The effect of geothermal waters on stream invertebrates

D.J. FORSYTH

Taupo Research Laboratory, Division of Marine and Freshwater Science, Taupo

DIVISION OF MARINE AND FRESHWATER SCIENCE

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Taupo Research Laboratory
Div. Marine & Freshwater Science, DSIR, Box 415.
Taupo

INTRODUCTION

Increasing pressure to find alternative sources of energy to fossil fuels places more emphasis on the search for geothermal steam fields as a source of energy production. In testing the potential of steam bores for geothermal power they must be run for extended periods for adequate characterisation with the consequent discharge of geothermal waste water. If this waste water is not reinjected, it must drain to the nearest stream. The effect of such waters on stream macroinvertebrate animals is not known.

In order to gain information on the effects of geothermal waters on stream macroinvertebrates in artifical and natural situations the following locations were chosen for study: -

1. the Waiaruhe-Waitangi Rivers which drain the proposed Ngawha geothermal field
2. the Ongarahu and Waipapa Streams draining the catchment of the proposed Mokai geothermal field
3. the Tarawera River, which receives geothermal inputs in the stretch between its outlet from Lake Tarawera and Kawerau township
4. the Hakereteke Stream and its confluence with the outlet from geothermal Lake Rotowhero.

MATERIALS AND METHODS

The stream faunas were sampled in winter in order to measure the maximum standing crop of animals.

Up to four drift nets of 30 cm mouth diameter and 400 µm mesh size were placed across each stream at selected sites for 30 minutes. Sites were chosen above and below geothermal inputs [(2) and (4) above], at intervals along the length of the waterway [(3) above], before and during a manipulated input of geothermal water to the water way [(1) above] and a comparison between two streams, one with, and one without geothermal input [(2) above]. This method of sampling provided a comparison between sites and/or times with and without geothermal influence.

The method was used at locations where geothermal input was manipulated at a single point source over time. Geothermal water was introduced in known amounts for known periods. It was assumed that if geothermal fluid was unfavourable to the fauna the numbers of organisms appearing in the drift net would be greater after the addition of geothermal water than before.

At locations 2, 3 and 4 drift nets were used to measure faunal differences along the course of the streams. Downstream of permanent, natural, geothermal inputs the fauna may be different from that upstream.

In conjunction with qualitative sampling by means of sieve sweeps of the stream bed and submerged vegetation at the margins, differences in the faunal assemblage could be measured.

The instability of the stream bed and/or rapid flow of water precluded the use of benthic samplers.

RESULTS

(1) The Waiaruhe and Waitangi Rivers draining the Ngawha geothermal area (Fig.1). Sampling sites were on the Waiaruhe River at State Highway 1 (site A) and at Oromahoe (site B), on the Waitangi River near Puketona Junction (site C) and at the Lily Pond motor camp (site D). Background of drift activity was measured on 11 August 1980 before the introduction of geothermal effluent from the NG4 bore. Sampling was repeated on 13 and 15 August 1980 as the input of geothermal effluent was increased, indicated by the increased conductivity and concentration of chloride at site A (Table 1).

The Waitangi River was also sampled upstream of its confluence with the Waiaruhe River at site E (beside State Highway 10) on 15 August to provide base-line data on a fauna with no history of geothermal influence.

Because of the rapid water flow and unstable nature of the river bed at sites A, B and C where the numbers of species were similar the distribution of the fauna was mainly restricted to the substrate and vegetation of the steep-sided river banks. But at site D the substrate was more stable and supported filamentous algae and diatoms. Consequently more species were recorded from there than elsewhere (Table 2).

At sites A, B and C the biota comprised mainly Zephlebia spp., Deleatidium spp., Zelandobius spp., Pycnocentria evecta, Syncricotopus pluriserialis Austrosimulium sp. and Potamopyrgus antipodarum. At site D their numbers increased and Coloburiscus humeralis, Nesameletus ornatus, Xanthocnemis zealandica, Limonia sp., Maoridiamesa harrisi, Harrisius pallidus, Paratanytarsus agameta, an indeterminate orthocladine chironomid, seven species of caddis larvae and Latia neritoides were generally more abundant or appeared for the first time (Table 2).

There was no significant change in the abundance or obvious change in the composition of the drift fauna because of the effects of increased discharge of geothermal water from NG4 at Ngawha during the period of this study (Table 3).

(2) The Ongarahu Stream was sampled on 27 July 1981 upstream of the Manawa Road crossing (site A) and the Tatua Road crossing (site B). The Waipapa Stream was sampled on 6 August 1981 at sites A, B and C, and 10 August 1981 at site D. These two streams provided a comparison between waters with and without a permanent geothermal influence.

The total number and kinds of animals taken in the drift nets was similar to the two sites on the Ongarahu Stream (Tables 4 and 5). They belonged mainly to Ephemeroptera, Trichoptera and Chironomidae. Water temperature and conductivity were similar at both sites (Table 1).

In the Waipapa Stream animals were more abundant at site A than at sites B and C, although the mean was similar to that of the Ongarahu Stream (Table 4). The fauna at site A was dominated by oligochaetes and small Potamopyrgus antipodarum, whereas at sites B and C Ephemeroptera, Trichoptera and Plecoptera were most abundant while P. antipodarum and oligochaetes declined. Inputs of geothermal water to the Waipapa Stream were indicated by higher water temperature and conductivity at site A than at sites B and C and here values and chloride concentration were greater than those of the Ongarahu Stream (Table 1).

Ephemeroptera and Trichoptera were more abundant in the Ongarahu Stream than the Waipapa Stream. On the other hand oligochaetes and gastropods were more common in the Waipapa Stream, particularly at site A downstream of the main geothermal input, than in the Ongarahu Stream.

On the basis of their invertebrate communities the two streams appeared to be different. The animal groups likely to be adversely affected by stream perturbations are the Ephemeroptera, Trichoptera and Plecoptera. Numbers of taxa in the first two orders are smaller in the Waipapa Stream (Table 5). The Plecoptera and Chironomidae showed little difference between sites on the Waipapa Stream but numbers of oligochaetes and gastropods were greater at site A in the Waipapa Stream than elsewhere. These two groups were absent from impounded waters of geothermal origin like Lake Rotowhero (Forsyth & McColl 1974); Rotokawa (Forsyth 1977) and North and South lakes in the crater of Rainbow mountain (Forsyth in press), but oligochaetes were found in low numbers in acid Opal Lake near Rainbow Mountain (Forsyth and MacKenzie 1981).

Chemical effects of geothermal water on the invertebrate fauna of the Waipapa Stream were not apparent. The maximum chloride concentration in January 1978 was at the hot springs (Fig.2) where it was 67.0 $g.m^{-3}$ falling to 64.0 $g.m^{-3}$ 3 kilometres downstream and 52.6 $g.m^{-3}$ at the Tirohanga Road bridge (Table 1). However, the relatively moderate geothermal influence in the lower reaches of the Waipapa Stream was possibly enough to stimulate planktonic production. The bottom sediments at site A appeared to be enriched, which would encourage the gastropod population, and partially oxygen depleted, which would enhance oligochaete production.

Most of the individuals of the winter population of P. antipodarum at site A were small and apparently immature. Individuals of populations elsewhere were of mature size at this time. This species normally breeds most commonly in October-November. Possibly the population was limited by high water temperatures in summer. In autumn and winter the snails could recolonise the lower reaches from upstream and the elevated temperatures could allow them to breed later than usual. Alternatively, in the absence of competition from other animals and fewer mature snails in autumn perhaps more of the juveniles survive than otherwise would.

To summarise, the slight geothermal influence in the upper reaches, and the more pronounced influence and obvious inputs of geothermal water into the middle reaches of the Waipapa Stream appear to influence the composition and numbers of some elements of the invertebrate fauna by comparison with the Ongarahu Stream which has no history of geothermal input.

(3) The Tarawera River (Fig.3).

The Tarawera River was sampled at three sites on 10 December 1980. These were: site A, the outlet from Lake Tarawera, site B, Edwards Road, site C, Tarawera Park on the outskirts of Kawerau township.

At site A the invertebrates were typical of a lake benthic community. Total numbers in the drift net samples were lower than at the other two sites (Table 4).

At site B the animals were typical of a stream riffle community dominated by Ephemeroptera, Trichoptera and elmid bettle larvae.

At site C the fauna was more diverse and the flow of water slower than upstream. The invertebrate community comprised most groups found at site B as well as Trichoptera larvae, *Parochlus* sp. and *Pisidium* sp. not found upstream.

Numbers of animals were higher at site B than elsewhere (Table 4).

The chloride flux (water flow in $m^3.s^{-1}$ x chloride concentrations in $mg.L^{-1}$) in the Tarawera River between Lake Tarawera outlet and Kawerau township increased downstream from 454 ± 9 at site A to 744 ± 30 at site B and 836 ± 33 at site C on 10 December 1980 (Findlayson and Nairn 1981, and chloride concentrations in Table 1) indicating geothermal inputs down the river. However the faunal differences between the three sites appeared to be influenced more by changes in the morphometry of the stream bed and the velocity of the flow of water than by any geothermal influence (Tables 4 and 5).

(4) The Hakereteke Stream and Lake Rotowhero outlet (Fig.4).

The Hakereteke Stream drains the cold, non-geothermal Lake Ngahewa, passes beneath State Highway 1 near Rainbow Mountain before it receives water of geothermal origin from the outlet of Lake Rotowhero. Samples were taken from the Hakereteke Stream above (site A) and below (site B) its confluence with the Lake Rotowhero outlet stream, and from Lake Rotowhero outlet stream (site C).

Larvae of Oxyethira albiceps, Austrosimulium sp., Deleatidium sp., Orthocladiinae and oligochaete worms were found in the Hakereteke Stream above and below the confluence (Table 5).

The stream draining Lake Rotowhero contained the same invertebrates as were found in Lake Rotowhero (Forsyth & McColl 1974) with the addition of larvae of Hemicordulia australiae and adult Rhantus pulverosus.

The species found in the drift at site A were found in greater numbers in the drift at site B (Tables 4 and 5). This suggests that either the increase in water temperature (9°C to 14°C) or changes in the chemistry of the water (conductivity increased from 69 $\mu S.cm^{-1}$ to 331 $\mu S.cm^{-1}$) may have caused more animals to enter the drift (Table 4).

However because the geothermal input is permanent it can have had no effect on the fauna except to prevent those elements of the drift fauna sensitive to geothermal waters from resettling in that stretch of the stream between the geothermal input and the drift nets. The numbers in the drift nets above the confluence suggest that this contribution would be small.

Alternatively it seems that the increased abundance and variety of marginal, submerged vegetation at and below the confluence provided an increased area of substrate and more niches for the invertebrate fauna.

The change in temperature and conductivity appears to have had no harmful effect on the stream fauna here. On the contrary the increased water temperature may have contributed to their abundance.

The species found at site C were also found at site B but in fewer numbers because of the increased volume of water.

CONCLUSIONS

This work provides a record of the winter composition of the macroinvertebrate fauna before the spring emergence of insects. Future assessment of biological change may be measured by comparison with these data.

The faunal composition of the streams or parts of streams not influenced by geothermal waters at Ngawha and Mokai was comparable with those recorded in recent studies of invertebrates in other New Zealand rivers and streams (Cadwallader 1975, Fowles 1975, Hopkins 1976, Winterbourn 1978, Graynoth 1979, Cowie and Winterbourn 1979) (Table 6).

However, the faunas of the Tarawera River and the Hakereteke Stream were probably less diverse because they were sampled close to the headwaters which are lake fed. The low diversity of standing water faunas (site A on Tarawera River) compared with that of flowing water faunas along with the fewer niches provided by the short reach of the Hakereteke Stream (site A) probably reduced the number of taxa present.

The manipulation of entry of geothermal water into the Waiaruhe River and Waitangi River system appeared to have no effect on the stream macroinvertebrates over the brief experimental period. However, nothing is known of the effect on the fauna of similar amounts of geothermal water for longer periods.

Of the two streams draining the catchment of the proposed Mokai geothermal field the Ongarahu Stream appeared to have no geothermal input and the invertebrate communities were typical of a stream unaffected by geothermal waters. On the other hand, the Waipapa Stream has obvious geothermal input downstream of which the fauna was less diverse but more abundant than would be expected if geothermal input was absent.

The Tarawera River receives geothermal waters upstream of Kawerau township but the fauna appeared to be influenced more by changes in the character of the stream than by any geothermal influence.

Influence of geothermal water from Lake Rotowhero on the fauna of the Hakereteke Stream was probably negligible.

Only the fauna of the Waipapa Stream showed any significant reaction to the effect of geothermal waters. Here the chloride concentration was similar to that in the Tarawera River where no faunal changes were evident (Coulter 1980, Findlayson and Nairn 1981). Possibly the changes in the fauna in the lower reaches of the Waipapa Stream were in response to the elevated water temperature alone. A more detailed chemical analysis of the water may clarify this.

The results of this study suggest that the chemical effects of geothermal water are negligible at least up to the levels of conductivity recorded. The water temperatures encountered appear to have had no harmful effect and could be beneficial to invertebrate growth in winter. However the raised water temperatures in summer could be lethal to some invertebrate groups, for example at site A on the Waipapa Stream and site B on the Hakereteke Stream.

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Table 1. Values for conductivity ($\mu S.cm^{-1}$), temperature (°C) and chloride concentration ($g.m^{-3}$) of waters at four locations influenced by geothermal inputs. * 20.11.70, McColl and Forsyth (1973); ** Coulter 1980; † January 1978, Coulter (1981); †† Findlayson and Nairn (1981).

Location	Site	Date	Conductivity	Temperature	Cl^-	
Ngawha						
Waiaruhe Stream	A	11.8.80	132	-	14.8	**
	A	13.8.80	215	-	37.6	**
	A	15.8.80	255	-	49.6	**
Mokai						
Ongarahu Stream	A	27.7.81	75	9.5	-	
	B	10.8.81	72	10.0	-	
confluence with L.Whakamaru		1.78	-	-	3.9	†
Waipapa Stream	A	6.8.81	291	20.0	-	
hot springs (Fig.2)		1.78	-	-	67.0	†
3 km downstream of springs		1.78	-	-	64.0	†
	B	6.8.81	104	12.5	-	
	C	6.8.81	102	13.0	6.8	†
	D	10.8.81	248	18.0	52.6	†
Tarawera River	A	10.12.80	-	-	77.0	††
	B	10.12.80	-	-	67.0	††
	C	10.12.80	-	-	44.0	††
Hakereteke Stream	A	24.6.81	69	9.0	-	
below confluence with						
Lake Rotokawa outlet	B	24.6.81	331	13.0	-	
Lake Rotowhero outlet	C	24.6.81	1130	23.0	175.0	*

Table 2. Taxa recorded from drift sampling and collections of the Waiaruhe and Waitangi Rivers 11-15 August, 1980. (+ = present).

	Waiaruhe River						Waitangi River						Waitangi R. above confluence wit Waiaruhe R. 15 Aug. site E
	Bridge S.H.1 August			Oromahoe August			Puketona Jct. August			Lily Pond Motor Camp August			
	11	13	15 A	11	13	15 B	11	13	15 C	11	13	15 D	
Oligochaeta			+	+			+		+				+
Ephemeroptera													
Nesameletus ornatus (Eaton)											+		
Coloburiscus humeralis (Walker)		+								+			+
Zephlebia spp.	+	+	+	+	+	+	+	+	+	+	+	+	+
Deleatidium sp.	+			+			+		+	+	+	+	
Odonata													
Xanthocnemis zealandica (McLachlan)	+									+	+	+	+
Plecoptera													
Zelandobius spp.	+				+	+	+			+	+	+	+
Hemiptera													
Microvelia macgregori (Kirkaldy)											+		
Anisops assimilis White (side pool)							+	+	+				
Diptera													
Limonia sp.							+			+	+	+	
Pentaneura harrisi Freeman		+											
Maoridiamesa harrisi Pagast					+					+	+	+	
Cricotopus zealandicus Freeman		+			+	+	+	+		+	+	+	
Harrisius pallidus Freeman										+	+		
Paratanytarsus agameta (Forsyth)										+	+	+	
Polypedilum sp.									+				
Orthocladine chironomid								+		+	+	+	
Austrosimulium sp.	+		+	+	+	+	+	+		+	+	+	+
Tricoptera													
Aoteapsyche colonica (McLachlan)										+	+	+	
Aoteapsyche raruraru McFarlane										+			
Polyplectropus puerilis (McLachlan)						+							
Ecnomina zealandica Wise											+		
Hydrobiosis umbripennis McLachlan								+		+	+	+	
Hydrobiosis parumbripennis (McFarlane)					+					+	+	+	
Psilochorema sp.						+							
Oxyethira albiceps (McLachlan)										+	+	+	
Pycnocentria evecta McLachlan			+				+	+	+	+	+	+	+
Pycnocentrodes aeris Wise										+	+	+	
Olinga feredayi (McLachlan)			+										
Hudsonema amabilis (McLachlan)			+									+	
Mollusca													
Potamopyrgus antipodarum (Gray)	+	+	+	+	+	+	+	+	+	+	+	+	+
Latia neritoides Gray										+	+	+	
Number of taxa			12			11			12			24	8

Table 3. Average number of animals per driftnet per hour in the Waiaruhe and Waitangi Rivers. (- = no record).

	1980			
	11 Aug	12 Aug	13 Aug	15 Aug
Waiaruhe River				
Site A	8	3	2	3
Site B	2	-	2	4
Waitangi River				
Site C	2	-	3	3
Site D	88	-	162	94
Total number of animals	100	3	169	104

Table 4. Average number of animals per drift net per hour. (- = no record).

	Site A	Site B	Site C
Ongarahu Stream	18	17	-
Waipapa Stream	39	6	20
Tarawera River	15	49	26
Hakereteke Stream and Lake Rotowhero outlet stream	64	286	2592

Table 5. Distribution of taxa in the Ongarahu Stream, Waipapa Stream, Tarawera River and the Hakereteke Stream and outlet stream from Lake Rotowhero.

	Ongarahu Stream sites		Waipapa Stream sites			Tarawera River sites			Hakereteke Stream sites		Lake Rotowhe outlet strea site
	A	B	A	B	C	A	B	C	A	B	C
Nematoda											
Annelida			+					+			
Oligochaeta	+	+	+	+	+				+	+	
Insecta											
Ephemeroptera											
Nesameletus ornatus (Eaton)	+										
Coloburiscus humeralis (Walker)	+			+			+	+			
Oniscigaster wakefieldi McLachlan	+										
Zephlebia spp.	+	+		+			+	+		+	
Deleatidium spp.	+	+		+	+				+	+	
Odonata											
Xanthocnemis zealandica (McLachlan)						+				+	
Hemicordulia australiae (Rambur)										+	+
Plecoptera											
Zelandoperla sp.					+						
Zelandobius sp.	+	+	+								
Acroperla trivacuata (Tillyard)				+			+				
Spaniocerca zelandica Tillyard	+										
Megaloptera											
Archichauliodes diversus	+		+				+				
Trichoptera											
Orthopsyche							+	+			
Aoteapsyche spp.			+				+	+			
Hydrobiosis panumbripennis (McFarlane)		+									
Neurochorema sp.								+			
Oxyethira albiceps (McLachlan)				+	+	+		+	+	+	
Paroxyethira hendersoni Mosley						+		+			
Pycnocentria funerea McLachlan	+	+	+								
Triplectides sp.	+		+								
Pycnocentrodes sp.	+	+	+				+	+			
Hudsonema sp.							+				
Hemiptera											
Microvelia macgregori (Kirkaldy)										+	+
Anisops sp.	+									+	+
Sigara sp.						+				+	+
Coleoptera											
Liodessus plicatus (Sharp)				+						+	+
Rhantus pulverosus (Stephens)										+	+
Enochrus tritus (Brown)										+	+
Hydora sp.							+	+			
Diptera											
Limonia sp.			+	+	+						
Austrosimulium sp.				+	+		+	+	+	+	
Parochlus sp.								+			
Macropelopia sp.						+					
Cricotopus sp.				+							
Syncricotopus sp.						+					
Orthocladiinae		+	+	+					+	+	
Chironomus zealandicus Hudson										+	+
Chironomus sp.a.			+			+		+			
Ceratopogonidae						+					
Mollusca											
Gastropoda											
Potamopyrgus antipodarum (Gray)	+	+	+	+	+	+		+	+		
Physa ?acuta						+					
Bivalvia											
Pisidium sp.						+					

Table 6. Comparison of number of taxa of the main orders recorded from some New Zealand stream studies.

	Cadwallader (1975)	Hopkins (1976)	Graynoth (1979)	Winterbourn (1978)	Cowie & Winterbourn (1979)	Fowles (1975)	Ngawha	Mokai	Tarawera River	Hakereteke Stream	Mean
Ephemeroptera	6	8	5	2	1	3	4	6	3	2	4
Plecoptera	4	3	2	8	5	0	2	4	0	0	3
Diptera	9	11	2	9	3	2	9	6	6	3	6
Trichoptera	14	21	8	9	7	3	14	7	9	1	9
Mollusca	0	2	1	0	0	0	2	1	2	1	1
Total taxa	33	45	18	28	16	8	31	24	20	7	23

Fig.1

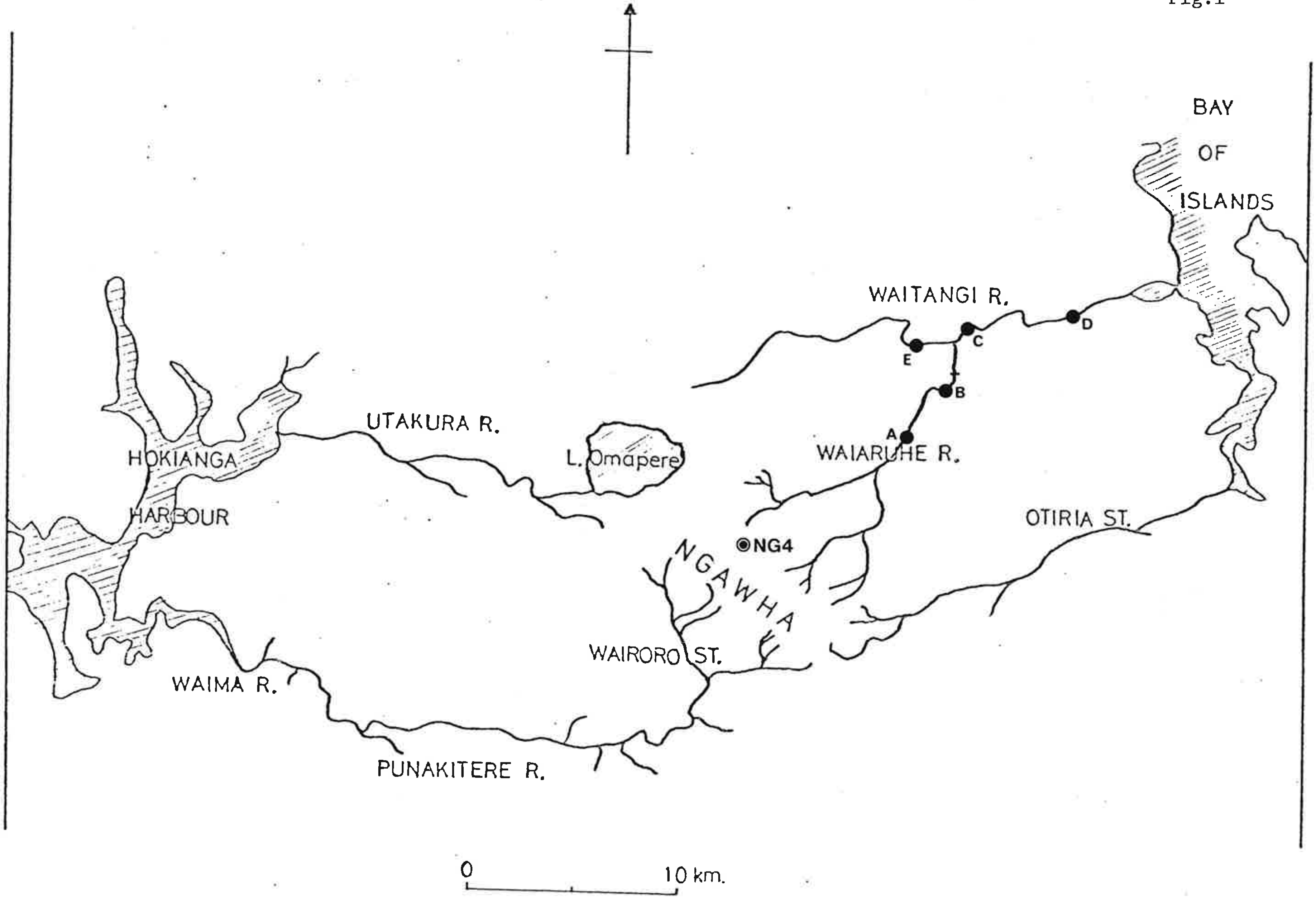
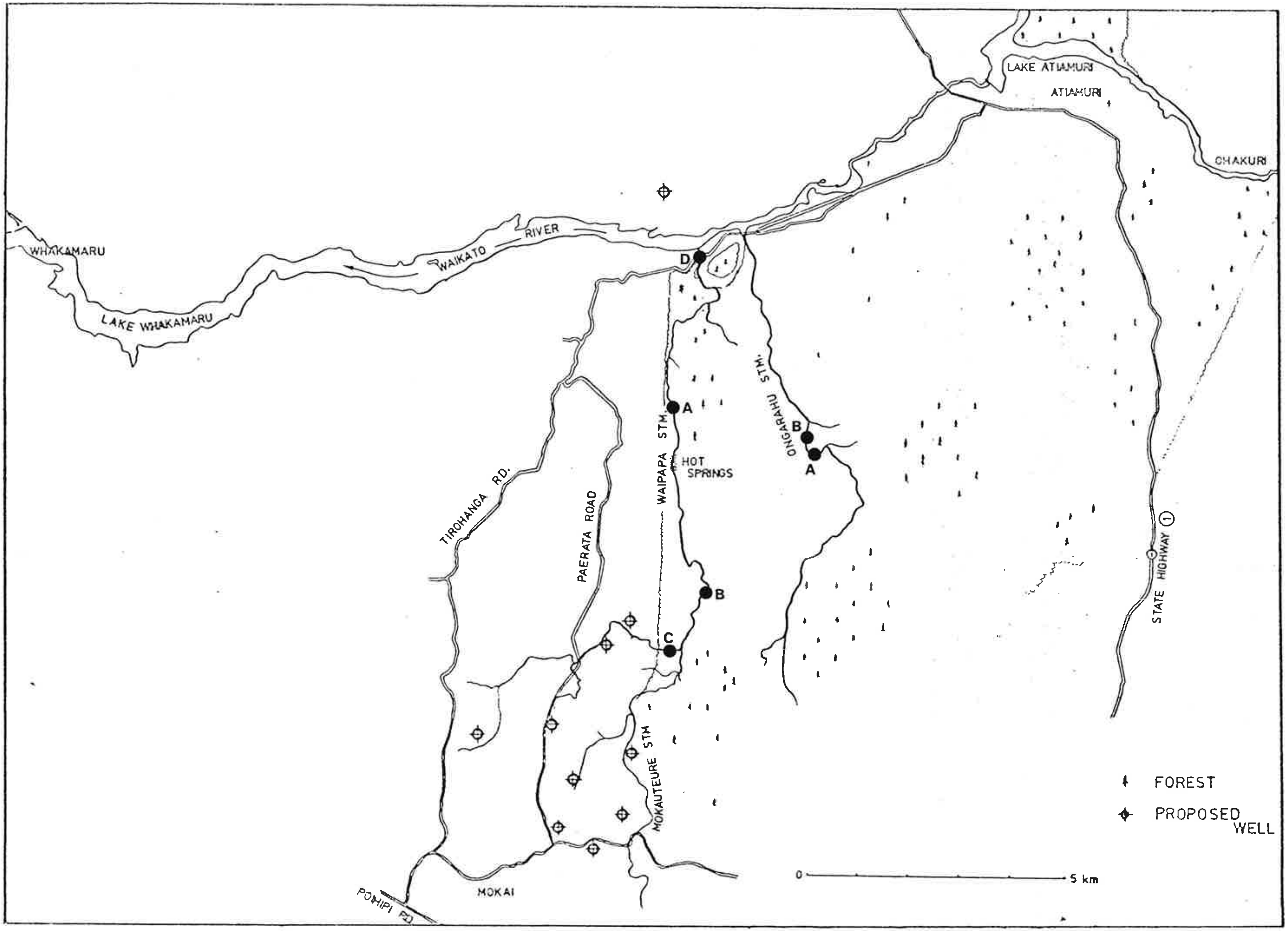

BAY
OF
ISLANDS
WAITANGI R.
D
C
E
B
A
WAIARUHE R.
UTAKURA R.
L. Omapere
HOKIANGA
HARBOUR
NG4
NGAWHA
OTIRIA ST.
WAIRORO ST.
WAIMA R.
PUNAKITERE R.
0
10 km.

Fig.2



LAKE ATIAMURI
ATIAMURI
OHAKURI
WHAKAMARU
WAIKATO RIVER
LAKE WHAKAMARU
D
A
B
A
B
C
WAIPAPA STM.
ONGARAHU STM.
HOT SPRINGS
TIROHANGA RD.
PAERATA ROAD
MOKAUTEURE STM
STATE HIGHWAY 1
MOKAI
POIHIPI RD
FOREST
PROPOSED WELL
0
5 km

Fig.3

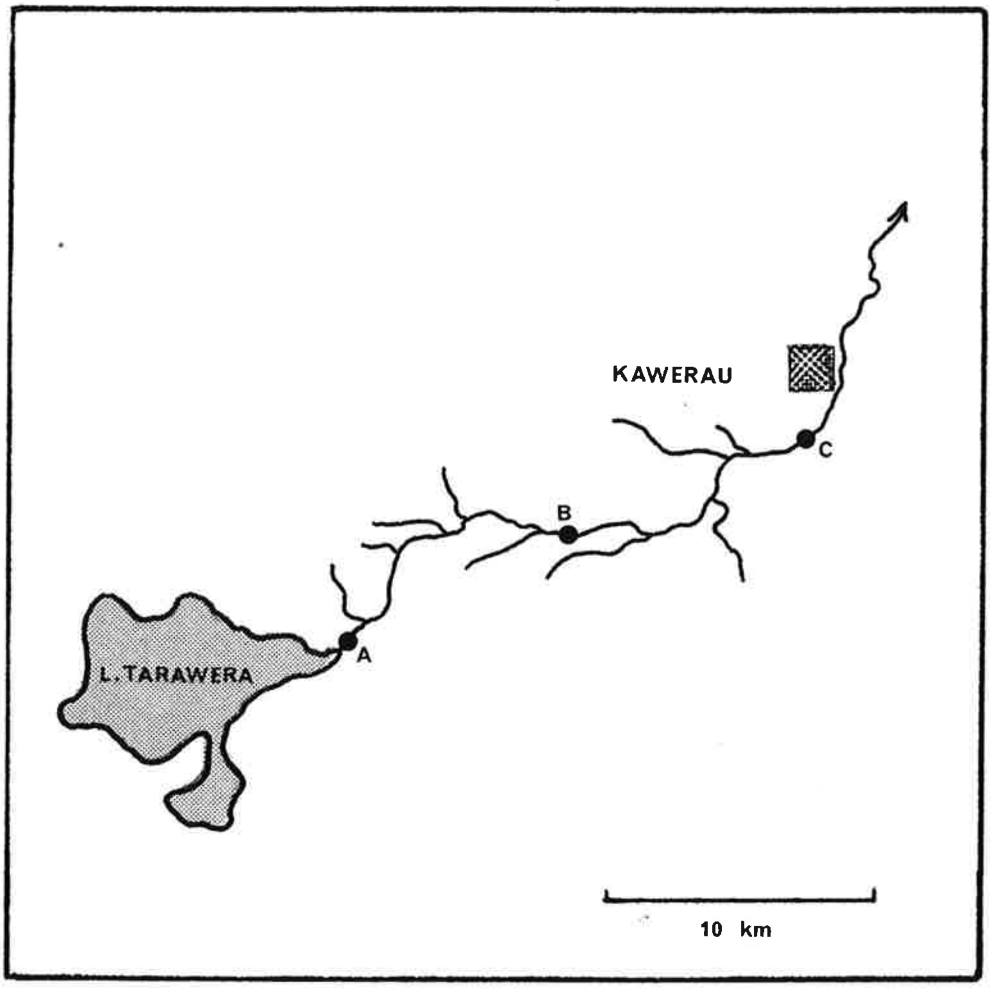


Fig.4