

## CONTAMINATION OF GROUNDWATER IN THE TE AROHA AREA BY HEAVY METALS FROM AN ABANDONED MINE

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### ABSTRACT

Groundwater contamination from the copper/lead Tui mine was investigated by modelling the groundwater flow regime, monitoring groundwater quality, and studying the retention of heavy metal contaminants by the lithologic units of the receiving environments. Metal (Cu, Pb, Zn, Cd, Fe, Mn) concentrations in the groundwater define a leachate plume extending approximately 1 km downgradient of the tailings pond. The contaminated groundwater discharges to surface mountain streams which in turn recharge and contaminate groundwater in downgradient alluvial fans. The contamination front of iron was close to the tailings source because of its high retardation by the andesite aquifer, while the contamination front of cadmium was the furthest from the source indicating that it is the least retarded of the heavy metals. The volume and timing of contaminant desorption from the tailings for each of the heavy metals indicates the tailings will be a pollution source for hundreds to thousands of years. A number of measures to prevent contamination, including minimising groundwater contact with the tailings, are suggested.

### INTRODUCTION

Located at Te Aroha, in the North Island of New Zealand, the study area is bounded by Tui Stream on the north, Waihou River on the west, north Tunakohoa Stream on the south, and the Kaimai Range watershed on the east (Fig. 1). The abandoned Tui Mine, from which copper, lead, and other metal concentrates were obtained, and its tailings pond are included within the study area.

Acidic leachates from the mine tailings pond and highly polluted drainage from old mine shafts have seriously polluted Tui Stream and north Tunakohoa Stream, which were used for township water supply. Town water is not currently supplied from the study area, but some shallow groundwaters in the area are used for domestic water supply. There is concern whether groundwater in the Te Aroha area also has been contaminated due to previous mining activities. Environmental investigations undertaken in the study area include geochemistry of some soils, stream sediments, and plants in the vicinity of the Tui Mine (Weissberg and Wodzicki 1968, Nicolas and Brooks 1969, Wards et al. 1976) and the impact of Tui mine discharge and tailings leachates on stream water pollution (Tay 1981). No previous work has been done on groundwater of the alluvial fans, nor on the hydrogeology of the study area, except for the tailings dam.

This study assesses the impacts of tailings leachates, mine drainage and polluted stream waters on groundwater quality, and heavy metal release, retention, and transport in the groundwater.

The lithologic units of the study area are: (1) fractured, altered and locally mineralized andesite in the mountain area, (2) alluvial fan debris derived from the mountain rocks between the mountain foot and the Waihou River, and (3) old river channel deposits along the river.

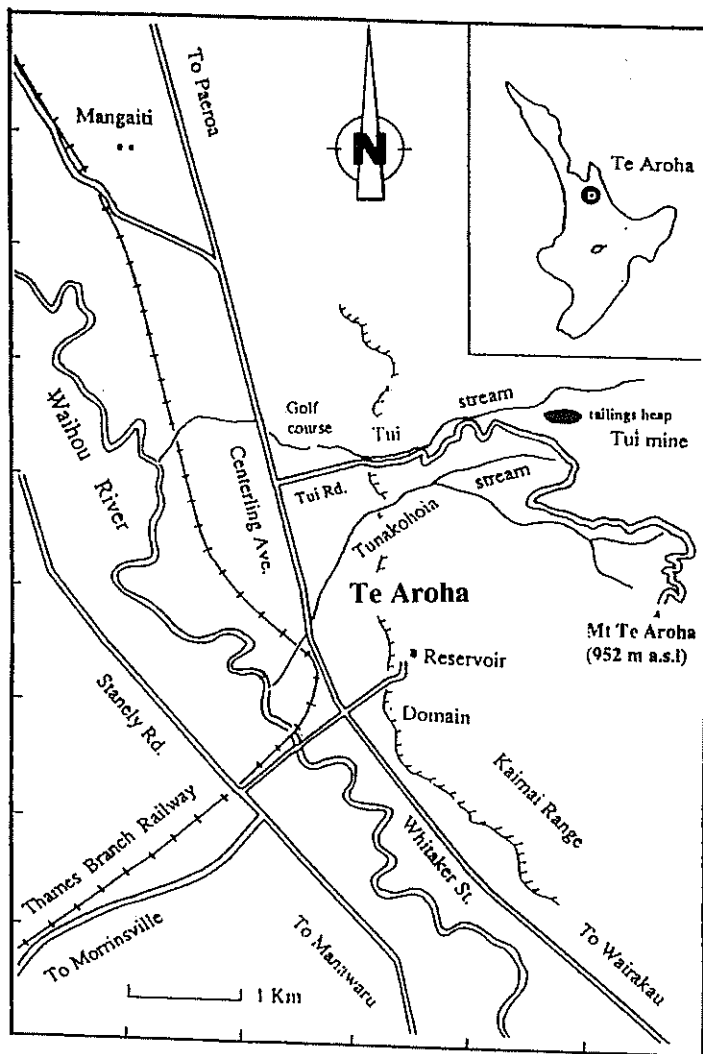


FIG. 1—Location map of the study area

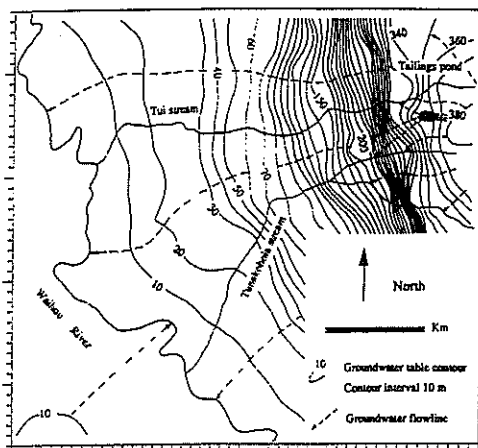


FIG. 2a—Groundwater level contours of the shallow unconfined aquifer of the Te Aroha area (1992)

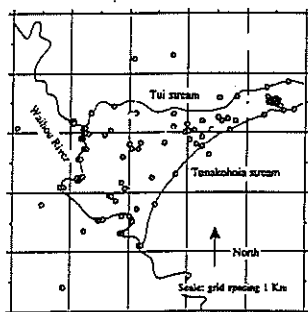


FIG. 2b—Location of groundwater level measures (93 data points)

## GROUNDWATER FLOW MODELLING

### Methods

A groundwater-level contour map of the study area (Fig. 2) is derived from borehole and spring investigations, and a seismic refraction survey, taking into account stream and river boundaries. Groundwater levels in the tailings pond area (Pang 1992) were mapped using previous piezometer data (Tonkin & Taylor 1974). The volume of leachate, with and without rainfall recharge, was estimated using the Dupuit Equation.

The AQUIFEM-N finite-element groundwater flow model developed by Townley (1990) was used in this study. This model requires a steady-state groundwater flow, and allows any combination of fixed-head and zero-flux boundaries. The free groundwater surface forms a fixed-head upper boundary, and the head values at this boundary equate with groundwater levels. The regionally distributed, relatively impermeable thick ignimbrite underlying the alluvial aquifer, and the greywacke basement underlying the fractured andesite aquifer are the lower zero-flux boundaries. Watershed and streams form the lateral zero-flux boundaries. To examine groundwater flow crossing the Waihou

River, the western boundary was selected as the alluvial plains. The plains act as a large static reservoir of groundwater and can be specified as a fixed-head boundary. The head values at this boundary are equal to the groundwater levels. The geological regions of the study area were simplified into two categories — fractured andesite in the mountain area and alluvium in the alluvial fans. The density of the nodes and elements is determined by the degree of interest and by the hydrogeological changes. The model requires values for conductivity of the geological regions and for fixed-head at selected nodes and solves a large number of unknown heads by Darcy's Equation. Figures 3 and 4 show examples of groundwater flow profiles derived from the model.

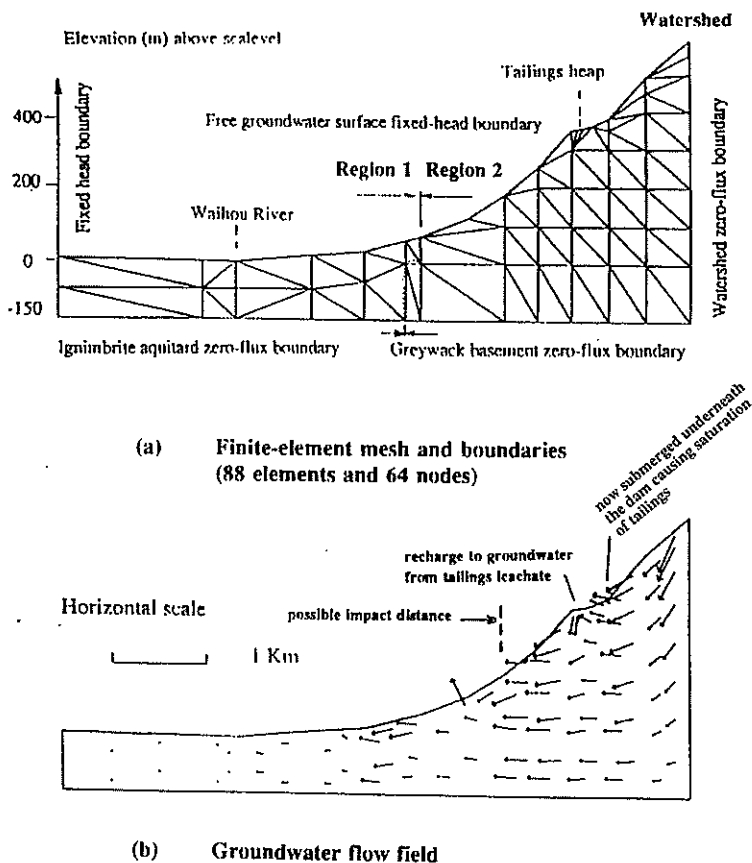
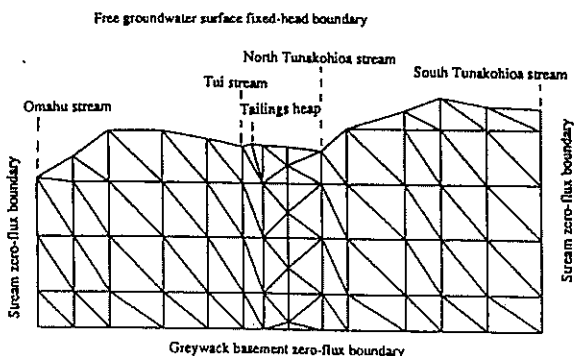
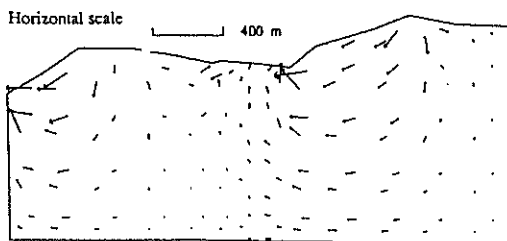


FIG. 3—Cross sections illustrating the groundwater flow field of the shallow unconfined aquifer, simulated by the finite-element flow model.



(a) **Finite-element mesh and boundaries**  
(119 elements and 78 nodes)



(b) **Groundwater flow field**

FIG. 4—Groundwater flow field of the shallow unconfined aquifer simulated by the finite-element flow model (cross section across Tui Stream and Tunakohioa Stream)

### Results

The groundwater flow field derived from the groundwater flow modelling and water level contours suggests that the tailings pond is a local discharge area due to its topographically low position. The tailings pond receives a large amount of groundwater discharged from the upgradient area (Fig. 3), including springs at the rear of the pond. About 200-450 m<sup>3</sup>/day of leachates are estimated to percolate into the groundwater from the tailings pond. The percolated leachates are probably diluted by upgradient groundwater, and finally discharge into the local mountain streams. Based on the flow path, the contamination plume from the tailings pond is predicted to extent less than 1 km downgradient of the pond.

Groundwater flow profiles (Fig. 4) suggest that the polluted Tui and north Tunakohioa Streams are unlikely to leak into adjacent streams. North Tunakohioa Stream may receive groundwater from south Tunakohioa Stream by deep lateral leakage. The tailings leachates probably discharge into Tui Stream and north Tunakohioa Stream, and to groundwater through the fractured andesite bedrock.

The flowlines along Tui Stream (Pang 1992) indicate that the stream continuously receives groundwater discharge in the mountain area, but stream water may recharge the groundwater at the alluvial fans. Tunakohoia Stream is estimated to show a similar pattern to Tui Stream. Therefore, the polluted streams may be the source of groundwater pollution in the alluvial fans. The modelling results also suggest that groundwater on the eastern side of the Waihou River is unlikely to cross the river to the western side.

The predicted groundwater flow paths may be tested by water quality monitoring.

## WATER QUALITY MONITORING

### *Monitoring and sample analysis*

Sixty-four sites of spring water, borehole water, tailings leachates, groundwater discharge from old mine shafts, stream water, river water, geothermal water, tap water, and rainwater were sampled. About 26 sites were monitored monthly for three to four months. The locations of sample sites are shown in Figure 5.

The plastic sample bottles were soaked and washed with acid, and then rinsed with distilled water. The bottles were rinsed several times with sample waters before the samples were collected. The samples were preserved by acidification and refrigeration before analysis. Turbid water samples were settled and filtered through Qualitative Whatman filter papers which had been washed by acid and rinsed with distilled water.

Electrical conductivity, pH, K, Na, Ca, Mg, Cu, Pb, Zn, Cd, Fe and Mn concentrations were analysed. Electrical conductivity and pH were measured mostly in the field. Water samples were analysed using a Flame Atomic Absorption Spectrometer (FAAS). The detection limits of the FAAS were of the order of (mg/L): Cu 0.01, Pb 0.01, Zn 0.01, Cd 0.05, Fe 0.1, and Mn 0.05. Concentrations of Cd and Pb in the groundwater samples, which were lower than the detection limit of the FAAS (except for the samples of December 1991), were determined using a Graphite Furnace Atomic Absorption Spectrometer (GFAAS). The detection limits of the GFAAS are 100-500 times lower than the FAAS.

### *Results*

Table 1 shows the concentration range of heavy metals in groundwater and stream water in the Te Aroha area. The surrounding groundwater of the study area, Tui Stream water upstream of the tailings pond, and stream water from south Tunakohoia Stream were selected as background controls. Compared to the drinking water standards, the background groundwater in the mountain area contains naturally high concentrations of Pb, Cu, Cd and Mn due to the mineralisation of andesite rock, and has a neutral pH range. The background groundwater in the alluvial fans, compared to the drinking water standards, contains high concentrations of Fe, Mn, Pb, Cd, and Cu with some acidification. The natural acidity probably results from solution of carbon dioxide from the soil horizon; the presence of acidic volcanic ash in Hinuera Formation sediments; and the oxidation of sulphuric minerals in debris deposits derived from the andesite rock. Acidic conditions promote the dissolution of heavy metals in the groundwater.

TABLE 1—Heavy metal concentration (in mg/L) in the groundwater and stream water of the Te Aroha area

Metal	Sample site	Sample time	Cu	Pb	Zn	Cd	Fe	Mn	pH
Drinking water standard (WHO 1971)			0.05	0.10	5.00	0.01	0.10	0.05	6.5-7.0
<b>1. Mountain area</b>									
Background	25, 53	Dec.91-Mar.92	<0.01-0.18	0.0003-0.50	<0.01-0.10	0.001	0.025	<0.10	<0.05-0.09
Groundwater drainage from old mine shafts	37,38,39	Dec.91	0.12-5.50	0.204,77	15.5-25.0	<0.05-0.43	3.47-9.75	0.50-1.81	6.6-7.8
Groundwater in the vicinity of the tailings pond	1-6,10,40,41,43-45	Dec.91-Mar.92	<0.01-3.13	0.001-8.20	<0.10-563	0.02-0.79	<0.10-6220	<0.08-123	2.6-6.9
Groundwater 1 km downgradient of the tailing pond and at mountain foot	28-32	Dec.91-Mar.92	<0.01-0.03	0.002-0.50	<0.01-0.10	0.0009-0.07	<0.1-3.48	<0.05-5.15	5.7-7.2
<b>2. Alluvial fan area</b>									
Background	56-62	Dec.91 -Mar.92	<0.01-0.09	0.001-0.50	<0.01-0.55	0.0002-0.03	<0.10-2.20	<0.05-0.29	5.7-6.2
Groundwater in alluvial fans	See Figure 5	Dec.91-Mar.92	<0.01-0.07	0.001-0.009	<0.01-0.45	0.0003-0.07	<0.10-4.20	<0.05-8.85	5.1-7.0
<b>3. Streams</b>									
Tunakohoia background - south branch	7	Dec. 91	0.02	<0.10	<0.10	<0.05	0.10	<0.09	6.9
North Tunakohoia downstream from mine drainage	8,9	Dec.91	<0.02-0.11	0.11-0.51	2.30-16.0	<0.05-0.14	0.20-4.05	<0.09-1.10	7.5
Tunakohoia downstream of confluence	47,18,15	Dec.91	<0.02	<0.10-0.26	0.75-3.60	<0.05	0.10-0.30	0.15-0.29	6.9-7.6
Tui Stream background	64	Feb. 92	<0.01	<0.10	0.10	<0.02	0.10	<0.05	6.5
Tui Stream in the alluvial fans	46,11,49,13	Dec.91-Jan.92	<0.02	<0.100.15	0.40-1.01	<0.05-0.03	0.10-0.55	0.15-0.42	6.5-6.9

Concentration contour maps indicate a contamination plume from the tailings pond. The background concentrations in the groundwater of the mountain area are used to distinguish the plume boundaries. Figures 6 and 7 give examples for Fe and Cd. Contour maps for other metals are given in Pang (1992). Groundwater within the contamination plume is highly polluted; however, the plume appears to extend less than 1 km downgradient of the tailings pond. This supports the prediction based on the groundwater flow path. Within the contamination plume, fronts of Fe and Zn seem to extend less and that of Cd further than fronts of other metals.

Monitoring results suggest that the chemistry of the groundwater in the vicinity of the polluted streams in the alluvial fans is linked with that of the stream water. For example, groundwater at sites 50, 51 and 27 appeared to contain higher concentrations of Cd (Fig. 6) and Pb than at other sites. This supports the interpretation from groundwater-flow modelling, that stream water recharges the groundwater in the alluvial fans.

TABLE 2—Experimental results of solution-solid interactions  
(solution:solid ratio = 2:1, reaction time 21 days).

Parameters	Tailing-rainwater	Andesite-leachate	Alluvial sand-polluted streamwater
Initial pH	6.30	2.50	5.30
Equilibrium pH	3.9-4.0	3.1-3.5	5.0-5.8
<b>(1) Adsorption/Desorption at equilibrium S (µg/g)</b>			
Cu	-0.60	2.80	not reactive
Pb	-5.44	1.06	below detection limit
Zn	-44.4	220	6.90
Cd	-15.5	0.05	0.04
Fe	-73.9	507	1.74
Mn	-23.5	45.5	-0.14
<b>(2) Reaction rate (µg/g.day):</b>			
Cu	-0.08	0.22	not reactive
Pb	-0.68	0.13	below detection limit
Zn	-5.55	27.5	0.86
Cd	-1.29	0.00	0.01
Fe	-7.39	63.4	4.64
Mn	-2.35	4.55	-0.01
<b>(3) Equilibrium distribution coefficients <math>K_d</math> (ml/g):</b>			
Cu	-2.00	2.37	not reactive
Pb	-1.74	1.38	below detection limit
Zn	-1.92	3.68	9.20
Cd	-2.00	0.12	< 2.4
Fe	-2.00	355	6.21
Mn	-1.98	1.91	-0.17

Positive value - adsorption; negative value - desorption.



The polluted streams have seriously affected the downstream ecosystem. According to local residents, Tui Stream between downstream of Tailings pond and the confluence of the Waihou River, and north Tunakohoa Stream between downstream mine shaft drainage and the confluence of south Tunakohoa Stream, are currently lifeless. The greens on the Te Aroha Golf Course died after being irrigated using the polluted stream water. Downstream of the confluence of south Tunakohoa Stream, pollution of Tunakohoa Stream is largely mitigated by dilution. In comparison with Tui Stream, Tunakohoa Stream has higher concentrations of Cu, Pb and Zn, lower concentrations of Fe and Mn, and lower acidity.

### Discussion

These observations suggest two questions: (1) Is this contamination plume still developing, or will it be limited to within the mountain area as suggested from the flow path? (2) Why does the distance of the contamination front from the tailings differs from metal to metal? To answer these questions, an understanding of rock/water interaction, mobility of heavy metals, and contaminant transport in the groundwater is required.

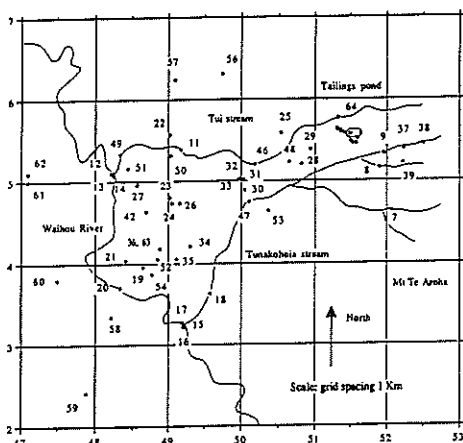
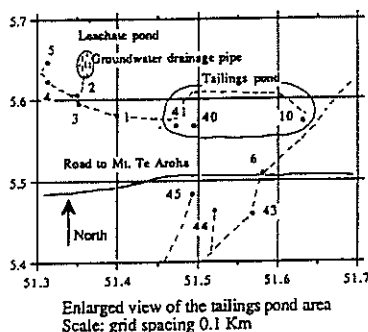


FIG. 5—Location of water sample sites.



No.10, 54 - groundwater from auger holes;  
 No.40, 41 - groundwater from piezometers;  
 No.48 - rainwater;  
 No.37, 38, 39 - groundwater from mine shafts;  
 No.22 - hot groundwater from deep bore;  
 No.19, 57 in 62 - groundwater from shallow bores;  
 No.63 - township tap water from the reservoir;  
 Others: spring waters and surface waters

## SOLUTION-SOLID INTERACTION AND HEAVY METAL TRANSPORT

### Concepts

Contaminant transport in a groundwater system can be described by the following retardation equations:

$$R = \frac{V_{gw}}{V}$$

(Yaron et al., 1984)

for porous media:

$$V_c = \frac{V_{gw}}{1 + \frac{\rho_b}{\eta} K_d}$$

(Freeze and Cherry 1979; Jackson et al., 1980; Yaron et al., 1984)

For fractured media:

$$V_c = \frac{V_{gw}}{1 + A K_d} \qquad V_c = \frac{V_{gw}}{1 + \frac{2}{b} K_d}$$

(Freeze and Cherry 1979; Jackson et al., 1980; Yaron et al., 1984).

In which: R is the retardation factor, which describes the delay of contamination transport velocity with respect to groundwater velocity;

$V_{gw}$  is the mean velocity of groundwater flow;

$V_c$  is the mean transport velocity of the contaminant in the groundwater;

$\rho_b$  is the bulk density of the aquifer;

$\eta$  is the porosity of the aquifer;

A is the surface area to void-space (volume) ratio for the fracture opening. For a planar fracture,  $A = 2/b$ ;

b is the aperture width of a fracture;

$K_d$  is the distribution coefficient, which describes the portion of a contaminant that can be adsorbed by a geological medium for a given concentration of a contaminant in groundwater.  $K_d$  is defined as (Maloszewski et al. 1980):

$$K_d = \frac{\text{mass of contaminant adsorbed in the solid phase (hg'/g or mg/kg)}}{\text{the mass of contaminant adsorbed in the liquid phase (mg/L)}}$$

$K_d$  values are commonly expressed in units of ml/g. However, they can be also expressed in ml/cm<sup>2</sup> for fractured media.

A  $K_d$  value is commonly deduced by the isotherm method. The slope of the isotherm curve, which plots the equilibrium concentration versus adsorption, is

equal to the  $K_d$  value (Fig. 8). Positive  $K_d$  values indicate adsorption, while negative  $K_d$  values indicate desorption (Figs. 8a and b). Concentration breakthrough experiments were conducted to test the kinetics of heavy metals and to examine the time required for reaching equilibria (Fig. 9). A breakthrough test can also be used to calculate a  $K_d$  value on a single point basis of the equilibrium concentration (Pang 1992).

#### Experimental methods

Isotherm tests in a laboratory commonly use the batch constant suspension method (Barrow and Shaw, 1979; Ditoro et al., 1986; McKinley and Jenne, 1991). The contaminated solution and the disaggregated geological material react as a result of continual shaking or stirring in a reaction vessel. This method is commonly used because it is simple and quick. However, as the sample is disturbed and conditions are not representative of reality, the reliability of constant suspension batch tests is often open to question (Barrow and Shaw, 1979; Lion et al., 1982). Shaking or stirring breaks down particles and increases particle surface area, hence adsorptivity or desorptivity increases. Capping during shaking may create anaerobic conditions and thus alter adsorptivities of oxidized materials. To maintain a suspension, the solution to solid ratio has to be much higher than that of natural aquifer systems, and the solid needs to be crushed into very fine particles (usually less than 2 mm).

This study uses an alternative method using unshaken batches. Samples of rainwater, leachate and polluted streamwater, at room temperatures, were applied to the tailings, andesite and alluvial sand. Low solution to solid ratios (2:1) were used because groundwater moves through pore spaces and fractures.

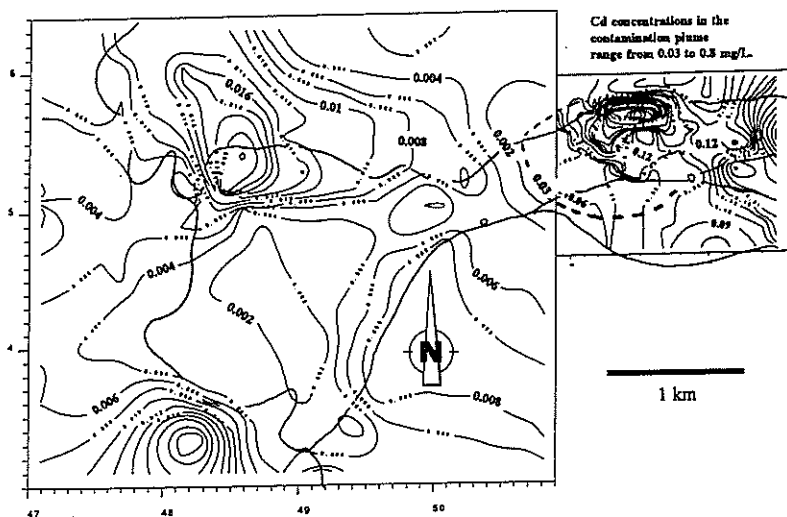


FIG. 6—Cadmium concentration (in mg/L) contours of the shallow groundwater of the Te Aroha area (1991/92 summer)

Tailing and alluvial sand samples were soaked in glass vessels; their original particle structures and surface areas were not altered during experiments. To simulate a fracture zone, andesite was broken into fragments and chips with a wooden hammer. In the reactor, contaminants diffused into pore spaces and aerobic conditions were maintained by using a slotted cap. In order to maintain a constant solution to solid ratio, the volume of each solution withdrawn was minimized to 10 ml, and an equal volume of new solution was added. Solutions sampled were analysed using FAAS. The replacement of small portion of solution also simulates a partial "flowing" condition of the groundwater.

### Results

It took 8-13 days for Cu, Pb, Zn, Cd, Fe, and Mn to reach equilibria for the unshaken batch tests. The reaction rates seem to follow an exponential function. Reaction rates were generally faster for Fe and Zn and slower for Cd than for other metals (Table 2). This offers an explanation for the reason that the distance of Fe and Zn fronts in the contamination plume extends less, and that of Cd further, than those of other metals. A shorter time to reach equilibration for Fe than for Cd is also reported by Li et al. (1984).

It is very difficult to compare the results from this study with those of other studies because of differing experimental conditions, materials and solutions used. Artificial solutions and single element/compound materials are often used in experiments (Griffin and Au 1977; Oakley et al., 1981; McKinley et al., 1991). However, the adsorptivity or desorptivity of a metal is actually the function of all other species reactions. Therefore, the mobility of a contaminant in groundwater is usually much different from the result derived from the

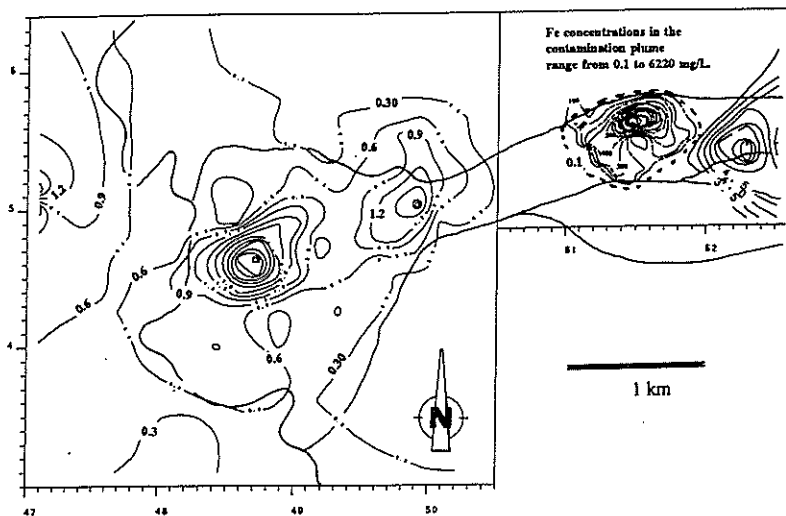


FIG. 7—Iron concentration (in mg/L) contours of the shallow groundwater of the Te Aroha area (1991/92 summer).

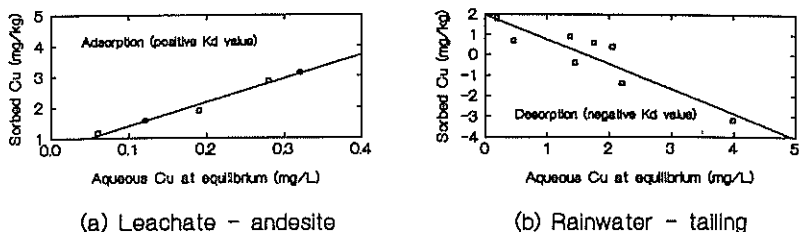


FIG. 8—Copper isotherms of the solution - solid interactions

interaction between a single element and an artificial solution. The  $K_d$  values derived from shaken batch tests using a single element and artificial solutions are normally much greater than those derived from the unshaken batch tests used in this study.

Comparison shaken tests were also undertaken in this study. Equilibrium could be reached in a very short time, but the balance was disturbed with further shaking (Fig. 9a).

#### Evaluation

If  $K_d$  values are known, heavy metal transport velocities in the groundwater can be estimated. Heavy metal transport in the contamination plume derived from the tailings are estimated to be at 1.1 to 345 times slower than the groundwater velocity in segregated zones of:  $Fe \ll Zn < Cu < Mn < Pb \ll Cd$ . Figure 10 illustrates schematically the retardation of heavy metal transport in the groundwater during leachate percolation through andesite bedrock.

The tailings pond has been in place for 24 years. If the contaminated groundwater had not been discharged into the local surface streams, the front of heavy metals in the contamination plume, except for Fe, would have extended more than 14 km. However, the concentration contours suggest that the contamination plume extends less than 1 km downgradient of the tailings pond. Therefore, the contaminated groundwater must have been discharged in the mountain area streams. This further confirms the previous prediction based on groundwater flow paths.

#### FATE OF HEAVY METALS IN THE GROUNDWATER ENVIRONMENT

Based on adsorption/desorption kinetics and isotherm laboratory experiments, it is estimated that, due to groundwater saturation and rainfall percolation, about 7.4 tonnes of Fe, 4.4 tonnes of Zn, 2.4 tonnes of Mn, 1.6 tonnes of Cd, 0.5 tonnes of Pb, and 60 kg of Cu may be released from the tailings over periods ranging from 370 to 34,000 years (Table 3a). The andesite bedrock may retain heavy metals from the tailings leachates with estimated efficiencies of: Fe 99%, Zn 63%, Cu 55%, Mn 49%, Pb 41%, and Cd 10%, in periods ranging from 43 to 690,000 years (Table 3b).

Fe should have the highest retention in the geological media and shortest residence time in the groundwater, while Cd would have the least retention and longest residence time. This is evident in both the andesite-leachate interaction and the alluvium-polluted stream water interaction (Table 3b).

TABLE 3—Estimated heavy metal release from the tailings and retention in the aquifer material

(a) Release from the tailings		
Metal	Mass release (kg)	Impact time (years)
Fe	7,390	371
Zn	4,440	494
Mn	2,350	1,166
Cd	1,550	2,124
Pb	544	4,029
Cu	60	34,247

(b) Retention in the aquifer material				
Metal	Retention (%)		Residence time (years)	
	andesite-leachate	alluvium-stream water	andesite-leachate	alluvium-stream water
Fe	99.8	82.6	43	590
Zn	62.6	82.2	100	3,186
Cu	55.4		12,453	
Mn	49.2		602	
Pb	40.8		21,075	
Cd	10.3	>50	684,932	547,945

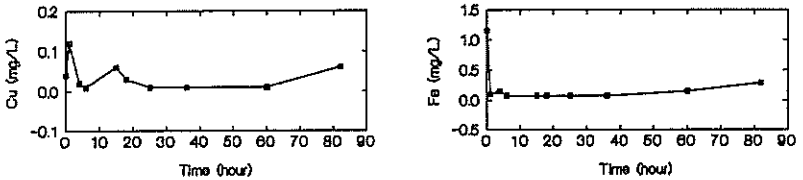
Dr Hendy of Waikato University estimated the equilibration time for Fe released from the tailings to the andesite bedrock is less than 100 years (pers. comm.) which is similar to the residence time of 43 years determined from this study. The residence times of Fe and Cu in the ocean are 200 years and 20,000 years respectively (Mason and Moore, 1982). These are of a similar orders of magnitude to those derived from this study. However, those of Zn and Mn differ by one or two orders of magnitude; the difference probably reflects the differing geochemical environments.

## RESTORATION

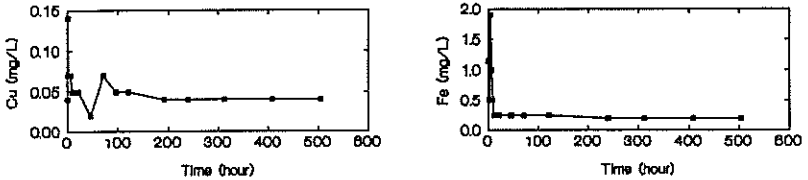
Leachates are generated by groundwater saturation of the tailings and by rainfall infiltration. These problems can be solved by isolating the tailings from groundwater and rainfall. Rainfall percolation could be prevented by sealing the pond surface with low permeability clay layers. Groundwater saturation can be prevented by constructing dewatering channels and installing pumping boreholes. Figure 11 illustrates methods for separating rainfall and groundwater from the tailings. Acidic leachates could be treated by limestone chips or powder, or by activated sludge from the domestic wastewater treatment plant of Te Aroha township. Crushed limestone acts as a natural barrier by directly absorbing heavy metals, and raising the solution pH level. Activated sludge, containing a high content of organic matter, attenuates heavy metals through biological activity.

For the old mine shafts with small discharges, fractured zones could be grouted and shaft walls sealed. For the mine shafts with large discharges, polluted drainage results from groundwater interaction with the mineralized host rock during ponding. Drainage pipes could be installed directly into the water sources to prevent the groundwater contacting the host rock.

After controlling or retaining the contamination sources at the tailings pond and mine shafts, stream water pollution can consequently be mitigated.



(a) Shaken batch test



(b) Unshaken batch test

FIG. 9—Concentration breakthrough curves of the interaction between alluvial and polluted streamwater.

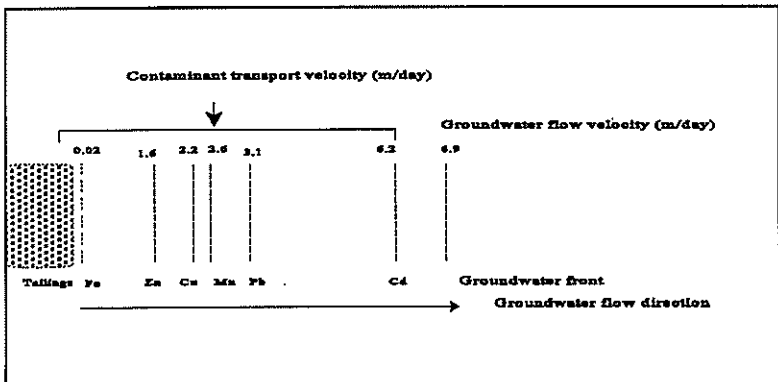


FIG. 10—Schematic illustration of heavy metal retardation within the groundwater in the andesite bedrock during leachate percolation

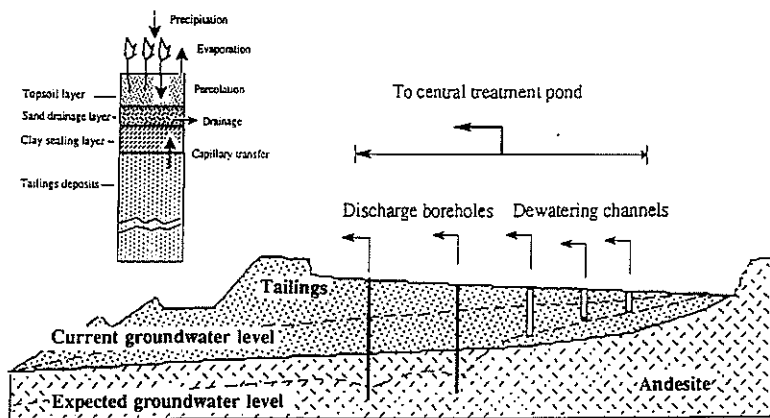


FIG. 11—Schematic illustration of leachate control by separating the tailings from groundwater and rainfall

Contaminated groundwater in the vicinity of polluted streams must be treated before being used as drinking water. Installation of pumping bores adjacent to the streams should be restricted to minimise the recharge of the shallow groundwater by polluted stream waters. Sand filters are recommended for the local residents who use the groundwater as their domestic water supply.

## CONCLUSIONS

The groundwater of the Te Aroha area is naturally enriched in heavy metals. Previous mining activities have resulted in highly polluted and toxic groundwater in the vicinity of the tailings pond and the old mine shafts. Tui Stream and north Tunakohoa Stream are basically lifeless, and groundwater in the alluvial fans is contaminated in the vicinity of the polluted streams.

Groundwater flow paths indicate that the contamination plume derived from the tailings pond is likely to be limited to the mountain area for a distance of 1 km downgradient of the tailings pond, and the polluted streams are unlikely to leak into the adjacent streams. Estimation of heavy metal transport in the groundwater further indicates that contaminated groundwater in the plume is discharged into the local mountain streams.

Study of heavy metal adsorption/desorption kinetics suggests that, if no control measures are undertaken, more than 16 tonnes of various heavy metals will be released from the tailings into the groundwater and streams over hundreds to thousands of years. The distance of heavy metals transport in the contamination plume is estimated to be the least for Fe and largest for Cd due to their different mobilities in the groundwater.

Relatively inexpensive restoration options are available to prevent heavy metal contamination of area groundwater.



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