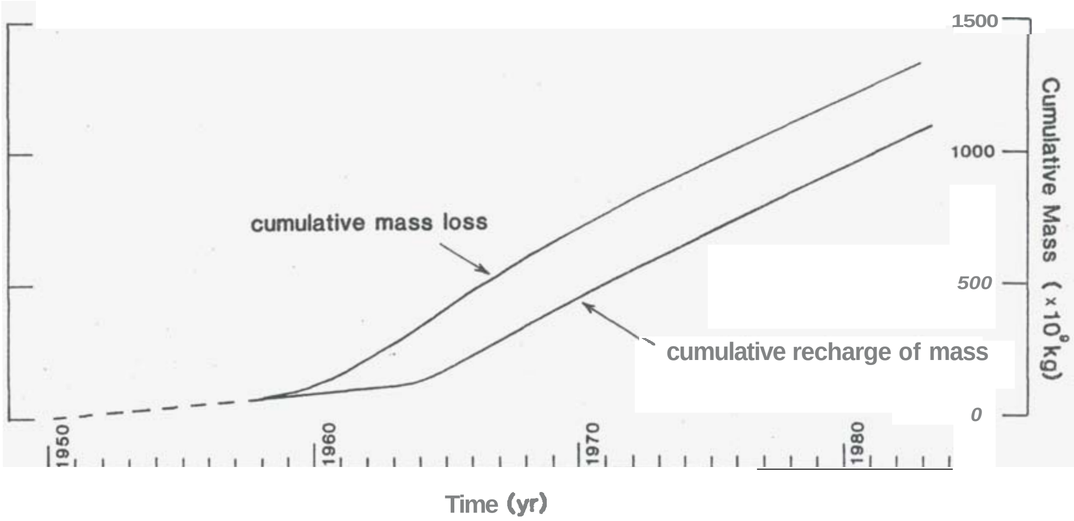

Fig. 7: Cumulative mass loss and cumulative recharge at Wairakei Geothermal Field. This graph is an update of Fig. 8 given in Hunt (1977). Values for mass loss were provided by M.W.D.; values for recharge were determined from repeat gravity measurements and have an estimated error of about ± 15%.

MASS CHANGES IN THE EASTERN BOREFIELD

The shape of the area with positive corrected gravity differences is elongated in an east-west direction, with greatest values at the western end and a 'tail' streching eastward towards the Power House (Fig. 5). The maximum value in the area is at benchmark P41 (+2.4 μN/kg) near bore WK14; and is six times the estimated amplitude of error. The area overlaps slightly, parts of the western borefield but in general the gravity differences in the western borefield are close to zero.

The largest positive difference occurs near the largest measured drop in shallow ground-water level (10 m in WK14/0 adjacent to WK14; Fig. 3). Furthermore the distribution of these differences approximates that of the shallow groundwater level changes, at least in the eastern borefield. The amplitudes of the differences, however, are much larger than might be expected from simply draining the equivalent mass of groundwater depletion down into the reservoir zone. In this case, the measured gravity differences uncorrected for groundwater level changes would be about zero, but this is not so; the gravity difference at benchmark P41, corrected only for subsidence, is +1.9 μN/kg.

The area of positive gravity difference overlaps the area of large (>1 m) subsidence but the two areas do not appear to be directly related. The largest gravity difference is located about 1 km west of the centre of subsidence. However, gravity differences of 1.9 μN/kg and 1.8 μN/kg at benchmarks P 147 and P 125 near the centre of subsidence are greater than at adjacent benchmarks, but this may be associated with ponding of the Wairakei Stream in the vicinity (Allis, 1982).

The positive gravity differences in this area are probably very significnat and can only be caused by a net mass increase in the reservoir zone beneath the eastern borefield. Such an increase may be due to cold (<200°C) water invading the reservoir zone or to an increase of saturation in the two-phase zone. Further interpretation is underway to try and isolate the cause.

CONCLUSIONS

1. There was no net mass loss from the field for the period 1974-1983; i.e. recharge has been about 100%.

2. There has been a net mass loss of about 7 x 10^9 kg from an area west of the main production borefield.

3. There has been a net mass gain of about 7 x 10⁹ kg in the reservoir zone beneath the eastern part of the borefield.

4. Further work should be done to monitor temperature and water-level in the shallow groundwater zone, particularly north of the borefield.

ACKNOWLEDGEMENTS

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