Geothermal Mercury Pollution in New Zealand

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Discharge from natural hot springs or from drillholes producing hot water or steam for geothermal power may constitute an important source of mercury pollution. Inorganic mercury discharged from these sources may accumulate in the sediments of rivers or lakes and, after microbiological methylation, may become concentrated as the more toxic compound, methylmercury, in the edible tissue of fish (1).

Most geothermal areas and mercury ore deposits are localized in two of the earth's major mobile zones, the Circum-Pacific Belt and the Mediterranean-Tethyean Belt which ranges from Spain through Italy, Yugoslavia, Turkey and Iran eastwards to link with the Circum-Pacific Belt in Malaysia-Indonesia (2). Precipitates rich in mercury are actively forming near the orifices of many hot springs in the Circum-Pacific Belt (3,4,5) and many mercury ore deposits are directly associated with active hot springs or exhibit mineral structures and textures that indicate they were deposited from hot spring systems now inactive (6). A close genetic relationship between naturally occurring ore concentrations of mercury and hot springs is widely accepted even though most hot spring waters contain very low concentrations of mercury (0.01 to 2 ug Hg/kg of water) (7).

In New Zealand's North Island (Fig.1 and Tables 1 and 2) the waters discharged from several thermal areas, not associated with mercury ore deposits, drain into the upper Waikato River or into lakes of explosive volcanic origin in the Rotorua area. The only known industrial source of mercury pollution in these waters is from a pulp and paper mill that discharges effluents into Lake Maraetai, one of the rivers artificial lakes about halfway down the Waikato River. The mill has been in operation about 19 years, and currently produces 10 tons of chlorine per day from a mercury cathode cell alkali-chlorine plant; until mid-1971 maximum total mercury losses were up to 830 kg per year, of which about one-half were estimated as loss

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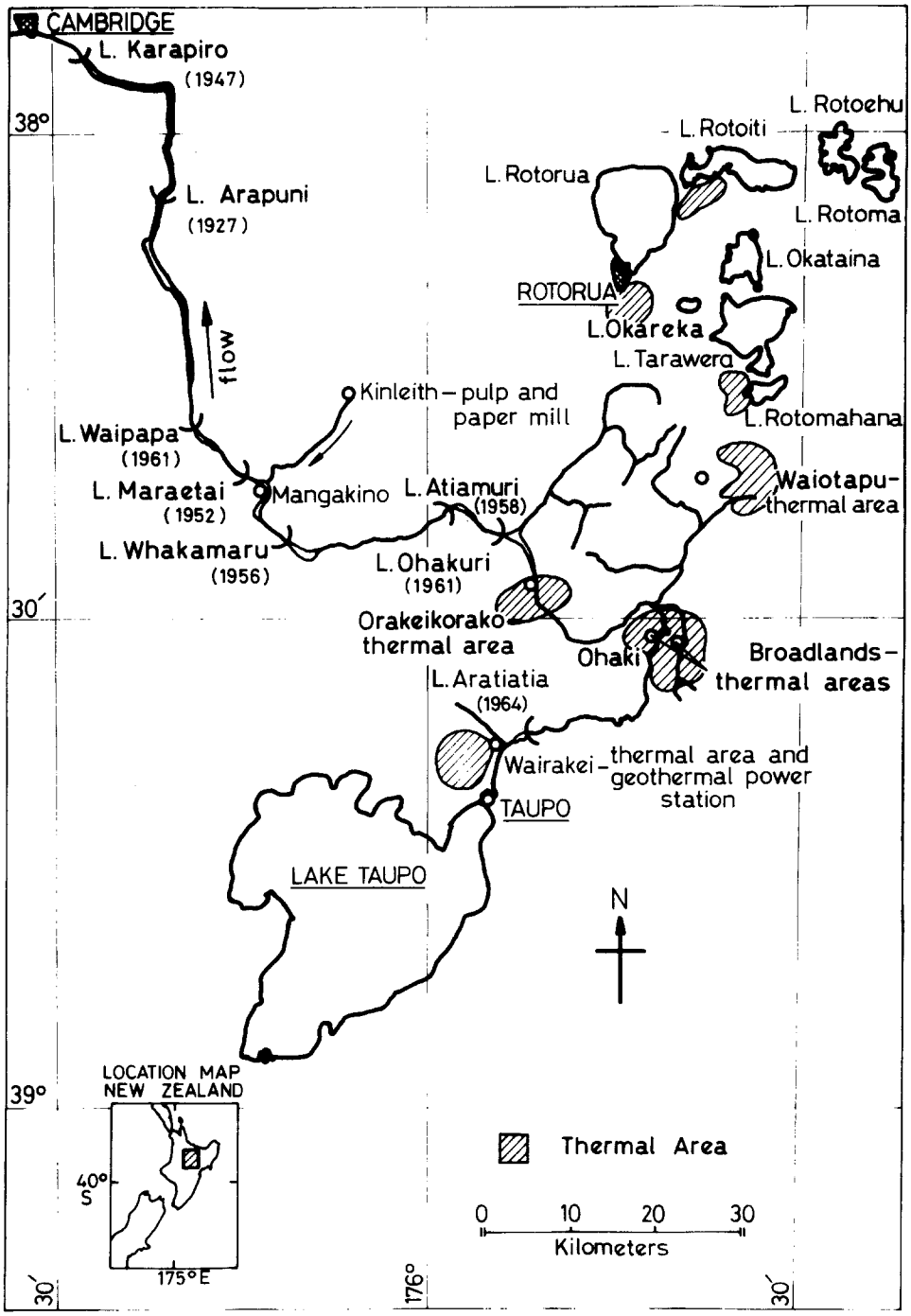

FIGURE 1 Location map showing Rotorua Lakes and Waikato River flowing north from Lake Taupo with dams and their dates of completion.

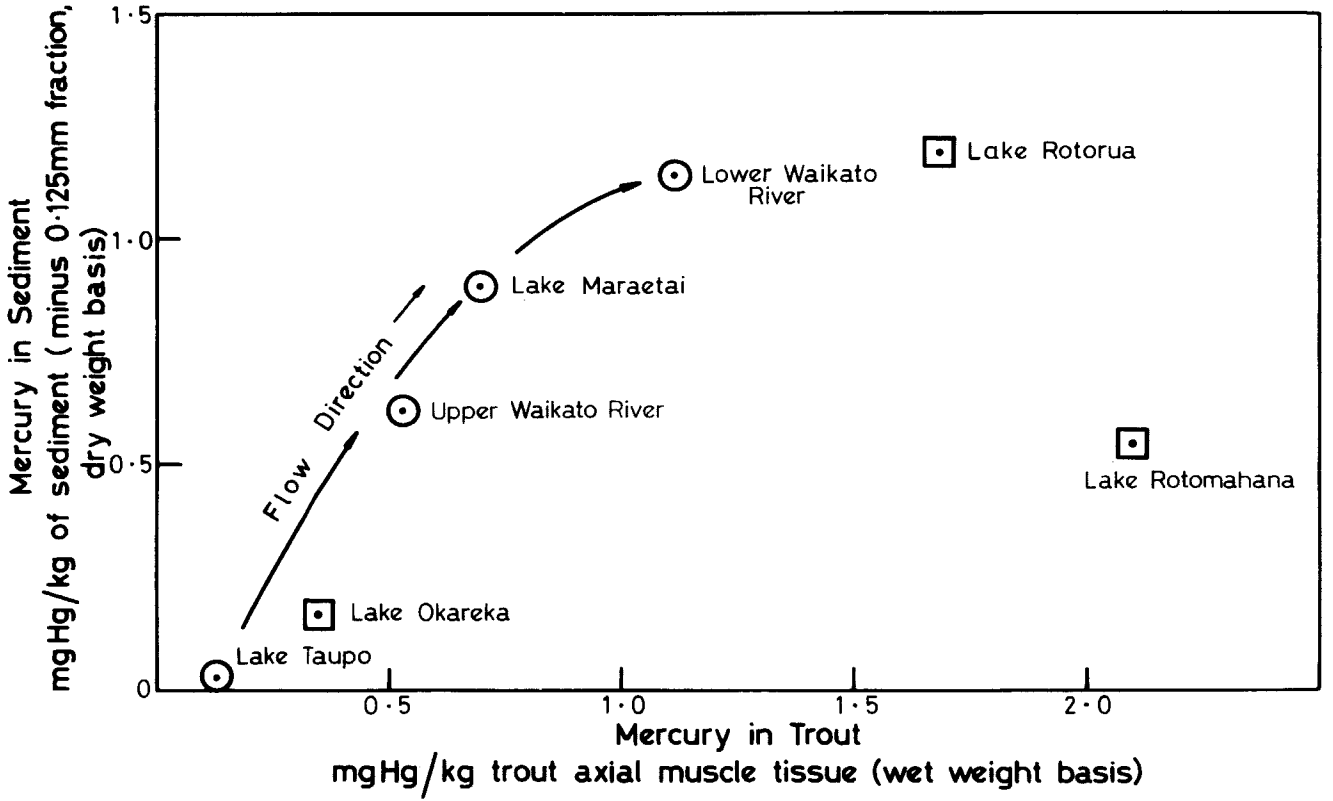

FIGURE 2 Relationship of mercury in sediments to mercury in co-existing trout.

to water effluents and one-half to the atmosphere. It was, in fact, a study of mercury pollution from this pulp and paper mill that led us to discover the magnitude and extent of natural mercury pollution arising from geothermal sources in New Zealand.

ANALYTICAL METHODS

Rainbow and brown trout and sediments from the Waikato River lakes and some of the Rotorua lakes were analysed for total mercury by flameless atomic absorption (8,9), utilizing a modified stannous chloride reduction-aeration technique, after wet ashing with nitric and sulphuric acids. The accuracy of the analyses is estimated to be $\pm$ 15 per cent of the amount present. Details of the equipment used are reported elsewhere (10). Check analyses, specific for methyl-mercury, were performed by gas chromatography (11) on about one-half of the trout samples; they indicate that essentially all of the mercury in the fish is present in the form of methylmercury.

Sediment core samples, obtained from water depths of up to 33m with a compressed air driven piston core-sampler (12), were divided into depth layers, double-wrapped in polythene bags, and frozen for storage. The sediment samples were later sun dried for 6 to 10 hours in porcelain evaporation dishes placed on a lawn, about 2m apart, and then stored in airtight glass vials until analysis. Trout samples were stored frozen and portions of the edible axial muscle tissue from the frozen fish were selected for analysis.

RESULTS

The results, presented in Tables 1 and 2, indicate much higher concentrations of mercury in trout living in waters receiving considerable geothermal discharges (Upper Waikato River, Lake Rotorua, and Lake Rotomahana) than in trout living in similar waters receiving little or no geothermal discharges (Lake Taupo and Lake Okareka). Average mercury concentrations in trout from the Lower Waikato River are higher than in those from the Upper Waikato River due to the introduction of mercury-bearing industrial effluents into Lake Maraetai, the point at which we arbitrarily divided the Waikato River into its upper and lower parts.

The concentrations of mercury in trout within a given lake increase with increasing fish weight, consistent with observations by others (1,14), and no distinct differences in mercury concentrations were

TABLE 1

Geothermal Mercury Pollution in the Waikato Hydro System

Locality	General Comments	Adjacent Population and Industrial Sources of Mercury	Geothermal Discharge Received in terms of natural surface heat flow (13) MJ/s	Weight of Trout kg	Mercury Concentration in Trout mg Hg/kg of axial muscle tissue (wet weight basis)	Mercury Concentration in top 30 cm of sediments mg Hg/kg of sediment (dry weight basis of minus 0.125 mm fraction)
Lake Taupo	Source water of Waikato River Area: 606 km^2 Max. depth: 159 m Outflow: 127 m^3/s Sportfishing trout harvest 700×10^3 kg/year	Population at Taupo 10,000 No known industrial sources of mercury	80	$*\bar{x}$ = 1.17 r = 0.45 - 1.81 σ = 0.43 n = 7	$\bar{x}$ = 0.12 r = 0.02 - 0.24 σ = 0.08	< 0.05 Coarse-grained pumice sand - only one core sample recovered.
Upper Waikato River (to Whakamaru Dam)	Average flow rate 160 m^3/s Total area of three hydro-lakes 23.3 km^2	None	2700 (plus the discharge from a geothermal power station, Wairakei, producing 180 MJ/s electrical power)	$\bar{x}$ = 1.29 r = 0.40 - 2.38 σ = 0.77 n = 33	$\bar{x}$ = 0.53 r = 0.03 - 1.14 σ = 0.31	$\bar{x}$ = 0.62 r = 0.05 - 2.13 σ = 0.38 n = 69
Lake Maraetai	Area 4 km^2	Population at Mangakino 2000 Effluents from pulp and paper mills 10 ton Cl_2/day alkali-chlorine plant	None directly - all from Upper Waikato River only.	$\bar{x}$ = 0.89 r = 0.23 - 2.61 σ = 0.69 n = 20	$\bar{x}$ = 0.70 r = 0.24 - 1.64 σ = 0.37	$\bar{x}$ = 0.89+ r = 0.45 - 1.43 σ = 0.26 n = 13
Lower Waikato River (to Karapiro Dam)	Average flow rate 200 m^3/s Total area of three hydro-lakes 22.3 km^2	Small scattered farming communities only	None directly - all from Upper Waikato River only.	$\bar{x}$ = 1.25 r = 0.28 - 2.61 σ = 0.89 n = 9	$\bar{x}$ = 1.12 r = 0.10 - 3.22 σ = 0.89	$\bar{x}$ = 1.13 r = 0.30 - 1.97 σ = 0.49 n = 9

Symbols: $*\bar{x}$ = arithmetic mean ; r = range ; σ = standard deviation ; n = number in sample

\+ = Excludes non-representative sediment samples from lake margins and arm receiving industrial effluent. Total range 0.07 - 30.0

TABLE 2

Geothermal Mercury Pollution in the Rotorua Lakes

Locality	General Comments	Adjacent Population and Industrial Sources of Mercury	Geothermal Discharge Received in terms of natural surface heat flow (13) MJ/s	Weight of Trout kg	Mercury Concentration in Trout mg Hg/kg of axial muscle tissue (wet weight basis)	Mercury Concentration in top 30 cm of sediments mg Hg/kg of sediment (dry weight basis of minus 0.125 mm fraction)
Lake Rotorua	Area: 80 km^2 Max. depth: 26 m Outflow: 14 m^3/s into Lake Rotoiti Sportfishing trout harvest 60 x 10^3 kg/year	Lake Rotorua receives the effluents, either directly or through ground water, from a population of 30,000. No known industrial sources of mercury.	1000	$\bar{x}$ = 1.28 r = 0.79 - 1.70 σ = 0.49 n = 4	$\bar{x}$ = 1.68 r = 1.10 - 2.67 σ = 0.68	$\bar{x}$ = 1.18 r = 0.57 - 2.40 σ = 0.57 n = 20
Lake Rotomahana	Area: 9 km^2 No outlet	None	250	$\bar{x}$ = 1.02 r = 0.82 - 1.31 σ = 0.24 n = 5	$\bar{x}$ = 2.10 r = 1.52 - 2.92 σ = 0.58	$\bar{x}$ = 0.54 r = 0.16 - 0.75 σ = 0.18 n = 10
Lake Okareka	Area: 3.2 km^2 Max depth: 40m No outlet	Population < 200 No industrial source of mercury	None	$\bar{x}$ = 1.03 r = 0.82 - 1.32 σ = 0.25 n = 5	$\bar{x}$ = 0.35 r = 0.33 - 0.37 σ = 0.02	$\bar{x}$ = 0.17 r = 0.15 - 0.19 σ = 0.02 n = 5

Key as Table 1

observed between rainbow and brown trout, or between male and female trout of the same species, apart from the weight factor.

The concentrations of mercury in sediments showed no apparent variation with increasing depth (i.e. age) of sediments.

DISCUSSION

The relationship between concentrations of mercury in the sediments and mercury in co-existing trout is shown in Fig.2. The deviation shown by Lake Rotomahana, from a rough one to one correspondence, may be due either to non-representative sampling or to the much larger surface area per unit volume of this lake combined with zero outflow.

Normal concentrations of mercury in fine-grained sediments and sedimentary rocks range from about 0.1 to 0.5 mg Hg/kg of sediment (2) (dry weight basis) and probably average around 0.3 mg Hg/kg of sediment. Normal concentrations of mercury in trout range up to about 0.2 mg Hg/kg of axial muscle tissue (wet weight basis). The data presented here are consistent with this picture and emphasize the narrow margin between normal background concentrations of mercury in the environment and the higher mercury level in sediments that arise from natural geothermal discharges and are sufficient to cause mercury concentrations in trout in excess of 0.5 mg Hg/kg of fish, the maximum concentration commonly considered acceptable for human consumption.

The magnitude of the problem is accentuated by the facts that:

(a) Mercury, although of extremely low concentrations in hot spring waters, has been accumulating in some sedimentary basins from natural geothermal discharges over the centuries whereas industrial sources of mercury are of recent origin.

(b) Natural geothermal discharges are less localized and more difficult to control than industrial sources of mercury. Some thermal areas are protected tourist attractions.

(b) A large sportfishing industry is immediately concerned; in areas affected, mercury concentrations in trout may rise to 3 mg Hg/kg of trout.

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