Monitoring of Hochstetter's frog (*Leiopelma hochstetteri*) populations near Golden Cross Mine, Waitekauri Valley, Coromandel

(*Above*) Hochstetter's frog (*Leiopelma hochstetteri*) near Golden Cross Mine, Waitekauri Valley, Waihi, 17 January 1996.
(*Left*) Typical frog habitat, with moss and liverwort-covered stones, and overhanging parataniwha, 17 January 1996.
(*Below*) Two frogs in situ, illustrating the difficulty of detecting such cryptic animals, 18 January 1998.
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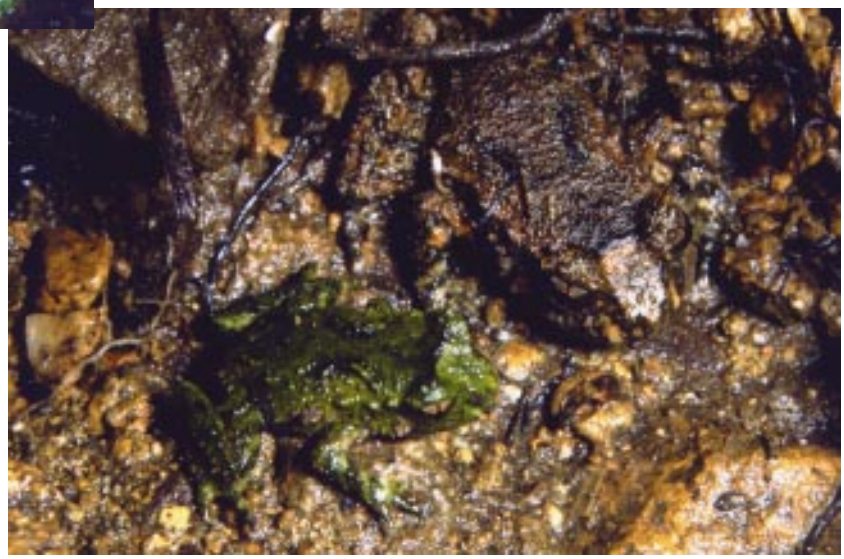

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A.H. Whitaker and P.A. Alspach

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A B S T R A C T

Biennial monitoring of Hochstetter's frog (*Leiopelma hochstetteri*) populations adjacent to the Golden Cross Mine, in the headwaters of the Waitekauri River, southern Coromandel Range, was undertaken in January 1998.

In 1998 the relative population density of frogs in the study streams (mean 17.7/100 m) was lower than, but comparable to, the density observed in 1994 and 1996 (21/100 m). The effect of rainfall on the number of frogs counted is sufficient to explain most of the variability in relative density that was observed between the baseline study in 1991 and the subsequent monitoring surveys. The extremely low number of marked frogs recaptured during the monitoring surveys could mean a higher than expected level of dispersion and/or that only a very small proportion of the population is accessible to the sampling method.

In 1998 the proportion of sub-adult frogs (1–2 years old) in the population was higher than observed in the earlier monitoring surveys. This difference in the age structure of the population did not appear to be the result of sampling bias and indicated successful recruitment had occurred in the period 1996–1998.

Comparisons of the relative density and age structure of frog populations in the study streams with new control streams nearby indicated that the monitoring methodology was not having a detrimental affect on the frog population.

There is no evidence that the activities of the Golden Cross Mine have impacted on the Hochstetter's frog populations in the study streams.

It is recommended that monitoring of the frog populations at Golden Cross be continued, that toe-clipping should not be undertaken in future monitoring surveys, and that detailed research be undertaken to determine the relationship between the relative population density—as revealed by current monitoring methods—and the absolute population density.

Keywords: Anura, Leiopelmatidae, *Leiopelma hochstetteri*, Hochstetter's frog, Coromandel, New Zealand, population density, recruitment, monitoring methodology, mining, environmental impact

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1. Introduction

The Golden Cross gold mine, in the headwaters of the Waitekauri River at the southern end of the Coromandel Range, North Island, New Zealand, was developed and is operated by Coeur Gold New Zealand Limited (CGNZL). Established in 1990, the mine closed prematurely in early 1998 due largely to falling gold prices in the mid- to late 1990s. At the time of the mine's closure the area of development (the open pit mine, tailings impoundment, processing plant and all ancillary facilities) covered approximately 390 ha, all on the true left of the Waitekauri River between the Waitekauri headwaters and Union Stream (see Fig. 1). Decommissioning of the mine, currently underway, involves the removal of most buildings and other structures from the site, partial back-filling of the open pit, de-watering and partial capping of the tailings impoundment, and grassing or replanting the entire area. This is expected to take up to five years. CGNZL intends to continue environmental monitoring at the site for several years beyond this time to determine whether there are any long-term effects on the environment from the mining activities.

The mining licence for the Golden Cross site (ML 32–2954) requires CGNZL to maintain rigorous environmental standards and undertake regular environmental monitoring, including surveys of 'indigenous wildlife'. One of the wildlife species chosen for regular monitoring was Hochstetter's frog (*Leiopelma hochstetteri*) (see Frontispiece). This selection is appropriate because of the high conservation concern for the species (Molloy & Davis 1994; Newman 1996; Bell 1994, 1997) and the sensitivity of frogs as indicator species for the 'health' of the environment (e.g. Heyer et al. 1994). Key supporting factors influencing this choice were the relative abundance of Hochstetter's frogs in the Waitekauri catchment (Anon. 1987) and the availability of good baseline data on the frog populations in streams immediately adjacent to the mine site from the period leading up to the establishment of the mine (Slaven 1992).

Monitoring of the Hochstetter's frog populations is being undertaken biennially. The first monitoring survey under the terms of the mining licence was in January 1994 (Slaven 1994), two and a half years after the completion of the baseline study, and it was repeated in January 1996 (Whitaker 1996). This report details the third of these monitoring surveys—undertaken in January 1998—and also examines the possible impact of the monitoring methodology itself on the Hochstetter's frog populations.

2. Objectives

The purpose of this study was to determine whether there were any changes occurring in the frog population that could be attributed to the mining activities by CGNZL. The primary objective of the January 1998 fieldwork was to survey the Hochstetter's frog populations in five study streams in the immediate vicinity of

the Golden Cross Mine. Surveying had to be done in a way that would enable direct comparison of the relative population density and the population structure with data from monitoring surveys made in the same streams in 1994 and 1996.

An additional aim was to survey the same population parameters in streams immediately adjacent to the study sites, and which had not previously been searched for frogs, in order to determine the likelihood that the monitoring methodology itself was adversely affecting the frog populations.

3. Study sites

The main study site, comprising five study streams (nos 4, 8, 9, 10, and 12), is in the headwaters of the Waitekauri Valley, at the southern end of the Coromandel Range, 8 km north-west of Waihi. It lies immediately to the west of the Golden Cross Mine. These study streams have been used for all monitoring since 1990 (Slaven 1992, 1994; Whitaker 1996). A control site established in January 1994 is in the headwaters of Barneys Stream, on the true left of the Waitekauri River, 2.5 km SE of the mine (Slaven 1994; Whitaker 1996). For the monitoring in January 1998 five new control streams were selected (nos 5, 7, 9a, 13, and 14). The location and details of all these sites are available from Waikato Conservancy, Department of Conservation (DOC), CGNZL, or the authors.

Selection criteria for the new control streams were that they should be within the headwaters of the Waitekauri River catchment, as close as possible to the study streams, and—in terms of all physical characteristics—closely match the study streams. Additionally, they should have had little or no previous history of frog surveys. Unfortunately, it was not possible to meet all these selection criteria for all the new control streams. In fact, a thorough search of all catchments on the true right of the headwaters of the Waitekauri River showed that the selected streams (nos 5, 7, 9a, 13, and 14) were the only available control sites in close proximity to the existing study streams. Only two of these new control streams (13 and 14) met all the selection criteria; streams 5, 7, and 9a appeared subjectively to have habitat that was deficient, and streams 7 and 9a had previously been searched for frogs[1].

The five main study streams and the five new control streams are deeply incised, east-facing, primary and secondary tributaries on the true right of the Waitekauri River (see Fig. 1). The gradient is steep; the streambed of gravel or boulders, with frequent areas of exposed bedrock, cascades and small waterfalls. The elevation of the study transects ranges from 350–420 m.

The entire catchments above and including the study transects are clothed with dense podocarp/tawa forest dominated by rimu (*Dacrydium cupressinum*), totara (*Podocarpus hallii*), miro (*Prumnopitys ferruginea*), tawa (*Beilschmiedia tawa*), pukatea (*Laurelia novae-zelandiae*), towai (*Weinmannia silvicola*)

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[1] Stream 7 had been searched once in July 1989 and stream 9a was searched six times between July 1989–May 1991 (Slaven 1992).

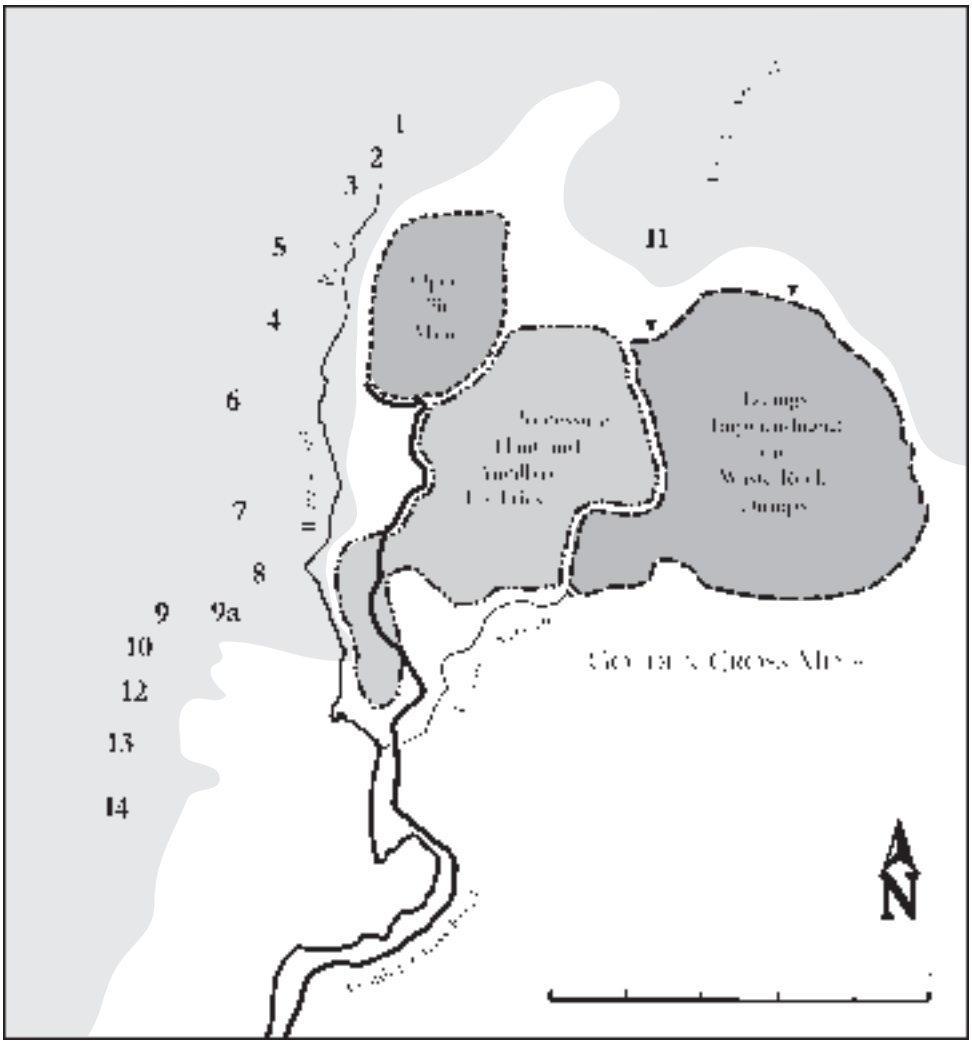

Figure 1. Headwaters of the Waitekauri River, Coromandel, showing the locations of the Golden Cross Mine and the study streams where Hochstetter's frog (*Leiopelma hochstetteri*) populations are being monitored. The lightly shaded area indicates the approximate extent of indigenous forest.

and tree ferns (*Dicksonia* and *Cyathea* species). The stream banks are covered with a thick growth of parataniwha (*Elatostema rugosum*) and terrestrial ferns (e.g. *Blechnum* spp.) that in most places completely shades the streambed (see Frontispiece). Where the boulders and stones are stable, they are covered by mosses and liverworts. Log jams and debris dams of leaves and twigs are common.

The main control study site is in the headwaters of a relatively open, west-facing, major tributary of the Waitekauri River (Barneys Stream). The gradient is moderate; the streambed, consisting mostly of large boulders embedded in fine gravels, is entrenched into an alluvial surface. The elevation of the control transect is between 380–400 m.

The upper catchment of Barneys Stream—including the control transect—is forested. However, the shrub layer is sparse, ferns are less prolific and parataniwha is absent, meaning the streambed is much more open than any in the main study area. There are several large log-jams but few debris dams.

4. Methods

The survey and monitoring methodology of choice for Hochstetter's frog populations is to search all available retreats over a given length of streambed during the day when the frogs are inactive and under cover (Newman 1996; Perfect 1996; Bell 1996; but see Thorsen 1998 for alternative view). If undertaken with care—and provided seasonal, climatic and observer biases are minimised—this method will produce consistent measures of relative population density (usually expressed as frogs per 100 m). This technique has been almost universally used in recent surveys for Hochstetter's frogs (e.g. Green & Tessier 1990; Parrish 1993, 1994; McNaughton & Greene 1994; Greene et al. 1995; Douglas 1997), and was used during the baseline study and previous monitoring at Golden Cross (Slaven 1992, 1994; Whitaker 1996).

Fieldwork for the 1998 monitoring was done between 17–25 January 1998. The same two people were involved in all the searching for frogs, working in concert along the stream transects.

The transects were all searched in an upstream direction. The search profile extended between the berms but did not include sites beneath water level. All available cover—such as loose stones, logs or other debris—was examined for frogs with the proviso that it could be lifted and returned to virtually the same position without posing a risk to any frogs that might be present.

All searching for frogs was done during the day (0820–1818 hours). The time and prevailing weather were recorded at the beginning and end of each transect, and any major changes in the weather during the search were noted (see Appendix 1). Relevant weather data from the meteorological station operated by CGNZL are summarised for the study period in Appendix 2. Although <1 km from the study streams, this facility is located on open ground at the mine site and will have recorded somewhat different figures to those occurring at the study transects within the forest. Unfortunately, data on relative humidity—perhaps the most important climate parameter—is not available due to equipment failure in mid-January 1998. Rain (5.5 mm) fell on the day prior to the survey commencing, and some rain fell on a further five of the nine days of the survey—being so heavy and persistent on 23 January (when 40 mm was recorded) that fieldwork had to be abandoned. Even when not raining, it was frequently overcast or cloudy about the hills. Air temperatures were quite variable during the survey, ranging from mild to warm (daily maxima 17.7–26.1°C, daily minima 10.9–16.4°C). Wind throughout the survey period was variable. Within the forest it was markedly less windy than on the mine site, though rarely completely calm.

If possible, all frogs were captured to enable the collection of morphometric data, and to check for existing toe-clips or to enable marking. Frogs were held in moistened plastic bags for no more than a few minutes and were released at the point of capture after the habitat had been restored.

Data collected for each frog were: the snout-vent length (SVL) (taken with dial callipers to 0.1 mm along the ventral surface while the frog was held on its

back); the predominant body colouration; its unique toe-clip code (animal number); and the position at which it was captured (expressed as the distance from the start of the transect to ±0.1 m). Adult Hochstetter's frogs are sexually dimorphic and the sex of individuals can be determined from differences in their body proportions (Bell 1978). However, for expediency this was not attempted in this project as the differences are subtle (Green & Tessier 1990) and the assignment of gender to most individuals in field studies is difficult (Slaven 1992).

If not already marked, any frogs of >20 mm SVL were marked with a unique toe-clip combination according to the marking and numbering protocols established during the baseline survey (Slaven 1992). The distal phalanges of the toes to be clipped were removed cleanly with a sharp pair of scissors. Immediately following removal the toe fragments were placed in 70% ethanol, then stored under refrigeration until they could be forwarded for genetic (DNA) analysis[2].

Data analysis and preliminary statistical testing were done with Microsoft Excel97™; additional statistical testing was done with MathSoft S-Plus™ (Anon. 1995). The relative population density (expressed as frogs/100 m) and the proportion of frogs in each size (= age) class in the captured population were compared to the earlier studies using a Randomisation Test[3] (Ludbrook & Dudley 1998). Regression was used to examine the dependency of frog numbers on rainfall. Statistical significance is taken as $p \leq 0.05$.

5. Results

5.1 GENERAL

Data from the survey are presented in Appendix 1 and summarised in Table 1. Eleven transects—ranging from 98–193 m in length and totalling over 1.5 km—were searched for Hochstetter's frogs. The search rate varied markedly according to the terrain, the amount of cover to search, and the number of frogs being captured, from a low of around 10 m/hour to nearly 30 m/hour (average approximately 18 m/hour).

Altogether 252 Hochstetter's frogs were found of which 224 (88%) were captured. There were no recaptures of previously marked frogs. Ten of the captured frogs were missing all or part of some toes but comparisons with all previous records showed these were natural losses. For six of these frogs the natural toe loss provided unique identification; for the others additional toes were

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[2] The genetic studies are being undertaken by Dr Bruce Waldman, Zoology Department, University of Canterbury, as part of on-going studies into the genetics of leiopelmatid frogs.

[3] A Randomisation Test involves comparing the magnitude of the difference between two sets of data with that achieved from all possible permutations of the data. This test was chosen for this study because it does not assume the streams surveyed are a random sample of all streams, which clearly they are not.

TABLE 1. SUMMARY OF MONITORING DATA FOR HOCHSTETTER'S FROGS (*Leiopelma hochstetteri*) NEAR GOLDEN CROSS MINE, COROMANDEL, 17–25 JANUARY 1998.

	STUDY STREAMS					NEW STREAMS					CONTROL	
STREAM NO.	4	8	9	10	12	5	7	9A	13	14	BARNEYS*	TOTAL
Search length (m)	176.5	132	193	180	143	145	98	100	156	123	100	1,546.5
Search time (hr)	10.9	12.2	10	10	5.9	6.9	3.4	5.1	8.5	7.8	6.4	87.4
Search rate (m/hr)	16.2	10.8	19.2	17.4	24.1	21.0	29.1	19.7	18.4	15.8	15.6	17.7
Total No. found	33	41	34	29	9	9	4	9	19	25	40	252
No. captured	30	36	29	26	7	7	3	9	18	24	35	224
No. marked	25	30	21	21	5	7	3	8	18	22	24	184

* Barneys Stream is on the true left of the Waitekauri River, 2.5 km SE of the mine site.

clipped. Of the remainder, 184 frogs were marked with new toe-clip combinations (see Appendix 3) and 34 were released as too small to mark. Genetic material was collected from 190 frogs.

5.2 POPULATION DENSITY

The relative population densities and the encounter rates for Hochstetter's frogs in the streams surveyed are summarised in Table 2. The mean relative population density of frogs in the five study streams was 17.7/100 m (6.3–31.1) and the mean encounter rate was 2.95/hr (1.5–3.4). Although the mean relative population density in the five new control streams was lower, with 10.6/100 m (4.08–20.3) and a mean encounter rate of 2.09/hr (1.2–3.2), these differences were not significant (Randomisation Test $p = 0.155$ and 0.123, respectively). Furthermore, the figures for the two streams (no. 13 and 14) in which the habitat most closely matched the study transects were very similar to those in the study streams (mean relative density 15.8/100 m, mean encounter rate 2.7/hour). The control transect in Barneys Stream had the highest relative density and encounter rate ever recorded in the Waitekauri catchment—40/100 m and 6.3/hour respectively.

TABLE 2. RELATIVE POPULATION DENSITY AND ENCOUNTER RATES FOR HOCHSTETTER'S FROG (*Leiopelma hochstetteri*) POPULATIONS NEAR GOLDEN CROSS MINE, COROMANDEL, 17–25 JANUARY 1998.

	STUDY STREAMS					NEW STREAMS					BARNEYS	MEAN*
STREAM NO.	4	8	9	10	12	5	7	9a	13	14	STREAM	
Relative density (number/100 m)	18.7	31.1	17.6	16.1	6.3	6.2	4.1	9.0	12.2	20.3	40.0	16.3
Encounter rate (frogs/hour)	3.0	3.4	3.4	2.8	1.5	1.3	1.2	1.8	2.2	3.2	6.3	2.9

* Mean excludes Barneys Stream.

5.3 POPULATION STRUCTURE

The frogs measured ranged in size from 10.3–42.9 mm SVL (n = 223). The size frequency distribution of all frogs measured (see Fig. 2) supports the earlier data (Whitaker 1996) showing that in mid-summer at least three cohorts can be easily distinguished. These correspond to: juveniles (less than 1 year old, <18 mm SVL), sub-adults (1–2 years old, 18–24 mm SVL), and older frogs (2+ years of age, >24 mm SVL). Had the gender of the captured animals been determined it is likely that one or more older cohorts may have been recognisable, although sexual dimorphism in adult size (Bell 1978; Green & Tessier 1990) means these older age-classes tend to be obscured. Note that in Fig. 2 the peak around 39 mm SVL is not an age cohort as such, but an accumulation of older females in the largest size range—animals >37 mm SVL are generally females (Bell 1978; Green & Tessier 1990). Juveniles (young from the current season) comprised just 3% of the total sample and sub-adults (young from the previous season) about 20% (see Fig. 2 and Table 3). However, the proportion of juveniles and sub-adults varied widely from stream to stream.

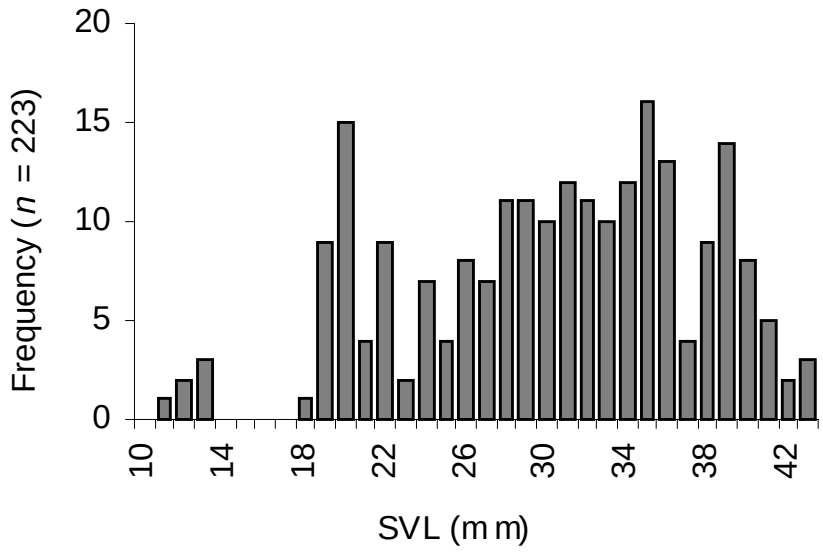

Figure 2. Size (SVL) frequency distribution for Hochstetter's frogs (*Leiopelma hochstetteri*) captured at Golden Cross Mine, Coromandel, January 1998.

TABLE 3. PROPORTION (%) OF THE HOCHSTETTER'S FROG (*Leiopelma hochstetteri*) POPULATION IN EACH SIZE CLASS (SVL) NEAR GOLDEN CROSS MINE, COROMANDEL, 17–25 JANUARY 1998.

STREAM NO.	STUDY STREAMS 4	8	9	10	12	MEAN	NEW STREAMS 5	7	9A	13	14	MEAN	BARN-EYS	GRAND TOTAL
<18.1 mm	6.7	2.9	6.9	3.8	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.1
18.1-24 mm	16.7	25.7	31.0	19.2	42.9	24.4	0.0	0.0	11.1	5.6	8.3	6.6	31.4	20.6
24.1-30 mm	23.3	34.3	34.5	19.2	0.0	26.8	0.0	0.0	22.2	16.7	12.5	13.1	25.7	22.9
30.1-35 mm	30.0	28.6	6.9	23.1	14.3	22.0	28.6	33.3	55.6	38.9	45.8	42.6	20.0	27.4
35.1-40 mm	20.0	5.7	17.2	34.6	14.3	18.1	71.4	33.3	11.1	38.9	25.0	32.8	14.3	21.5
40.1-45 mm	3.3	2.9	3.4	0.0	28.6	3.9	0.0	33.3	0.0	0.0	8.3	4.9	5.7	4.5
n =	30	35	29	26	7	127	7	3	9	18	24	61	35	223

Important information on the population structure and population dynamics—such as the relationship of individuals in a sub-population—can be determined from genetic data. All Hochstetter's frogs >20 mm SVL captured in the study streams during the monitoring surveys (1994, 1996 and 1998) were individually marked with a unique toe-clip combination and genetic material (tissue from clipped toes) was collected from each of them (Slaven 1992, 1994; Whitaker 1996). To date the DNA testing of these tissue samples has not been undertaken.

6. Discussion

The baseline population study and subsequent monitoring surveys on Hochstetter's frogs in streams adjacent to the Golden Cross Mine detected an apparent increase in relative population density between 1991 and 1994–1996 while at the same time recording an apparent decline in recruitment over the same period (Slaven 1992, 1994; Whitaker 1996) (see Table 4, Table 6, and Fig. 3). It was unclear whether these observed differences were real or the result of some sampling bias but, because the differences were significant, a variety of possible interpretations and explanations were examined. On balance, it was accepted at the time that both trends were likely to be genuine but the reasons for them were not known (Slaven 1994; Whitaker 1996).

6.1 POTENTIAL IMPACT OF MINING

If the population density and level of recruitment to the Hochstetter's frog population had changed significantly since the mine commenced operation, it was important to identify whether this was a direct or indirect consequence of the mine's operation and activities, or whether it was the result of some independent action or effect. Of the potential impacts from mining activities—light, sound, vibration, water pollution, air-pollution, and biotic factors—all except the latter two were dismissed as being irrelevant (Whitaker 1996). Air-borne pollutants, and in particular their potential for contaminating waterways, were examined in more detail but there was no evidence they were an issue. Biotic factors (for example the effect of the increased vegetation density in the study transects following goat control) were considered more likely causal agents of the observed changes, but again hard evidence was lacking. However, the operation of the mine had continued more or less unchanged up to the beginning of 1998, so one test of whether it was the mine's activities, rather than some independent effect, that was affecting frog populations would be to check whether the observed population trends had continued over the two-year period to the January 1998 monitoring.

6.1.1 Population density

For *Leiopelma* species, relative density indices based on area—or in the case of Hochstetter's frog, a transect length—are much better measures of abundance

than calculations based on time (frogs per person hour) or cover (frogs per retreat site) (Newman 1996; Perfect 1996). However, a wide variety of factors are recognised as affecting both the precision and the accuracy of all density indices, including climatic and weather variables (season, rainfall, temperature), habitat variation, and observer bias (Greene et al. 1995; Bell 1996; Perfect 1996; Whitaker 1996; Thorsen 1998, and references therein). (*See the Frontispiece for an illustration of the cryptic nature of these frogs.*)

For Hochstetter's frogs, the area surveyed is effectively a greatly elongated 'strip plot' along the sample stream, the width of which extends between the stream berms. Inasmuch as the width of this strip plot is variable in both time and space it is most practical to treat it as a transect and express the population density of frogs as the number per lineal metre—usually as frogs/100 m—rather than per square metre. It is not possible to express relative density of Hochstetter's frogs in relation to cover because potential retreat sites vary so widely in form (e.g. rock crevices, gravel banks, loose stones, boulders, leaf dams, logs) and size that they defy simple definition.

The mean relative population density of Hochstetter's frogs recorded in the five study streams in January 1998 was lower, but not significantly so, than densities recorded in January 1994 and January 1996, which in turn were significantly higher than the relative density recorded in January 1991 (see Table 4 and Fig. 3) (Whitaker 1996). The relative population densities in each of the study streams is also comparable, except for stream 12 where the 1998 population

TABLE 4. RELATIVE POPULATION DENSITY (frogs/100 m) OF HOCHSTETTER'S FROGS (*Leiopelma hochstetteri*) IN THE STUDY STREAMS NEAR GOLDEN CROSS MINE, COROMANDEL, FROM JULY 1989 TO JANUARY 1998.
Earlier data from Slaven 1992, 1994; Whitaker 1996. **Bold** entries compare January samples.

STREAM NO.	4	8	9	10	12	BARNEY'S STREAM	MEAN*
Jul 89	4.4	–	4.5	8.9	–	–	5.8
Apr 90	14.1	12.7	4.7	7.5	21.2	–	10.3
Jul 90	12.9	12.4	13.5	12.5	16.2	–	13.2
Dec 90	17.4	18.4	13.4	13.5	17.2	–	15.8
Jan 91	**12.2**	**16.4**	**9.8**	**7.9**	**12.1**	**–**	**11.5**
Mar 91	32.2	26.0	21.7	18.1	22.6	–	24.1
Apr 91	13.8	16.4	16.3	15.2	17.0	–	15.7
May 91	5.6	7.6	7.7	5.1	2.8	–	5.6
May 91	23.3	16.7	8.2	12.4	17.0	–	15.3
Jul 91	15.6	16.6	16.5	16.9	12.8	–	15.8
Jan 94	**24.4**	**24.7**	**17.5**	**23.2**	**16.3**	**33.0**†	**21.2**
Jan 96	**22.8**	**31.5**	**15.0**	**20.0**	**19.3**	**12.0**	**21.1**
Jan 98	**18.7**	**31.1**	**17.6**	**16.1**	**6.3**	**40.0**	**17.7**
Mean Jul 89–Jan 96	16.6	18.2	12.1	13.3	15.0		

* Mean does not include Barneys Stream.

† Not comparable to 1996 and 1998 figures, as a different transect was surveyed (Whitaker 1996).

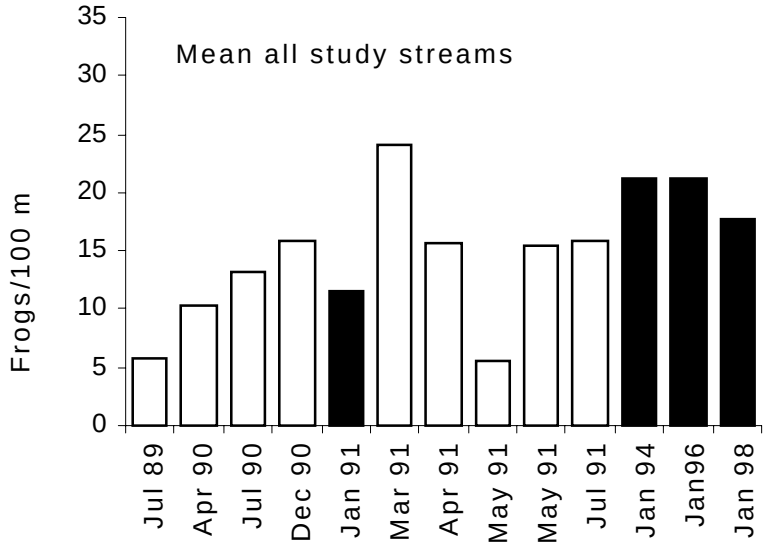

Figure 3. Changes in the mean relative population density (frogs/100 m) of Hochstetter's frogs (*Leiopelma hochstetteri*) in the study streams near Golden Cross Mine, Coromandel, from July 1989 to January 1998 (earlier data from Slaven 1992, 1994; Whitaker 1996). Black columns compare January samples.

was around one third of that recorded in 1994 and 1996 and half that recorded in 1991 (see Table 4). The relative density of frogs in Barneys Stream went against the trend in that it showed a more than threefold increase between 1996 and 1998[4].

The relative population densities observed at Golden Cross in January 1998 are typical of those recorded in the Waitakere Range, and for various sites in Coromandel, the Bay of Plenty, and on East Cape, but they are higher than those recorded for sites in Northland and Auckland (Greene et al. 1995; Whitaker 1996 and references therein; Douglas 1997; Anon. 1997). The relative density of frogs recorded in Barneys Stream (40/100 m) in January 1998 is the highest recorded at any time within the Waitekauri catchment (Slaven 1992, 1994; Whitaker 1996) and one of the highest relative densities for Hochstetter's frogs recorded anywhere.

Whitaker (1996) concluded that the apparent change in the population density between 1991 and 1994–1996 represented a real increase. In contrast, the new data, and especially their variability between streams, suggest that the apparent changes may not be real and are merely the consequence of sampling bias. Of potential factors affecting sampling that were examined (including weather variables, the observer, and the number of observers), the one that seemed likely to have the greatest effect is the variability in the rainfall immediately preceding and during the survey period (see Table 5). In wet weather Hochstetter's frogs move away from streams into surrounding forest habitats—or conversely, it could be said that in dry weather the high moisture requirements of the frogs means they congregate along streams (Slaven 1992, 1994). The response of the frog population to the onset of rain can be rapid (Slaven 1994).

[4] Comparison with 1994 is not possible because a different transect was used on the initial survey (see Whitaker 1996).

TABLE 5. TOTAL RAINFALL (MM) DURING AND PRECEDING MONITORING SURVEYS FOR HOCHSTETTER'S FROGS (*Leiopelma hochstetteri*) IN THE STUDY STREAMS NEAR GOLDEN CROSS MINE, COROMANDEL, JANUARY 1991 TO JANUARY 1998.

DAYS BEFORE SURVEY PERIOD	1991	1994	1996	1998
6–10	6	113.5	2.5	0
3–5	0.5	4	1.5	1
1–2	12	19	45.5	5.5
During survey	75	7.5	1	24

As rainfall at the time of counting clearly could have a marked influence on the number of frogs recorded, the challenge was how to best quantify this effect. A series of exploratory plots using data for the years 1991, 1996 and 1998[5] revealed that by taking the weighted mean of rainfall on the day of counting and adding the mean rainfall on the preceding day—giving double weight to the rainfall on the day of counting—a good linear fit was obtained irrespective of year (see Fig.4). A straight line through the five study streams explained about 44% of the variation whilst using less than 15% of the degrees of freedom. ANOVAs conducted on the residuals from this line (frogs/100 m = 22–0.59 × weighted mean rainfall) showed no difference among the years (*F*-prob = 0.368), but some differences among the streams (*F*-prob = 0.040). Stream 8 had a higher than expected frog count, and that of stream 12 was lower (7.2 frogs/100 m more and 5.2 frogs/100 m less, respectively; sed = 5.82).

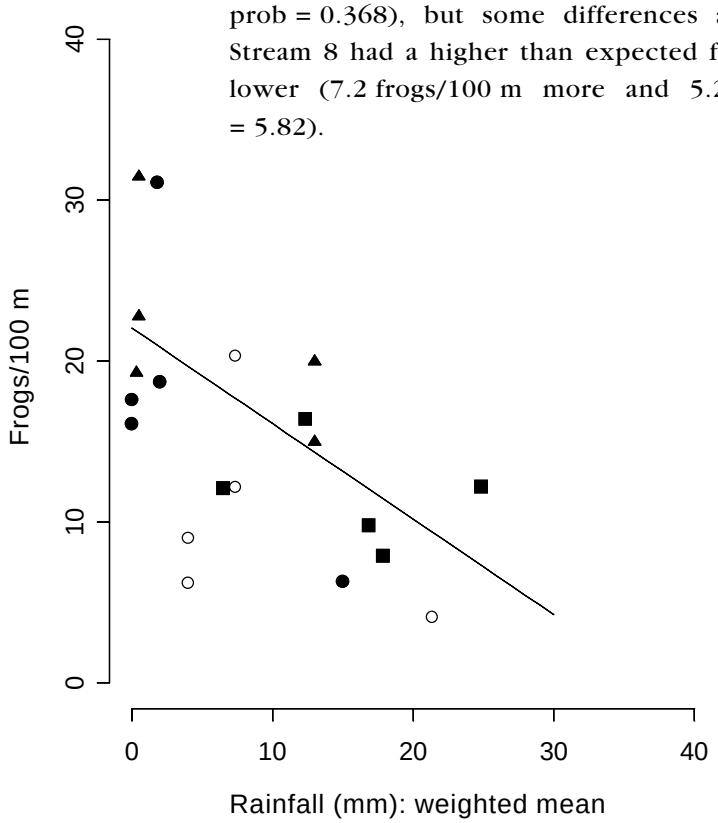

Figure 4. Effect of rainfall (weighted mean expressed as 2× rainfall on day of counting + rainfall for preceding day) on numbers of Hochstetter's frogs (*Leiopelma hochstetteri*) found in study streams near Golden Cross Mine between 1991 and 1998. Study streams are represented by closed symbols (solid squares=1991, solid triangles=1996, solid circles=1998), and the new control streams surveyed in 1998 are represented by the open circles.

[5] Data from 1994 could not be used because the precise date on which each count was made was not recorded (David Slaven pers. comm.).

The effect of rainfall on the observed relative density (frogs/100 m) was further examined using a Randomisation Test. Comparison of the number of frogs observed before and after rain showed that there was a significant decline in relative density (p = 0.029).

Although Slaven (1992) recorded 123 recaptures of 92 individuals (n = 578) during a detailed ecological study of the frogs in the study streams over the two-year period from July 1989 to July 1991, most individuals were recaptured only once (>93%) and most recaptures were within a relatively short period (70% in <4 months, 98% in <1 year). Since that time the recovery rate of marked frogs has declined steadily from 3.8% in January 1994, to 0.8% in January 1996, and nil in the present survey (down from 10% in January 1991 in the middle of the baseline study) (Slaven 1992, 1994; Whitaker 1996).

Leiopelmatid frogs are slow to mature and are known to be long-lived (Bell 1978, 1996; Green & Tessier 1990). Therefore, in the absence of a dramatic decline in the numbers counted, the extremely low proportion of marked frogs being recaptured in the study streams during the biennial monitoring is not indicative of a high population turn-over. Instead it could mean one (or both) of two things: (1) the sample methodology is locating only an extremely small proportion of the frog population resident within the stream berms during any one sampling period; or (2) the frog population is not sedentary and dispersion (emigration/immigration) is accounting for the failure to find marked individuals. The evidence to hand does not favour either one of these explanations.

Slaven (1992) used Minimum Number Alive (MNA) calculations to estimate a mean density of 65 frogs per 100 m (range 56–77/100 m) in the study streams and, independently, modelling with the software Capture7™ to derive a mean density of 140/100 m (range 104–184/100 m) (though error margins were very wide) at the same sites. The total lack of recaptures means such modelling is not possible with the present data. However, if Slaven's estimates are reasonably realistic it suggests the mean capture rate recorded for frogs in the 1998 survey (17.7/100 m) is detecting between 12–26% of the population. This is much higher than the recapture data indicate and shows the sampling methodology alone cannot account for the low recapture rate.

Based on observations of captive animals, a short-term (2 months) field study, and the genetic distinctiveness of many populations, Hochstetter's frogs have been described as 'sedentary' (Green & Tessier 1990; Tessier et al. 1991). However, the baseline study at Golden Cross suggested that this was not the case, and that Hochstetter's frogs move widely within and between streams (Slaven 1992). Data collected during the monitoring between 1994 and 1998 also supports the concept the population is relatively mobile.

Movement of frogs away from the streambed during times of high humidity would take them outside the search profile, and purely random movements along the stream—though there is no evidence that within-stream movements are in fact random—would result in dispersion beyond the study transects. Furthermore, variations in the structural complexity of the habitat within and between streams would affect the proportion of the frog population available for sampling. Together, the variability in these factors between sites and between surveys means the comparison of relative population densities of Hochstetter's frogs needs to be treated with caution.

6.1.2 Population structure

In the study streams the proportion (%) of the Hochstetter's frog population in each size class (see section 5.3 for definition) changed significantly between 1991 and 1994–1996 (Whitaker 1996). The decreasing proportion of frogs in the smallest size classes (juveniles and sub-adults) and the corresponding increase in the proportion of larger animals was interpreted as evidence of declining recruitment and an increasingly ageing population (Slaven 1994; Whitaker 1996) (see Fig. 5 and Table 6).

In January 1998 the proportion of juveniles recorded was 4.9%, the lowest yet, but there was a marked increase in sub-adults (up 12% to 25.2%) and 2-year-old animals (up by 5%). Generally, the proportion of sub-adult Hochstetter's frogs in the population is a better measure of recruitment than the proportion of juveniles. There are two reasons for this. Firstly, juvenile frogs are much more difficult to see than sub-adults and hence are often overlooked, leading to an underestimation of their numbers. Secondly, the distribution of suitable nesting sites is patchy, thus—because the distribution of small juveniles is likely to reflect this patchiness—the likelihood that juvenile frogs will be missed during a survey is greatly increased.

The possibility that climatic variables at the time of the survey might bias the observed age structure, as earlier suggested (Slaven 1994; Whitaker 1996), was examined using a Randomisation Test to compare the modal size classes before and after rain events. This showed the observed age structure was not significantly different in dry or wet weather (p = 0.667).

Because neither the monitoring methodology nor the impacts of the mine have changed between 1994 and 1998, the observed changes in age structure suggest the fluctuations in recruitment are real and the result of some independent factor such as long-term variations in the regional climate. They indicate there has been some effective recruitment into the population between 1996 and 1998.

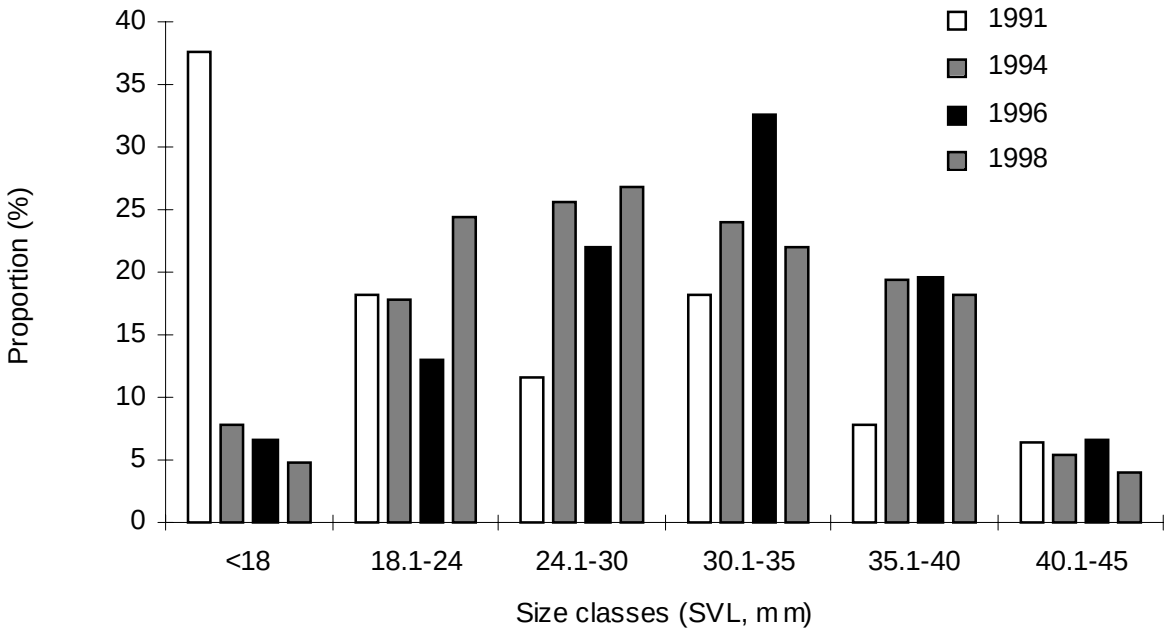

Figure 5. Proportion (%) of Hochstetter's frogs (*Leiopelma hochstetteri*) in each size class (SVL) in the study streams near Golden Cross Mine, Coromandel: comparison of January 1991 (n = 77), 1994 (n = 129), 1996 (n = 123), and 1998 (n = 127) (data from Slaven 1992, 1994; Whitaker 1996; this study).

TABLE 6. PROPORTION (%) OF HOCHSTETTER'S FROGS (*Leiopelma hochstetteri*) IN EACH SIZE CLASS (SVL) IN THE STUDY STREAMS NEAR GOLDEN CROSS MINE, COROMANDEL: CHANGES BETWEEN 1991 AND 1998. Data from Slaven 1992, 1994; Whitaker 1996; and this study.

STREAM NO.	*n*	SIZE CLASSES (SVL mm) <18	18.1–24	24.1–30	30.1–35	35.1–40	40.1–45
	January 1991						
4	21	28.6	38.1	9.5	9.5	9.5	4.8
8	17	35.3	11.8	17.6	23.5	5.9	5.9
9	17	58.8	11.8	11.8	5.9	0.0	11.8
10	11	27.3	9.1	0.0	45.5	18.2	0.0
12	11	36.4	9.1	18.2	18.2	9.1	9.1
Mean		37.7	18.2	11.7	18.2	7.8	6.5
	January 1994						
4	32	9.4	9.4	34.4	34.4	6.3	6.3
8	30	10.0	30.0	20.0	10.0	23.3	6.7
9	24	8.3	12.5	16.7	25.0	29.2	8.3
10	29	3.4	24.1	31.0	20.7	20.7	0.0
12	14	7.1	7.1	21.4	35.7	21.4	7.1
Mean		7.8	17.8	25.6	24.0	19.4	5.4
	January 1996						
4	31	6.5	16.1	12.9	32.3	29.0	3.2
8	30	6.7	13.3	33.3	33.3	3.3	10.0
9	20	20.0	15.0	25.0	20.0	15.0	5.0
10	22	0.0	9.1	27.3	27.3	27.3	9.1
12	20	0.0	10.0	10.0	50.0	25.0	5.0
Mean		6.5	13.0	22.0	32.5	19.5	6.5
	January 1998						
4	30	6.7	16.7	23.3	30.0	20.0	3.3
8	35	2.9	25.7	34.3	28.6	5.7	2.9
9	29	6.9	31.0	34.5	6.9	17.2	3.4
10	26	3.8	19.2	19.2	23.1	34.6	0.0
12	7	0.0	42.9	0.0	14.3	14.3	28.6
Mean		4.7	24.4	26.8	22.0	18.1	3.9

6.2 POTENTIAL IMPACT OF MONITORING METHODOLOGY

Results of monitoring undertaken in 1994 and 1996 have been interpreted as showing a significantly lowered recruitment to the frog population in comparison with 1991 before the Golden Cross Mine was fully functional. The lack of an obvious causal link between this apparent reduction in recruitment and the activities of the mine raised the possibility that it might be a consequence of the monitoring methodology itself (Whitaker 1996). The perceived primary risk was that the sampling method (turning stones to locate inactive frogs) might be

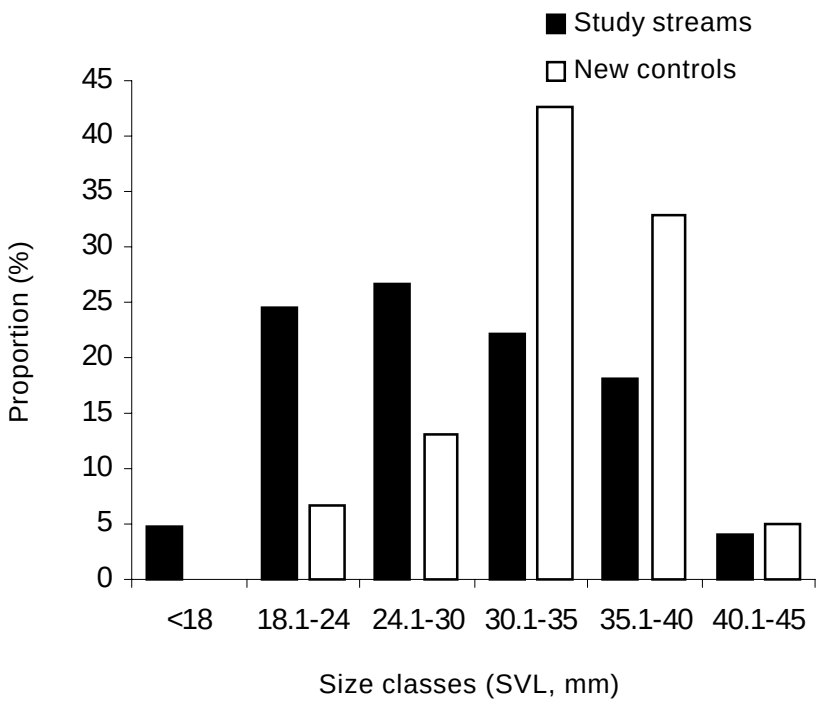

Figure 6. Proportion (%) of Hochstetter's frogs (*Leiopelma hochstetteri*) in each size class (SVL) in streams near Golden Cross Mine, Coromandel, January 1998: comparison of the study streams (n = 127) with the new controls (n = 61).

unduly disruptive and lead to unnatural movement of the population or affect breeding sites.

To test this hypothesis, the relative density and the structure of the Hochstetter's frog populations in the study streams in January 1998 was compared with populations in nearby streams that were not part of the regular frog-monitoring programme (the 'new controls').

The relative population density of Hochstetter's frogs in the new control streams was lower than in the study streams (see Table 2). Even after making adjustment for rainfall (see section 6.1.1) the mean density was 6.5 frogs/100 m fewer than expected (se = 2.75). However, only the new streams 13 and 14 closely matched the physical characteristics of the original study streams and in them the relative density was comparable—mean deviation from the fitted line was only 1.4 fewer frogs per 100 m (see Fig. 4).

The age structure of the frog population in the new control streams was compared with that of the study streams by using a Randomisation Test on the modal size class. Although the average age structure of the frog population in the study streams is lower than in the new streams (see Fig. 6), and the mean SVL was smaller (28 mm cf. 33 mm), the differences between them was not significant (p = 0.135).

The higher relative population density and evidence of higher recruitment in the study streams compared with the new control streams indicates that previous monitoring surveys have not had a lasting adverse effect on the frog populations.

7. Conclusions and recommendations

As a result of the monitoring undertaken in January 1998 the following conclusions can be made with respect to the Hochstetter's frog populations in streams adjacent to the Golden Cross Mine:

- The variation in relative population densities observed for Hochstetter's frogs in the study streams between 1991–1998 is more likely the result of sampling bias than a change in actual numbers. The single most significant factor affecting the number of frogs found is rainfall and most of the observed variation in frog numbers can be explained by the rainfall during and immediately preceding the day of capture.
- There is no evidence that the observed population structure is seriously affected by sampling bias. Therefore, increased recruitment to the frog population in the past two years indicates that the declines in recruitment reported for earlier monitoring periods were neither a consequence of mining activity, nor of the monitoring methodology.
- No evidence has been detected that the activities of the Golden Cross Mine have affected frog populations or frog habitat in the study streams.
- It appears that the survey methodology is not having a detrimental impact on the Hochstetter's frog populations.

Recommendations resulting from the latest survey are:

- Monitoring of the Hochstetter's frog populations in the study streams at Golden Cross should be continued. Newman (1996) recommended DOC undertake long-term monitoring of population trends of leiopelmatid frogs in the 'southern Coromandel' and, more specifically, Thorsen (1998) called for monitoring of frogs in the 'Waitekauri/Maratoto' area. Furthermore, following the detection of dramatic declines of Archey's frog (*Leiopelma archeyi*) populations at some sites on the Coromandel Peninsula in 1998 (Bell 1999), including the Waitekauri area (Thorpe 1999), Thorpe (1999) urged the implementation of regular monitoring of Archey's frogs at Whakamoehau, the peak immediately adjacent to the Golden Cross Mine.
- The CGNZL study streams have high value as the location for this long-term research because detailed population data on Hochstetter's frogs from this site already covers a 10-year period. With a possible amphibian decline event now identified in Coromandel frog populations (Bell 1999; Thorpe 1999) the next monitoring at the site should be undertaken in January 2000, but—unless the next survey shows otherwise—monitoring thereafter could be continued at approximately 5-yearly intervals. Future monitoring need not include the new control streams.
- Toe-clipping need not be undertaken during future frog monitoring at the Golden Cross site. The very low rate of recovery of marked animals between 1994 and 1998 means that marking is not making an important contribution

to understanding the population dynamics of Hochstetter's frogs—other than to show there is a high rate of population turn-over—and is therefore unnecessary (but see next recommendation).

- To better interpret the results of surveys for and monitoring of Hochstetter's frogs, detailed research into the relationship between the 'relative' and 'absolute' population density should be undertaken. This will require a population of marked individuals but need not necessarily be done at the Golden Cross site.

8. Acknowledgements

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Appendix 1

FIELD DATA

From monitoring of Hochstetter's frog (*Leiopelma hochstetteri*) populations, Golden Cross Mine, Coromandel, January 1998.

Stream 4

Total length = 182 m; search length = 176.5 m (43.5–49 m not checked because of tree-fall).
0–182 m searched 0843–1410 hours 20 January 1998; weather—0843 hours: 8/8, calm, mild, forest wet from overnight rain; 1410 hours: 5/8, partly sunny, calm, warm.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
26.6	867	38.4	brown	98-97	
25.0	–	–	–	–	Adult; escaped
40.4	868	34.4	brown	98-98	
68.9	869	25.5	dark brown	98-99	Same rock as escapee
68.9	–	–	–	–	Adult; escaped; same rock as # 869
65.7	870	22.0	green	98-100	
65.5	871	34.2	orange/brown	98-101	
67.7	–	19.7	orange/brown	–	
70.7	872	37.7	brown	98-102	
70.8	873	26.3	brown	98-103	
69.1	–	18.3	green	–	
77.4	874	32.8	light brown	98-104	
94.5	875	25.3	green/brown	98-105	
95.4	876	28.5	dark brown	98-106	
93.1	877	25.7	brown	98-107	
88.9	878	34.6	dark brown	98-108	
113.2	879	27.7	green	98-109	
115.5	1780	40.9	dark brown	98-110	Toes '900' & '80' were off already, toe '800' was cut
121.9	860	34.7	orange/brown	98-111	Duplicate toe code with frog in Barneys Stream
119.4	861	30.9	brown	98-112	Duplicate toe code with frog in Barneys Stream
124.3	880	31.0	brown	98-113	
139.4	–	11.8	dark brown	–	
138.2	881	32.4	dark brown	98-114	
136.3	–	19.6	green	–	
140.2	882	33.4	brown	98-115	
149.3	883	28.8	dark brown	98-116	
159.5	–	–	–	–	Adult; escaped
161.3	–	11.7	brown	–	
164.0	884	38.2	brown	98-117	
170.7	885	35.6	light brown	98-118	
176.3	886	38.2	light brown	98-119	Under same rock as # 887
176.3	887	23.6	brown	98-120	Under same rock as # 886
178.9	888	38.3	brown	98-121	

33= total number of frogs found
18.7= number of frogs/100 m
30= total number of frogs captured
0= total number recaptured
25= total number marked

Stream 5

Total length = 145 m (65 m and 80 m, with unmeasured gap in between); searched length = 145 m.
0–145 m searched 0755–1122 hours, 25 January 1998; weather—0755 hours: 3/8, partly cloudy, mild, forest wet from rain; 1122 hours: 8/8, high thin cloud, weak sun.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
Downstream section (65 m)					
8.6	935	35.2	dark brown	98-170	
15.3	936	30.4	brown	98-171	
30.6	–	–	–	–	Juvenile; escaped
47.9	940	38.1	brown	98-172	Toe '40' missing due to natural loss; toe '900' was cut
Upstream section (80 m)					
5.5	937	38.5	brown	98-173	
5.8	938	31.9	brown	98-174	
10.5	–	–	–	–	Adult; escaped
17.2	1339	37.0	brown	98-175	Marked # 939, but toe '400' also missing through natural loss
29.7	941	35.6	brown	98-176	

9= total number of frogs seen
6.2= number of frogs/100 m
7= total number of frogs captured
0= total number recaptured
7= total number marked

Stream 7

Total length = 98 m; searched length = 98 m (65m and 80m with unmeasured gap in between).
0–98 m searched 1455–1636 hours, 24 January 1998; weather—1455 hours: 6/8, calm, mild, forest wet from rain until after noon; 1636 hours: 8/8, calm, mild, hint of drizzle.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
5.0	–	–	–	–	Adult; escaped
17.6	932	32.9	brown	98-167	
81.4	933	37.7	brown	98-168	
88.6	934	42.4	dark brown	98-169	

4= total number of frogs seen
4.1= number of frogs/100 m
3= total number of frogs captured
0= total number recaptured
3= total number marked

Stream 8

Total length = 148 m; searched length = 132 m (130–146 m not searched due to massive tree fall).
0–73 m searched 1430–1800 hours, 17 January 1998; weather—1430 hours: 5/8, mild, partly sunny, moderate breeze; weather—1800 hours: unchanged.
73–145 m searched 0845–1122 hours, 18 January 1998; weather—0845 hours: 8/8, mild, calm; weather 1122 hours: 3/8, partly sunny, mild, calm.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
2.4	–	–	–	–	Sub-adult; escaped
5.8	–	–	–	–	Adult; escaped
6.2	–	–	–	–	Adult; escaped
9.1	772	31.2	dark brown	98-1	
13.5	773	31.5	dark brown	98-2	
14.7	774	23.6	dark green	98-3	
14.7	775	29.6	dark brown	98-4	
14.7	776	34.9	light brown	98-5	
16.0	777	29.0	dark brown	98-6	
16.0	778	37.4	dark brown	98-7	
16.0	779	40.8	green	98-8	
16.0	780	35.0	light brown	98-9	
25.0	782	27.2	brown	98-11	
28.0	781	24.7	green	98-10	
31.0	783	29.1	light brown	98-12	Same rock as # 784
31.0	784	34.1	light brown	98-13	Same rock as # 783
33.8	786	27.7	dark brown	98-15	
35.8	785	23.7	light brown	98-14	
48.0	788	21.4	orange	98-17	
49.3	787	21.4	light brown	98-16	
70.0	'960'	31.9	green	–	Toes '900', '40' and '20' missing
71.9	–	–	–	–	Adult; escaped
73.2	789	25.3	green/brown	98-18	
79.5	–	18.8	green/brown	–	
80.0	791	31.8	dark brown	98-20	
82.3	790	Ad	green/brown	98-19	Escaped part way through marking
84.5	793	24.8	light brown	98-22	Same rock as # 794
84.5	794	32.4	green	98-23	Same rock as # 793
85.0	–	18.1	green	–	Same rock as # 792
85.0	792	27.7	light brown	98-21	Same rock as unmarked
93.0	–	19.1	dark brown	–	
93.9	795	28.4	brown	98-24	
99.6	796	24.0	brown	98-25	
101.8	797	37.1	dark brown	98-26	
105.6	–	18.3	light brown	–	
109.4	798	30.6	lt. green/brown	98-27	
109.6	–	–	–	–	Adult; escaped
114.5	–	12.4	green	–	
114.8	799	33.1	light brown	98-28	
120.4	800	28.1	light brown	98-29	Same rock as # 801
120.4	801	26.1	dark brown	98-30	Same rock as # 800

41= total number of frogs seen
31.1= number of frogs/100 m
36= total number of frogs captured
0= total number recaptured
30= total number marked

Stream 9

Total length = 200 m; searched length = 193 m (161–168 m not searched due to massive tree fall).
0–200 m searched 1300–1801 hours, 18 January 1998; weather—1300 hours: 0/8, calm, mild; 1801 hours: 0/8, light breeze, mild.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
0.0	802	38.9	brown	98-31	
6.4	803	21.5	light brown	98-32	
24.8	804	24.4	green	98-33	
30.4	805	29.9	light brown	98-34	
32.6	806	35.5	brown	98-35	
43.0	–	–	–	–	Adult; escaped
43.0	–	–	–	–	Adult; escaped
47.6	807	21.4	green	98-36	
53.2	–	19.9	brown	–	
61.3	808	23.1	green	98-37	
68.3	820	31.0	brown	98-38	Toe '20' is natural loss; toe '800' was cut
82.6	–	–	–	–	Adult; escaped
83.5	809	25.2	dark brown	98-39	
84.4	810	40.0	light brown	98-40	
89.6	811	26.7	brown	98-41	
90.6	–	19.1	dark brown	–	
96.4	812	29.4	green/brown	98-42	
107.5	–	–	–	–	Sub-adult; escaped
114.6	813	21.9	green	98-43	Same rock as # 814
114.6	814	27.3	brown	98-44	Same rock as # 813
116.7	–	10.3	green	–	
119.9	815	39.7	dark brown	98-45	
122.1	817	25.6	brown	98-47	Same rock as # 900
122.1	'900'	41.5	green/brown	–	Natural loss of toes '400' and '500'; same rock as # 817
128.1	816	26.5	green	98-46	
130.0	–	19.7	light brown	–	Same rock as next juvenile
130.0	–	17.9	dark brown	–	Same rock as last juvenile
131.8	–	20.6	dark brown	–	
131.9	'500'	39.4	brown	98-48	Natural loss of toes '200' and '300'
132.4	818	29.6	dark brown	98-49	
137.2	819	31.0	brown	98-50	Same rock as escaped adult
137.2	–	–	–	–	Adult, escaped; same rock as # 819
142.6	–	19.8	light brown	–	
158.8	821	30.0	dark brown	98-51	

34= total number of frogs seen
17.6= number of frogs/100 m
29= total number of frogs captured
0= total number recaptured
21= total number marked

Stream 9a

Total length = 100 m; searched length = 100 m.

0–100 m searched 1300–1532 hours, 25 January 1998; weather—1300 hours: 6/8, high cloud, partly sun, calm, warm; weather—1532 hours: 7/8, calm, mild, no sun.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
10.6	942	27.9	dark brown	98-177	
35.5	943	35.1	brown	98-178	
35.5	–	18.9	dark brown	–	
46.8	944	29.9	light brown	98-179	
54.6	945	32.3	brown	98-180	
59.2	946	32.8	brown	98-181	
70.9	947	33.4	brown	98-182	
68.1	948	31.4	brown	98-183	
68.1	949	32.5	brown	98-184	

9= total number of frogs seen

9.0= number of frogs/100 m

9= total number of frogs captured

0= total number recaptured

8= total number marked

Stream 10

Total length = 180 m; searched length = 180 m.

0–180 m searched 0820–1330 hours, 19 January 1998; weather—0820 hours: 8/8, light drizzle but dry below canopy, moderate wind, mild; 0858 hours: 7/8, partly sunny, no drizzle; 1330 hours: 1/8, sunny, windy, warm.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
17.9	–	12.3	green	–	
23.7	–	19.8	light brown	–	
36.8	822	35.9	brown	98-52	
40.3	823	37.5	brown	98-53	Same rock as next juvenile
40.3	–	19.8	light brown	–	Same rock as # 823
54.7	824	39.7	brown	98-54	
60.8	825	30.8	brown	98-55	
61.6	–	19.4	green	–	
72.8	826	21.1	light brown	98-56	
110.0	827	27.0	brown	98-57	
110.8	828	28.5	orange	98-58	
113.5	–	18.3	green	–	
114.8	829	28.0	green/brown	98-59	
116.4	830	39.0	light brown	98-60	
119.0	832	27.9	light brown	98-62	
119.5	833	37.7	light brown	98-63	
122.1	831	30.9	light brown	98-61	
125.3	834	37.8	brown	98-64	
125.3	835	34.7	light brown	98-65	
134.2	–	–	–	–	Sub-adult; escaped
144.2	836	30.7	dark brown	98-66	
157.3	837	39.8	dark brown	98-67	
159.9	838	35.6	brown	98-68	
161.2	839	34.7	light brown	98-69	
163.9	840	27.5	brown	98-70	
166.0	–	–	–	–	Adult; escaped
168.7	841	33.7	dark brown	98-71	
178.2	–	–	–	–	Sub-adult; escaped
178.8	842	35.3	brown	98-72	

29= total number of frogs seen

16.1= number of frogs/100 m

26= total number of frogs captured

0= total number recaptured

21= total number marked

Stream 12

Total length = 143 m; searched length = 143 m.
0–143 m searched 0825–1123 hours, 21 January 1998; weather—0825 hours: 8/8, calm, mild, drizzling; forest very wet from overnight rain; 1123 hours: 8/8, calm, mild, raining steadily from 0900 hours onwards.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
17.5	–	–	–	–	Sub-adult, escaped
21.2	889	38.2	dark brown	98-122	
24.7	–	18.9	–	–	
26.8	'800'	20.8	orange/brown	–	Toes '200' and '600' missing
83.6	890	21.8	dark brown	98-123	
107.4	–	–	–	–	Adult; escaped
110.1	891	41.0	brown	98-124	
127.0	893	34.3	orange/brown	98-126	
128.0	892	42.9	green/brown	98-125	

9 = total number of frogs seen
6.3= number of frogs/100 m
7 = total number of frogs captured
0 = total number recaptured
5 = total number marked

Stream 13

Total length = 168 m; searched length = 156 m (79–83 m and 88–96 m not searched due to massive tree fall).
0–168 m searched 0850–1305 hours, 22 January 1998; weather—0850 hours: 8/8, light wind, mild; light levels very low in forest; 1305 hours:8/8, light breeze; mild.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
40.1	894	25.7	dark brown	98-127	
51.0	–	–	–	–	Adult; escaped
70.9	895	21.5	dark brown	98-128	
112.6	896	35.4	dark brown	98-129	
112.7	897	31.2	brown	98-130	
112.8	898	34.9	dark brown	98-131	
119.4	899	34.0	dark brown	98-132	Under same rock as # 900
119.4	900	34.5	dark brown	98-133	Under same rock as # 899
121.6	901	33.3	dark brown	98-134	
131.9	902	33.3	green/brown	98-135	
137.2	903	24.6	green	98-136	
137.2	904	37.7	brown	98-137	Under same rock as # 905
137.2	905	38.3	brown	98-138	Under same rock as # 904
139.5	906	38.6	dark brown	98-139	
142.4	907	34.7	brown	98-140	
143.3	908	37.2	orange/brown	98-141	
152.1	909	39.6	dark brown	98-142	
159.1	910	35.3	dark brown	98-143	
163.2	911	28.4	dark brown	98-144	

19 = total number of frogs seen
12.2 = number of frogs/100 m
18 = total number of frogs captured
0 = total number recaptured
18 = total number marked

Stream 14

Total length = 131 m; searched length = 123 m (73–81 m not searched due to massive tree fall).
0–131 m searched 1343–1736 hours, 22 January 1998; weather—1343 hours: 8/8, mod breeze, mild; weather 1736 hours: 8/8, light wind, mild.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
5.1	912	34.7	dark brown	98-145	Duplicate toe clip in Stream 14
13.1	912	38.8	dark brown	98-146	Duplicate toe clip in Stream 14
11.1	913	42.6	dark brown	98-147	
19.1	–	–	–	–	Adult; escaped
20.6	308	28.1	dark brown	–	Natural loss of toes '1', '7' and '300'
20.8	914	33.7	dark brown	98-148	
27.1	915	35.9	dark brown	98-149	
37.1	916	38.1	dark brown	98-150	
35.2	917	34.7	brown	98-151	
35.6	918	26.2	orange/brown	98-152	
36.5	919	31.9	brown	98-153	
38.4	920	31.8	dark brown	98-154	
37.9	921	32.0	dark brown	98-155	
37.9	922	32.1	dark brown	98-156	
40.8	923	32.8	brown	98-157	
44.1	924	38.1	brown	98-158	
49.5	925	23.2	brown	98-159	
70.1	926	36.6	brown	98-160	
70.2	927	30.4	brown	98-161	
102.2	'600'	34.0	brown	–	Natural loss of toe '600'
102.2	930	39.7	brown	98-164	
108.3	928	27.8	dark brown	98-162	
109.0	931	34.0	dark brown	98-165	
110.0	932	40.2	brown	98-166	
110.2	929	22.3	dark brown	98-163	

25= total number of frogs seen
20.3= number of frogs/100 m
24= total number of frogs captured
0= total number recaptured
22= total number marked

Barneys Stream

Total length = 100 m; searched length = 100 m.

0–131 m searched 1506–1818 hours, 19 January 1998; weather—1506 hours: 4/8, moderate wind, warm; weather 1818 hours: 4/8, light cloud, moderate W wind.

SITE (m)	TOE CLIP	SVL (mm)	COLOUR	TOE SAMPLE NO.	NOTES
1.2	–	19.4	golden	–	
1.3	843	36.5	brown	98-73	
2.3	844	30.3	orange/brown	98-74	
2.4	845	22.5	green/brown	98-75	
7.0	846	30.0	orange	98-76	
14.5	847	31.5	brown	98-77	
14.5	848	28.8	green/brown	98-78	
21.0	–	20.7	dark brown	–	
34.4	849	36.5	dark brown	98-79	
39.1	–	–	–	–	Adult; escaped
39.1	–	–	–	–	Adult; escaped
56.9	850	39.3	dark brown	98-80	
57.0	851	40.1	brown	98-81	
57.0	852	28.9	brown	98-82	
57.5	–	–	–	–	Adult; escaped; all 7 at 57.5 m under same stone
57.5	853	30.7	light brown	98-83	All 7 at 57.5 m under same stone
57.5	854	36.0	dark brown	98-84	All 7 at 57.5 m under same stone
57.5	855	34.5	brown	98-85	All 7 at 57.5 m under same stone
57.5	856	23.6	green/brown	98-86	All 7 at 57.5 m under same stone
57.5	857	25.9	dark brown	98-87	All 7 at 57.5 m under same stone
57.5	–	18.4	green/brown	–	All 7 at 57.5 m under same stone
62.9	858	32.6	dark brown	98-88	
64.0	859	26.7	brown	98-89	
64.1	–	–	–	-	Adult; escaped
64.7	860	29.6	green/brown	98-90	
75.1	–	–	–	–	Adult; escaped
78.2	–	19.4	orange/brown	–	
79.6	–	20.0	green/brown	–	
85.0	861	33.2	dark brown	98-91	
88.4	'200'	41.5	brown	–	Natural loss of toe '200'. Under same rock as # 862
88.4	862	35.6	brown	98-92	Under same rock as # 200
92.0	863	29.1	brown	98-93	Under same rock as # 864
92.0	864	28.2	brown	98-94	Under same rock as # 863
94.6	–	19.3	orange/brown	–	
99.0	865	27.5	brown	98-95	
99.5	–	12.9	green	–	
100.0	–	18.6	green	–	
100.0	–	19.9	brown	–	Under same rock as # 866
100.0	866	34.0	green/brown	98-96	Under same rock as juvenile above
100.0	–	20.7	green/brown	–	

40= total number of frogs seen

40.0= number of frogs/100 m

35= total number of frogs captured

0= total number recaptured

24= total number marked

Appendix 2

SELECTED CLIMATE DATA

From the meteorological station operated at Golden Cross Mine, Coromandel, during the period of monitoring the Hochstetter's frog (*Leiopelma hochstetteri*) populations, January 1998. Note this table includes data for the two days preceding the survey. Equipment failure meant data on relative humidity is unavailable.

DATE (JAN 1998)	15	16	17	18	19	20	21	22	23	24	25
Solar Radiation (MJ/m²)	28.84	17.03	25.80	28.85	29.24	20.67	7.30	9.23	10.21	10.41	24.11
Wind Speed—mean (m/sec)	2.14	3.65	2.29	2.17	4.62	1.94	2.61	2.03	3.00	2.09	1.17
Wind Run—total (km)	185.1	310.5	196.9	187.3	392.9	168.4	225.7	173.4	259.2	180.0	100.0
Air Temperature—max (°C)	25.6	22.2	19.8	22.8	19.8	24.2	17.7	19.5	18.4	19.9	26.1
Air Temperature—min (°C)	11.5	13.1	10.9	11.1	12.3	14.6	16.1	15.9	15.0	16.4	15.0
Rainfall (mm)	0.0	5.5	0.0	0.0	0.0	3.0	21.0	0.5	40.0	12.0	0.0

Appendix 3

TOE CODE NUMBERS OF FROGS MARKED IN JANUARY 1998

Field data from monitoring of Hochstetter's frog (*Leiopelma hochstetteri*) populations, Golden Cross Mine, Coromandel. Numbering system follows protocols established by Slaven (1992, 1994).

TOE CODE	STREAM NO.	SVL (mm)	NOTES	TOE CODE	STREAM NO.	SVL (mm)	NOTES
200	Barneys	41.5	Natural loss of toe '200'	812	9	29.4	
308	14	28.1	Natural loss of '1', '7' and '300'	813	9	21.9	
500	9	39.4	Natural loss of '200' and '300'	814	9	27.3	
600	14	34.0	Natural loss of toe '600'	815	9	39.7	
772	8	31.2		816	9	26.5	
773	8	31.5		817	9	25.6	
774	8	23.6		818	9	29.6	
775	8	29.6		819	9	31.0	
776	8	34.9		820	9	31.0	Natural loss of '20', clipped '800'
777	8	29.0		821	9	30.0	
778	8	37.4		822	10	35.9	
779	8	40.8		823	10	37.5	
780	8	35.0		824	10	39.7	
781	8	24.7		825	10	30.8	
782	8	27.2		826	10	21.1	
783	8	29.1		827	10	27.0	
784	8	34.1		828	10	28.5	
785	8	23.7		829	10	28.0	
786	8	27.7		830	10	39.0	
787	8	21.4		831	10	30.9	
788	8	21.4		832	10	27.9	
789	8	25.3		833	10	37.7	
790	8	Ad		834	10	37.8	
791	8	31.8		835	10	34.7	
792	8	27.7		836	10	30.7	
793	8	24.8		837	10	39.8	
794	8	32.4		838	10	35.6	
795	8	28.4		839	10	34.7	
796	8	24.0		840	10	27.5	
797	8	37.1		841	10	33.7	
798	8	30.6		842	10	35.3	
799	8	33.1		843	Barneys	36.5	
800	8	28.1		844	Barneys	30.3	
800	12	20.8	Natural loss of '200' and '600'	845	Barneys	22.5	
801	8	26.1		846	Barneys	30.0	
802	9	38.9		847	Barneys	31.5	
803	9	21.5		848	Barneys	28.8	
804	9	24.4		849	Barneys	36.5	
805	9	29.9		850	Barneys	39.3	
806	9	35.5		851	Barneys	40.1	

TOE CODE	STREAM NO.	SVL (mm)	NOTES	TOE CODE	STREAM NO.	SVL (mm)	NOTES
807	9	21.4		852	Barneys	28.9	
808	9	23.1		853	Barneys	30.7	
809	9	25.2		854	Barneys	36.0	
810	9	40.0		855	Barneys	34.5	
811	9	26.7		856	Barneys	23.6	
857	Barneys	25.9		904	13	37.7	
858	Barneys	32.6		905	13	38.3	
859	Barneys	26.7		906	13	38.6	
860	4	34.7	Duplicated in Barneys	907	13	34.7	
860	Barneys	29.6	Duplicated in stream 4	908	13	37.2	
861	4	30.9	Duplicated in Barneys	909	13	39.6	
861	Barneys	33.2	Duplicated in stream 4	910	13	35.3	
862	Barneys	35.6		911	13	28.4	
863	Barneys	29.1		912	14	34.7	Duplicated in stream 14
864	Barneys	28.2		912	14	38.8	Duplicated in stream 14
865	Barneys	27.5		913	14	42.6	
866	Barneys	34.0		914	14	33.7	
867	4	38.4		915	14	35.9	
868	4	34.4		916	14	38.1	
869	4	25.5		917	14	34.7	
870	4	22.0		918	14	26.2	
871	4	34.2		919	14	31.9	
872	4	37.7		920	14	31.8	
873	4	26.3		921	14	32.0	
874	4	32.8		922	14	32.1	
875	4	25.3		923	14	32.8	
876	4	28.5		924	14	38.1	
877	4	25.7		925	14	23.2	
878	4	34.6		926	14	36.6	
879	4	27.7		927	14	30.4	
880	4	31.0		928	14	27.8	
881	4	32.4		929	14	22.3	
882	4	33.4		930	14	39.7	
883	4	28.8		931	14	34.0	
884	4	38.2		932	7	32.9	
885	4	35.6		932	14	40.2	
886	4	38.2		933	7	37.7	
887	4	23.6		934	7	42.4	
888	4	38.3		935	5	35.2	
889	12	38.2		936	5	30.4	
890	12	21.8		937	5	38.5	
891	12	41.0		938	5	31.9	
892	12	42.9		940	5	38.1	Natural loss of '40', clipped '900'
893	12	34.3		941	5	35.6	
894	13	25.7		942	9a	27.9	
895	13	21.5		943	9a	35.1	
896	13	35.4		944	9a	29.9	
897	13	31.2		945	9a	32.3	
898	13	34.9		946	9a	32.8	
899	13	34.0		947	9a	33.4	
900	13	34.5		948	9a	31.4	
900	9	41.5	Natural loss of '400' and '500'	949	9a	32.5	
901	13	33.3		960	8	31.9	Natural loss of '900', '40' and '20'
902	13	33.3		1339	5	37.0	Natural loss of '400'; clipped '939'
903	13	24.6		1780	4	40.9	Natural loss '80' and '900'; toe '800' was clipped