WAIKATO VALLEY AUTHORITY TECHNICAL REPORT 1988/4

THE IMPACT OF SULPHUR MINING ON LAKE ROTOKAWA

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1.0 INTRODUCTION

Lake Rotokawa, situated approximately 12 km to the northeast of Taupo, is the dominant feature of the Rotokawa Geothermal Field, a high temperature field with significant energy potential (Figure 1).

Natural surface discharge conditions at Rotokawa have changed from alkali-chloride waters to acid-sulphate activity within the last 20,000 years (Collar, 1985), resulting in the formation of sulphur. Sulphur deposits in the vicinity of Lake Rotokawa have been sporadically investigated and occasionally mined since their existence was reported by European explorers in the 1840's. Before and after the 2nd World War the deposits were worked in desultory fashion in an attempt to establish a commercial mining operation.

Recent investigations into the feasibility of mining and processing the subsurface ore-body at Rotokawa have proven the viability of the project and a mine plan for the expansion and development of the existing sulphur mine has been developed (Fletcher Challenge Limited, 1987). The viability of the project relies upon the use of local geothermal water and steam for process heating and for the generation of electricity required for sulphur mining and processing. Water rights for extraction and disposal of geothermal fluids have recently been granted by the Waikato Valley Authority (water rights currently under appeal).

The present application from Balcairn Mining and Investments Limited seeks the following water rights for the mining and processing of the sulphur deposits in the vicinity of Lake Rotokawa (for a period of 10 years):

(1) A right to take up to 9000 cubic metres of water per day from the open pit.

(2) A right to discharge up to 9000 cubic metres of water and waste per day into the ground.

(3) A right to take up to 4000 cubic metres of water per day from the Waikato River for make up water requirements.

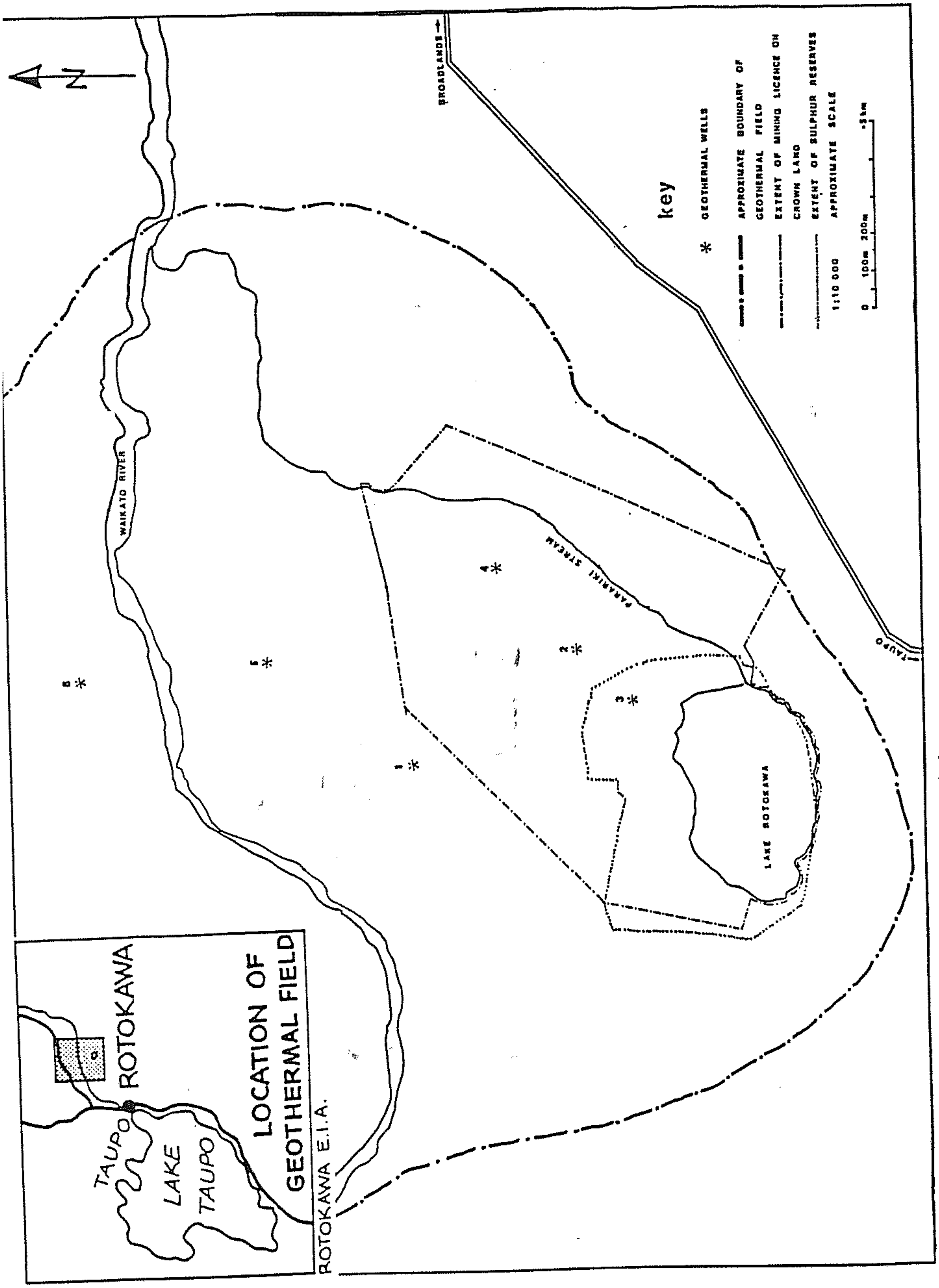

FIGURE 1: Location of Rotokawa Geothermal Field showing Lake Rotokawa and the mining licence boundary.

This report describes:

- The geochemical processes involved in the formation of the sulphur deposits and the origin of Lake Rotokawa, and its scenic, biological, and scientific value,

- the likely extent and significance of impacts on Lake Rotokawa as a result of the proposed mining project, and

- the present and likely future changes in the thermal surface activity, including a list of all significant geothermal features within the mining licence area.

Also included in the report are recommendations regarding

- the mining operation,

- the conditions of a water right, and

- the required impact monitoring.

2.0 THE ROTOKAWA GEOTHERMAL FIELD AND THE FORMATION OF THE SULPHUR DEPOSITS

The Rotokawa geothermal system is located near the southern end of the Taupo Volcanic Zone, lying on the axis of the Taupo-Reporoa basin. The Waikato River dissects the field into a northern and a southern portion. Originally the system was discharging near-neutral alkali-chloride fluids, but hydrothermal eruptions occurring between 11,000 and 18,000 years ago may have lowered the water table of the deep chloride waters allowing acid-sulphate waters to become more widespread with time (Collar, 1985). These acidic waters are the result of the oxidation of ascending H_2S gas to sulphuric acid.

H_2S is exsolved from deep alkali-chloride waters, with or without boiling, and oxidation takes place by atmospheric oxygen according to equation 1:

(1) $H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+$

The oxidation reaction may only proceed as far as producing elemental sulphur, so (equation 2):

(2) $H_2S + 1/2\ O_2 \rightarrow S_0 + H_2O$

Sulphur is actively precipitating in the Rotokawa geothermal field (visible in some of the cliffs north of Lake Rotokawa).

Widespread sulphur deposition in the Rotokawa basin (=the area around Lake Rotokawa) started after 6060 B.P. (Collar, 1985). Today extensive sulphur ores occur around the lake shore and in the bed of Lake Rotokawa.

Beside the abundance of sulphur, cinnabar occurs locally as red and yellow metal-rich precipitate around active springs and discharge from deep drill holes deposited a precipitate containing high concentrations of arsenic, as well as antimony, gold, silver, and thallium (Weissberg, 1969).

3.0 VEGETATION AND WILDLIFE

The natural vegetation of the Rotokawa Geothermal Field has already been extensively modified by the sulphur workings, geothermal investigations and conversion to exotic forest and pasture.

The thermal vegetation is now of little botanical interest, as the acidic soil conditions are limiting plant establishment and many areas are devastated by the extensive sulphur mining over the last decades. In a summary of a botanical survey carried out in the late 70's, the geothermal vegetation and flora at Rotokawa were given low priority and a low ranking compared to other geothermal sites within the Taupo-Rotorua Volcanic Zone (Given, 1980).

Lake Rotokawa and the Parariki Stream are important water fowl habitats in the Taupo area, with significant numbers of teals and grey ducks, plus other common water fowl species. Their favoured habitat appears to be around the western and south-western margin of Lake Rotokawa where extensive areas of raupo (Typha orientalis) exist (Dept of Conservation, Taupo, pers. communication).

A colony of black-billed gulls was observed on the north-eastern lake margin on a visit in 1984 (B. Zuur, pers. comm.).

4.0 LAKE ROTOKAWA

4.1 Formation of the Present Lake

Lake Rotokawa is located in the southern part of the field (38° 37.8' S, 176° 11.2'E), occupying the largest of about 35 eruption craters identified in the area. Present Lake Rotokawa is a remnant of an older, larger lake, whose sediments are deposited beneath and to the north of the present lake. These lake beds contain much of the sulphur-bearing ore within a lens of silt and muds and are overlain by pumice from the Taupo eruption (about 1800 years ago) forming a near surface layer of high porosity and permeability.

A sequence of events, including hydrothermal eruptions, led to the present configuration of Lake Rotokawa (Collar, 1985). Ancestral Lake Rotokawa formed after hydrothermal eruptions in the area ca. 9000-9700 years ago. A further hydrothermal eruption occurred around 6060 B.P. creating the present lake. Groundwater intrusion has subsequently flooded the eruption vent. The bathymetry of the lake (see figure 2) suggests that further eruptions (following the deposition of Taupo Pumice) may have occurred, causing the vent-like depression in the eastern lake bottom.

Alternatively the depression in the lake (Fig. 2) may simply be an outflow which maintained a pathway of deeper waters to the surface. Little changes in the temperature and chloride concentrations with respect to this depression indicate however that this outflow or vent is now inactive.

4.2 General Description

Lake Rotokawa lies at an altitude of 334 metres above mean sea level, covering an area of about 0.62 km^2 with a total shoreline of 3.375 km. The greatest length of the lake is 1175 m and its greatest width 680 m. Lake Rotokawa is relatively shallow (mean depth 2.75 m), but the above mentioned depression has a maximum depth of 27 m (Fig. 2).

4.3 Surface Hydrology

The catchment area of Lake Rotokawa is about 10.15 km^2 (Lawless, 1987) comprising gently sloping pasture land and some areas of scrub to the south and west, and the main Rotokawa Thermal Area to the North. Some drainage from this area may flow directly to the Parariki Stream.

Due to the porous nature of the pumice soil surrounding the lake, inflow channels are generally dry except during periods of heavy rainfall. Annual rainfall (measured at the Tauhara Forest Station) is 1220 mm.

Hot spring waters discharging into the northern margin of the lake are the only permanent surface inflows to the lake with a flow rate of 5.5 l/s in 1975-76 (Forsyth, 1977).

Parariki Stream, the sole outflow, drains the lake from its eastern end and flows in a generally north-easterly direction for 6.2 km towards the Waikato River. In addition to the water derived from the lake, the stream is fed by numerous small thermal springs along its course, mainly at its upper and lower reaches. A cold groundwater spring is located in its middle reach.

A mean flow rate of 68 l/s (ranging from 20-490 l/s, measured from December 1985-July 1986; Fletcher Challenge Ltd, 1987) for the Parariki Stream at its outlet from Lake Rotokawa suggests a considerable influx of groundwater into the lake. An inflow of thermally heated waters through the lakebed is inferred from chloride mass balances (Forsyth, 1977).

4.4 Water Quality Characteristics

The physico-chemical water quality of Lake Rotokawa was studied in detail during 1975-76 by Forsyth (1977), and during 1981-82 by Timperley and Vigor-Brown (1986). The bathymetry of Lake Rotokawa is shown in Fig. 2 and a summary of its chemical characteristics is given in Table 1. The temperature range of surface water ranged from 10.1°C in Winter to 23.1°C in Summer. Lake Rotokawa appears to

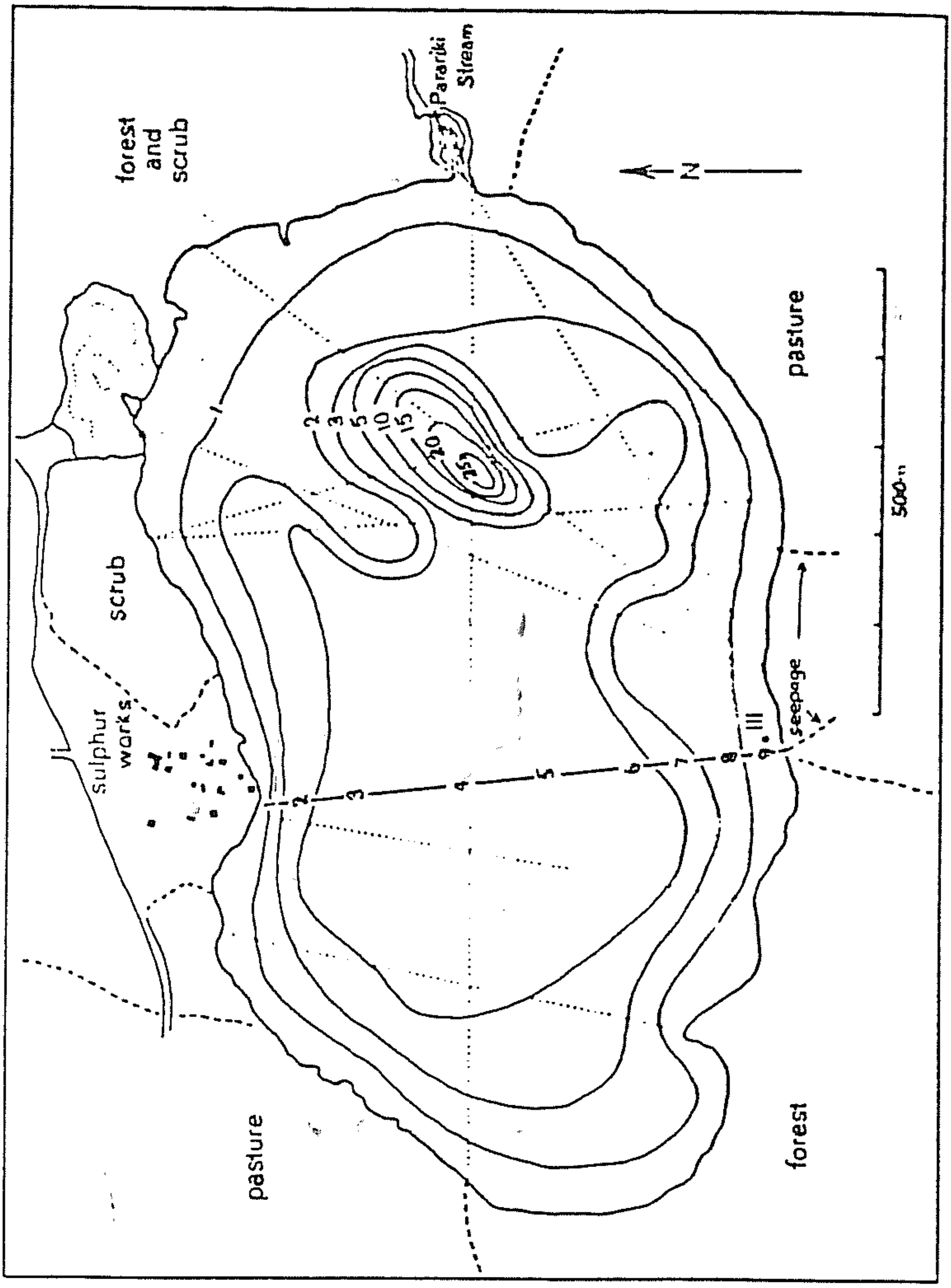

FIGURE 2: Bathymetry of Lake Rotokawa showing depth in metres (after Forsyth, 1977).

be boiling, however the bubbles are gas (mainly H_2S). Due to the oxidation of the H_2S, as it passes upwards through the water column, sulphur and high concentrations of sulphate are formed, resulting in very acidic waters. The mean pH recorded was 2.1, explaining the Maori meaning of 'Rotokawa' (=bitter lake).

Lake Rotokawa usually has a yellow-grey turbid appearance, mainly due to the presence of elemental sulphur. Clarity in 1975-76 was greater in the western part of the lake than in the eastern and northern part, where shore erosion and thermal inflows may contribute suspended inorganic material. Suspended solids were 30 g/m^3, but chlorophyll a was generally less than 5 mg/m^3 (Vincent and Forsyth, 1987). Due to biological activity, suspended solids, chlorophyll a and total pigments showed an increase during summer.

The chemical composition of the lake water is summarised in Table 1. Sulphate is the predominant anion followed by chloride. Sulphate concentrations in the lake are of the same magnitude as in selected inflows from hot springs, however chloride concentrations in the lake are much lower, suggesting a considerable groundwater inflow, some of which may be thermally heated. The strong influence of geothermal waters and steam on the chemical composition of Lake Rotokawa was also shown in a comparative study of 32 lakes within the Taupo Volcanic Zone (Timperley and Vigor-Brown, 1986). They demonstrated that lakes with total dissolved solids (TDS) greater than 90 g/m^3 present clear evidence of substantial geothermal influence (Lake Rotokawa: TDS = 958 g/m^3). Geothermal water and steam account for about 80% of the lakewater dissolved solids.

Oxygen levels in Lake Rotokawa never rise above 20% air equilibrium, also reflecting the geothermal origin of the lake water. Chemical scavenging of O_2 by reduced compounds and physical stripping of bubbles of H_2S and CO_2 are other factors possibly responsible for the low oxygen levels in the lake.

Table 1: The chemistry of Lake Rotokawa
(after Timperley and Vigor-Brown, 1986)

Parameter	Concentration [g/m^3]
pH = 2.3	
Total Dissolved Solids	958
Sodium	225
Potassium	25
Calcium	15
Magnesium	3.0
Chloride	282
Sulphate	408
Bicarbonate	0

4.5 Flora and Fauna

Geothermal waters generally support a simple community of low species richness, but some populations may become unusually abundant in the absence of competition and predators.

The biota of Lake Rotokawa is very restricted as a result of the unusual environmental conditions (low pH, high salinity, presence of toxic geothermal components). In low pH aquatic environments, cyanobacteria (= blue-green algae) are absent and eucaryotes (higher organisms) dominate the plankton. Microscopic examinations of water samples from Lake Rotokawa revealed that the phytoplankton consists predominantly of the pigmented flagellate Euglena deses (Forsyth, 1977). Algal populations were much higher in summer, causing chlorophyll a concentrations of up to 500 mg/m^3 in blooms of Euglena. For most months of the year however there is a lack of detectable photosynthesis, probably due to the relatively high light attenuation by suspended particles (such as sulphur). The bacterial biomass is also high, with abundant numbers of Thiobacillus sp., a bacterium that oxidises sulphides and sulphur to sulphuric acid and which may therefore contribute to the acid pH in the lake.

Macrophytes observed by Forsyth (1977) included the emergent species Eleocharis sphacelata growing on the south side of the lake and Typha orientalis, which was present at the south-western lake margin.

Generally the geothermal fauna is dominated by the Arthropoda (insects, mites, and crustaceans), which possess a thickened cuticle providing protection from acid corrosion. Of these, the insects are the most successfully adapted group. Soft-bodied forms (e.g. worms) are more inhibited by low pH.

The fauna of Lake Rotokawa consists exclusively of insects (larvae of Chironomus zealandicus), apart from the leech Helobdella. Zooplankton is completely absent (Forsyth, 1977). Insect larvae of the midge Chironomus zealandicus can tolerate extreme acidity and salinity, low dissolved oxygen concentrations, and high levels of organic matter (Vincent and Forsyth, 1987).

The presence of the unusual leech Helobdella sp. in Lake Rotokawa is notable as this represents the only record for the genus in New Zealand (Forsyth, 1977).

4.6 Scientific Value

Geothermal waters provide a habitat where life has been evolved to adapt to extreme conditions of high temperature, acidity, chemical concentrations, turbidity and low dissolved oxygen. The biota are therefore restricted in terms of numbers of groups and species compared with freshwaters.

The Taupo region has attracted investigators from all over the world and the information derived from these studies comprises a significant part of our understanding of geothermal environments in general. Most of the work to date has centred around distributional studies of the flora and fauna, and the major physical and chemical characteristics of their geothermal habitats. More recently, increasing emphasis has focused on the biochemical and physiological properties of geothermal organisms with the aim of understanding the basic mechanisms of survival in these extreme conditions at a cellular level.

Recent progress in molecular biology and biotechnology has proven the potential commercial value of geothermal organisms, particularly of bacteria.

Although geothermal habitats display some general characteristics, each spring or lake has its own distinctive biota. The main factors governing the floral and faunal species distribution are temperature, pH, turbidity, light, and chemical composition (toxicity).

Thermal lakes of the size of Lake Rotokawa are rare and their chemistry and biology is not very well known. The simplicity of the community structure in those lakes in comparison with other freshwater habitats has proved an attractive feature for aquatic ecologists unravelling the structure and functional organisation of aquatic ecosystems at large.

Lake Rotokawa has many unusual chemical features that attest to the geothermal origin of its waters (low pH, low dissolved oxygen, suspended sulphur, high salinity), but the temperature lies close to that in nearby non-geothermal lakes (Vincent and Forsyth, 1987).

The fauna of Lake Rotokawa includes the leech Helobdella, the only known record of the genus in New Zealand (Forsyth, 1977). At its outlet (Parariki Stream), Cyanidium caldarium was found. This unusually pigmented alga is found only in very acidic waters (pH 1-5) and at temperatures up to 57°C representing the highest temperature range of higher organisms (eucaryotes).

5.0 THE IMPACTS OF THE PROPOSED SULPHUR MINING PROJECT

This report describes the potential impacts of the proposed project on Lake Rotokawa and on the geothermal surface features within the mining area. These concerns are closely linked to other issues, such as groundwater hydrology, physical impacts of sulphur mining and processing, impacts on Maori cultural values and conflicts resulting from multiple resource use in the area (forestry, geothermal resource, mining, recreation, tourism, scientific and cultural values), which will be covered in separate reports.

5.1 Impact on Lake Rotokawa

Because the lake occupies a former eruption crater covered with Taupo Pumice, the shoreline is extremely unstable. Environmentally unsound mining practices in the past have caused accelerated erosion and increased runoff on the northern shore of the lake. The resulting turbidity has probably already altered the chemistry and biology of Lake Rotokawa (Forsyth, 1977).

The new water rights applied for take account of the greater need for resource conservation and environmental protection than was originally required. The document accompanying the present water right application (Fletcher Challenge Ltd, 1987) provides a comprehensive description of the project and the included technical information greatly facilitates evaluation of the proposal.

Potential impacts of the proposed mining project on Lake Rotokawa include:

- discharge of surface waters (overflow from ponds, stormwater runoff etc).

- infiltration of potentially contaminated groundwater (flow pattern changes, leachate).

- emergencies, accidental spillages.

5.1.1 Direct Discharge of Water to Lake Rotokawa

As opposed to the previous water right the new proposal does not seek a right for the discharge of water to Lake Rotokawa. Instead, water - used as a transporting and suspending medium in the mining and processing of the sulphur - is being recycled and reused in the following way:

Slurries containing overburden, ore and tailings will be pumped to an overburden waste bund, a stockpiling/blending pond and a tailings dump respectively. The water in the waste and the tailings dump will either evaporate, seep to the groundwater or will be returned via toe drains, diversion ditches, and decanting pipes to the surge tank for further use. The water in the stockpiling/blending pond is used to convey the blended ore to the processing plant, with any excess water decanted and pumped to the surge tank. Providing the project will be undertaken as outlined in the report accompanying the water right application, there should be no significant direct discharge of water into Lake Rotokawa. Important points to consider are summarised in the recommendations (see 6.0).

5.1.2 Groundwater Seepage

The hydrology of groundwater in the region, particularly the recharging mechanisms of Lake Rotokawa, is not very well understood. In the proposed mining area shallow groundwaters radiate towards the lake and partly to the Parariki Stream. These shallow groundwaters exist either as thermal waters (influenced by the geothermal aquifer) or cold groundwaters. The latter occur within the Taupo Pumice Alluvium and are perched above the low permeability silts and muds which contain the sulphur ore (Lawless, 1987).

Potential impacts of the seepage from the impoundments include:

- induced changes in groundwater flow patterns.

- changes in the chemical composition of groundwater.

Based on the values given in Figures 1 and 2, and Table 2 in the report accompanying the water right application (Fletcher Challenge Ltd, 1987) the following calculations can be made:

On an annual basis approximately 60% of the total water used is being recycled, 30% is seeping to the groundwater and the remaining 10% is lost to the atmosphere. The seepage from the waste bunds (overburden and tailings) is about 8-20% of the total seepage occurring in the Lake Rotokawa catchment area (assuming an evapo-transpiration of 80-100% of maximum). The proposed taking of water via recharge groundwater from the dredge pond amounts to 6-14% of the total inflow in the Lake Rotokawa catchment area by seepage (assuming 80-100% of potential evapo-transpiration).

These figures for seepage represent maximum values and include losses via solids moisture content. Also, given the nature of the soil structure in the mining area, there will be a considerable clogging and eventual sealing in the base of the impoundments by settling particles such as silts, further reducing seepage losses significantly. Consequently the overall impact on the hydrology of the catchment as a result of increased seepage will be small.

The dredge pond, located close to the lake, will probably act as a local sink of shallow groundwater. Assuming that the water level in the dredge pond is maintained at the same level as Lake Rotokawa (as proposed), no significant induced seepage from the lake to the dredge pond or vice versa is expected.

Leachate, from overburden and tailings which are exposed to the atmosphere (oxidation) and rainfall, may potentially affect the chemical composition of the groundwater. Both overburden and tailings have a similar geochemical composition (Table 3 in Fletcher Challenge Ltd, 1987) reflecting the geochemistry of the surface strata (Taupo Pumice, Parariki Breccias). As such leaching during movements of groundwater is a naturally occurring process and the increased seepage from the waste dump bunds is relatively minor, the overall impact on the chemical composition of the groundwater and Lake Rotokawa (via recharge mechanisms) will be small. Lake Rotokawa and some shallow groundwaters are already significantly enriched with geothermal components such as sulphate, chloride, sodium, lithium, arsenic etc.

5.1.3 Emergencies and Accidental Spillages

Failure of pumps and pipelines transporting slurries could result in large scale spillages and subsequent runoff into surface waters. The proposal includes the following safety measures:

- slurry pipelines will be bedded on concrete foundations spaced out along a shallow trough, which will act as a safety containment in the event of a pipeline break. No estimation of storage volume is given however.

- extensive pipeline maintenance work will be carried out regularly.

- if the pipeline discharge is interrupted, an automatic pipeline flushing and shutdown sequence will be activated.

Chemicals used include pine oil, oils and fuels for mining machineries and the processing plant. It is not known if any additional chemicals will be used in the final process of obtaining pure sulphur (confidential information).

Pine oil (chemical name α - terpinol, ($C_{10}H_{18}O$) is used as a frothing agent in the flotation process. It is mainly composed of biodegradable terpene alcohols and does not contain potentially toxic resin-acids or double aromatics. Pine oil is water-insoluble and non-volatile and can therefore easily be recycled and reused. Of the 1.8 kg of pine oil required per hour (25 g per tonne of ore), 1.45 kg/h (80%) will be recycled, 0.22 kg/h (12%) will be contained in the tailings and 0.14 kg/h (8%) will be lost during the filtration/drying process.

5.2 Impact on Geothermal Surface Features

The Rotokawa area is characterised by numerous thermal features, with a total heat output that is large compared to many other significant geothermal fields. Evidence from hydrothermal alterations at depth (indicating lower temperatures than measured in wells) suggests that the Rotokawa system is relatively young (in geological terms) and that little fluid has as yet passed through the rocks.

Natural surface activity today is dominated by steam-influenced thermal features such as fumaroles, mudpools, steaming ground, collapse craters and some acid sulphate or mixed sulphate-chloride springs. The principal thermal features are shown in Figure 3.

Most of the activity is concentrated immediately to the north of the lake, and in the graben extending to the NE from the lake, along the Parariki Stream and on the banks of the Waikato River where large springs discharging diluted neutral chloride waters occur. North of the river only few steam vents and some areas of hot ground occur.

Many surface features have been adversely affected by past sulphur mining activities.

Potential impacts of the proposed project on the geothermal surface features include:

- Physical modification or destruction of thermal features.
- Changing the nature and chemical characteristics of thermal features.
- Affecting cultural values (e.g. the spiritual value attached to some thermal features by local Maori tribes). This is being dealt with in a separate report.

In its report accompanying the present water right application the applicant states that "geothermal springs and craters will not be mined, areas of unique geothermal activity will become special reserve areas, with accesses and facilities provided". The proposed reserve areas are shown in Figure 3, together with other relevant thermal features within or adjacent to the mining area. Thermal features within the mining licence area are described in Table 2.

The only feature directly affected by the mining proposal is feature no. 20, which will be covered by the tailings pond. The report (Fletcher Challenge Ltd, 1987) states that "some very small geothermal areas will be vented prior to covering with tailings". The detailed procedure and potential consequences are not mentioned in the report.

Note also that the well RK-2 lies within an area proposed for the tailings pond at a later stage of mining (see BMIL 3 in Fletcher Challenge Ltd, 1987).

Direct impacts on thermal features within the mining area are difficult to predict and are likely to be affected by other factors as well (withdrawal of geothermal fluid, reinjection, natural variation). An extensive monitoring programme of those features is included as part of the conditions of the granted water rights for the investigation and the development of the geothermal resource (see also section 7.0).

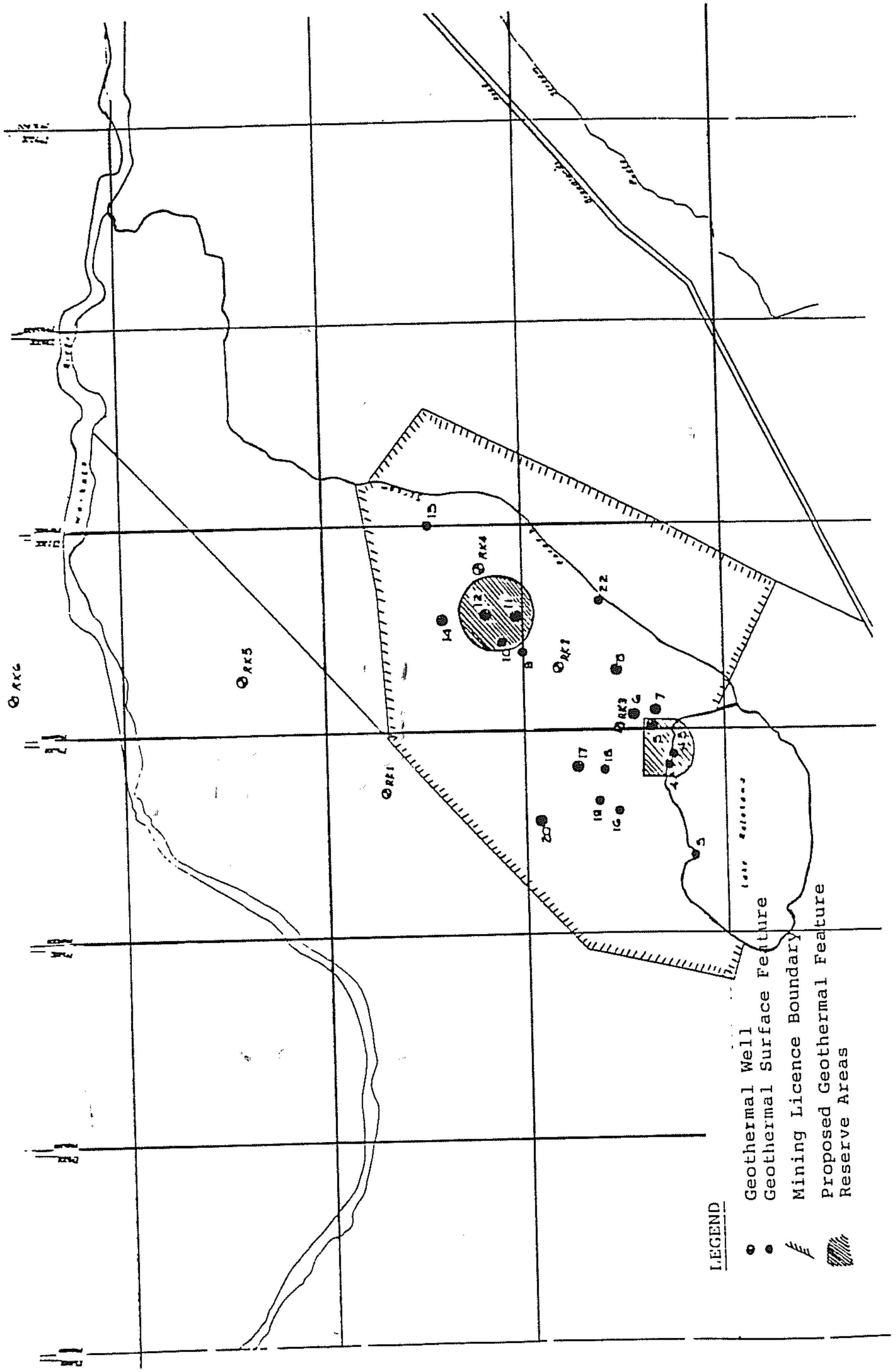

FIGURE 3: Geothermal surface features within the mining licence area (after Lawless, 1987).

Predictions of future changes in surface activity are somewhat hypothetical. Recent evidence (Lovelock, 1987) suggests an increase in the areal extent as well as in the intensity of thermal activity, particularly north of Lake Rotokawa (adjacent to the mining area).

Large eruptions as have happened in the past at Rotokawa are usually occurring in or close to existing thermal areas and may be indicated by a gradual increase in heat flow. The suggested monitoring programme (Section 7.0) would assist to assess the likelihood of an eruption event in the Rotokawa basin, the most likely location for a shallow seated steam eruption to occur (Collar, 1985).

Table 2: Thermal features within the mining licence area (after Lawless, 1987).

Feature No.	Location	Description
3	N shore of lake, immediately W of sulphur plant.	Small hot area now utilised for ore-drying. Two main pools 1x1m, 2x3m. A smaller black pool to the SW is vigorously emitting gas.
4A,B (*)	N shore of lake, E of sulphur plant.	Area about 100m x 150m with numerous points of upwelling and ebullition, forming two large shallow hot pools. The two pools have separate outlets.
5 (*)	N shore of lake, E of sulphur plant.	Area with several warm pools contained within pit 2m deep. Mainly black and turbid, some gas bubbling.
6	100m N of NE corner of lake.	Pit 3m deep with several black, vigorously bubbling pools.
7	200m N of NE corner of lake immediately S of access road.	Pit 3-4m deep including two black pools, no outflow.

8	In scrub 400m NE corner of lake.	Pit, 10m deep, 20x15m. Very actively steaming black pool in bottom. Sulphur being deposited on walls. Similar feature 10m to W.
9	100m W of road to RK-4, 800m NE of lake.	Crater 2m deep, 75m diam. containing four 10m deep pits. Southern one most active. All contain grey turbid pools, ebullition up to 1m.
10 (*)	200m W of road to RK-4, 900m NE of lake.	20m deep pit, 50 x 30m contains 10m diam. clear green pool, smaller vigorously bubbling pools on N side.
11 (*)	Immediately W of RK-4, 950m NE of lake.	10m deep pit, 20 x 30m, road to containing vigorously bubbling grey pool with sulphur.
12 (*)	100m W of road to RK-4, 1100m NE of lake.	20m deep pit, 50 x 40m. Contains 3 pools, the northern most of which is vigorously bubbling.
13	400m NE of RK-4, E side of road.	L-shaped series of 3 or 4 pools, total 30m long x 2m wide, in pit 5m deep. Very black and turbid, bubbling.
14	600m NW of RK-4.	Strongly steaming fumarole, within area of hot ground 100 x 200m.
16	300m NE of sulphur plant.	Area of 5 large & some small hot pools. Black and turbid, vigorously bubbling. Northernmost area most actively steaming.

17	500m NE of sulphur plant.	10m deep pit, 10 x 8m. Several vigorously boiling pools in bottom.
18	450m NE of sulphur plant.	Area of hot pools, much modified by mining. Mainly clear, bubbling pools.
19	450m NNE of sulphur plant.	Vigorously bubbling (0.5m) pools, 1 x 1m in 2m deep pit. Connects to 3 x 3m pool to S. Further S is another steaming pit. Water grey and turbid. Area modified by mining.
20	700m N of sulphur plant.	Area of vigorous steaming ground running 150m along foot of fault scarp.
22	At bend of Parariki Stream 700m NE of lake (left bank).	8 x 2m hot pool with many in flow points, depositing sulphur.

(*) Features Lying within the proposed geothermal reserve areas.

6.0 RECOMMENDATIONS

The following recommendations are considered important with regard to potential impacts of the proposed mining project on the physio-chemical water quality and the biology of Lake Rotokawa.

- Location of overburden/tailings dumps:
  Keep outside the Parariki Stream catchment (and hence the Waikato River).
  Avoid potential losses into the deep groundwater system.
  Keep clear of any major geothermal features or areas of hot ground.

- Sediment and leachate control measures:
  Avoid excessive water and wind erosion from cleared areas, spoil piles and stockpiles. Bunds and impoundments have to be designed so that they have sufficient freeboard during times of high rainfall periods and sufficient area for the settlement of all the contained solids. Runoff and seepage should be intercepted wherever practical and recycled.
  A buffer strip of vegetation between Lake Rotokawa and the dredge pond may minimise any impacts from the mining activity on the water quality of Lake Rotokawa.

- Groundwater infiltration:
  The water level in the dredge pond should be maintained at a level where no significant transfer of lake water and pond water occurs.

- Emergencies, accidental spillages:
  Potential toxic chemicals and fuels should be stored adequately and provision should be made so that no contamination of surface or groundwater occurs.
  A contingency plan should be drawn up to provide for accidents such as the breakage of a slurry pipeline, overflowing, leaking or wall instability of an impoundment etc.

7.0 MONITORING

A monitoring programme should involve

(a) baseline data, and
(b) impact monitoring.

To determine the impact of the proposed sulphur mining project, baseline data prior to setting up the mine, are required.

7.1 Baseline Data

- The chemical characteristics of geothermal and non-geothermal groundwater in and adjacent to the mining area.

- Hydrology of geothermal and non-geothermal groundwater (aquifer locations, areal extent, depth, water level and flow directions of aquifers and their recharge mechanisms), in particular with respect to Lake Rotokawa.

- Water quality, water level and water budget (including geothermal and non-geothermal surficial and subsurface inflows and outflows) of Lake Rotokawa. Establish the natural variations of these characteristics.

- Mapping, describing and characterisation of thermal surface features within the mining area.

Many baseline data outlined above have already been collected and are summarised in unpublished reports e.g.:

- A compilation of chemistry and hydrology data for the Parariki Stream Rotokawa.
  B. Lovelock, KRTA. Unpublished report to Fletcher Challenge Ltd.

- Rotokawa Sulphur Deposit Geotechnical Report.
  T. Sullivan Coffey & Partners. Unpublished report to Fletcher Challenge Ltd.

- Lake Rotokawa sulphur deposit hydrogeology - desk study.
  Murray-North Partners. Unpublished report to Fletcher Challenge Ltd.

- Lake Rotokawa sulphur deposit surface water hydrology - desk study.

  Murray-North Partners. Unpublished report to Fletcher Challenge Ltd.

- Geothermal Investigations and Development of the Rotokawa Geothermal Field.
  Water right hearing (March, 1987).

7.2 Impact Monitoring

The aim of an impact monitoring programme is to detect spatial and temporal changes of the collected baseline data and to interpret them with respect to the project.

Details of sampling frequency, distribution and density of sampling points and relevant chemical and physical parameters are best defined following the collection and interpretation of the baseline data. An impact monitoring programme should include at least:

- Recording of lake water level, lake outflow (at Parariki Stream) and, possibly, water levels in the dredge pond.

- Recording of daily rainfall.

- Water quality of Lake Rotokawa (at outflow), including the following parameters: flow, temp, pH, conductivity, turbidity, suspended solids, colour, lithium, sulphate, chloride, arsenic, ammonia, total nitrogen, total phosphorus, mercury.

- Geothermal surface features:
  Discharge flows, chemical characterisation. Photographic records.

  Note: An extensive monitoring programme covering the thermal surface features within the Rotokawa geothermal field is part of the water rights granted to Geothermal Developments and Investments (Rotokawa)Ltd. and Balcairn Mining and Investments Ltd for the geothermal resource.

- Waterfowl habitats:
  Alterations in surface activity, changes in lake levels or flows in Parariki Stream can influence the present waterfowl habitats.

8.0 CONCLUSIONS

The present application by Balcairn Mining and Investments Limited, seeking water rights asscoiated with the mining and processing of sulphur, continues the history of sulphur mining in the vicinity of Lake Rotokawa, which began with the discovery of the sulphur deposits in the 1840's. While in the past environmentally unsound mining practices and insufficient regulations have caused increased erosion and runoff on the northern shore of Lake Rotokawa and the destruction or modification of many surface features in the area, the proposed expansion and developments take account of a greater need for environmental protection. Land use changes, (conversion to exotic forests and pasture) and geothermal investigatons in the Rotokawa field also caused adverse effects on water and soil resources.

Lake Rotokawa, an acidic thermal lake situated in an ancient eruption crater, harbours an unique biota specifically adapted to these extreme conditions and is of significant scientific value. The lake also represents an important waterfowl habitat in the Taupo/Broadlands region. The main geothermal area on the northern lake shore discharges geothermal water into the yellow-grey coloured lake, adding to the scenic attraction of the area and is of significant cultural value to the Ngati Tahu.

The applications do not include discharging water from the mining or sulphur processing directly into Lake Rotokawa, however potential impacts such as shore instability, runoff, infiltration of (contaminated) groundwater could directly or indirectly affect its hydrology, chemistry and biology. As the sole outflow of the lake (Parariki Stream) runs to the Waikato River, any adverse effect would ultimately have an impact on the Waikato River.

Recommendations to avoid such adverse impacts by taking preventative measures are included and a monitoring programme for their early detection is suggested.

9.0 REFERENCES

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