DEVELOPMENTS IN KAWERAU GEOTHERMAL FIELD

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The effects of industrial and geothermal discharges on the Tarawera River are being reviewed by the Regional Council. Improvements to the BOD loading on the river from the geothermal discharge have been achieved by the construction of a 1000m long cooling channel. A reinjection strategy considers the implications of reinjection on the geothermal resource and the river. Shallow reinjection trials have been operating in KAMl since June 1991 and in KA38 since April 1993. Monitoring results and tracer test results are presented.

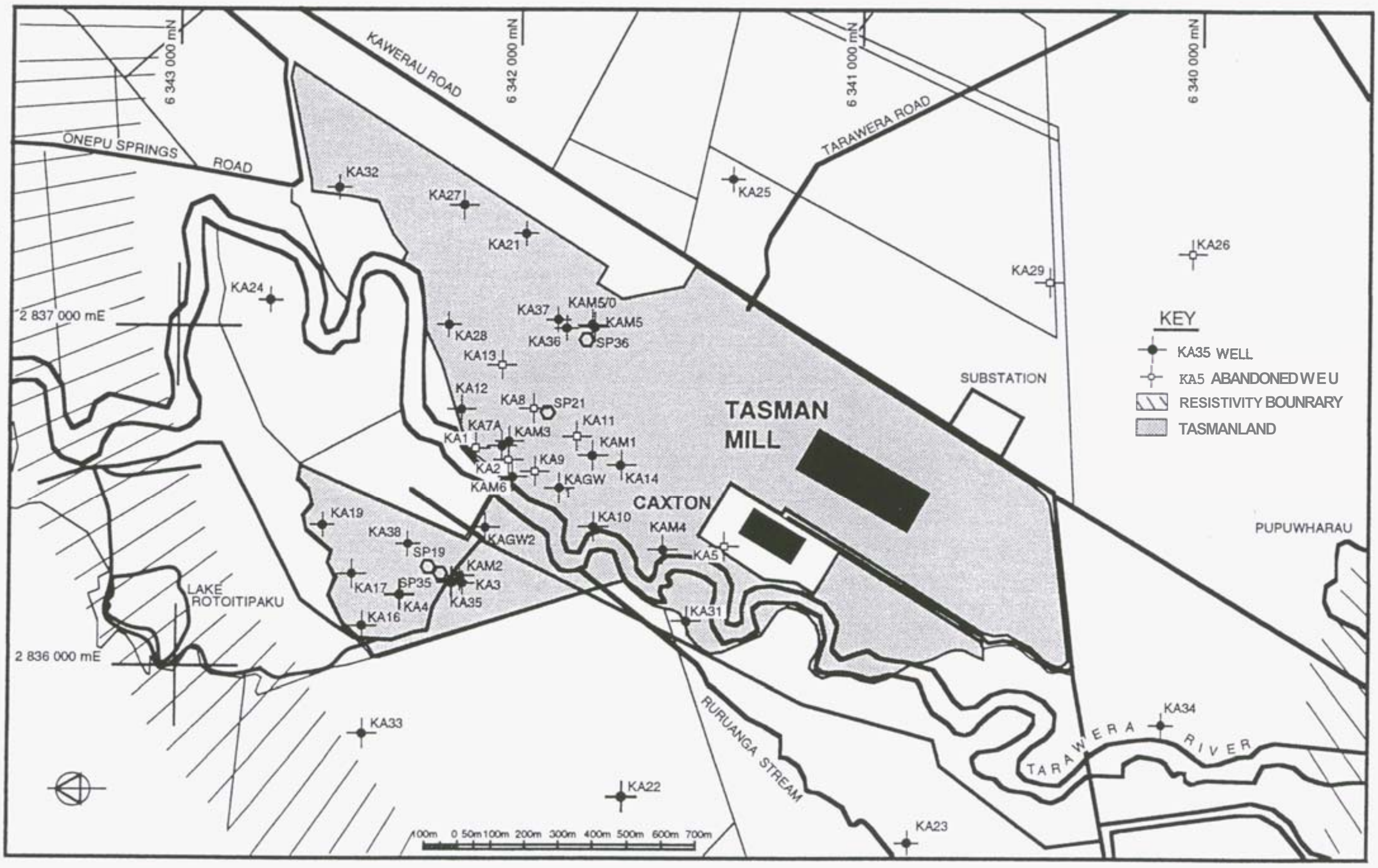

Figure 1 Kawerau Production Field

1. INTRODUCTION

This is an outline of recent developments in the Kawerau geothermal field which are pertinent to the long term use of the resource. Perhaps the most critical aspect of sustainable management is the strategy adopted for disposal of separated water. Historically this has been discharged to the Tarawera River. Concerns over pollution of the river, caused by the discharges from two pulp and paper mills and geothermal discharges both man made and naturally occurring, are being addressed in the Regional Council's river management plan. Any proposal to reduce the geothermal discharge to the river by reinjection requires proper evaluation with reservoir studies and field trials before the effects on the geothermal resource can be quantified. Likewise the actual improvements to river quality achievable by a reduction in geothermal discharge need to be quantified to show that the gains are real. The costs of reinjection will add significantly to the steam price, with obvious commercial implications.

Measures have already been put in place to reduce the BOD loading on the river which is derived from the geothermal discharge. Investigations into reinjection have resulted in field trials, as described below.

2. PRODUCTION OVERVIEW

The production field is located on Tasman Pulp and Paper Company land as shown on fig 1. Development of the field commenced in the early 1950's with the first well on production to the mill in 1957. A total of 18 wells, cased below 300m, were drilled for production purposes prior to June 1993. 12 of these wells have been useful producers. The 2 wells cased shallow (308, 334m) had a production life of 8 years, compared with a production life exceeding 16 years for wells cased through the Huka formation at 500+ m depth. Refer also to Allis et al, this volume.

Evidence of cool downflows affecting production from middle reservoir wells (500-1000m) has resulted in the present policy of targeting production from basement greywacke, requiring wells to be cased 1000+m depth.

Calcite deposition occurs within the casing and liner of most producing wells and is reamed out at intervals of 9-24 months. Decline in well output coupled with an increasing steam demand has led to new production wells being drilled at intervals of 3-5 years. The current maximum daily average steam supply is 300 t/h. Production history mass flow rates are shown on fig 2.

3. COOLING CHANNEL

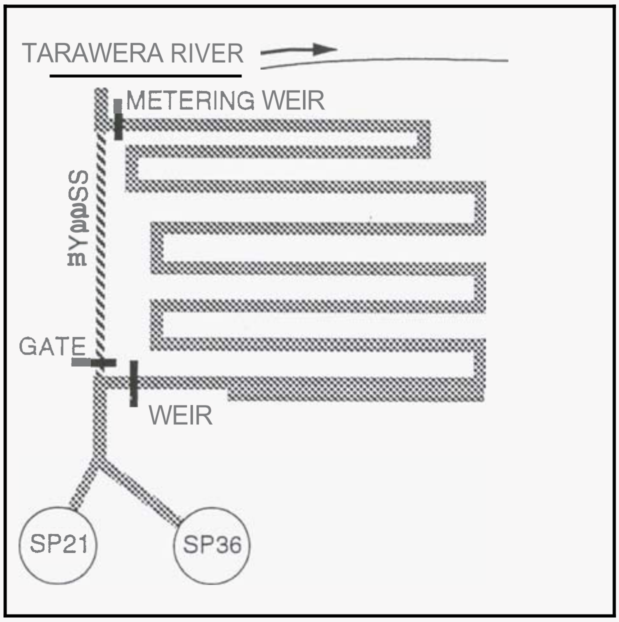

Fig 3 East Bank Cooling Channel

A significant reduction in the BOD loading of the river could be achieved by the removal of heat and H_2S from the separated water discharge. A natural lagoon effectively achieved this on the west bank of the Tarawera River and the construction of a similar pond was proposed for the east bank. The initial concept of a cooling pond was changed to that of a cooling channel, providing two advantages:

- Avoids short circuiting of hot fluid inflow to the point of outflow, a problem which can occur in large cooling ponds.
- The channel will more easily comply with the natural fall to the river, reducing construction costs.

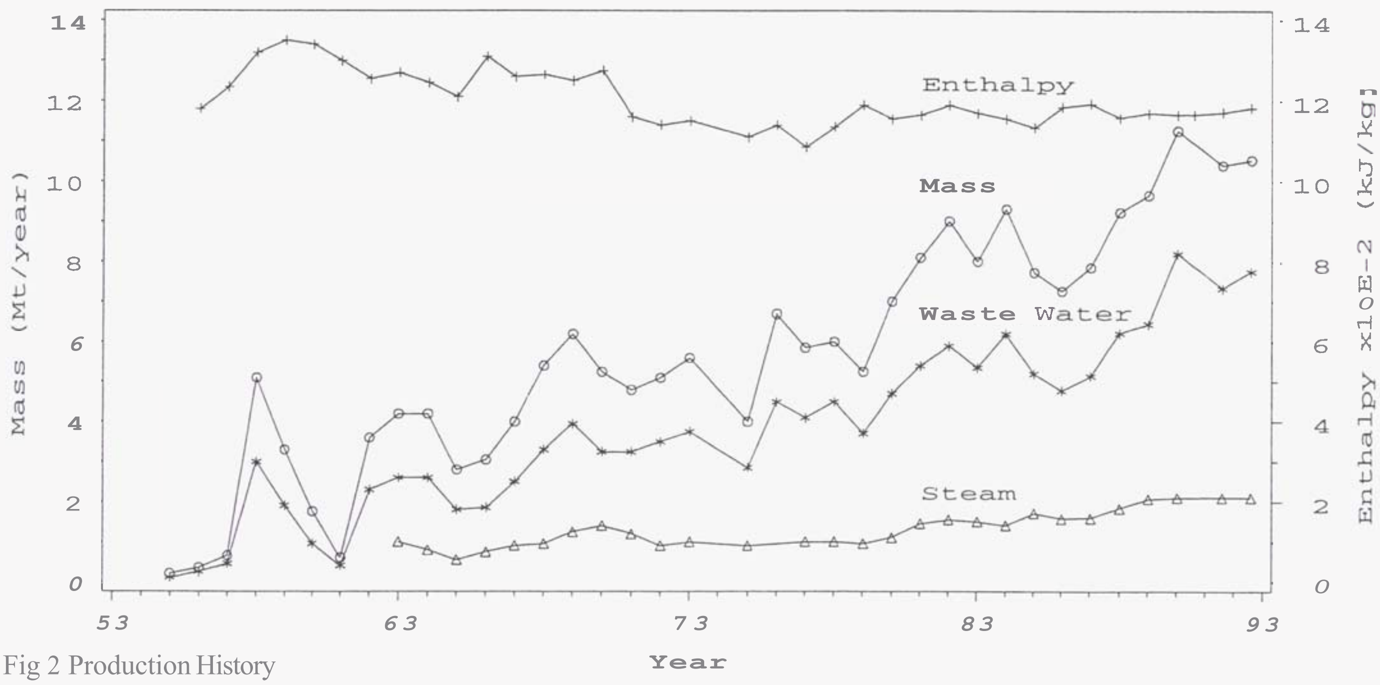

Fig 2 Production History

The cooling channel was designed to make best use of the available land and takes the serpentine shape shown in Fig **3.** Total length is approximately 1000m, 3.5m wide at the water surface, 0.5m deep, the fall from inlet weir to metering weir is lm.

Construction required the excavation of some 1700 m^3 **of** material, comprising volcanic sands and gravels of the river flood plain. The floor and sides are unlined, relying on silica deposition to form an effective seal which has proved to be satisfactory in service.

Performance of the cooling channel can be judged from the water right monitoring results covering the period before and after commissioning in June 1989 (Figs **4** and *5).* The heat discharge has been reduced by some 12 MW at normal operating flow; similarly the H_2S discharge has been reduced by some 90%.

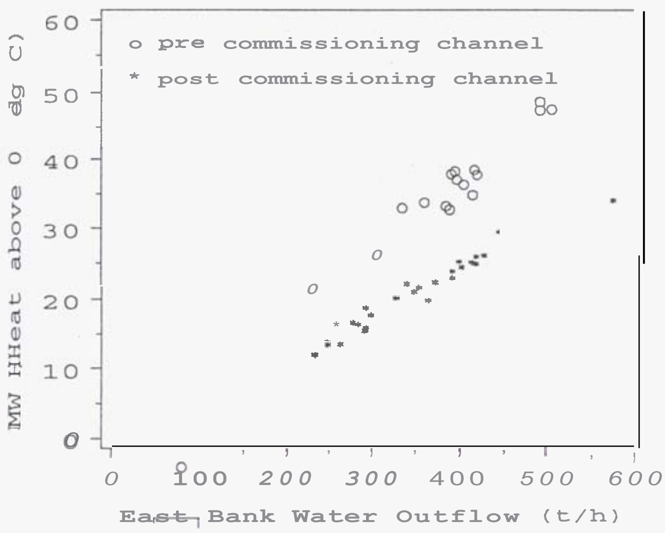

Fig **4** Heat Discharge to River, East Bank

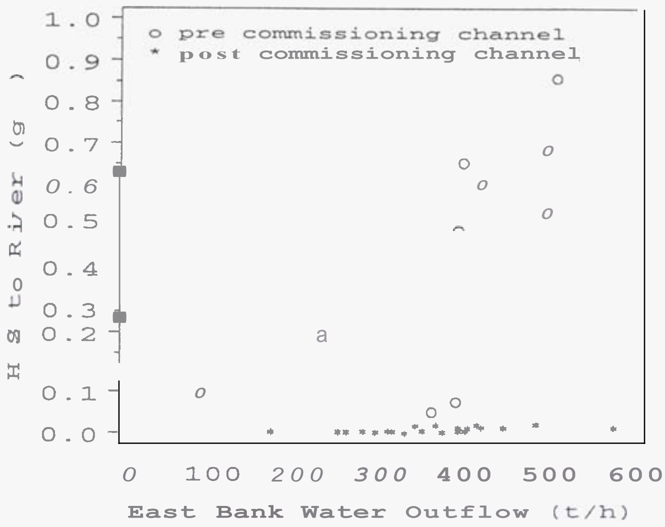

Fig **5** H_2S Discharge to River, East Bank

4. REINJECTION STRATEGY

Reservoir studies have been made on three reinjection options (shallow, middle, deep reservoir) to assess their effects on future production. No single reinjection option emerged as clearly the best solution, with each having significant risks or costs. The best practicable option is likely to comprise a mix of discharge to the river coupled with one or more of the reinjection options, with the distribution changing as more is learnt of the field behaviour.

A primary consideration under the Resource Management Act is whether reinjection will improve the sustainability **of** the resource. One possible opportunity is in the northwest *area* of the field where there **is** evidence **of** cool inflow. With separated water at 170°C it would be necessary to reinject at a point which intercepts and displaces the inflow of cooler water for there to be any improvement in reservoir temperature. There is insufficient knowledge of the field boundary conditions for a well to be targeted with any certainty of remedying this situation.

Modelling studies for reinjection below 500m within the field boundary have not identified any improvement to the sustainability of the resource. On the contrary, the task has devolved to one of minimising the effect of the cold front spreading from the reinjection well and affecting production wells. The risk of inadvertently cooling the production fluid will always be present when reinjecting in or over the field.

Reinjection can provide recharge to a system where mass extraction has resulted in pressure drawdown. Pressure drawdown may affect the output of production wells, it may also be correlated with ground level subsidence. In these circumstances reinjection can be advocated to sustain the resource and mitigate against the adverse environmental effects of subsidence. At Kawerau there is very little evidence of pressure drawdown. Pressure decline measured over the period of field development is negligible, ie within instrument error. Should drawdown become evident then a reinjection program to counter the effects may be the appropriate solution.

Where subsidence originates in the shallow, compressible breccias and is caused by previous reduction in pore pressure, some recovery may be achieved by recharging pore pressure through reinjection into this aquifer.

Reinjection is perceived as mitigating the adverse effects which geothermal development may have on the environment, by reducing the quantity of waste geothermal water which discharges to the Tarawera river. In view of the significant costs associated with reinjection, parallel studies on the effects which this geothermal discharge has on total river quality are essential in order to quanti@ these effects and allow the determination of acceptable discharge limits. These studies should recognise the natural geothermal inflows and the inherent geothermal nature of this river.

Until reservoir conditions change, the grounds for continuing with reinjection are primarily for disposal purposes, in which case the lowest cost reinjection option is preferred subject to there being no adverse effects on the resource.

Reinjection into the shallow aquifer overlying the field is the lowest cost option. The attendant risks of possible downflow to the production aquifer and dispersal into the Tarawera river are sufficient to suggest an initial limit be placed on the total shallow reinjection flowrate of some **300** t/h. Information gained from trials may revise this limit.

Middle reservoir (500-1000m depth) reinjection is the second lowest cost option. The preferred location in order to minimise adverse effects on the resource is in the outflow path to the north and west of the field. Since there is again the possibility of downflow, the quantity reinjected to this aquifer must also be regulated.

Reinjection near the perimeter of the field, several kilometres from production wells, would minimise the likelihood of cooling the resource. The reinjection of 170°C separated water would incur relatively high costs for pipeline and pumping facilities. Capital costs would be significantly less if the water can be piped at low pressure and temperature conditions (preferably below 70°C), provided that the possibility of silica deposition within the transmission system, wells and formation can be eliminated. Reinjection will need to be at sufficient depth to provide buffering with the groundwater.

5. REINJECTION INVESTIGATIONS

In 1983 a series of tests commenced, to obtain information on possible hydrological connections in the shallow aquifer.

Four monitor wells were drilled to investigate reinjection. KAMl, M2, M3 and M4 (fig 1) were drilled to intercept a permeable zone at lOOm to 150m depth.

A radioactive tracer test using Iodine-131 with continuous pumping was carried out into KAMl from August to October 1984. Separated water from SP21 weirbox was reinjected into KAMl at 80 t/h flowrate. Downhole sampling for returns was carried out in KAM2, M3 and M4. Bleedline sampling was carried out at KA7A, 10, 11, **14,** 24 and 28. Production weir boxes were sampled at KA16/17, SP19 and SP21, and the Tarawera River was also sampled. Continuous monitoring by tracer tanks and radioactive counters was undertaken at KA11, KA14 and SP21. Sampling continued from 23 August to 1 October. No tracer returns were detected at any of the locations sampled or monitored.

A combined radioactive tracer test with Iodine-131, and interference test with continuous pumping was conducted in KAM3 commencing in February 1985. Water from the SP21 weirbos was reinjected using KAM3 as the interference source and tracer injection well. The reinjection flowrate was initially 150 t/h but the pump performance declined when silica was deposited on the impeller, and by 11 May the flow had reduced to 53 t/h. Sampling for tracer returns was undertaken from bleedlines on KA7A, 24 and 28; production weir boxes at KA16, SP19 and SP21; the Tarawera River. The sampling for tracer continued from 26 February to 11 May and again no returns were detected.

Interference was measured between KAM3 and KAM1, M4, KA11, and KA14.

In September 1985 cold river water was injected into KAM3 at 110t/h. Wells M1, M2, M4, 11, 14, 17 and 31 were monitored for pressure interference. Definite responses were recorded in the M wells and KA11.

Following the injection test, data recording using the monitoring system continued and it was possible to detect a response in the deep monitors (KA17 and 31) due to production well shutdowns at KA21 and KA35.

Studies continued into the likely effects of reinjection on the reservoir and future production. These studies were assisted by computer simulation of the known reservoir characteristics. The computer model was run for a number of production/reinjection scenarios. Monitoring of reservoir pressures, temperatures and geochemistry was intensified in some areas to improve the database for future decision making. Future reinjection of geothermal water would be of unaerated, pressurised, separated water to minimise silica deposition.

It was considered the next best step was to implement a long term reinjection trial for disposal of the separated water. This would also provide an opportunity to further refine the computer model.

6. REINJECTION TRIALS

6.1 KAMl Reinjection

Reinjection commenced into KAM1 on 6 June 1991 utilising water from separation plant SP21 after passing through the BOP Electricity Ormat plant.

The water was a mixture from wells KA21, KA27 and subsequently KA36. Water has been reinjected continuously other than during plant shuts, and the reinjection flowrate has been typically 140 t/h with 4.0 bars wellhead pressure at KAM1. The reinjection depth is 140m. There has been no significant silica deposition in the reinjection line or the well, and no change in KAMl injectivity. The temperature of the reinjected water is dependent on the heat estracted by the Ormat plant and is typically 110°C to 130°C. The shallow aquifer is monitored for any changes in water level, temperature and chemistry.

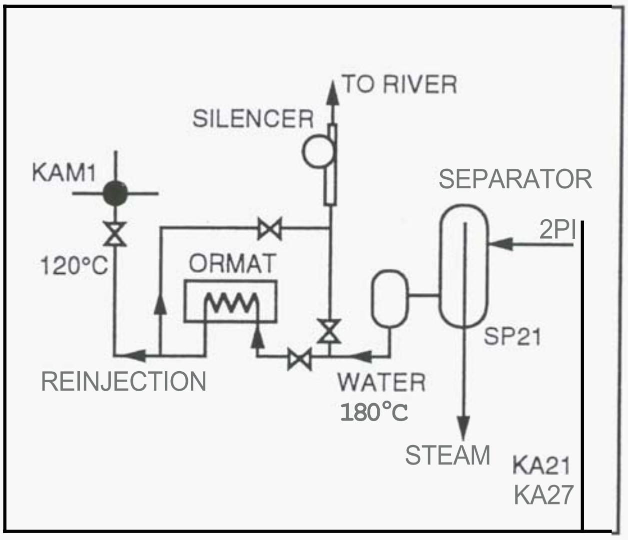

Fig 6 KAM1 Reinjection Layout

Water levels are recorded continuously in KAM2, KAM3 and KAM4. The water level was about 4m below the casing head flange (CHF) in KAM3 and 7m below in KAM4, prior to reinjection. Water levels at KAM6 were measured with spot measurements from CHF. Water levels are plotted as Reduced Levels (to sea level) and the RL's of CHF of these wells are: KAM3 24.6m, KAM4 25.9m and KAM6 20.6m. KAM3 monitoring operated from 1990 recording 6 months of background data. When reinjection commenced the water level in KAM3 (250m from KAM1) increased reaching a maximum of 1m increase in early November 1991. The water level then declined to pre reinjection levels by June 1992 and has remained relatively constant since.

Monitoring at KAM4 (350m from KAM3) commenced in May 1991 and the water level changes followed similar trends to KAM3 but the maximum water level increase at KAM4 was 0.4m, declining to below pre reinjection levels and then remaining constant. KAM6 was drilled to 30m in October 1991 and the water level dropped 0.3m from December 1991 to June 1992 and then remained constant. Water levels in the 'M' series wells respond to changes in reinjection flowrate.

Temperatures have been monitored in KAM2, KAM3 and KAM4 and show some cooling. KAM3 temperature declined 10°C from September 1989 to May 1991 prior to reinjection, and a further 15°C to April 1992. At 100m RL in KAM4 and KAM2, 10°C temperature declines were measured over 12 months. Aquifer temperatures at about 100m depth in the area of the monitor wells are in the range 130°C to 170°C. The reinjection temperatures of 110°C to 130°C have decreased the aquifer temperature and thus increased the density. The water level change due to this cooling can be estimated if the thickness of the cooled zone is known. The estimated temperature decline in the reservoir of up to 10°C would correspond to a 0.5m decline in water level, which is in the order of changes that have been observed. Allowing for the temperature decline, the resulting water level decline with injection cooling means that increased reinjection will not necessarily imply increased seepage to the river. Two seeps were monitored on the East Bank of the Tarawera River, one located upstream and one downstream of KAM1. The seep temperatures have remained in the range 50°C to 55°C and the flow at each seep has been reasonably constant at less than 1 litre per minute.

Chemical sampling commenced at reinjection startup with samples being analysed for Na, K, Mg and Cl. Sampling locations included: the monitor wells KAM3, KAM4 and KAM6; groundwater well GW1; and the two seeps on the East Bank of the Tarawera River. Monthly

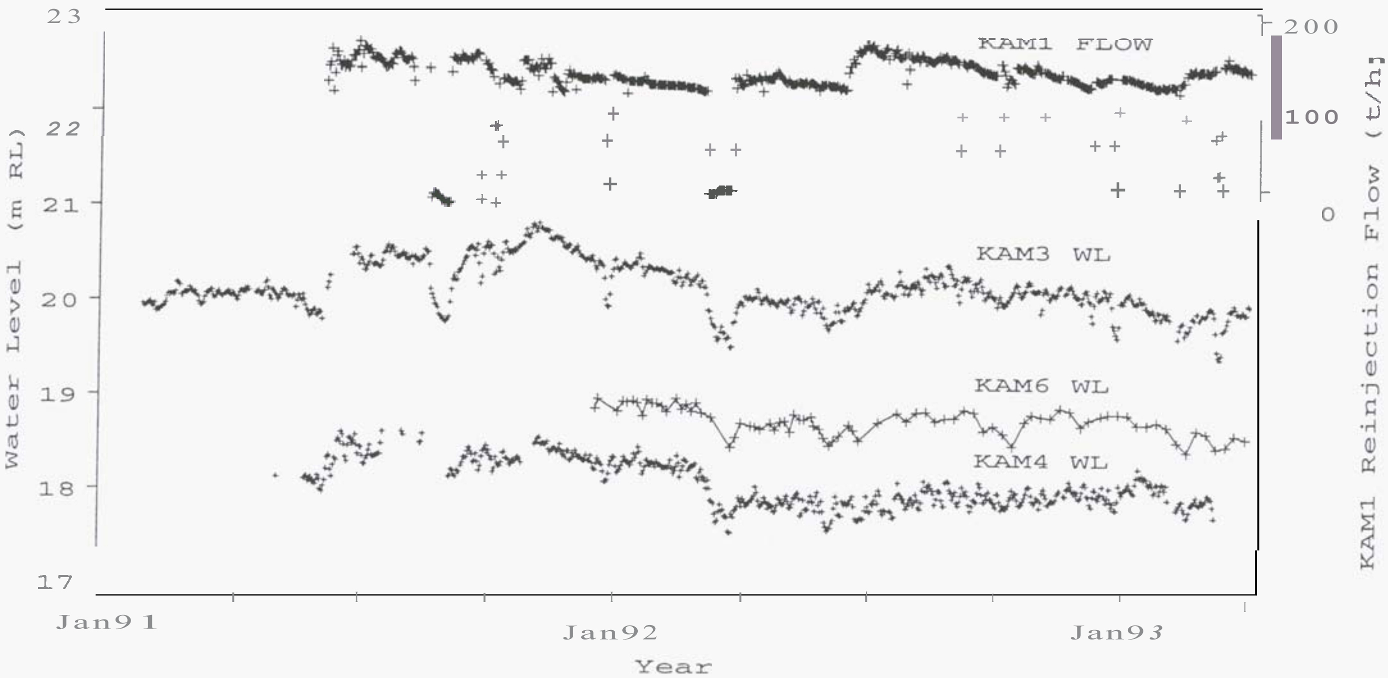

Fig 7 KAM1 Flow and Water Level Monitoring

chemical sampling continues. The reinjected water is chloride rich with values about 1000ppm. Chloride increased in **KAM3, M4, M2** and **M6.** Sodium concentrations showed a similar response to chloride with a smaller amplitude. Magnesium had very little change. The two seeps produced variable results, possibly sensitive to variation in ***the*** river level. Increased chloride (probably reinjectate) has been identified in the **M** series wells **and** it appears to be dispersing in the geothermal groundwater aquifer adjacent to KAM1.

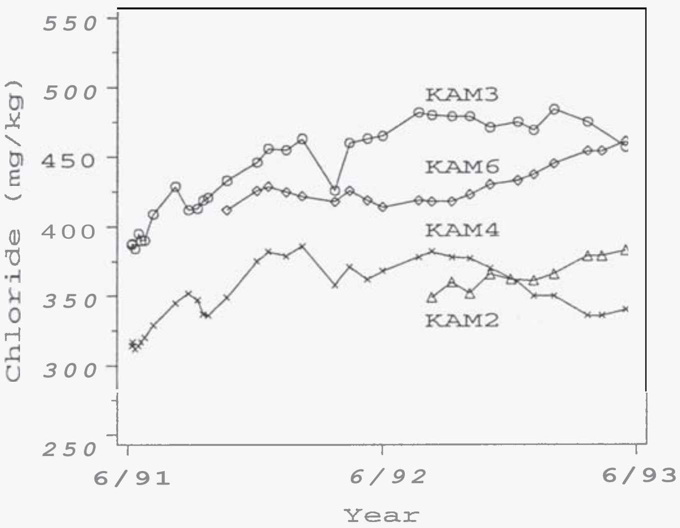

Fig 8 Chloride Monitoring Results for KAMl Test

Modelling the chloride increase in KAM3 and KAM4 using the leaky box analogy obtains the best fit with an aquifer mass of 5 Mt with the scatter in the data giving an uncertainty of $\pm$1Mt. The mass of 5 Mt can be converted to an order of magnitude area and aquifer thickness of 50m over an area of 0.5 km^2 or 100m thickness over 0.25 km^2. The effective mixing mass of 5 Mt suggests that the reinjection fluid is dispersing locally, possibly within a 500m radius rather than dispersing into a large laterally unconfined aquifer. This analogy fits the period up to late 1992 but does not explain some of the more recent data.

A comparison of chemical data from downhole samples and production weir boses indicates there is no chemical evidence of reinjectate returns to the medium or deeper levels of the reservoir.

Tracer testing has been carried out during the KAMl reinjection test. One kg of sodium fluorescein was injected into KAMl at reinjection startup and sampling continued from June to July 1991. Returns were detected in KAM3 and KAM4. A second fluorescein dosing with 10 kg was injected in October 1991. KAM6 was drilled prior to this test. Sampling continued for one month but the results were not conclusive. **A** radioactive tracer test using Iodine-131 was run in KAMl from **4** August 1992 to 11 September 1992. Sampling for tracer returns was undertaken from: discharging KAM3 and KAM4; downhole samples at GW1, **KAM6, KA7A,** KA14, **and** KA31; production weir boxes at SP21, SP19 and SP35. There were no returns **of** tracer fiom any locations.

From the chemistry we have definite observation **of** reinjectate in the monitor wells. Information fiom the fluorescein testing is inconclusive, while information from the Iodine-131 shows no returns. Further radioactive tracer testing using a longer half life isotope, to increase the time span **of** the sampling program, **may** be necessary to investigate the dispersal paths.

6.2 KA38 Reinjection

Prior to the drilling of KA38 a tracer test using Iodine-131 was carried out in KAM2 **from 20** May to 30 June 1992. This test was to determine any local connection between the shallow and deep aquifers. **A** new monitor well was drilled between KA38 and the river. GW2 was drilled to 30m depth and was used to provide further information for the tracer test. The sampling program continued for **6** weeks including production weirbox samples from SP19 and SP35, and downhole samples from KA3, KA17 and GW2. No returns were detected in any of the wells sampled so the drilling of KA38 proceeded.

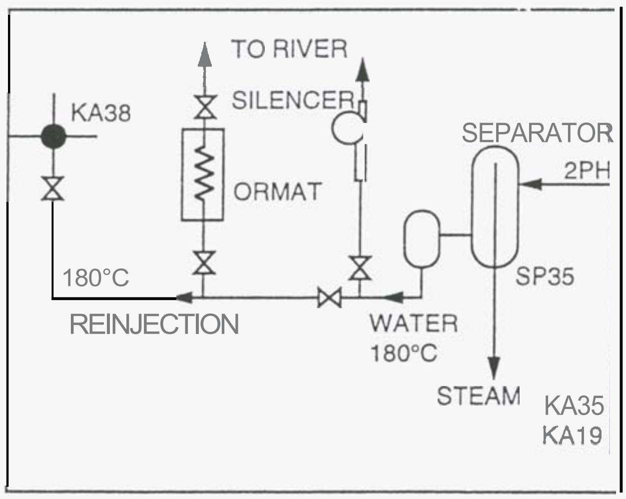

Fig 9 KA38 Reinjection Layout

KA38 was drilled as a reinjection well with 8 5/8" casing to 157m depth and 6 5/8 liner to 380m. Prior to reinjection the main loss zone at 190m was 208°C and bottom hole temperature 236°C. Reinjection on the west bank into KA38 commenced on 5 April 1993 using water from SP35. The initial reinjection flow was 105 t/h and the flow gradually increased to 155 t/h over **4** months. The temperature nominally is 180°C. The increasing injectivity is probably due to cooling the formation.

SF6 tracer was injected into KA38 after 2 weeks reinjection. Sampling locations included SP19 and SP35 steamlines. Chlorides were monitored at SP19 and SP35 weirboxes and from downhole samples in KA3 and KA17.

No return of SF_6 tracer was detected in any of the samples collected and there is no chloride change attributable to the reinjection to date.

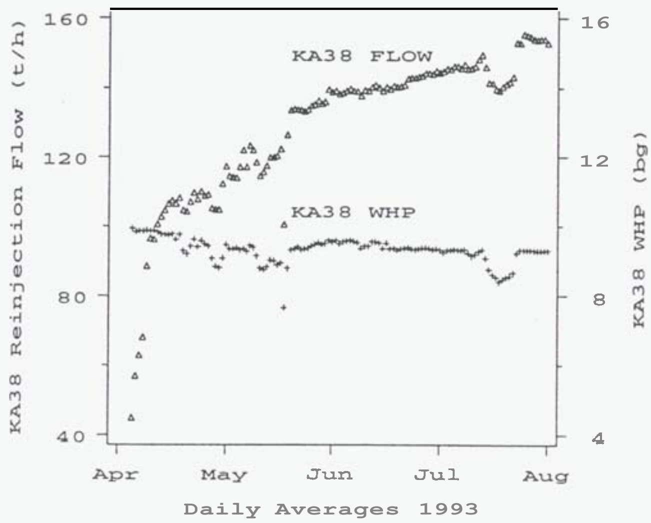

Fig 10 KA38 Reinjection Flow and Wellhead Pressure

7. CURRENT STATUS

August 1993. Variations in shallow aquifer water levels measured during the reinjection trials are considered acceptable. Although there is no evidence of reinjection returns to production wells, the dispersal path of the water has not been determined with sufficient confidence to support any increase in the shallow reinjection flow rate above 300 t/hr.

To maintain the improvements achieved from the reduction in geothermal water discharged to the river and to extend our understanding of the shallow reservoir, the reinjection trials will be continued.

The effectiveness of the cooling channel and the reinjection trials in reducing the BOD loading on the Tarawera River are evident in Fig 11.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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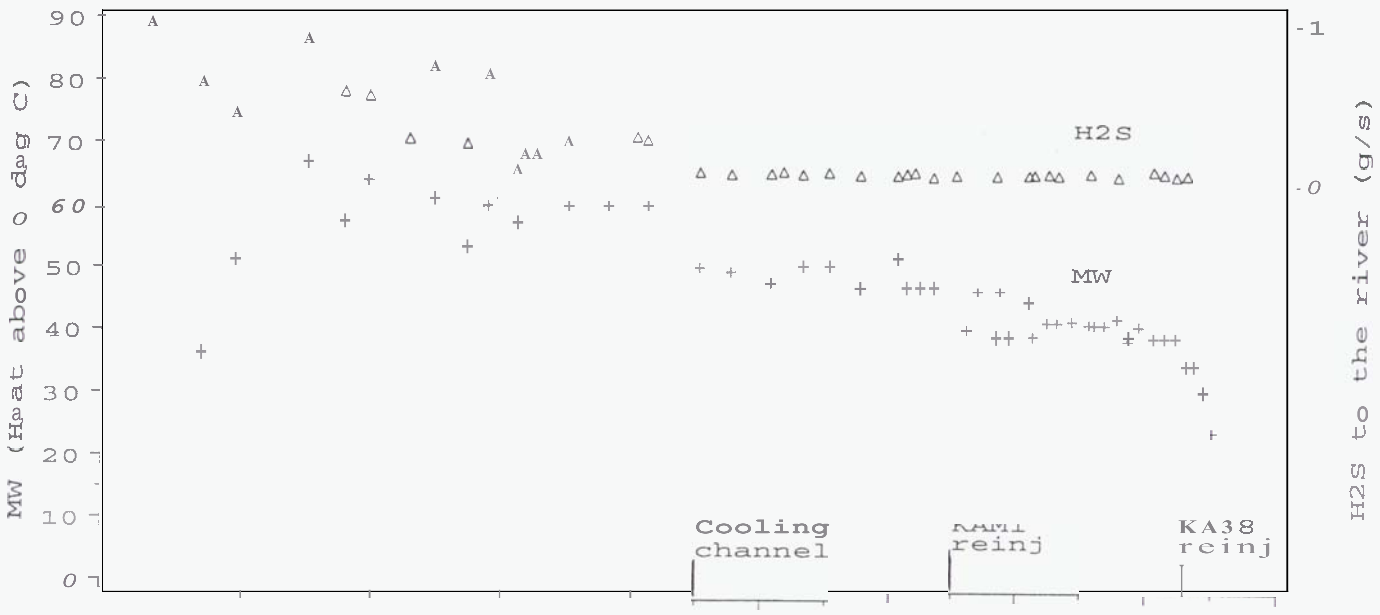

Fig 11 H_2S and Heat Discharge to the Tarawera River, (East & West Banks), from Water Right Monitoring Data