Background Concentrations of Inorganic Elements in Soils from the Auckland Region

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Auckland Regional Council
TE RAUHITANGA TAIAO

Background Concentrations of Inorganic Elements in Soils from the Auckland Region

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Summary

The objective of this Auckland Regional Council (ARC) study was to establish background total recoverable levels of a number of trace elements in soil samples from major soil groups of the Auckland Region. Soil samples were collected from 91 locations in May 1999 from publicly owned rural and urban land on soils derived from the major lithological units of the region. In October 2001, to confirm the validity of outlier data obtained during the 1999 survey, fifteen of these sites were revisited, and sampled for further analysis.

The survey's design comprised geographically directed near-surface sampling with categories being based on underlying rock type. Sites were selected to be representative of the lithological units, with specific sites chosen based on evidence of minimal surface disturbance and ease of access. Samples of surficial soils (0-150 mm) were collected and analysed by varying methods for total recoverable arsenic (As), barium (Ba), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), phosphorus (P), potassium (K), nickel (Ni), nitrogen (N), sulphur (S), tin (Sn), vanadium (V), zinc (Zn), and total organic carbon (TOC).

Environmental investigation threshold levels should be related to the local or regional background levels of the elements. Certain environmental investigation threshold levels need to be reconsidered for the Auckland context in view of these results. The Australian and New Zealand Guidelines for Assessment and Management of Contaminated Sites (ANZECC/NHMRC 1992) recommends the evaluation of background levels as a consideration in the determination of remediation goals. The data collected in this survey of total recoverable trace elements in soils of the Auckland Region can be used in this context, with the general background data reported by this study substantiated by site specific information where required.

1. Introduction

In the absence of New Zealand-based criteria for determining whether the investigation of contaminants in soils is required, there has emerged a reliance on the response of overseas authorities to the management of contaminated land. The practice of consultants and health and environmental authorities using offshore information in the absence of New Zealand soil and groundwater quality or background standards has resulted in the application of criteria based on soil types, climate, hydrogeology and a groundwater consumption pattern not especially relevant to the New Zealand situation. The promotion and development of a site-specific, risk-based approach to the assessment of the health and environmental effects of soil and groundwater quality presents the opportunity for the investigation of criteria relevant to New Zealand.

The Resource Management Act, 1991, (RMA) promotes effects-based consideration of environmental quality, prioritising a need to know the background levels and their corresponding effects, prior to consideration of detected levels and their effects on the environment or human health. The introduction of appropriate investigation or trigger levels for contaminants must be carried out with an awareness of background levels of those contaminants in New Zealand, or sub-regions of the country. Trace metal levels and some corresponding inorganic trace elements are the most commonly studied due to their ease of determination and will form the focus of this report.

There is little published specific information on background levels of trace elements in Auckland soils although a large corpus of information resides in University theses, consultancy and soil laboratory archives and various governmental department files. The on-going redevelopment of land and increasing numbers of investigations of suspect sites being conducted are describing levels of metals, the significance of which may be difficult to interpret without knowledge of local background values.

The development of a site-specific, risk-based approach to the assessment of contaminants in land needs soil criteria relevant to the Auckland context and establishing background levels of contaminants in soils is basic information required for this task.

1.1 Trace Elements in the Environment

Concentrations of trace metals in surface soils are primarily the result of local geological and soil forming factors. Accumulation or dilution of trace elements within the environment occurs due to physical deposition, or other geo- or hydro-chemical processes. Redistribution from subsurface mineral deposits into the surface environment, commonly associated with urbanisation, agricultural and industrial activities, has also resulted in the accumulation of these elements in near-surface soils and sediments. Historically therefore, human exposure to some trace element concentrations in soil would have been lower than those detected today.

The effects of such changes in soil quality and the resulting increase in exposure over long time-scales are unknown. In considering "background" concentrations of trace elements in soils, particularly heavy metals, we must take note of the variable and dispersed emissions that occur in urbanised areas. Additionally the long half-lives of uncomplexed metal contaminants in soils must also be considered.

The Auckland urban environment may have levels of heavy metals and other contaminants that are elevated compared to those found in natural, pristine soils. Any elevated levels tend to be trace element specific, such as the contribution of vehicle emissions and removal of lead-based paints to lead levels in urban soils.

1.2 What Does "Background" Mean?

There is always a range of concentration values associated with, or typical of an area for any trace element investigated. The Australian and New Zealand Guidelines for the Assessment of Management of Contaminated Land (ANZECC/NHMRC, 1992) define background levels as "ambient levels of a contaminant in the local area of the site under consideration." Background may be taken to be "pristine" soils unaffected or relatively so by human activity. Due to the development history of the Auckland Region, and global transport of contaminants even in the hinterlands, pristine background areas may be rare.

The definition of "background level" used in this report is *"concentrations of an element in soils which can not be attributed to any identifiable event or activity other than normal lithological processes and is considered representative of the levels to be found wherever relatively undisturbed soil derived from an identifiable parent rock material exists at or near the surface".*

Soils at or near sites known to be contaminated due to nearby activities would be excluded as part of this survey regardless of other elements being within "background" concentrations. Decisions as to where point source effects end and ambient levels begin made in the course of this exercise have been somewhat arbitrary but are based on knowledge of activities and contaminated sites throughout the Auckland Region held by the ARC.

A statistical evaluation of analytical data distributions and characteristics of the soil that differentiate trace element sources is required in order to comprehensively understand the meaning of background concentrations. While urban soil concentrations may have contributions from regional and local urban activities, elevated rural soil levels are equally likely to arise from incremental additions of soil amendments as a result of rural activities. Regional scale effects such as leaching due to acid rain and resultant transport of heavy metals through soil are much less relevant in New Zealand than in the Northern Hemisphere. Very low, but detectable levels of trace element deposition do occur from Australia but these are thought to be relatively uniform and are not considered separately.

Background values of heavy metals commonly reflect variations in the composition of parent rock material that can be quite localised, e.g. in the Auckland Region the isthmus volcanic field has a naturally high level of nickel, generally exceeding published investigation levels.

Interpretation of ambient soil metal concentration data requires an understanding of how sample site selection, sample depth, sample preparation and analytical technique, bias analytical determinations. This is important where a range of sources, metal species and soil particle size distributions contribute to metal concentrations but is beyond the scope of this report.

Geographic scale of an investigation may render studies incomparable from place to place so some account of data distributions should be investigated prior to designing studies to determine what levels may be representative of large areas. When soil-type background concentrations are related to specific areas of contaminated land, local background concentrations should also be assessed, where possible.

1.3 Why Attempt to Determine Background Levels?

In 1992 the Australian and New Zealand Environment and Conservation Council (ANZECC) and the National Health and Medical Research Council (NHMRC) jointly developed technical guidelines for use as a framework for the assessment and management of contaminated sites. These Guidelines have been adopted by the New Zealand Government for guidance only; they do not have statutory force, however they have become widely used throughout New Zealand, and are the basis for a number of other guideline documents.

Information on background soil levels is required to provide a baseline on which site remediation can be based. The ANZECC/NHMRC (1992) guidelines recommend the evaluation of background levels as a consideration in the determination of site specific clean up and that such guidelines will have regional and site specific uses. The ANZECC/NHMRC (1992) background soil concentrations were compiled from Australian soil data derived from parent rock types significantly distinct from Auckland rock types. Compiled data from this study will therefore be used to place Auckland's regional soil inorganic element concentrations into context, giving a realistic reflection of inorganic element distributions in soils specific to the Auckland region.

1.4 What is an Appropriate Methodology?

Sample site selection, sampling methodology, and analytical protocols need to be carefully considered in order for investigations of background values to have meaning. Distances from point, linear and non-point (diffuse) sources of trace elements may all influence concentrations determined in soils. Determinations of average soil concentrations of an area are not universally meaningful. Any data obtained will only have meaning if there is an accurate description of survey methodology.

Averages obtained can be meaningless, particularly in environmental data sets that are commonly significantly skewed. Additional measures of distribution and central tendency such as median and geometric means can be useful depending on the particular issues being dealt with. For soils there needs to be confidence in the identification of the soil type sampled to confirm that the relevant information is applied to the sample and interpreted from its results.

While interpretations of soil surveys using only total metal extraction techniques on single measured soil intervals may have limited practical value beyond the local setting, such information provides the basis for further more detailed studies including individual location sampling, vertical interval sampling, metal speciation studies and bioavailability assessment. In this study only total metals values have been reported.

1.5 Background Concentrations and the Auckland Regional Sampling Program

A key requirement for obtaining background levels is to find soils which have been relatively undisturbed since their formation. Given that anthropogenic disturbance is ubiquitous across the Auckland Region, soils that have not been significantly disturbed for a significant period was the best alternative. All sampling locations were assessed for the likelihood of anthropogenic disturbance in the last 50 years. Where it was considered disturbance had not occurred or was unlikely, samples were acquired.

Soils were not sampled in urban situations where there were nearby anthropogenic sources of trace metals from local industries likely to provide spurious outliers in the data set. Analytical results for the uppermost 150 mm of soil have been emphasised as this represents a commonly investigated initial or screening sample interval.

Localised dustfall or stormwater ponding could focus concentration of elements at the surface in certain locations. For this reason low-lying areas and sites near to significant dust generating sites were avoided where possible. Soil organic and clay matter can intercept and retain trace elements so soil carbon levels were collected for assessment, however particle size analysis was not considered in these studies.

Contaminant concentrations within soils derived from similar geological parent materials may show some heterogeneity both within a localised area and over long distances. Single "point" samples were collected from each site in the 1999 investigation, giving a range of concentrations within a single soil type across the Auckland Region. Insufficient samples were collected during the 1999 study to delineate the variation within soils at each sampling locality. The purpose of the October 2001 investigation was to both re-sample sites where 'outlier' or 'extreme' concentrations of individual elements were recorded, and to collect additional samples for analysis to gauge variability of trace element concentrations within a localised area.

To further assess the impact of anthropogenic sources on soils sampled as "background" and undisturbed, a vertical profile of trace element concentrations should be established. Stratification of trace elements results from air deposition of particulates, which, if present, would be present in higher concentrations in the upper soil layer than lower ones.

2. Sampling Design

2.1 Soils

Baseline data for trace element concentrations were determined on 91 undisturbed soil samples believed to be only minimally contaminated by human activity. These were all collected from Parks, Forests and public lands from the 8 predominant soil groups in the Auckland Region.

The eight major soil groups are: Volcanic (Isthmus and South Auckland Volcanic Fields, as well as one sample from Kerikeri Volcanics at Ti Point), Waitemata Group Flysch, Quaternary Sedimentary Deposits, Sands, Greywacke, Limestone, Onerahi Chaos Breccia and Manukau Breccia. These are commonly recognised names for major geological units within the Auckland Region and sampling locations were selected from 1:250,000 Geological Maps of New Zealand assisted by topographical information from NZMS260 series maps.

In 1999, a total of 91 different sites were examined, and at each site a single 150 mm cubic soil monolith was taken at a single point location. Due to budgetary constraints the values represent single sample maxima and no statistical confidence could be given to values obtained. Fifteen selected sites were re-visited in October 2001 to enable the validation of outliers reported in the 1999 data set. To gauge the variability of trace element concentrations at individual sites, and to gain statistical confidence and improve data quality, composite sampling was undertaken. The validation samples comprised four samples from each sampling location, with each sample consisting of four soil cores over a local area (refer to Section 2.2 for sample collection methodologies). Exact locations were made with the aid of map co-ordinates. The sampling locations are shown on Figures 1 and 2.

Where practicable, samples were collected on topographic highs where the soil profile was relatively thin and only weakly developed. Collection of samples in low-lying areas was deliberately avoided as these soils could have higher than normal background levels as a result of leaching of trace elements from the surrounding hillsides. Pristine soil sample collection was considered unnecessary and impracticable given the historic development of the region. The criterion of "estimated greater than 50 years since soil profile disturbance" was subjective but commonly involved sampling in areas where access by mechanical diggers etc. would be restricted and where vegetation or other indicators suggested this as realistic. Soil surfaces were observed for signs of disturbance and once a hole had been dug for sampling the soil profile was assessed for signs of disturbance such as interrupted stratigraphy or anthropogenic inclusions.

2.2 Sample Collection

In the initial 1999 survey, soil samples were collected from the surface to a depth of 150 mm. Soils were commonly dug to approximately 0.5 m at each site to assess the soil profile. A polyester-coated garden spade was used for digging and all the material (0 to 150 mm), including soil adhered to surface grass, was collected and double bagged for further preparation at the laboratory.

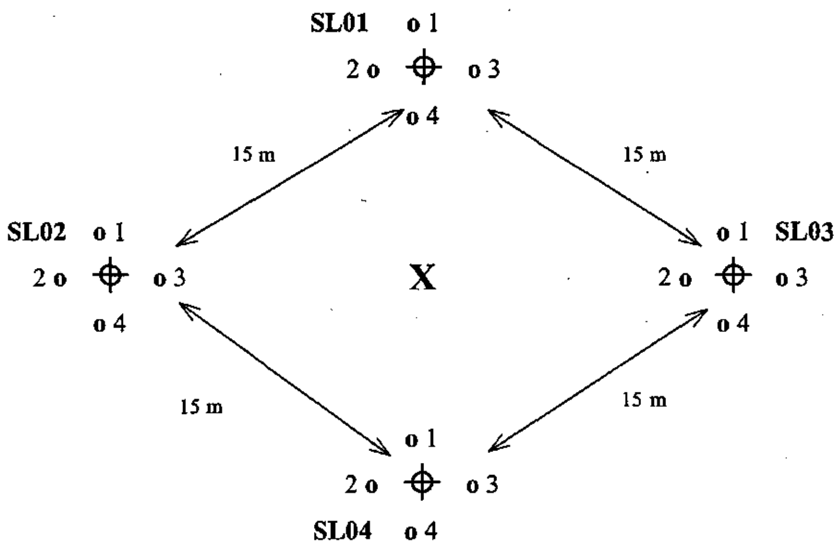
Soil samples were collected as a monolith by delineating an area of approximately 150mm square at the soil surface and excavating, as a single piece where possible, all soil to a depth of 150mm. The resulting monolith, weighing between 1.5 and 3kg when bagged, had been only minimally disturbed during excavation and had a minimum of surficial contamination. The spade was double washed and rinsed with clean tap water and allowed to air dry between each sample collection.

In the October 2001 survey, the 1999 sampling sites were relocated using the given map co-ordinates, and their suitability for sampling was visually assessed. Selected locations were rechecked for potential anthropogenic impact. Since sample localities needed an area large enough to support the collection of samples from 4 locations, spaced approximately 15 m apart, some sample sites were relocated when more appropriate sampling localities existed within a 1 km radius and remained within the same soil type.

At the selected validation sampling sites, four sample locations were pegged out (where possible, in cardinal directions from the original 1999 sample site), at approximately 15 m spacing (see Figures 3 and 4). From each of these sample locations (SL01, SL02, SL03, SL04), four individual soil cores were collected at approximately 1.0 m spacing (e.g. SL01-o1, SL01-o2, SL01-o3, SL01-o4). The four samples were subsequently composited at the laboratory to provide the composite sample. Soil samples were collected using a stainless steel push-tube soil sampler, which collects samples from 0-150 mm depth. Clean latex gloves were worn at each site when handling the soils. Green vegetation was removed from the samples, which were collected into 350 ml glass jars with polyethylene seals as supplied by the analytical laboratory. At one location at each site, a polyester-coated garden spade was used to dig four holes to 300 mm depth, to log the soil profile and collect samples from 150 – 300 mm depth. These samples are intended for subsequent analyses for further assessment of the impact of anthropogenic sources on the soils.

All sampling equipment was decontaminated between sites by washing and rinsing with clean tap water, and allowing to air dry between each site.

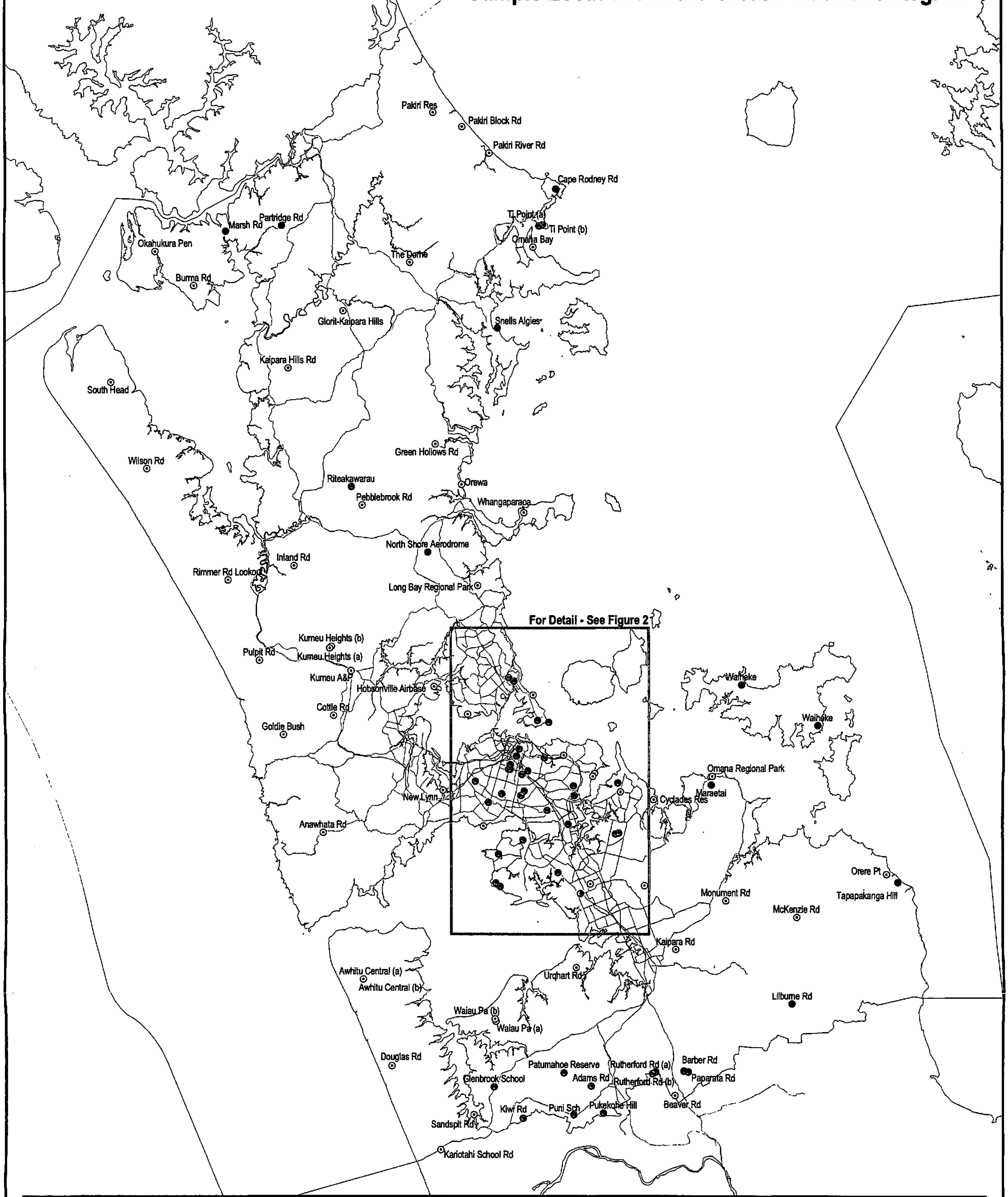
Figure 3: Schematic plan showing sample layout around a central point 'X'



The 4 main sample locations (SL01 to SL04) were spaced approximately 15 m apart, with 4 individual cores (o1, o2, o3 and o4) collected at each location spaced approximately 1.0 m apart.

FIGURE 1

Sample Locations in the Greater Auckland Region



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October 2001

Digital Cadastral Database, LINZ
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0 5 10 15 20 Kilometers
1:400000

LEGEND

- Volcanics
- Waitematas
- Quaternary Sediments
- Sands
- Greywacke
- Limestone
- Onerahi Chaos Breccia
- Manukau Breccia

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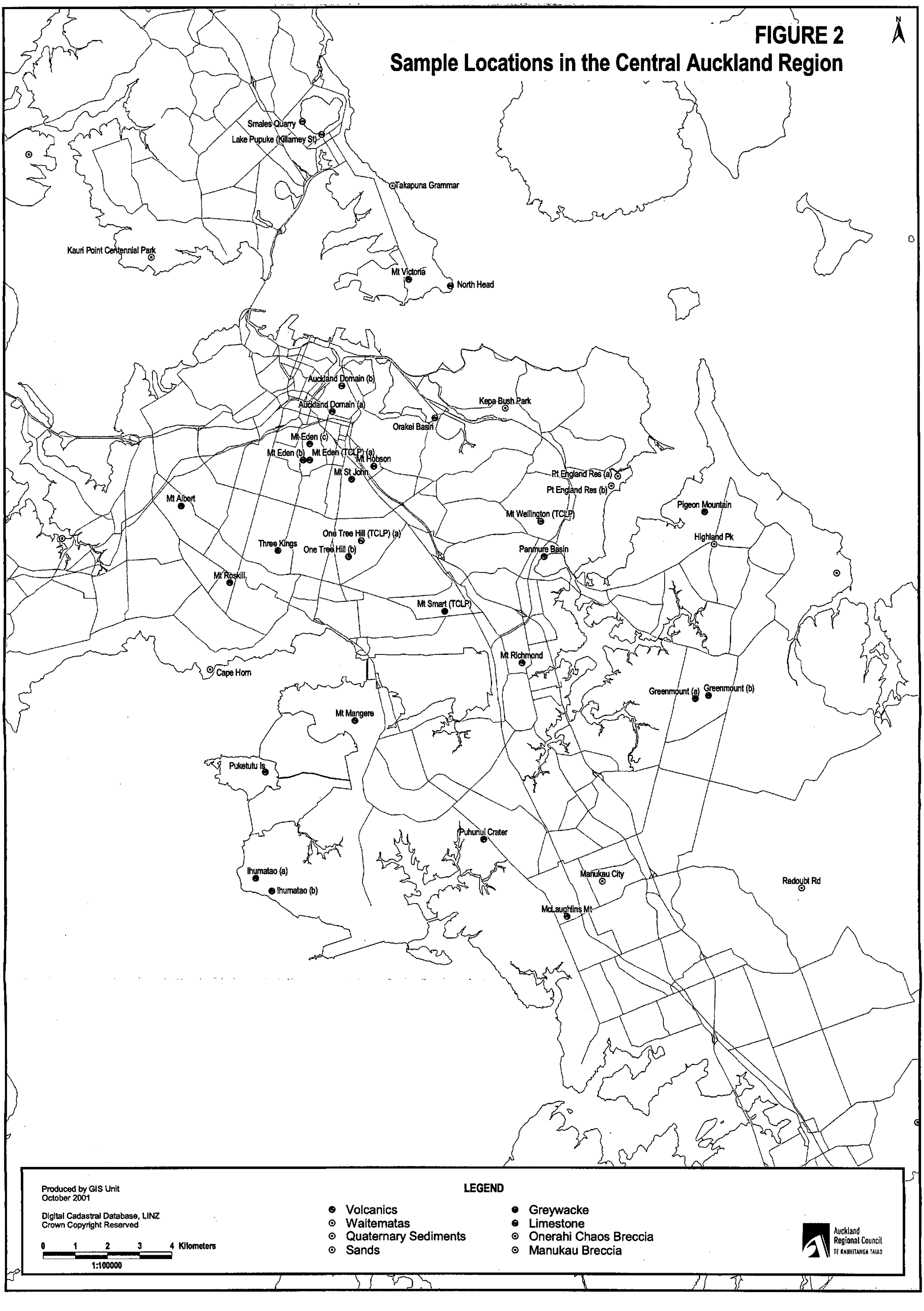
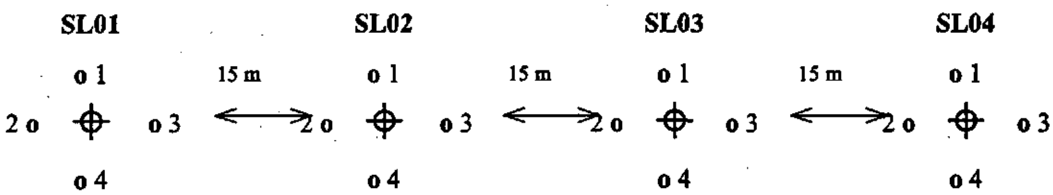


FIGURE 2
Sample Locations in the Central Auckland Region

Figure 6: Linear Sample Location Layout



The linear sampling layout was used when the sampling location area could not accommodate the cardinal sample layout (Figure 3).

2.3 Sample Preparation and Analysis

For the samples collected in May 1999, Watercare Services Laboratory Limited, of Auckland, were contracted for sample preparation and analyses. The bagged samples were composited using a quartering technique except where the monolith was intact. 600-800g of sample was retained for trace element analysis and 50-150g for total organic carbon analysis. The sample was then dried and passed through a 2 mm sieve. An aliquot was taken and pulverised in a ball mill.

For total soil trace element levels a 2g aliquot of sample was digested to USEPA 3051a standards (microwave digestion), and the resultant sample was analysed using inductively coupled plasma optical emission spectroscopy (ICP-OES) for boron, phosphorus, lead, sulpher and tin, atomic absorption spectroscopy (AAS) for barium, cadmium, cobalt, chromium, copper, potassium, magnesium, manganese, nickel, vanadium and zinc, AAS/hydride for arsenic, AAS cold vapour for mercury, titrimetric analysis for total nitrogen and Leco FP2000 for total organic carbon .

For toxicity characteristic leaching procedure (TCLP) analyses a 2g aliquot of sample was extracted by USEPA 1312 (TCLP). The resulting sample analysed by ICP-OES for boron, barium, cadmium, cobalt, chromium, copper, magnesium, manganese, nickel, lead, sulphur, tin, vanadium and zinc, by AAS for potassium, AAS/hydride for arsenic, AAS cold vapour for mercury, digestion/SFA for nitrogen and phosphorus and Leco FP2000 for total organic carbon.

Quality assurance, in addition to standard quality control procedures, involved the use of a secondary standard, and NBS certified soil standard with each batch of samples analysed. All data were reported in milligrams per kilogram (mg/kg). Detection limits (in mg/kg) are summarised in Table 1.

Table 1: Laboratory Detection Limits for 1999 Samples

Parameter (Total Recoverable)	*Detection Limit (mg/kg)*
Arsenic (As)	0.025
Barium (Ba)	0.5
Boron (B)	3
Cadmium (Cd)	0.1
Chromium (Cr)	1
Cobalt (Co)	1.5
Copper (Cu)	1
Lead (Pb)	1.5
Magnesium (Mg)	5
Manganese (Mn)	0.5
Mercury (Hg)	0.03
Nickel (Ni)	0.7
Nitrogen (total, N)	10
Phosphorus (P)	0.5
Potassium (K)	2
Sulpher (S)	1
Tin (Sn)	1
Vanadium (V)	5
Zinc (Zn)	0.15
Total Organic Carbon (TOC)	0.0002%

For the samples collected in the October 2001 survey, RJ Hill Laboratories Ltd, of Hamilton, were contracted for sample preparation and analysis. The samples were air dried overnight in a forced air oven at 35°C. The dried samples were then hand ground using a mortar and pestle and passed through a 2 mm sieve. Composites were made from individual samples by quartering each sample, then selecting opposite quarters that are placed in a 'composite' tray. The composite is thoroughly mixed before being placed in a container.

Weighed subsamples are digested using US EPA Method 200.2. One gram of sample plus 7 mL of nitric/hydrochloric/water (1.5:3.5:5) is heated in a water bath at 85°C for 45 minutes, made to 20 mL with Type 1 water, filtered or centrifuged and the filtrate/centrifugate analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

The analyses for total sulphur were sub-contracted to SGS, Waihi. Analysis was carried out by LECO SC32 Sulphur Determinator, high temperature furnace, infra-red detector, ASTM 4239.

The respective detection limits reported are summarised in Table 2. The analytical methods used in the 2001 survey are more commonly used for contaminated land reporting, and the detection limits are well within the thresholds required.

Table 2: Laboratory Detection Limits for 2001 Samples

Parameter (Total Recoverable)	*Detection Limit (mg/kg)*
Arsenic (As)	0.2
Barium (Ba)	0.02
Boron (B)	2
Cadmium (Cd)	0.01
Chromium (Cr)	0.2
Cobalt (Co)	0.04
Copper (Cu)	0.2
Lead (Pb)	0.04
Mercury (Hg)	0.01
Nickel (Ni)	0.2
Phosphorus (P)	40
Sulphur (S)	400
Tin (Sn)	0.1
Vanadium (V)	10
Zinc (Zn)	0.4

2.4 Recommended Standards of Analysis for Comparison to Background Ranges

Standard preparation methods are required for comparison to the background concentrations given in this document. It is recommended that soils for analysis are dried overnight at about 30°C and passed through a 2 mm sieve. The digestion and analysis of the samples may be carried out by any standard method that gives results comparable to reference standards. The analytical method used should have a demonstrable 95% precision of 20% or better and the laboratory should be able to show satisfactory performance in a suitable Interlaboratory Comparison Programme (e.g. Wageningen) for analyses of inorganic elements in soils samples. Detection limits should be 10 times lower than the minimum background values given in Table 3. Where the minimum value is preceeded by the '<' symbol, this value is the appropriate detection limit.

3. Results from Regional Soils

A list of the sample site locations for each of the eight major soil types is given in Appendix 1, and includes sample identification numbers and NZMS 260 map references for each sample site. A summary of the complete analytical results (i.e. all raw data) for all soil samples is given in Appendix 2.

Identification of statistically outlier and extreme values provides grounds to question the representitiveness of those results, and to determine whether these values were likely to be part of the actual background soils data set, or whether they may have been affected by anthropogenic input, and therefore should be excluded from the background soils data set.

3.1 Analytical Approach

The method used for validating soil data and determining background ranges for these elements is described below. The following are definitions for the data sets obtained and used in this report:

Raw Data Set: The full set of results for all soil samples obtained from all sites from both the 1999 and 2001 investigations (included in Appendix 2).

Site Data Set: The total set of data from a single site that was re-sampled in 2001 (these sites now have a total of five analyses, 1 from 1999 and 4 from 2001). These data sets were utilised for the purpose of comparing anomalous results obtained in the 1999 investigation and validating them with the additional results from the same site obtained in the 2001 investigation.

Partially Evaluated Data Set: The raw data set with values removed which failed the site data set validation. This data set still includes anomalous results that were subsequently validated by the 2001 investigation (i.e. 'Special Case' sites) and outliers and extremes identified in the 1999 investigation where the site in question was not revisited. This data set was used to calculate the statistics given in Appendix 3.

Validated Background Soils Data Set: The partially evaluated data set with the statistical outlier and extreme values above the 'non-outlier' volcanic range and the 'special case' sites removed, to include only those values deemed as background. This data set was summarised to give the background ranges in Table 3.

The principal process used to assess and validate the collected soil data is described below and illustrated in the flow chart given in Figure 5. Details of the statistical analysis used, including definition of outlier and extreme values, are given in Section 3.2.

A key approach adopted was to include any non-volcanic soil outlier or extreme values that lay within the non-outlier range for their respective volcanic soils. This was based on:

i) the potential for a component of volcanic ash to occur within any soil type due to the natural processes of volcanic eruptions, whereby ash is deposited by aerial distribution, and

ii) that the greatest range of trace element concentrations were frequently exhibited by the volcanic soils.

In 2001, re-sampling of outlier and extreme values at sites identified from the 1999 data set was undertaken to provided a set of five data points per locality. This enabled a site- specific statistical evaluation of site sample variability and an assessment of the validity of these values at the given site.

The principal steps involved in analysing the soils data set, including the process of outlier and extreme value validation is described below.

i) Site specific verification of the re-sampled sites, using statistical methods to validate or exclude values.

ii) Statistical analysis of each trace element within the resultant partially evaluated data set to determine the elements' distributions and to identify any remaining outlier or extreme values within each data set.

iii) Assessment of the validity of the identified outliers and extremes to be background values, involving:

a) including all non-volcanic outliers and extremes which lie within their equivalent volcanic soils range.

b) excluding the remaining volcanic soil outliers and extremes that lie outside the non-outlier volcanic soils range (except of the major elements K, Mg, N, P, S, TOC)

c) tagging the data excluded above for further work or, where relevant, identifying a 'Special Case' locality.

In some instances, validation testing at sites confirmed elevated concentrations, however, the complete set remained outside expected ranges. This situation was identified in volcanic soils at Ti Point (Cr), Mt Smart (Pb, Sn), and the Franklin Basalts (Sn), and within Awhitu Mineral Sands (Mn, V). It is likely that these concentrations are a reflection of the mineralogy of the parent material, although at Mt Smart anthropogenic activities may have had some effect. The values obtained from these sites have been excluded from the statistical analyses in Appendix 3, and the resultant background ranges, however it is recognised that soils from these locations need to be considered individually.

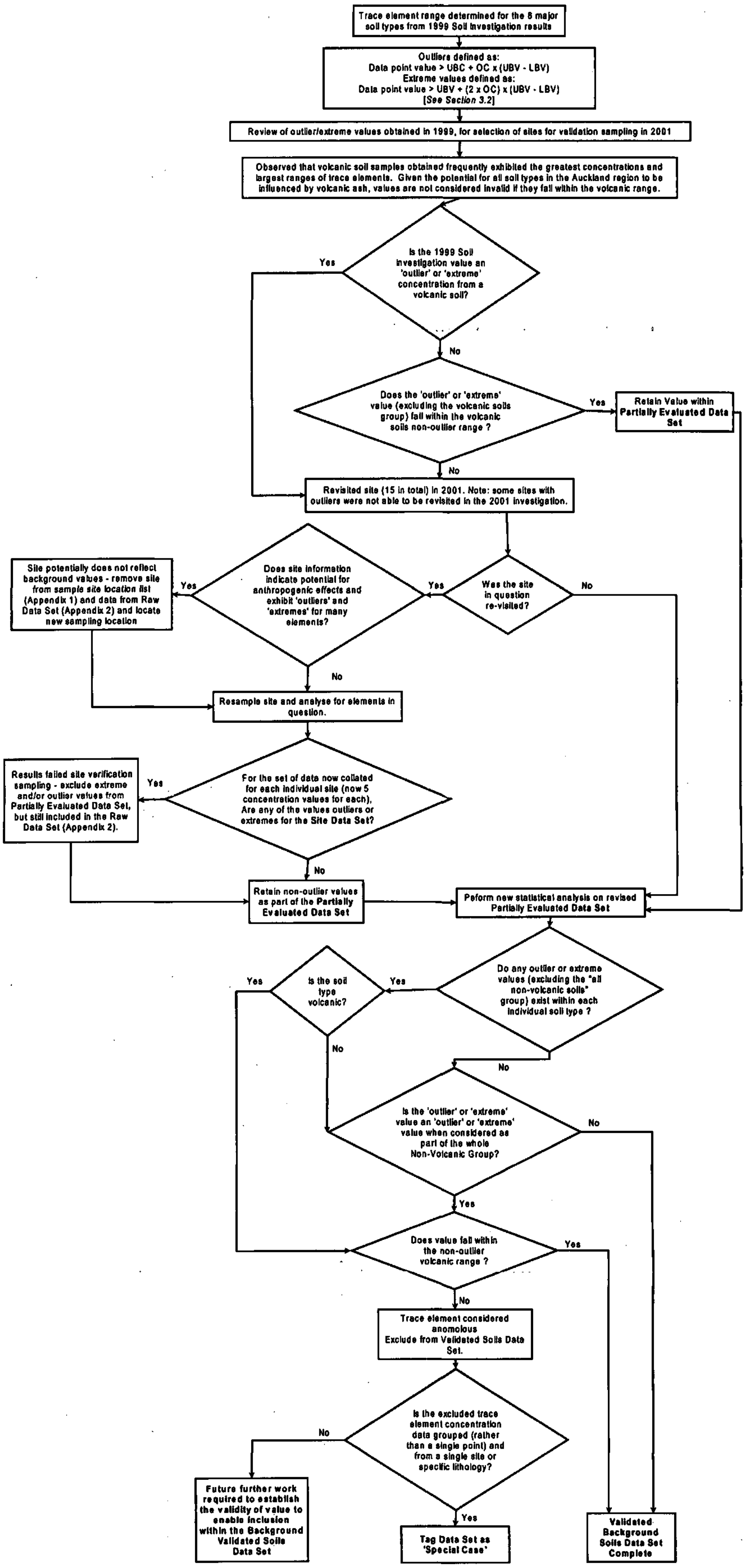
It was not considered feasible to place any real confidence on the status of the outliers or extreme values identified in magnesium, nitrogen, phosphorus, potassium, sulphur or total organic carbon ranges since these are all major earth elements, are commonly found in soil additives and fertilisers, and total organic carbon is simply a reflection of the organic matter present in soil.

3.2 Statistical Analyses of Elements Within the Major Soil Groups for the Determination of Background Ranges

To ascertain appropriate background ranges for each trace element, statistical analyses were carried out for each data set for 6 of the 8 major soil groups. Due to only 2 samples being taken for both Onerahi Chaos Breccia and Manukau Breccia soil types, no statistics have been calculated and descriptions do not apply to them unless specified. For the purpose of this report, statistics for five of the non-volcanic soil types have been included individually (Waitematas, Quaternary Sediments, Sands, Greywacke and Limestone), as well as categorised together as 'non-volcanic', for comparison to volcanic soil types. Where results were less than the limit of detection, a value of half the limit of detection was assigned to enable statistical analysis.

Many statistical methods assume the data sets have a normal distribution. The ability to undertake distribution analysis of the soils data sets is limited due to the small sample sizes of the soil type categories. A Shapiro-Wilkes test for normality was carried out on the larger volcanic data set for each element analysed. This test concluded with a 95% probability that each element, with the exception of nitrogen and total organic carbon, was not normally distributed. As environmental data is often negatively skewed, a log-normal distribution was then applied to each volcanic

Figure 5: Process and Decision Tree for Inclusion or Exclusion of Outlier and Extreme Data Values Within the Background Soils Data Set



data set, and the Kolmogorov-Smirnov test was performed to determine the "goodness of fit" to a 95% level of confidence. As an alternate method for validating the log-normal distribution of the volcanic data, a Shapiro-Wilkes test for normality was applied to a log transformation of the original data set. While analyses show the distribution of most elements in volcanic soils is log-normal, a normal distribution must be assumed for the other soil types until enough data is collated to prove otherwise.

To identify values obtained from soils that lie outside the expected distribution range based on the total sample set, box and whisker plots were constructed (see Appendix 3). The median values are represented by the small central box, while the large outer box represents the 25^{th} to 75^{th} percentile range, and the whiskers represent the 'non-outlier range', which is defined here as 1.5 times the large outer box height (i.e. the interquartile range, see Figure 6). Values that exceed the expected distribution range are referred to as outliers and extreme values.

A data point is deemed to be an **outlier** if the following conditions hold:

data point value > UBV + OC x (UBV - LBV)

A data point is deemed to be an **extreme** value if the following conditions hold:

data point value > UBV + (2 x OC) x (UBV - LBV)

where UBV is the upper value of the box in the box plot (i.e. the 75th percentile);

LBV is the lower value of the box in the box plot (i.e. the 25th percentile); and

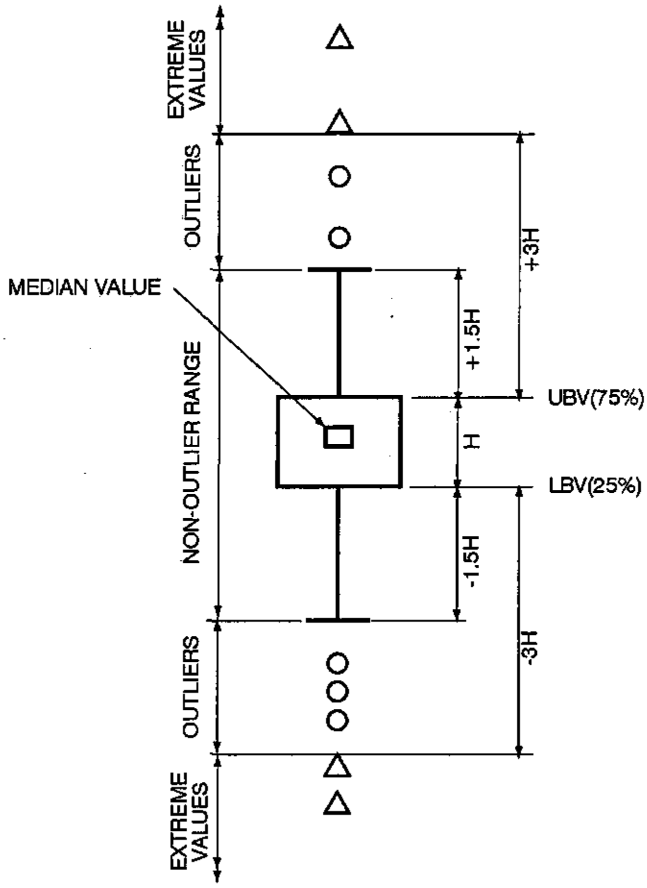
OC is the outlier coefficient (1.5 is used for this data set).

A visual interpretation of outlier and extreme values is shown in Figure 6.

This definition of outliers and extremes, calculated using a co-efficient of 1.5, is bought about by the use of the median as the mid-point rather than the mean. If the mean were employed, the standard deviation would be used to calculate outlier and extreme values, instead of the interquartile range. Thus the value of 1.5 * the interquartile range approximates 2 standard deviations (i.e. 97.7%, values above which are 'outliers') and 3 * the interquartile range approximates 3 standard deviations (i.e. 99.9%, values above which are 'extremes'). The median is used in this investigation because of the potential non-normal distribution of the data, as discussed below.

Outliers and extreme values are measurements that are extremely large or small relative to the rest of the data, and therefore are suspected of misrepresenting the population from which they were collected. They may represent analytical or sampling errors, or true elevated values of a distribution (e.g. hotspots), indicating more variability in the population than was expected. Not removing true outlier and extreme values, and removing false outlier and extreme values both lead to a distortion of estimates of population parameters.

Figure 6: Definition of Outliers and Extremes



Outlier and extreme values require further investigation. It is good practice not to discard any data based solely on the statistical test. However, if a sound reason is found to support that the data point is in error or non-representative of background, then the value should be excluded from further analysis. In this investigation, the data points were excluded when further sampling and analysis from that sample site could not validate the outlier or extreme value (indicating possible sampling or analytical error, or the presence of a 'hotspot'), or when the sample site itself was suspected of recent disturbances that may have interfered with background element levels. The potential for a component of volcanic ash to occur within any soil type has also been noted as a source of outlier and extreme measurements in these soil types, as discussed above.

In the 2001 investigation, not all sites with outlier or extreme values were re-visited, and hence these sites were unable to be validated and evaluated. Where the outliers and extremes were within the non-outlier range for volcanic soils they were included in the validated background soils data set. As the aim of this investigation is to identify background concentration ranges for soil types in the Auckland Region, spurious outlier and extreme values were removed from the validated background soils data set, and tagged for further work.

The outlier and extreme definition given above, and shown in Figure 6 was obtained, and the statistical analyses performed in this investigation, using STATISTICA Version 6 software developed by Statsoft Inc.

The box and whisker plots in Appendix 3 show the normal distribution spreads for all non-volcanic soil types, while the volcanic box and whiskers were created using the log transformed data and then replotted to fit the original concentrations on the y-axis. The log normal transformation has the effect of including what in a normally distributed data set were outlier and extreme values, within the non-outlier range.

3.3 Arsenic

Arsenic concentrations in all soil types in the 1999 survey ranged between 0.41 – 17.83 mg/kg. The outlier of 17.83 mg/kg in the Quaternary deposits at Waiau Pa was resampled in the October 2001 survey, and the sampling site relocated to Waiau Pa Domain Reserve. A limited variance between 8.2 and 10.6 mg/kg was obtained from the four 2001 samples, indicating the 17.83 mg/kg value as an outlier in the site data set, and as such the 17.83 value was excluded from the resultant validated background soils data set. It is understood that concentrations of this order have been observed in Holocene Sands in the Auckland Region, however to date no supporting data exists. Therefore the current background range of arsenic concentrations for all soil types is 0.4 – 12 mg/kg.

Geometric mean values ranged between 1.65 - 6.51 across all soil types.

Further analyses for arsenic concentrations in sand-derived soil types are recommended, and also the assessment of the validity of outliers in Waitemata soils at Cape Horn (11.54 mg/kg) and McKenzie Rd (10.16 mg/kg).

3.4 Barium

The 1999 survey found barium concentrations in all soil types ranged from 8.7 – 803 mg/kg. Barium outliers at Auckland Domain (691 mg/kg), Greenmount (786 mg/kg) and Point England Reserve (803 mg/kg) were re-sampled in 2001, and gave barium concentrations of between 77 – 112 mg/kg, 128 – 193 mg/kg, and 287 – 325 mg/kg respectively. The 1999 values have therefore been removed from the validated background soils data set as extreme values, refining the background range for all soil types as 8 – 350 mg/kg.

The geometric mean of the volcanic soils is 155 mg/kg, and ranges from 45 – 105 mg/kg for the other non-volcanic soil types.

Further work is required to assess the validity of the 313 mg/kg concentration recorded in Waitemata Group sediments at McKenzie Rd in the Hunua Ranges. Should this value not be validated, a distinct difference in volcanic and non-volcanic background ranges becomes apparent, with volcanic soils ranging from 30 – 350 mg/kg, and all other soil types ranging from 8 – 215 mg/kg.

3.5 Boron

The 1999 survey found boron concentrations in volcanic soils ranged from 2 – 839 mg/kg, and in all other soil types ranged from 2 – 63 mg/kg. To verify the statistically extreme concentration detected in the volcanic soil at Paparata Rd in the 1999 survey (839 mg/kg) the site was re-visited in 2001. The four composite samples all recorded boron concentrations of <2 – 3 mg/kg. Therefore the 1999 Paparata Rd result has been removed from the validated background soils data set as an extreme value, resulting in a refined background range for volcanic soils of <2 – 260 mg/kg.

The 1999 boron outlier of 63.3 mg/kg in the Awhitu Sands was also resampled in 2001, all four composite samples for this site gave values of 2 mg/kg. The 1999 results have therefore been removed from the validated background soils data set, resulting in a refined non-volcanic background range of 2 – 45 mg/kg.

The geometric mean of the volcanic soils is 46 mg/kg, and ranges between 8 – 17 mg/kg for all other soil types.

3.6 Cadmium

Thirty-six of the 91 soil samples were below the limit of detection for cadmium by the method employed (i.e. less than 0.1 mg/kg) in the 1999 survey, however cadmium was detected in at least one sample of each soil type. The range detected in all soil types in the 1999 sampling was <0.1 – 0.8 mg/kg.

The outlier cadmium concentrations reported at Mt Smart (0.77 mg/kg) and Waiau Pa (0.5 mg/kg) were resampled in 2001, and reported cadmium concentrations of between 0.27 – 0.48 mg/kg and 0.23 – 0.33 mg/kg, respectively. The 0.77 and 0.5 mg/kg values were outliers within their respective site data sets, and therefore each was removed from the validated background soils data set. The refined background range for cadmium is <0.1 – 0.65 mg/kg for all soil types.

The geometric mean for volcanic soils is 0.23 mg/kg and 0.07 - 0.14 mg/kg for the other soil types.

Further work could be carried out in the Quaternary Sands at Orere Point to determine the validity of the 0.46 mg/kg outlier value.

3.7 Chromium

The 1999 survey found chromium concentrations in volcanic soils ranged from 3 – 286 mg/kg, and in all other soil types ranged from 2 – 149 mg/kg. The maximum recorded concentrations for chromium in the 1999 survey was from Ti Point Basalt (286 mg/kg). This site was resampled and concentrations of chromium were reported at 195-260 mg/kg. When included as part of the volcanic data set, these concentrations are outliers/extremes, however, the verification of the chromium concentrations in soils at this location likely reflects the Kerikeri Volcanics mineralogy (with respect to the Auckland Isthmus and South Auckland Volcanic fields).

The extreme chromium concentration obtained from Waitemata Group soils at McKenzie Road (149 mg/kg) was unable to be accurately located and re-sampled to verify the elevated result with respect to the Waitemata Group data set. As this value exceeds the non-outlier range of concentrations recorded for both non-volcanic and volcanic soil groups it has been removed from the validated background soils data set. The refined background range for non-volcanic soils is 2 – 55 mg/kg, while the background range for volcanic soils (excluding Ti Point/Kerikeri Volcanics) is 3 – 125 mg/kg.

The geometric mean for chromium in volcanic soils is 48 mg/kg, and ranged between 7.0 – 14 mg/kg for the other soil types.

3.8 Cobalt

The 1999 survey found cobalt concentrations in volcanic soils ranged from 10 – 385 mg/kg, and in all other soil types ranged from 0.2 – 55 mg/kg. The cobalt outliers and extreme values at Paparata Road (385 mg/kg), Smales Quarry (228 mg/kg) and Mt Eden (223 mg/kg) were resampled in 2001, giving cobalt values of between 10.5 – 11.1 mg/kg, 13.5 – 51.8 mg/kg and 33 – 49.4 mg/kg, respectively. The 1999 values have therefore all been removed from the validated background soils data set, giving a refined volcanic background range of between 10 – 170 mg/kg.

The cobalt outlier of 54.4 mg/kg measured in sands at Awhitu in 1999 was resampled in 2001 and returned values of 24.3 – 30.4 mg/kg. The resampling results showed the value of 54.4 mg/kg to be an outlier of the site data set, and it was therefore excluded from the validated background soils data set. The revised background values for cobalt in non-volcanic soils is therefore 0.2 – 35 mg/kg.

The geometric mean for volcanic soils is 48 mg/kg, and ranges between 1.6 – 9.2 mg/kg for the other soil types.

3.9 Copper

The 1999 survey found copper concentrations in all soil-types ranged from 20 – 111 mg/kg. The copper outliers identified within the volcanic soils at Rutherford Road (111 mg/kg), and sand-derived soils at Awhitu (33 mg/kg) were resampled in 2001. The volcanic soils at Rutherford Rd returned copper values of between 51 – 60 mg/kg, therefore the 111 mg/kg value has been removed from the validated background soils data set.

The Awhitu sands recorded copper concentrations of 20.2 – 27.1 mg/kg at three of the four locations, with one location reporting the highest level detected of 135 mg/kg. The 135 mg/kg concentration from sand-derived soils at Awhitu was removed from the validated soils data set as an extreme value, although further work is recommended to be undertaken to ascertain whether higher background copper levels specific to the Awhitu sands exist. The refined background range of copper concentrations for volcanic soils is at 20 – 90 mg/kg, and for all other soil types is 1 – 45 mg/kg.

The geometric mean of copper in volcanic soils is 44.5 mg/kg, and ranges from 3.6 – 17.2 mg/kg in other soil types.

3.10 Lead

The 1999 survey found lead concentrations in all soil types ranged from 0.5 – 1280 mg/kg. The outlier lead concentrations reported in Ti Point (1280 mg/kg) and Mt Smart (475 mg/kg) and Ihumatao (128 mg/kg) volcanic soils were resampled in the 2001 survey, and reported lead concentrations of 13.4 – 15.8 mg/kg, 61.7 – 143 mg/kg and 14.3 – 33.7 mg/kg respectively. The 1999 values were therefore removed from the validated background soils data set as extreme values.

The 2001 concentrations of 88.5 – 143 mg/kg obtained at Mt Smart are the four greatest lead concentrations recorded within volcanic soils. While they are not outlier or extreme values given the log-normal distribution of lead in volcanic soils, it is unclear if these values are specific to the Mt Smart basalts or whether they are a result of anthropogenic effects. The Mt Smart data has therefore been removed from the validated background soils data set, and the background range for lead in all soil types shall remain at <1.5 – 65 mg/kg until further works can be conducted. Vertical soil profiling is recommended at Mt Smart.

The lead concentration reported in the 1999 survey for Awhitu sands was an outlier value for the sand soil type (31.4 mg/kg). The site was resampled in 2001, and returned lead concentrations of 15.1 – 38.3 mg/kg at three of the four locations, with one location reporting 538 mg/kg. The 538 mg/kg concentration from sand-derived soils at Awhitu was removed from the validated background soils data set as an extreme value.

The geometric mean of lead concentrations ranges between 5.6 - 25 mg/kg in all soil types.

3.11 Magnesium

The 1999 survey found magnesium concentrations in volcanic soils ranged from 190 – 76,600 mg/kg, and in all other soil types ranged from 470 – 10,300 mg/kg. Volcanic soils have a geometric mean of 7024 mg/kg and a 95th percentile of 47,300 mg/kg, while all the other soils have a geometric mean around 1500 mg/kg.

3.12 Manganese

The 1999 survey found manganese concentrations all soil types ranged from 20 – 8500 mg/kg. The outlier of 8496 mg/kg in the sand-derived soils at Awhitu was resampled in 2001 and returned values of between 3390 – 5890 mg/kg, indicating the presence of mineral sands at this location. This set of values remain extreme in relation to the overall concentration of manganese in sand, therefore the manganese background range has been refined to exclude the Awhitu sand data, which appears to be specific to only this lithology. The revised manganese background concentration range is 10 – 2,500 mg/kg for all soil types, excluding the Awhitu sands.

The geometric mean concentration in volcanic soils is 1075 mg/kg, while the geometric mean concentration ranges from 86 – 417 mg/kg across the other soil types.

Further work could be carried out in the Okahukura Peninsula sand-derived soils to determine the validity of the extreme manganese value of 1704 mg/kg recorded at this locality. Should this value not be validated, a difference in volcanic and non-volcanic background ranges becomes apparent, with volcanic soils ranging from 360 – 2,500 mg/kg, and all other soil types ranging from 10 – 1460 mg/kg.

3.13 Mercury

The 1999 survey found mercury concentrations in all soil types ranged from <0.03 – 2.3 mg/kg. Most soil samples recorded mercury concentrations above the detection limit of 0.025 mg/kg. The 1999 survey recorded extreme mercury concentrations of 2.3 mg/kg at One Tree Hill, which was resampled in 2001 and recorded mercury concentrations of between 0.08 – 0.11 mg/kg. Hence the 1999 mercury concentration was removed from the validated background soils data set, confirming the background range of <0.03 – 0.45 mg/kg in all soil types.

The geometric mean concentration range of mercury for all soil types is 0.07 – 0.2 mg/kg.

3.14 Nickel

The 1999 survey found nickel concentrations in volcanic soils ranged from 4 – 320 mg/kg, and in all other soil types ranged from 0.9 – 35 mg/kg. Concentrations of nickel are generally higher among the volcanic soils of the Auckland isthmus.

Although not initially recorded as an anomalous value, the 317 mg/kg nickel concentration reported in the 1999 investigation from Mt Smart was removed from the validated background soils data set when the 2001 validation testing (for a full suite of elements) returned nickel concentrations of between 28.7 – 104 mg/kg.

The geometric mean for nickel concentrations in volcanic soils is 87 mg/kg, and ranges between 2.7 – 9.0 mg/kg in all other soil types.

3.15 Nitrogen

The 1999 survey found total nitrogen concentrations in all soils ranged from 320 – 8430 mg/kg. The geometric mean for nitrogen concentrations ranged from 1375 – 3200 mg/kg in soil types across the Auckland Region.

Further work could be undertaken to assess the validity of the volcanic outlier of 8422 mg/kg observed at Mt Smart.

3.16 Phosphorus

Phosphorus levels in soil samples indicated that there are higher levels in volcanic derived soils than in all other soil types. The 1999 survey found phosphorus concentrations in volcanic soils is 245 – 3730 mg/kg, and the range for non-volcanic soil types is 75 – 1220 mg/kg.

The geometric mean for phosphorus concentrations in volcanic soils is 1180 mg/kg, and ranges between 220 – 530 mg/kg in all other soil types.

Further work could be undertaken to assess the validity of the volcanic outlier of 3729 mg/kg observed at Mt Smart.

3.17 Potassium

The 1999 survey found potassium concentrations in all soil types ranged between 226 – 5840 mg/kg, with geometric means of between 713 – 1275 mg/kg.

The extreme potassium concentration of 5840 mg/kg obtained from the Waiheke greywackes soils exceeds the non-outlier range of concentrations recorded for both the 'all non-volcanic soils group' and the volcanic soils group, and has therefore been removed from the validated background soils data set. The refined background range for potassium in all soil types is therefore 226 - 3660 mg/kg until further work can be conducted to assess the validity of the 5480 mg/kg extreme value.

3.18 Sulphur

The 1999 survey found sulphur concentrations in all soil types ranged from 85 – 2513 mg/kg. The geometric mean of sulphur concentrations in soils varied between 333 and 740 mg/kg.

To verify the outlier sulphur concentration of 2513 mg/kg reported at Kumeu Heights in 1999, the site was resampled in 2001, and returned values of 400 – 500 mg/kg. The 2513 mg/kg value was therefore excluded from the validated background soils data set, giving a revised background range of 85 – 2,300 mg/kg for all soil types.

Further work could be undertaken to assess the validity of the volcanic outlier of 2288 mg/kg observed at Puhinui Crater.

3.19 Tin

The 1999 survey found tin concentrations in all soil types ranged from <0.7 – 11.5 mg/kg. Concentrations of tin detected in soils in the Auckland Region were generally low to below the analytical detection limit (0.7 mg/kg in the 1999 survey). The 1999 survey reported an extreme value at Ti Point (411 mg/kg), which was resampled and reported tin concentrations of between 0.8 – 1.0 mg/kg. The 411 mg/kg value was therefore excluded from the validated background soils data set.

Two site specific sets of outlier and extreme tin values in volcanic soils have been identified; four locations within a 5 km radius in the Franklin Basalts (Glenbrook, Kiwi Rd, Puni and Patumahoe) recorded tin concentrations between 1.85 – 3.44 mg/kg, while tin values obtained from Mt Smart soils in 2001 ranged from 1.8 – 5.5 mg/kg.

The values of 11.5 mg/kg and 7.48 mg/kg obtained from Quaternary sediments at New Lynn and Hobsonville Airbase respectively, are statistically extreme and outlier values for their own soil type, and are outside the non-outlier volcanic soils data range. These values have therefore been removed from the data set, resulting in a refined range of 0.35 – 4 mg/kg for all soil types. Further work could be undertaken to ascertain the validity of the extreme values measured at New Lynn and Hobsonville Airbase.

The geometric mean of tin concentrations ranged between 0.4 – 1.9 mg/kg in all soil types.

3.20 Vanadium

The 1999 survey found volcanic soils recorded a wide distribution of vanadium concentrations particularly within the Auckland isthmus basalts. South Auckland basalts showed limited variance, with concentrations of 147 to 181 mg/kg recorded, compared to a range of 15.6 to 603 mg/kg for all other volcanic samples. The outlier vanadium concentrations reported in the Auckland Domain (603 mg/kg) and One Tree Hill (508 mg/kg) volcanic soils were resampled in 2001, and reported vanadium concentrations of 50 – 68 mg/kg, and 116 – 137 mg/kg respectively. The 1999 values were therefore removed from the validated background soils data set. The revised background range for vanadium concentrations in volcanic soils is therefore 15 – 370 mg/kg.

To assess the extreme vanadium concentration measured in Awhitu sands (303 mg/kg) the site was resampled in 2001. Vanadium concentrations were measured between 271 – 320 mg/kg, indicating that the data is valid and possibly lithology specific. These values are outliers within the sand-derived soil type, and as part of the non-volcanic group as a whole, therefore they were removed from the validated background soils data set, resulting in background vanadium concentrations in non-volcanic soil types between 8 – 160 mg/kg, with the exception of Awhitu (mineral) sands.

The geometric mean for vanadium concentrations in volcanic soils was 133 mg/kg, and ranged between 27 – 57 mg/kg in other soil types.

3.21 Zinc

A wide distribution of zinc concentrations was recorded in volcanic soils in 1999, particularly within the Auckland isthmus basalts. South Auckland basalts showed limited variance, with concentrations of 70 to 166 mg/kg recorded (although Pukekohe Hill recorded a concentration of 789 mg/kg), compared to a range of 54 to 1160 mg/kg for all other volcanic samples. The 1999 survey found zinc concentrations in all other soil types ranged from 9.2 – 179 mg/kg.

The geometric mean for zinc concentrations in volcanic soils was 252 mg/kg, and ranged between 18 – 59 mg/kg in other soil types.

3.22 Total Organic Carbon

The analysis of total organic carbon was undertaken to provide some measure of the variability of carbon levels in surficial soils in undisturbed environments of the Auckland region. The identification and assessment of any relationship between anomalous trace element levels and either elevated or depressed carbon levels is beyond the scope of this report. The 1999 samples from all soil types recorded values of between 0.6 – 14 % dry weight.

4. Discussion

4.1 Volcanic Soils in the Auckland Region

Results obtained from volcanic soils in the Auckland region indicate that for many parameters (barium, boron, cadmium, chromium, cobalt, copper, magnesium, manganese, nickel, phosphorus, vanadium and zinc) the distribution of levels of the trace element is elevated compared to other derived soil types. In addition, the volcanic centres – Auckland Isthmus (central), Franklin Basalts (south) and Kerikeri Volcanics (north), are often geochemically distinct from each other; for example, the elevated chromium concentrations in the Ti Point Basalts, or the low concentrations and low variance of vanadium distribution in the Franklin Basalts.

4.2 Volcanic Processes and Potential Impact on Other Soil Types

Consideration of each of the soil types as having a distinct geochemical range would be useful in the setting of acceptable background concentrations for the Auckland Region for a number of parameters. However, due to the geologically young age of the volcanic deposits and the explosive nature of their formation, the surficial layer of other geological deposits (and indeed to greater depths in Holocene Sands and Quaternary Sediments) have the potential to be affected by the presence of airfall tephra. It is therefore recommended that the ranges reported for a given soil type are compared to the ranges listed for that soil type, however, if exceedences occur within that soil type, that consideration be given to the potential for a significant volcanic component within the given soil type.

4.3 The Non-Volcanic Soils Grouping

It is recognised that there is little validity in grouping the non-volcanic soil types together, as each of the parent lithologies are potentially chemically very different. However, for the purpose of statistical analysis in this report the grouping is made to compensate for the small number of samples within each of the non-volcanic soil data sets currently collated. Volcanic soils have a minimum of 33 samples for each element, while minimum sample sizes for the non-volcanic soils are as follows: Waitematas (19), Quaternary (12), Sands (12), Greywackes (6), Limestone (4), Onerahi Chaos Breccia (2) and Manukau Breccia (2).

As the number of samples for each of the non-volcanic soil types increases, the 'all non-volcanic soils' grouping may be reconsidered in favour of ranges for each of the non-volcanic soil types individually.

4.4 Specific Lithologies

Validation testing has confirmed elevated concentrations (above the background ranges for their own soil types) of certain elements in the following lithogies: Volcanic derived soils at Ti Point (Cr), Mt Smart (Pb, Sn), and Franklin (Sn), and sand-derived soils at Awhitu (Mn, V).

It is likely that these concentrations are a reflection of the mineralogy of the parent material, although at Mt Smart anthropogenic activities may have had some effect. While the values obtained from these sites have been excluded from the statistical analyses in Appendix 3, and the resultant background ranges, it is recognised that soils from these locations need to be considered individually.

4.5 Auckland Region Background Ranges

Table 3 summarises the background ranges for trace elements in Auckland soils based on the statistical analysis of results from soils analysed in the 1999 and 2001 studies. In some cases, a single range is given to include both volcanic and non-volcanic soil types. When the range of concentrations in volcanic soils is greater than that of non-volcanic soils, to the extent that the volcanic median value is approximately equal to or greater than the non-volcanic soils maximum non-outlier value, a range for each type (volcanic and non-volcanic) is given.

Table 3: Background Ranges of Trace Elements in Auckland Soils
(all values in mg/kg unless otherwise specified)

Element (Total Recoverable)	Non-Volcanic Range	Volcanic Range
Arsenic (As)	0.4 – 12	
Barium (Ba)	8 – 350	
Boron (B)	2 - 45	<2 – 260
Cadmium (Cd)	< 0.1 – 0.65	
Chromium (Cr)	2 – 55	3 – 125*
Cobalt (Co)	0.2 – 35	10 – 170
Copper (Cu)	1 – 45	20 – 90
Lead (Pb)	< 1.5 – 65*	
Magnesium (Mg)	470 – 10,300	190 – 76,600
Manganese (Mn)	10 – 2,500*	
Mercury (Hg)	<0.03 – 0.45	
Nickel (Ni)	0.9 – 35	4 – 320
Nitrogen (total, N)	300 – 8,500	
Phosphorus (P)	75 – 1,220	245 – 3,730
Potassium (K)	220 – 3,660	
Sulphur (S)	85 – 2,300	
Tin (Sn)	< 0.7 – 4*	
Vanadium (V)	8 – 160*	15 – 370
Zinc (Zn)	9 – 180	54 – 1,160
Total Organic Carbon (TOC)	0.6 – 14%	

Notes:

1. Background ranges for major elements (N, P, S, TOC) include statistical outlier and extreme values outside the non-outlier volcanic soil range. All other elements do not include values obtained that were statistical outliers or extremes outside the non-outlier volcanic soil range.
2. *Work suggests special cases have been found to apply for Ti Point Basalts (Cr), Mt Smart Volcanics (Pb, Sn), Franklin Basalts (Sn), and Awhitu-type Mineral Sands (Mn, V) and as such these lithologies need to be considered individually.

The background levels given in Table 3 are the maximum and minimum values from the validated background soils data set as determined by statistical analysis of the current set of soil data (raw data) included in Appendix 2. Further investigations and analysis are ongoing, and the background levels will become refined as more data is collated. In particular the Greywacke, Limestone, Manukau Breccia and Onerahi Chaos Breccia derived soil types require more data to provide for statistical analysis and refinement of their background soil ranges.

4.6 Background Soil Concentrations Applicability to Soil Investigations in Auckland

While the ANZECC/NHMRC (1992) Guidelines proposed setting health-based and environmental-based investigation thresholds, they also indicated the need to identify local background soil levels of trace elements to provide a suitable context for decision making. Where soils are investigated and decisions regarding contaminant removal or trace element treatment are considered readily available regional background soil level information provides a baseline below which levels are acceptable within the region. This data may assist in minimising costly sampling or soil removal / treatment.

Two means of identification for soils have been used in this study, the identification by geological map and by excavation of the soil profile as well as the "fingerprint" associated with the limited range of analyses undertaken. In assessing the soils at any location in the Auckland region these should both be undertaken. This allows identification of the likely ranges of trace elements for a site from details in this study as well as comparison of site samples to confirm that soils are, at least in places on or near that location, representative of the soil type described.

5. Recommendations

The ANZECC/NHMRC Guidelines for Assessment and Management of Contaminated Sites recommend the evaluation of background levels as a consideration in the determination of clean-up standards. The data collected in this survey on trace metals in soils from the Auckland Region can be used in this context.

Environmental investigation threshold levels should be related to the background levels of the elements. Certain environmental investigation threshold levels may need to be reconsidered dependent on the soil terrains investigated in the Auckland setting; in particular, those where samples considered to be undisturbed and uncontaminated soil were found to contain total recoverable levels of elements at concentrations above the currently accepted environmental investigation levels.

Where 'site/lithology specific' elevated concentrations were observed, further samples from additional sites with soils derived from the same lithologies should be collected to further validate the consistently elevated concentrations observed there. The lithologies and elements to be further validated include:

1) Kerikeri Volcanics for chromium;
2) Mt Smart Volcanics for lead and tin;
3) Franklin Basalts for tin; and
4) Holocene Mineral Sands (Awhitu-type) for manganese and vanadium.

In addition the anomalous concentrations observed at the following locations should be resampled and evaluated:

- Volcanic soils at Mt Smart for nitrogen and phosphorus, and Puhinui Crater for sulphur;
- Awhitu sands for copper and Okahukura sands for manganese;
- Waitemata-derived soils at McKenzie Rd in the Hunua Ranges for arsenic, barium and chromium; at Cape Horn for arsenic;
- Quaternary sediments at Hobsonville Airbase and New Lynn for tin, and at Orere Point for cadmium;
- Greywacke-derived soils at Waiheke Island for potassium.

At all future sites sampled, it is recommended that a vertical profile of the soil chemistry be established, by collecting a second sample at 150 – 300 mm depth to help identify any anthropogenic input to the near-surface soils.

Collection of the above data may be undertaken by either directed surveys or by collation of independently collected data providing that in the second case the same or similar sampling and site identification methodologies are utilised.

6. Acknowledgements

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7. References

ANZECC / NHMRC (1992) *Guidelines for the Assessment and Management of Contaminated Sites*, Australian and New Zealand Environment and Conservation Council.

Canadian Council of Ministers of the Environment (1999), Canadian Environmental Quality Guidelines.

Patil G.P., Rao, C.R. (editors), *Handbook of Statistics Volume 12; Environmental Statistics* (1994), Elsevier Science B.V.

Ministry for the Environment and Ministry of Health (June 1997) *Health and Environmental Guidelines for Selected Timber Treatment Chemicals.*

Ministry for the Environment, (2001) *Hierarchy and Application of Environmental Acceptance Criteria in New Zealand.* Draft Version.

Ministry for the Environment, (June 1999) *Guidelines for the Assessing and Managing of Petroleum Hydrocarbon Contaminated Sites in New Zealand.*

Ministry for the Environment, (August 1997) *Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand.*

Ministry of Housing, (1994) *Environmental Quality Objectives in the Netherlands.* Risk Assessment and Environmental Quality Division Directorate for Chemicals, External Safety and Radiation Protection, and Ministry of Housing, Spatial Planning and the Environment.

National Environment Protection Council (1999) *National Environment Protection (Assessment of Site Contamination) Measure.*

NZ Government (1991) *Resource Management Act* Government Printer

Statsoft Inc., (2001), *Statistica Version 6*, statistical analysis software.

Wageningan SETOC Soils ILCP, Dr V Houba, PO Box 8005, 700 EC, Wageningan, The Netherlands.

United States Environmental Protection Agency (2000), *Preliminary Remediation and Goals, Region 9.*

United States Environmental Protection Agency (July 2000), *Guidance for Data Quality Assessment; Practical Methods for Data Analysis.* EPA QA/9.

APPENDICES

Appendix 1: Sampling Site Locations

(TCLP) indicates that sample was additionally submitted for TCLP testing

Soil Parent Rock	Sample ID	Site Name	Map Reference
Volcanics	101	Ti Point	R09:715410
	TP01-TP04	Ti Point	R09:711409
	102	Smales Quarry	R11:675895
	LP01-LP04	Lake Pupuke (Killarney St Reserve)	R11:681891
	103	Mt Victoria	R11:708846
	104	North Head	R11:721844
	105	Riteakawarau	Q10:496113
	106	Mt Roskill	R11:652752
	107	Mt Albert	R11:637776
	108	Mt Eden (& TCLP)	R11:675790
	ME01-ME02	Mt Eden	R11:677790
	ME03-ME04	Mt Eden	R11:677795
	109	Mt Hobson	R11:697788
	110	Mt Smart (& TCLP)	R11:719743
	111	Mt Wellington (& TCLP)	R11:749771
	112	Mt Mangere	R11:691709
	113	Mt Richmond	R11:743727
	114	One Tree Hill (& TCLP)	R11:693765
	OT01-OT04	One Tree Hill	R11:689760
	115	Greenmount	R11:797716
	GM01-GM02	Greenmount	R11:801717
	116	Ihumatao	R11:660660
	IH01-IH04	Ihumatao	R11:665656
	117	Puhinui Crater	R11:731672
	118	McLaughlins Mt	R11:757648
	119	Three Kings	R11:667762
	120	Pigeon Mountain	R11:800774
	121	Orakei Basin	R11:716803
	122	Panmure Basin	R11:750760
	124	Puketutu Is	R11:663693
	125	Mt St John	R11:690784
	126	Auckland Domain	R11:684805
	AD01-AD04	Auckland Domain	R11:687813
	127	Glenbrook School	R12:658427
	128	Puni School	R12:749395
	129	Patumahoe Reserve	R12:738443

Soil Parent Rock	Sample ID	Site Name	Map Reference
Volcanics	130	Kiwi Rd	R12:691391
	131	Pukekohe Hill	R12:783397
	132	Adams Rd	R12:769428
	133	Rutherford Rd	R12:843444
	RR01-RR04	Rutherford Rd	R12:875445
	134	Paparata Rd	R12:880444
	PR01-PR04	Paparata Rd	R12:839442
	310	Pt England Reserve	R11:773785
	PE01-PE04	Pt England Reserve	R11:771782
Soil Parent Rock	*Sample ID*	*Site Name*	*Map Reference*
Waitematas	201	Pakiri Reserve	R08:590538
	202	Burma Rd	Q09:317342
	203	Kaipara Hills Rd	Q09:424248
	204	Green Hollows Rd	R10:592161
	205	The Dome	R09:563368
	206	Inland Rd	Q10:430023
	207	Kumeu Heights	Q10:473931
	KH01-KH04	Kumeu Heights	Q10:471929
	208	Whangaparaoa	R10:693083
	209	Long Bay Regional Park	R10:640000
	KP01-KP04	Kauri Point Centennial Park	R11:628853
	211	Cottle Rd	Q11:475852
	212	Cape Horn	R11:646725
	213	Kepa Bush Park	R11:738806
	214	Redoubt Rd	R11:830657
	215	Cyclades Reserve	R11:841755
	216	Kaipara Rd	R12:866584
	217	Beaver Rd	R12:865417
	218	McKenzie Rd	S11:004621
	219	Takapuna Grammar	R11:703875
Soil Parent Rock	*Sample ID*	*Site Name*	*Map Reference*
Quaternary Sediments	301	Sandspit Rd	R12:635395
	302	Waiau Pa	R12:660501
	WP01-WP04	Waiau Pa Domain Reserve	R12:659504
	303	Urqhart Rd	R12:752563
	304	Manukau City	R11:768659
	305	Orere Point	S11:106670
	306	Monument Rd	S11:923640
	307	Omana Regional Park	S11:908782

Soil Parent Rock	Sample ID	Site Name	Map Reference
Quaternary Sediments	308	Highland Park	R11:803764
	309	New Lynn	R11:600766
	311	Hobsonville Airbase	R11:590885
	312	Kumeu A&P Showgrounds	Q10:495902
Soil Parent Rock	**Sample ID**	**Site Name**	**Map Reference**
Sands	401	South Head	Q09:222232
	402	Wilson Rd	Q10:263134
	403	Rimmer Rd Lookout	Q10:355007
	404	Pulpit Rd	Q10:391915
	405	Okahukura Peninsula	Q09:273381
	406	Pakiri Block Rd	R08:623522
	407	Pakiri River Rd	R09:654492
	408	Omaha Bay	R09:704385
	409	Awhitu Central	R12:509550
	AW01-AW04	Awhitu Central	R12:509550
	410	Douglas Rd	R12:541451
	411	Kariotahi School Rd	R12:597355
	412	Orewa	R10:622115
Soil Parent Rock	**Sample ID**	**Site Name**	**Map Reference**
Greywacke	501	Cape Rodney Rd	R09:730451
	502	Lilburne Rd	S12:998521
	503	Tapapakanga Hill	S11:119661
	504	Maraetai	S11:907772
	505	Waiheke	S11:941887
	506	Waiheke	S11:028840
Soil Parent Rock	**Sample ID**	**Site Name**	**Map Reference**
Limestone	601	Marsh Rd	Q09:353404
	602	North Shore Aerodrome	R10:583038
	603	Snells Algies	R09:663293
	604	Partridge Rd	Q09:417410
Soil Parent Rock	**Sample ID**	**Site Name**	**Map Reference**
Onerahi Chaos Breccia	701	Glorit-Kaipara Hills Rd	Q09:487313
	702	Pebblebrook Rd	R10:508092
Soil Parent Rock	**Sample ID**	**Site Name**	**Map Reference**
Manukau Breccia	801	Anawhata Rd	Q11:463718
	802	Goldie Bush	Q11:418830

Appendix 2: Analytical Results

VOLCANIC SAMPLES

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
101	3.68	120	174	0.32	89.5	286	82	0.081	903	1151	1826	3842	128	1260	1280*	733	411.3*	196	84	4.97
TP01	-	-	-	-	-	195	-	-	-	-	-	-	-	-	14.6	-	0.9	-	-	-
TP02	-	-	-	-	-	196	-	-	-	-	-	-	-	-	15.8	-	0.9	-	-	-
TP03	-	-	-	-	-	200	-	-	-	-	-	-	-	-	13.4	-	0.8	-	-	-
TP04	-	-	-	-	-	260	-	-	-	-	-	-	-	-	15	-	1.0	-	-	-
102	1.67	119	224	0.19	228.4*	124	36.5	0.265	751	8612	2110	3779	253	804	23.3	700	<0.7	256	748	4.39
LP01	-	-	-	-	51.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LP02	-	-	-	-	34.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LP03	-	-	-	-	22.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LP04	-	-	-	-	13.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	1.99	66.4	243	0.27	90.9	72.1	28.3	0.215	1130	3767	1354	4817	315	1259	46.6	915	<0.7	125	362	5.97
104	2.02	18.5	149	0.27	57.4	53.8	25.5	0.146	1280	8558	1008	3028	120	1014	13.7	601	<0.7	41.6	108	4.07
105	0.41	239	220	0.15	143.4	3.6	38	0.085	3660	7230	1498	5190	4.6	592	3.04	1036	<0.7	268	114	8.77
106	1.08	71.5	288	0.28	83.2	101	53.1	0.125	2530	34188	1006	1762	251	1325	13.1	407	<0.7	127	280	3.78
107	0.48	40.1	34	0.18	32.9	101	53.8	0.06	1580	30483	848	530	235	246	3.3	389	<0.7	74.2	127	0.85
108	2.15	249	123	0.31	223*	98.8	79.9	0.235	1270	22612	1502	4732	223	1592	34.1	805	<0.7	366	1038	6.47
ME01	-	-	-	-	49.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ME02	-	-	-	-	45.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ME03	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ME04	-	-	-	-	41.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
109	7.8	31.8	76	0.28	63.6	35.3	36.6	0.098	1520	31820	768	2976	229	2344	23.9	422	<0.7	72.2	191	3.37
110	6.61	57*	116	0.77*	45.7	61.3	88.6	0.271	498	22217	2484	8422	317*	3729	475*	1520	<0.7	104	484*	11.64
MS01	4.5	4	-	0.33	26.3	55.1	65.0	0.11	-	-	-	-	50.8	-	88.5	-	3.1	-	142	-
MS02	3.7	3	-	0.27	24.4	42.5	65.9	0.06	-	-	-	-	28.7	-	61.7	-	1.8	-	116	-
MS03	4.8	5	-	0.40	29.8	64.4	84.1	0.18	-	-	-	-	46.7	-	102	-	5.5	-	205	-
MS04	4.8	17	-	0.48	37.9	71.6	81.2	0.13	-	-	-	-	104	-	143	-	4.5	-	258	-
111	1.92	15.4	49	0.59	30.5	9.1	26.6	0.059	681	23384	429	6366	121	1373	11.8	669	<0.7	15.6	54.5	10.66
112	5.82	163	207	0.63	121	105	39.1	0.12	1290	10705	1325	5093	168	2228	21.9	762	<0.7	291	549	6.78
113	2.8	43.1	88	0.57	36.2	15.5	34.7	0.084	1350	16273	877	3669	93.4	1992	15.7	539	<0.7	28	143	4.85
114	4.33	179	197	0.39	119	54.5	33.9	2.303*	1480	4157	1565	5790	98.3	1935	16.3	938	<0.7	508*	742	6.55
OT01	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-	-	-	120	-	-
OT02	-	-	-	-	-	-	-	0.11	-	-	-	-	-	-	-	-	-	137	-	-
OT03	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	132	-	-
OT04	-	-	-	-	-	-	-	0.09	-	-	-	-	-	-	-	-	-	116	-	-
115	3.55	196	786*	0.39	124	73.2	42.1	0.146	1880	11964	1749	5689	149	2830	32.8	887	<0.7	331	1160	6.32
GM01	-	-	193	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GM02	-	-	128	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GM03	-	-	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GM04	-	-	139	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
116	5.29	55.9	239	0.48	34.7	72.5	28.7	0.167	1930	3948	2420	5149	84.1	1086	128*	679	<0.7	87.9	547	6.56
IH01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.8	-	-	-	-	-
IH02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33.7	-	-	-	-	-
IH03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.3	-	-	-	-	-
IH04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.4	-	-	-	-	-
117	0.69	198	123	0.24	138	114	75.9	0.047	747	37795	1063	1577	227	1152	11.2	2288	<0.7	313	853	1.88
118	4.14	29.4	151	0.21	27.6	38.4	22.9	0.148	1280	3579	1010	3505	41.4	901	55.4	496	<0.7	66	235	3.94
119	2.27	107	72	0.43	105	89.1	53.2	0.147	1510	33794	1321	7237	320	2068	43	1026	<0.7	155	421	9.47
120	1.99	35.7	347	0.31	61.1	46.8	51.4	0.093	2110	64998	1088	3392	207	2590	19.2	1593	<0.7	326	728	3.91
121	4.12	227	142	0.15	128	79.6	48.5	0.143	2160	13300	1217	2709	164	1610	60.2	790	<0.7	310	913	4.72
122	6.61	73	301	0.3	50	53.1	55.1	0.107	2080	76564	992	3730	137	3366	39.6	649	<0.7	128	363	4.43
124	1.93	18.7	69	0.11	29.1	39.7	37.2	<0.03	1600	17327	634	324	95.6	1269	13.1	475	<0.7	23	88.3	1.42
125	1.6	81	279	0.27	93.6	110	41.5	0.169	927	14992	1436	3240	223	972	23.2	732	<0.7	208	288	5.42
126	0.62	243	691*	0.15	134	67.3	81	0.219	978	3594	710	3172	161	1343	27.4	783	<0.7	603*	835	4.56
AD01	-	-	112	-	-	-	-	-	-	-	-	-	-	-	-	-	-	68	-	-
AD02	-	-	83.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	-	-
AD03	-	-	77.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50	-	-
AD04	-	-	98.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	57	-	-
127	7.77	54.6	230	<0.1	23.4	13.7	20.6	0.333	489	1419	497	2678	13.6	333	26.2	753	1.85	147	70.6	4.58
128	6.85	60.9	216	0.13	53.4	11.6	51	0.377	1150	1414	675	2147	11.9	361	52.1	801	3.14	158	166	2.65
129	6.83	61.7	204	<0.1	33.5	27.2	33.4	0.351	1200	194	1516	2904	30.1	598	31	767	3.44	150	109	4.49
130	8.45	57.3	213	<0.1	34.1	14.2	24.9	0.401	496	1753	2094	2798	9.7	376	36.9	742	3.13	151	86.1	4.22
131	0.78	255	132	0.22	114	49.4	57.2	0.184	735	1004	436	4347	17.8	1122	21.2	769	<0.7	158	789	7.11
132	2.41	190	97	0.12	166	98.4	21.8	0.208	493	3281	362	1107	22.7	399	14.1	313	<0.7	155	71.4	1.89
133	2.56	157	157	0.31	93.1	80.3	111*	0.187	275	750	1480	3767	116	1812	13.4	775	<0.7	158	70	5.4
RR01	-	-	-	-	-	-	56.7	-	-	-	-	-	-	-	-	-	-	-	-	-
RR02	-	-	-	-	-	-	51.3	-	-	-	-	-	-	-	-	-	-	-	-	-
RR03	-	-	-	-	-	-	51	-	-	-	-	-	-	-	-	-	-	-	-	-
RR04	-	-	-	-	-	-	60.3	-	-	-	-	-	-	-	-	-	-	-	-	-
134	3.17	839*	181	0.24	385*	64	46.6	0.202	406	860	685	4118	107	955	15.4	863	<0.7	181	87.5	5.83
PR01	-	<2	-	-	11.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR02	-	2	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR03	-	3	-	-	10.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR04	-	3	-	-	10.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
310	3.15	190	803*	<0.1	75.8	40.1	20.8	0.074	1900	4812	907	3750	57.2	2148	17.3	670	<0.7	335	689	4.76
PE01	-	-	287	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PE02	-	-	325	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PE03	-	-	304	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PE04	-	-	317	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

WAITEMATA GROUP SAMPLES

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
201	2.63	42.2	188	0.25	23.6	20	35.3	0.113	2730	10261	876	607	23.2	770	6.6	1064	<0.7	56.3	106	7.93
202	4.57	19.2	27	0.21	3	8.1	5.7	0.18	389	872	376	4322	3.6	454	7.22	902	<0.7	49.3	43	5
203	1.58	14.8	218	0.14	18.3	25	9.3	0.058	830	3095	966	1982	6.9	227	6.08	425	<0.7	61	46	2.41
204	2.48	30.8	95.3	<0.1	6.2	26.3	21.8	0.096	2310	5110	133	5141	11.7	580	7.2	819	1.49	91.1	98.3	6.43
205	1.36	41.1	30	0.15	5.3	38.3	29	0.13	1300	3844	334	1934	15.7	482	8	1532	<0.7	135	123	4.43
206	4.02	23.6	81	<0.1	8.5	16.9	16.8	0.074	3070	3601	332	3844	6.8	531	21.1	661	<0.7	54.3	57.1	5.03
207	2.12	8.4	12.1	<0.1	0.2	3.7	2.2	0.137	520	654	56	1650	0.93	163	3.74	2513*	1.87	41	11.5	2.44
KH01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500	-	-	-	-
KH02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	400	-	-	-	-
KH03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	400	-	-	-	-
KH04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	400	-	-	-	-
208	1.93	7.4	16.1	<0.1	0.7	2.2	4.1	0.071	275	474	338	1083	1.5	92	13.9	265	<0.7	40.3	16.3	2.36
209	1.32	4.8	8.7	<0.1	1	2.4	4	0.131	226	743	42	1032	2.38	76	10.7	180	<0.7	21.9	9.6	2.05
KP01	-	-	-	-	-	-	7.1	0.06	-	-	-	-	-	216	8.26	-	0.5	-	-	-
KP02	-	-	-	-	-	-	6.7	0.06	-	-	-	-	-	217	8.34	-	0.4	-	-	-
KP03	-	-	-	-	-	-	4.9	0.07	-	-	-	-	-	185	7.36	-	0.4	-	-	-
KP04	-	-	-	-	-	-	5.0	0.09	-	-	-	-	-	158	9.07	-	0.5	-	-	-
211	5	20.8	15.2	<0.1	1.9	5.5	10.8	0.145	348	904	28	1626	3.3	250	9.64	1145	2.11	114	32.2	3.88
212	11.54	5.8	29	0.14	2.4	7.6	7.5	0.092	401	597	384	2363	3.46	309	17.6	401	<0.7	33.5	24.9	2.67
213	2.93	30.2	71	<0.1	26.3	40.4	11.1	0.154	908	1585	1121	2821	19.5	417	25.7	586	<0.7	65.4	71.3	4.14
214	5.17	11.5	58	<0.1	1.7	14.6	13.9	0.035	2490	2394	13	805	11.5	122	12.7	103	1.18	29	45.5	0.84
215	2.29	8.2	74	<0.1	5.3	19.8	4.6	0.196	724	951	60	1168	12	137	9.8	338	<0.7	63.8	28.1	1.7
216	1.7	13.6	182	<0.1	5.5	4.9	2.8	0.049	847	909	61	1944	2.5	173	2.78	322	1.55	45.8	43.6	3.18
217	6.07	34.2	31.2	<0.1	3.6	149*	11.7	0.048	1230	2492	33	532	25.8	237	6.31	168	1.8	96.7	82.3	0.63
218	10.16	37.3	313	0.15	9.3	18.5	21.3	0.313	1030	782	586	3198	15	824	40.9	748	3.91	105	68.5	4.5
219	3.1	16.7	53	0.17	18.6	25.4	21.5	0.067	2040	7563	104	4644	34.1	597	8.9	913	<0.7	41.3	70.6	6.84

QUATERNARY SEDIMENTS

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
301	3.98	14.8	179	<0.1	10.9	16.5	20.5	0.325	1380	2411	389	4127	20.2	666	44.3	802	2.41	64	92.5	5.99
302	17.83*	30.6	117	0.5*	13.4	11.5	23.7	0.302	447	1417	520	5202	10.7	1213	28.7	1191	<0.7	111	111	7.45
WP01	8.2	-	-	0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WP02	10.1	-	-	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WP03	10.6	-	-	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WP04	8.3	-	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
303	6.97	35.2	198	<0.1	8.8	8	27.4	0.337	1510	1172	150	346	12.6	454	26.7	1202	1.5	113	78.7	2.14
304	3.11	17.7	98	0.27	17.1	21.1	8.3	0.11	861	2344	1391	2070	11	457	21.3	475	2.44	43.2	63.9	2.65
305	7.07	21	211	0.46	3.7	5.4	8.3	0.165	281	645	284	3749	5.9	756	19.3	722	3.61	74	90	4.92
306	1.91	9.6	47.2	<0.1	0.5	3.9	7.6	0.169	777	847	83	2728	5.4	363	11.2	426	1.21	34.2	36.9	3.49
307	3.76	9	47.1	0.15	2.9	3.9	4.8	0.107	624	656	397	3416	2.7	486	16.4	570	1.49	30.1	28.2	3.89
308	2.75	17.6	68	<0.1	15.8	28.1	11.5	0.106	1270	3529	612	3101	23.2	632	12.9	562	<0.7	51.8	55.9	3.78
309	6.09	12.1	28	0.15	3.4	7.9	15.2	0.247	700	1118	39	2066	8.53	350	56.2	585	11.47*	41.8	52.1	6.67
311	7.6	29.6	183	0.21	5.6	11.1	25.7	0.311	906	1555	96	2327	23.3	401	52.6	529	7.48*	118	96.6	3.74
312	9.11	8.7	42.1	<0.1	1.5	4.8	17.7	0.421	648	886	39	6108	2.8	465	22.6	1178	2.17	33	21	13.96

SANDS

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
401	5.33	20.4	81	<0.1	9.9	10.6	8.3	0.26	867	1805	376	1950	7.1	358	10.4	470	<0.7	68.3	95.3	3.49
402	8.34	24.1	170	<0.1	6.8	9.1	8.6	0.296	1050	1328	101	1069	9.3	240	12.4	358	1.24	80.3	91.7	1.45
403	6.73	39.3	109	<0.1	13.6	11.6	11	0.191	1020	2084	429	2491	8.9	548	12.8	545	<0.7	95.6	179	4.31
404	3.4	17.9	47.9	<0.1	8.8	5.9	2.8	0.124	350	1020	393	336	5.6	140	14.2	325	<0.7	72.3	61.8	1.21
405	4.02	23.7	78	0.18	20.9	19.1	10.2	0.12	873	2310	1704	1993	11.7	303	9.6	618	<0.7	81	106	2.23
406	7.44	3.6	13.4	0.11	1.5	5.5	1.1	<0.03	308	583	58	926	1.94	611	1.7	103	<0.7	12.2	16.6	1.04
407	5.23	3.9	12.2	<0.1	1.3	4.9	1.1	<0.03	547	802	45	1509	1.94	196	3.04	197	<0.7	9.6	12.8	2.12
408	3.92	3	11	<0.1	1.6	5.8	2.2	<0.03	259	635	49	538	2.21	220	<1.5	85	<0.7	8.6	10.7	0.85
409	5.49	_63.3*_	202	0.22	_54.4*_	33.1	33.1	0.319	1060	2212	***8496***	4224	18.1	633	31.4	1009	<0.7	***303***	158	5.39
AW01	-	2	-	-	28.2	52.3	20.2	-	-	-	***3390***	-	-	-	15.1	-	-	***320***	-	-
AW02	-	2	-	-	30.4	47.4	_135*_	-	-	-	***3730***	-	-	-	38.3	-	-	***299***	-	-
AW03	-	2	-	-	24.3	48.2	26.8	-	-	-	***4050***	-	-	-	22.5	-	-	***301***	-	-
AW04	-	2	-	-	29.3	41.3	27.1	-	-	-	***5840***	-	-	-	_538*_	-	-	***271***	-	-
410	5.09	23.7	55	<0.1	23.1	20.2	7.9	0.047	750	3107	544	2265	9.5	598	4.14	411	<0.7	151	78.1	2.69
411	7.56	23.6	73.5	<0.1	17	11.1	17.2	0.198	676	2324	462	3624	9.6	505	12.7	787	<0.7	129	70.4	4.98
412	7.22	5.2	30	<0.1	2.4	4.5	3.7	<0.03	436	1468	61	1954	3.4	281	11.6	180	<0.7	19	20.7	2.03

GREYWACKE

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
501	9.78	20.4	36	0.12	4.2	13.3	28.2	<0.03	2380	1171	453	1563	3	855	26.7	345	1.5	26.5	29.8	2.06
502	4.74	13.2	178	<0.1	5.2	6.1	12.9	0.117	1550	1903	337	1776	5.6	233	13.5	392	1.76	47.7	42.2	2.42
503	6.98	20.2	85.5	<0.1	2.7	4.8	8.4	0.12	448	843	179	558	3	316	17.8	349	2.71	86.1	43.7	0.96
504	3.91	10.9	63.1	<0.1	2.8	8.5	7.3	0.061	1380	1182	142	1685	2.7	321	13.6	219	0.91	46.4	36.1	2.33
505	8.6	21.1	212	0.17	31.8	23.8	44.8	0.104	_5840*_	590	1460	732	26.3	471	25.7	370	<0.7	17	103	3.86
506	7.01	13.4	181	0.17	4.4	12.1	25.6	0.081	3500	2109	924	3535	8.96	439	19.1	448	<0.7	14	34	4.69

LIMESTONE

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
601	1.72	9.7	31.1	0.12	0.6	7.9	1.5	0.073	888	1450	50	1028	2.11	177	2.42	375	<0.7	26.5	10.5	2.85
602	2.3	22.1	120	0.18	9.3	10.2	17.1	0.086	949	2487	464	4427	8.29	448	12.6	755	<0.7	38.4	63.9	4.54
603	1.19	7.5	17	<0.1	0.5	3.5	1.3	0.063	601	814	28	1141	0.94	117	6.6	607	0.94	20.6	9.2	2.68
604	1.57	10	63	<0.1	2.1	8.6	5.1	0.097	1160	1539	85	4085	3.32	260	4.83	525	<0.7	27	17.7	3.2

ONERAHI CHAOS BRECCIA

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
701	3.03	16.6	78	0.2	10.4	11.2	8.6	0.091	1890	2312	1202	3392	6.6	348	9.13	537	<0.7	14.7	36.5	4.63
702	4.88	28.7	49.5	<0.1	<0.2	10.9	4	0.099	1580	2504	14	1495	2.5	223	13	255	2.16	37.4	27.2	2.47

MANUKAU BRECCIA

ID	As	B	Ba	Cd	Co	Cr	Cu	Hg	K	Mg	Mn	N	Ni	P	Pb	S	Sn	V	Zn	TOC
801	1.49	77.8	41	0.12	7.4	4	53.2	0.245	434	1283	117	3543	4.96	420	16	767	<0.7	362	143	7.19
802	4.92	184	50.6	<0.1	2.3	13.8	49.5	0.114	1340	5315	193	1500	5.4	188	10.8	597	3.69	506	333	2.91

*Results considered anomalous and excluded from the validated soils data set for statistical purposes. ***Bold Italic*** _values: considered as lithology specific_

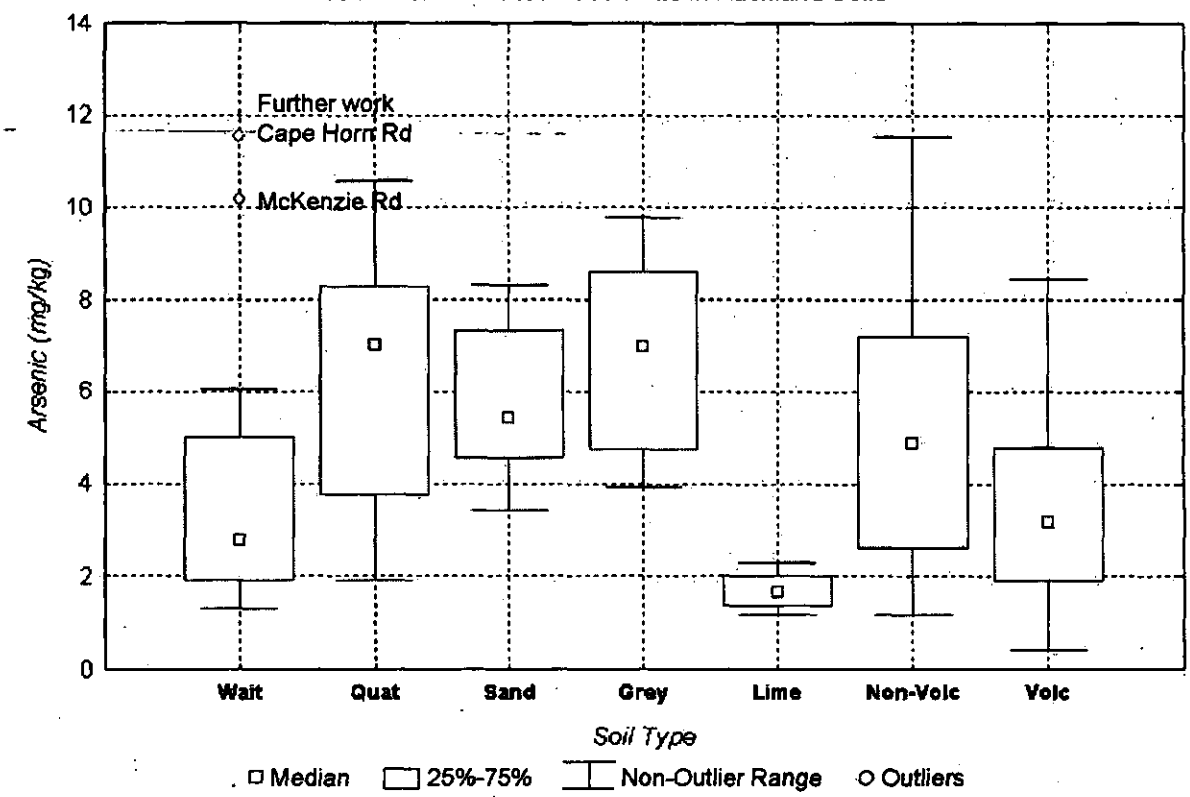
Appendix 3 – Statistical Analysis

Arsenic	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	54	38	18	14	12	6	4	2	2
Arithmetic mean	5.13	2.76	3.89	6.40	5.81	6.84	1.70		
Standard Deviation	2.83	NA	2.91	2.84	1.62	2.23	0.46		
Geometric Mean	4.31	NA	3.14	5.69	5.60	6.51	1.65		
Median	4.87	3.16	2.78	7.02	5.41	7.00	1.65		
Minimum	1.19	0.41	1.32	1.91	3.40	3.91	1.19	3.03	1.49
Maximum	11.54	8.45	11.54	10.60	8.34	9.78	2.30	4.88	4.92

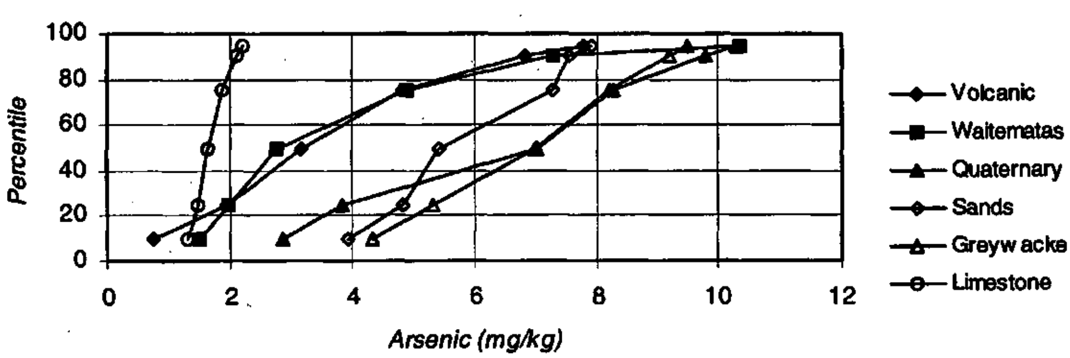
All values in mg/kg

Distribution (percentiles)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone
10	1.71	0.75	1.51	2.86	3.93	4.33	1.30
25	2.66	1.95	1.98	3.82	4.82	5.30	1.48
50	4.87	3.16	2.78	7.02	5.41	7.00	1.65
75	7.18	4.80	4.89	8.28	7.28	8.20	1.87
90	8.96	6.84	7.30	9.80	7.55	9.19	2.13
95	10.12	7.77	10.37	10.28	7.91	9.49	2.21

Box & Whisker Plot for Arsenic in Auckland Soils



Cumulative Arsenic Distribution of Auckland Soils

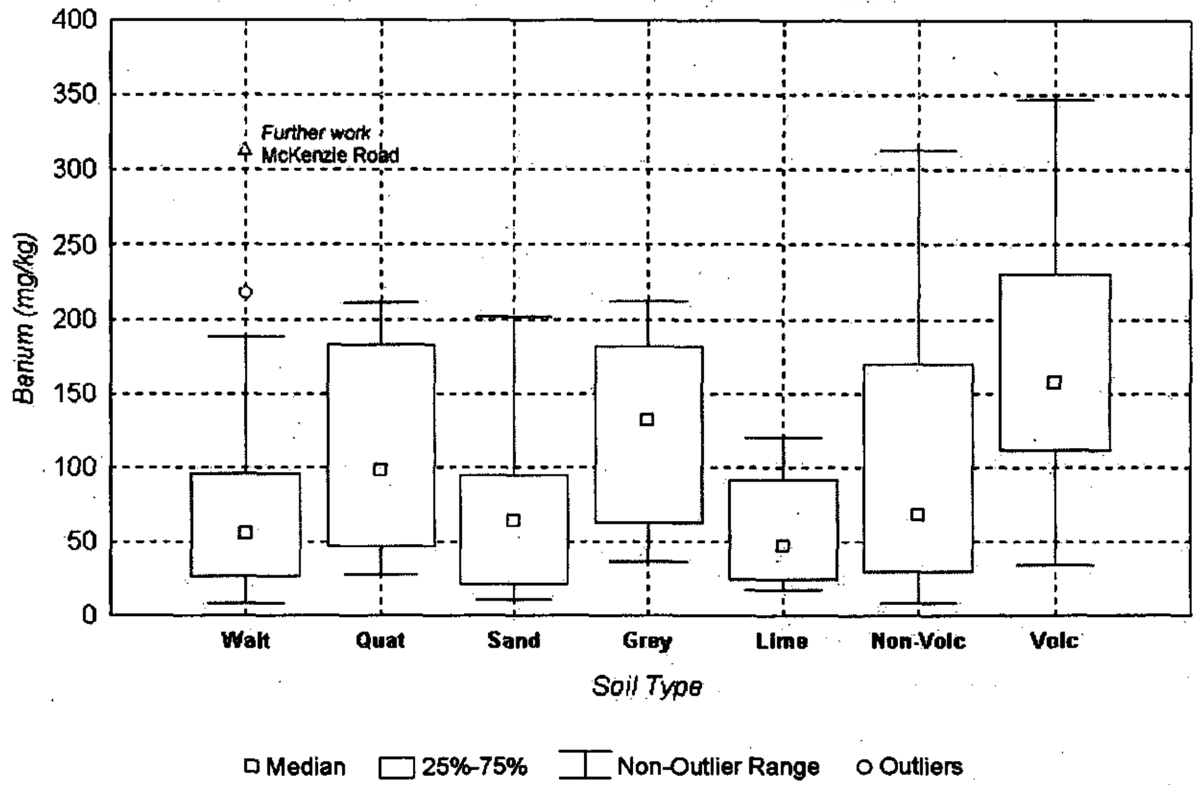


Barium	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	43	18	11	12	6	4	2	2
Arithmetic mean	90.0	154.6	83.5	110.8	73.6	125.9	57.8		
Standard Deviation	72.7	NA	85.7	70.2	61.3	73.2	45.7		
Geometric Mean	61.7	150	51.0	89.1	50.1	104.8	44.7		
Median	68	157	55.5	98	64.3	131.8	47.1		
Minimum	8.7	34	8.7	28	11	36	17	49.5	41
Maximum	313	347	313	211	202	212	120	78	50.6

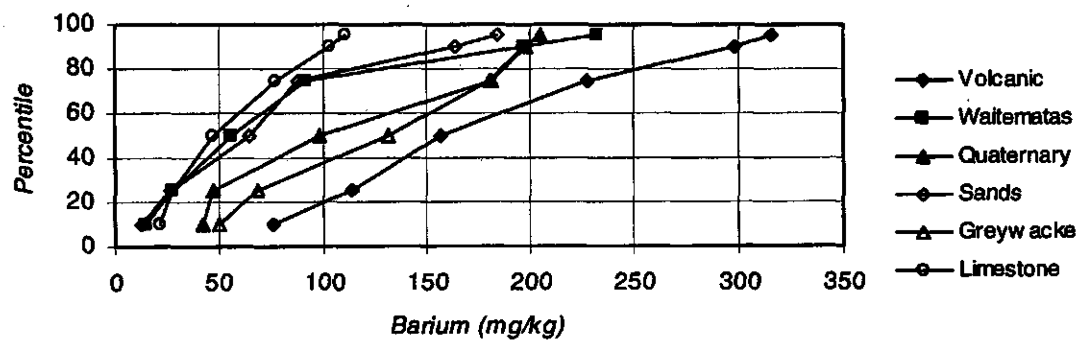
All values in mg/kg

Distribution (percentiles)									
10	15	76	14	42	12	50	21		
25	31	114	28	47	26	69	28		
50	68	157	56	98	64	132	47		
75	145	227	92	181	88	180	77		
90	198	298	197	198	164	197	103		
95	212	316	232	205	184	204	111		

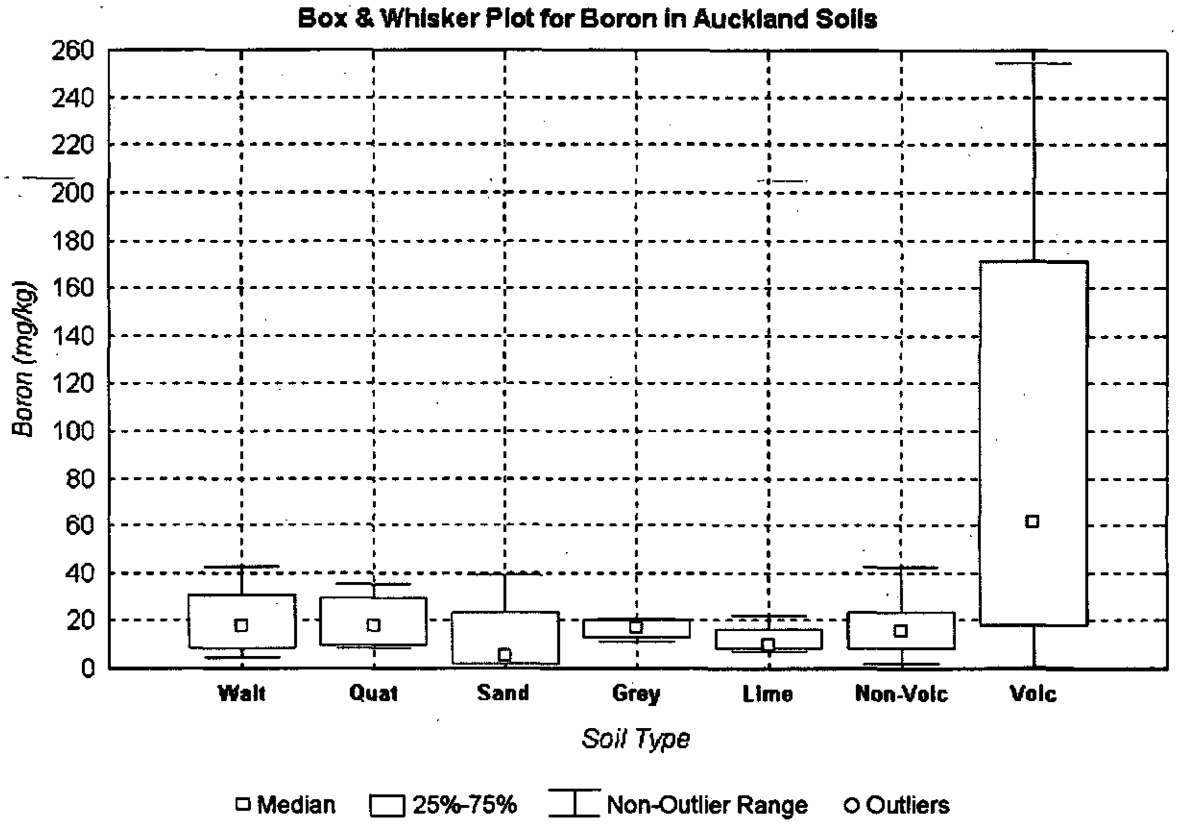
Box & Whisker Plot for Barium in Auckland Soils

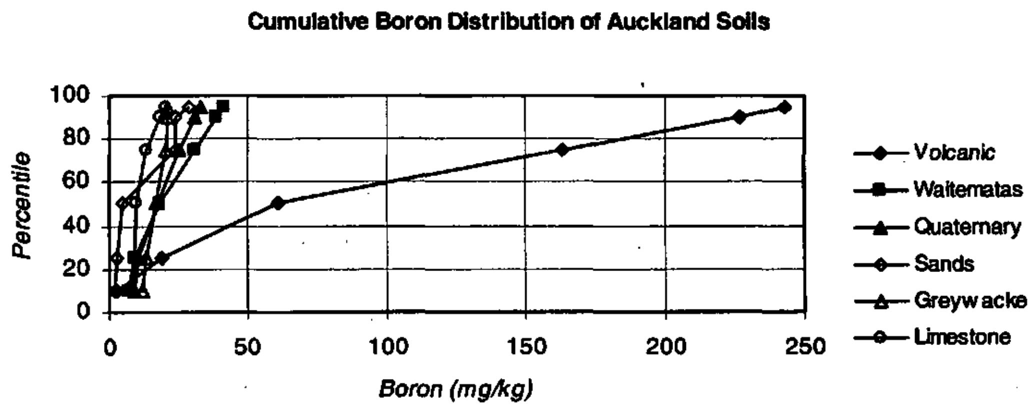


Cumulative Barium Distribution of Auckland Soils



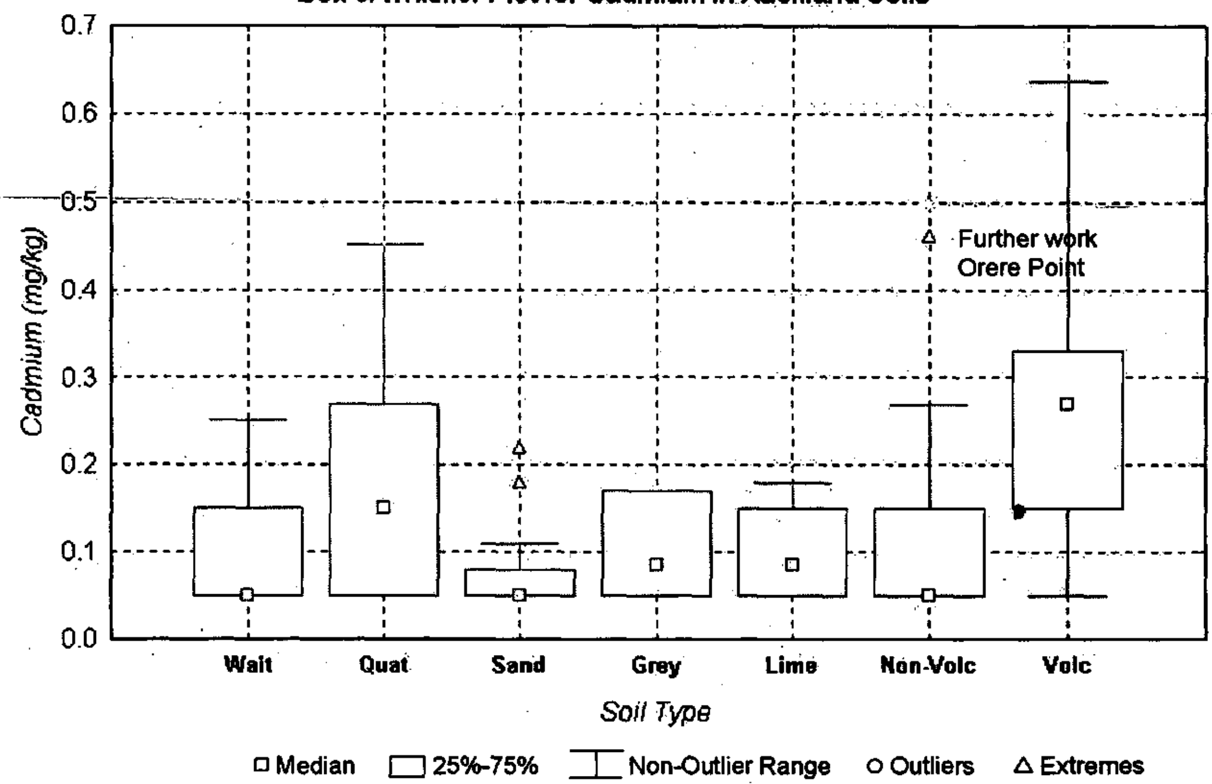
Boron	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	54	41	18	11	15	6	4	2	2
Arithmetic mean	17.1	45.5	20.6	18.7	13.1	16.5	12.3		
Standard Deviation	11.0	NA	12.6	9.4	12.1	4.5	6.6		
Geometric Mean	13.0	29.2	16.7	16.7	7.6	16.0	11.3		
Median	15.8	60.9	18.0	17.6	5.2	16.8	9.9		
Minimum	2	<2	4.8	8.7	2	10.9	7.5	16.6	77.8
Maximum	42.2	255	42.2	35.2	39.3	21.1	22.1	28.7	184
All values in mg/kg									
Distribution (percentiles)									
10	3.7	3.0	6.9	9.0	2.0	12.1	8.2		
25	8.5	18.7	9.2	10.9	2.5	13.3	9.2		
50	15.8	60.9	18.0	17.6	5.2	16.8	9.9		
75	23.6	163	30.7	25.3	23.7	20.4	13.0		
90	33.2	227	38.4	30.6	23.9	20.8	18.5		
95	38.0	243	41.3	32.9	28.7	20.9	20.3		



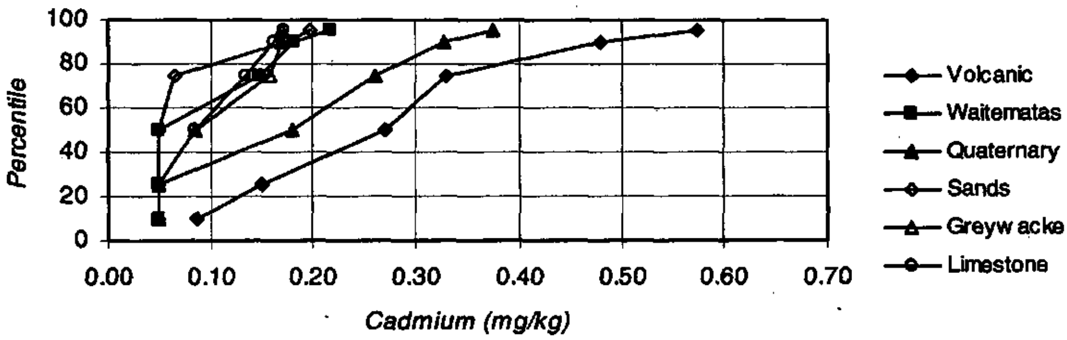


Cadmium	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	54	37	18	14	12	6	4	2	2
Arithmetic mean	0.12	0.23	0.10	0.19	0.08	0.10	0.10		
Standard Deviation	0.09	NA	0.07	0.13	0.06	0.06	0.06		
Geometric Mean	0.09	NA	0.08	0.14	0.07	0.09	0.09		
Median	0.05	0.27	0.05	0.18	0.05	0.085	0.085		
Minimum	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Maximum	0.46	0.63	0.25	0.46	0.22	0.17	0.18	0.2	0.12
All values in mg/kg									
Distribution (percentiles)									
10	0.05	0.08	0.05	0.05	0.05	0.05	0.05		
25	0.05	0.15	0.05	0.05	0.05	0.05	0.05		
50	0.05	0.27	0.05	0.18	0.05	0.09	0.09		
75	0.17	0.33	0.15	0.26	0.07	0.16	0.14		
90	0.23	0.48	0.18	0.33	0.17	0.17	0.16		
95	0.29	0.57	0.22	0.38	0.20	0.17	0.17		

Box & Whisker Plot for Cadmium in Auckland Soils



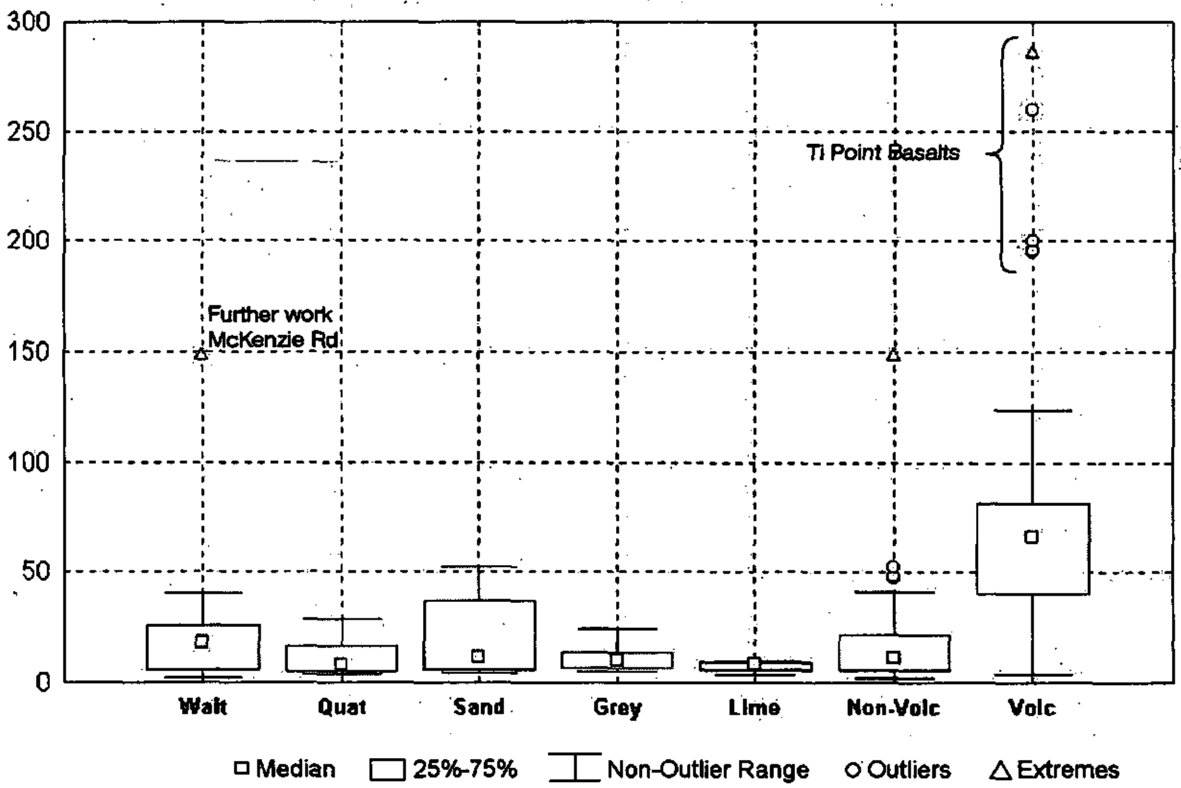
Cumulative Cadmium Distribution of Auckland Soils



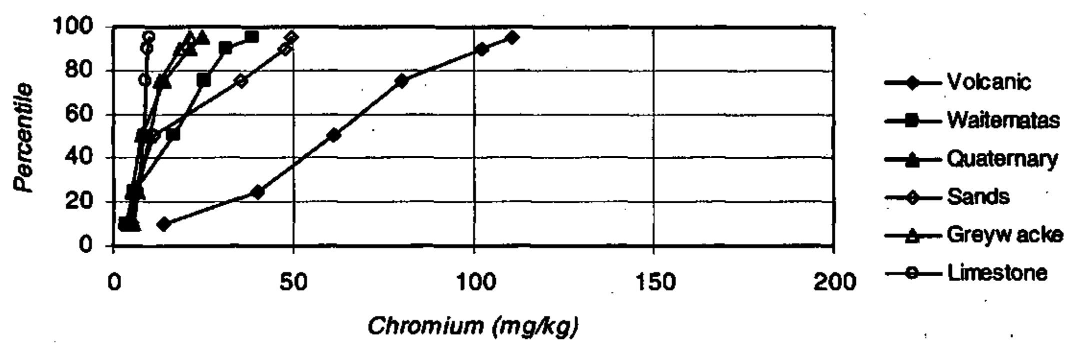
Chromium	All Non-Volcanic Soils	Volcanic*	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	54	37	17	11	16	6	4	2	2
Arithmetic mean	15.4	48.5	16.5	11.1	20.7	11.4	7.6		
Standard Deviation	12.9	NA	12.0	7.8	17.6	6.9	2.9		
Geometric Mean	11.2	43.4	11.7	9.0	14.4	9.9	7.0		
Median	10.9	61.3	16.9	8	11.4	10.3	8.3		
Minimum	2.2	3.6	2.2	3.9	4.5	4.8	3.5	10.9	4
Maximum	52.3	124	40.4	28.1	52.3	23.8	10.2	11.2	13.8
All values in mg/kg									
Distribution (percentiles)									
10	4.1	14.0	3.2	3.9	5.2	5.5	4.8		
25	5.6	39.7	5.5	5.1	5.9	6.7	6.8		
50	10.9	61.3	16.9	8	11.4	10.3	8.3		
75	20.2	80.3	25	14	35.2	13	9		
90	36.7	102.6	31.1	21.1	47.8	18.6	9.7		
95	43.4	110.8	38.7	24.6	49.2	21.2	10.0		

*Specific lithology data removed for statistical analysis

Box & Whisker Plot for Chromium in Auckland Soils



Cumulative Chromium Distribution of Auckland Soils

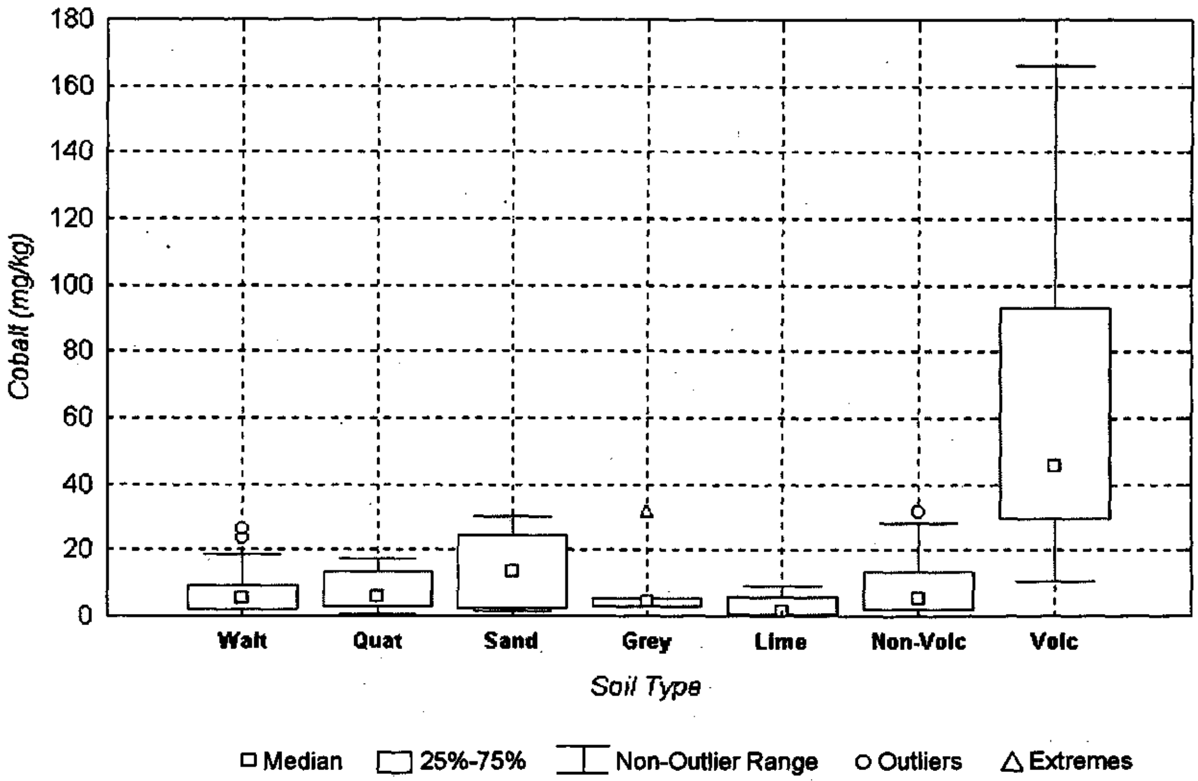


Cobalt	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	54	47	18	11	15	6	4	2	2
Arithmetic mean	9.4	47.5	7.86	7.60	14.61	8.52	3.13		
Standard Deviation	9.2	NA	8.18	5.92	10.84	11.45	4.16		
Geometric Mean	5.19	43.9	4.23	5.04	9.23	5.34	1.56		
Median	5.4	45.7	5.3	5.6	13.6	4.3	1.35		
Minimum	0.2	10.5	0.2	0.5	1.3	2.7	0.5	0.2	2.3
Maximum	31.8	166	26.3	17.1	28.2	31.8	9.3	10.4	7.4

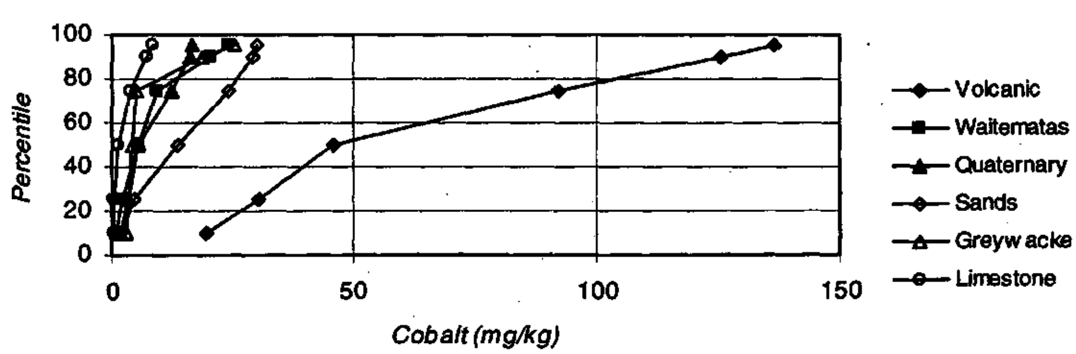
All values in mg/kg

Distribution (percentiles)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
10	1.1	18.5	0.9	1.5	1.5	2.8	0.5		
25	2.4	30.2	2.0	3.2	4.6	3.2	0.6		
50	5.4	45.7	5.3	5.6	13.6	4.3	1.4		
75	15	92	9.1	12	24	5	3.9		
90	24	126	20.1	16	29	18.5	7.1		
95	29	137	24	16	30	25	8.2		

Box & Whisker Plot for Cobalt in Auckland Soils

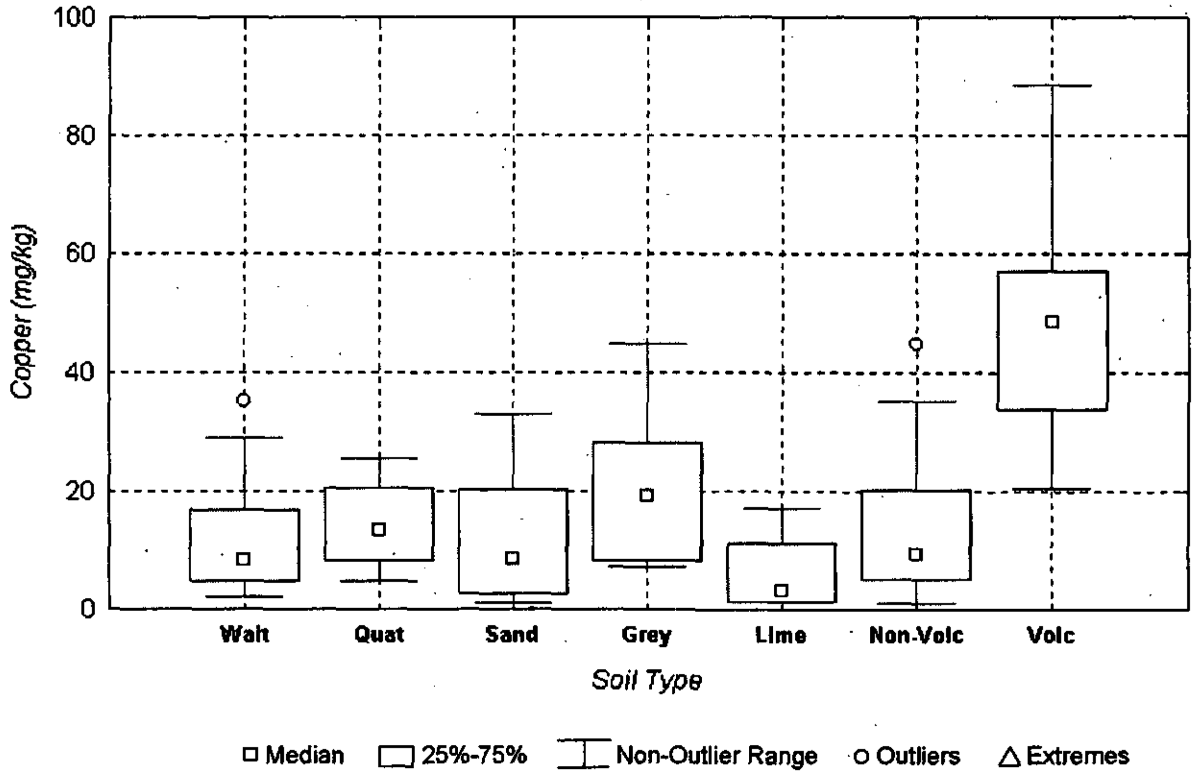


Cumulative Cobalt Distribution of Auckland Soils

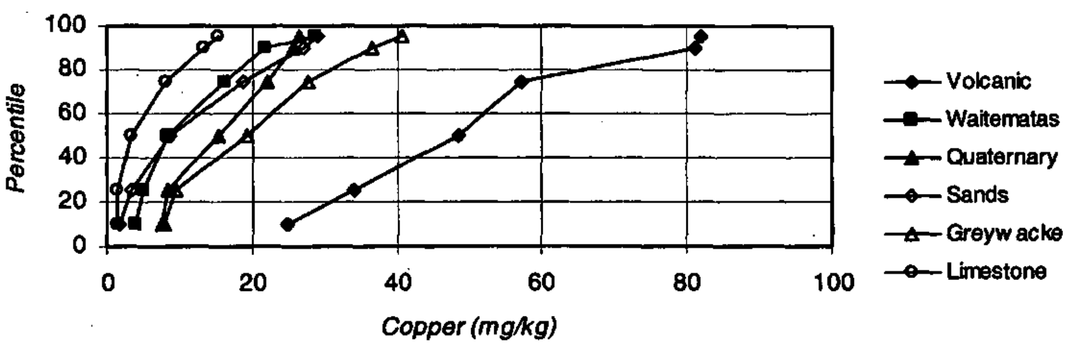


Copper	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	58	42	22	11	15	6	4	2	2
Arithmetic mean	13.1	44.5	11.7	15.5	12.1	21.2	6.3		
Standard Deviation	10.1	NA	9.0	8.00	10.4	14.5	7.4		
Geometric Mean	9.3	43.5	8.9	13.5	7.5	17.2	3.6		
Median	9.8	48.5	8.4	15.2	8.6	19.3	3.3		
Minimum	1.1	20.6	2.2	4.8	1.1	7.3	1.3	4	49.5
Maximum	44.8	88.6	35.3	27.4	33.1	44.8	17.1	8.6	53.2
All values in mg/kg									
Distribution (percentiles)									
10	2.6	24.9	4.0	7.6	1.5	7.9	1.4		
25	5.0	33.9	4.9	8.3	3.3	9.5	1.5		
50	9.8	48.5	8.4	15.2	8.6	19.3	3.3		
75	20.4	57.2	16.1	22.1	18.7	27.6	8.1		
90	27.2	81	21.8	25.7	27.0	36.5	13.5		
95	29.6	82	28.6	26.6	28.9	40.7	15.3		

Box & Whisker Plot for Copper in Auckland Soils



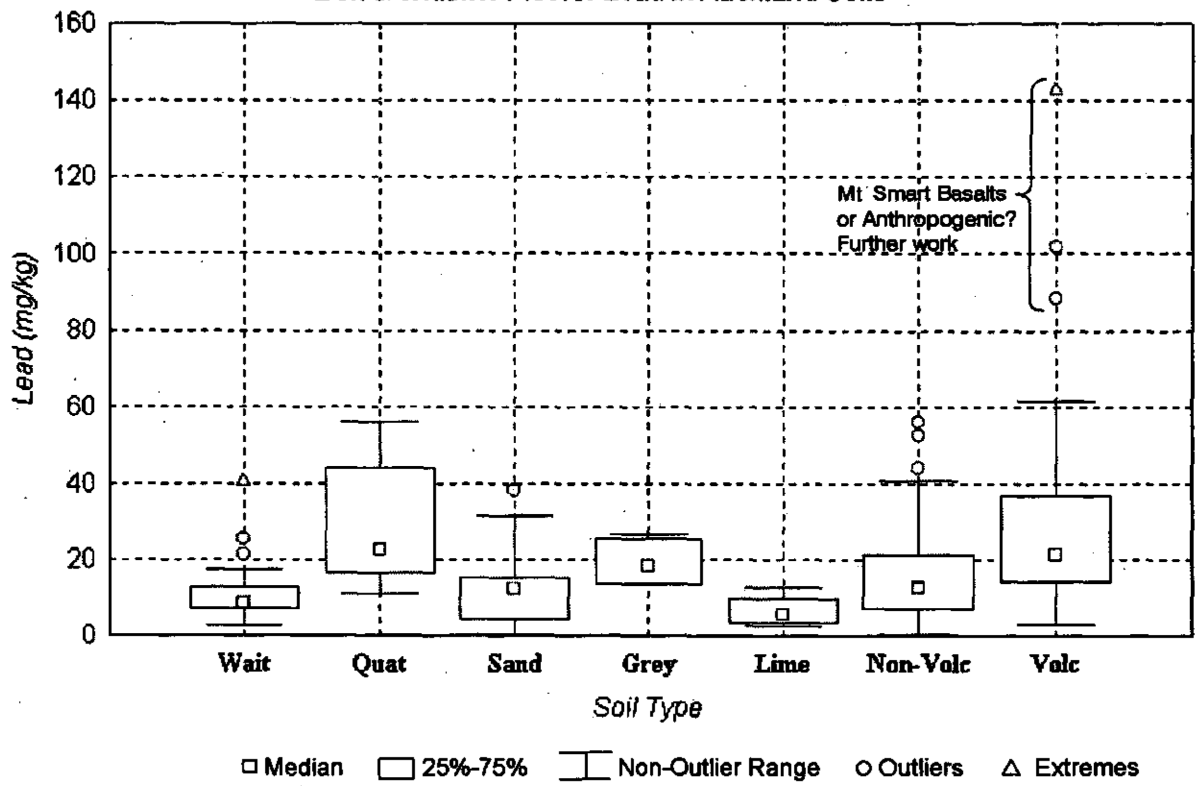
Cumulative Copper Distribution of Auckland Soils



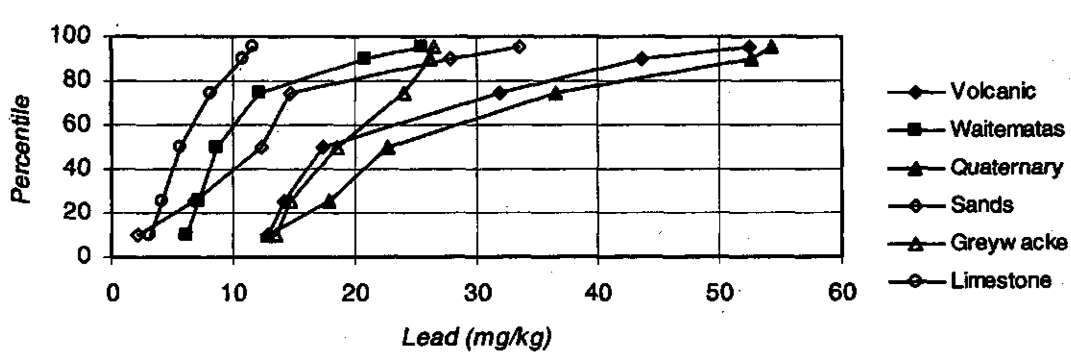
Lead	All Non-Volcanic Soils	Volcanic*	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	58	39	22	11	15	6	4	2	2
Arithmetic mean	15.6	19.8	11.45	28.4	13.3	19.4	6.6		
Standard Deviation	12.2	NA	8.52	15.7	10.5	5.7	4.3		
Geometric Mean	11.6	18.1	9.48	24.8	8.8	18.7	5.6		
Median	12.7	17.3	8.62	22.6	12.4	18.5	5.7		
Minimum	<1.5	3.0	2.78	11.2	<1.5	13.5	2.4	9.13	10.8
Maximum	56.2	60.2	40.9	56.2	38.3	26.7	12.6	13	16
All values in mg/kg									
Distribution (percentiles)									
10	4.0	12.8	6.1	12.9	2.2	13.6	3.1		
25	7.5	14.2	7.2	17.9	6.9	14.7	4.2		
50	12.7	17.3	8.6	22.6	12.4	18.5	5.7		
75	20.7	31.9	12.2	36.5	14.7	24.0	8.1		
90	29.5	43.7	20.8	52.6	27.8	26.2	10.8		
95	41.4	52.4	25.5	54.4	33.5	26.5	11.7		

*Specific lithology data removed for statistical analysis

Box & Whisker Plot for Lead in Auckland Soils



Cumulative Lead Distribution in Auckland Soils

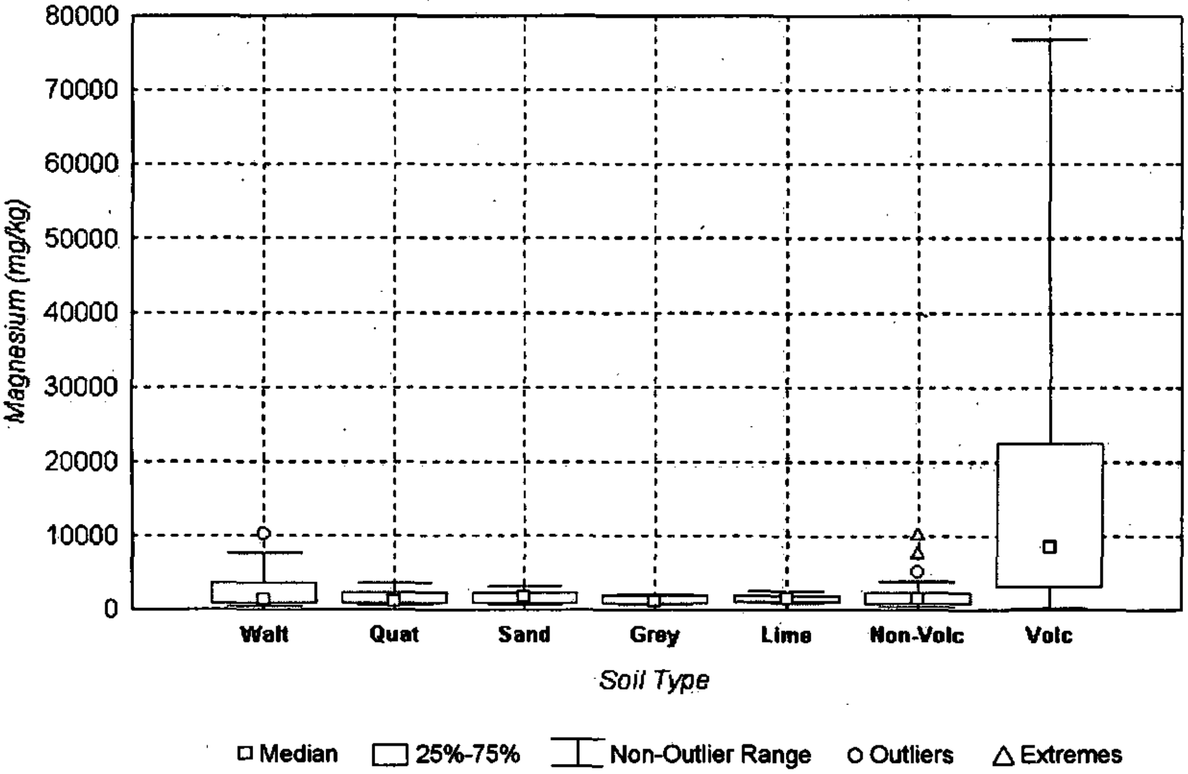


Magnesium	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	34	18	11	12	6	4	2	2
Arithmetic mean	1905	7024	2601	1507	1640	1300	1572		
Standard Deviation	1768	NA	2700	904	796	594	690		
Geometric Mean	1457	6206	1683	1302.36	1444	1185	1458		
Median	1417	8585	1268	1172	1637	1177	1495		
Minimum	474	194	474	645	583	590	814	2312	1283
Maximum	10261	76564	10261	3529	3107	2109	2487	2504	5315

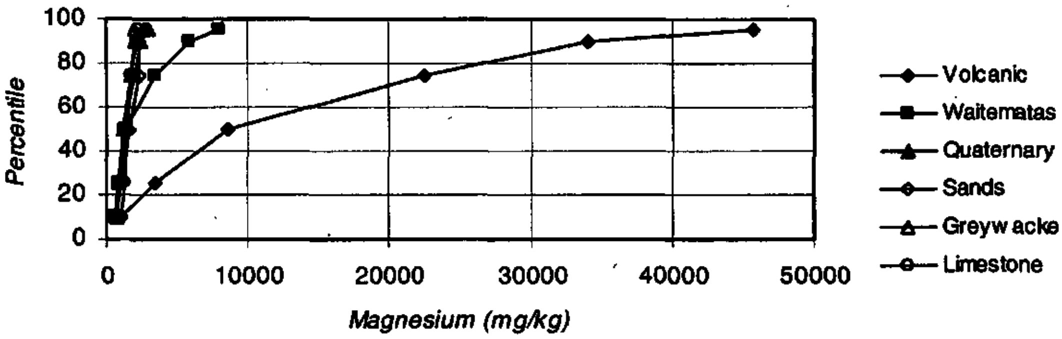
All values in mg/kg

Distribution (percentiles)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
10	645	1046	637	656	652	717	1005		
25	845	3353	805	867	966	925	1291		
50	1417	8585	1268	1172	1637	1177	1495		
75	2334	22513	3475	1950	2237	1723	1776		
90	3529	34070	5846	2411	2323	2006	2203		
95	4477	45693	7968	2970	2676	2058	2345		

Box & Whisker Plot for Magnesium in Auckland Soils



Cumulative Magnesium Distribution of Auckland Soils



Manganese	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands*	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	50	34	18	11	11	6	4	2	2
Arithmetic mean	364	1075	325	364	384	583	157		
Standard Deviation	460	NA	349	395	479	514	206		
Geometric Mean	190	1056	159	210	201	417	86		
Median	308	1076	233	284	376	395	68		
Minimum	13	362	13	39	45	142	28	14	117
Maximum	1704	2484	1121	1391	1704	1460	464	1202	193

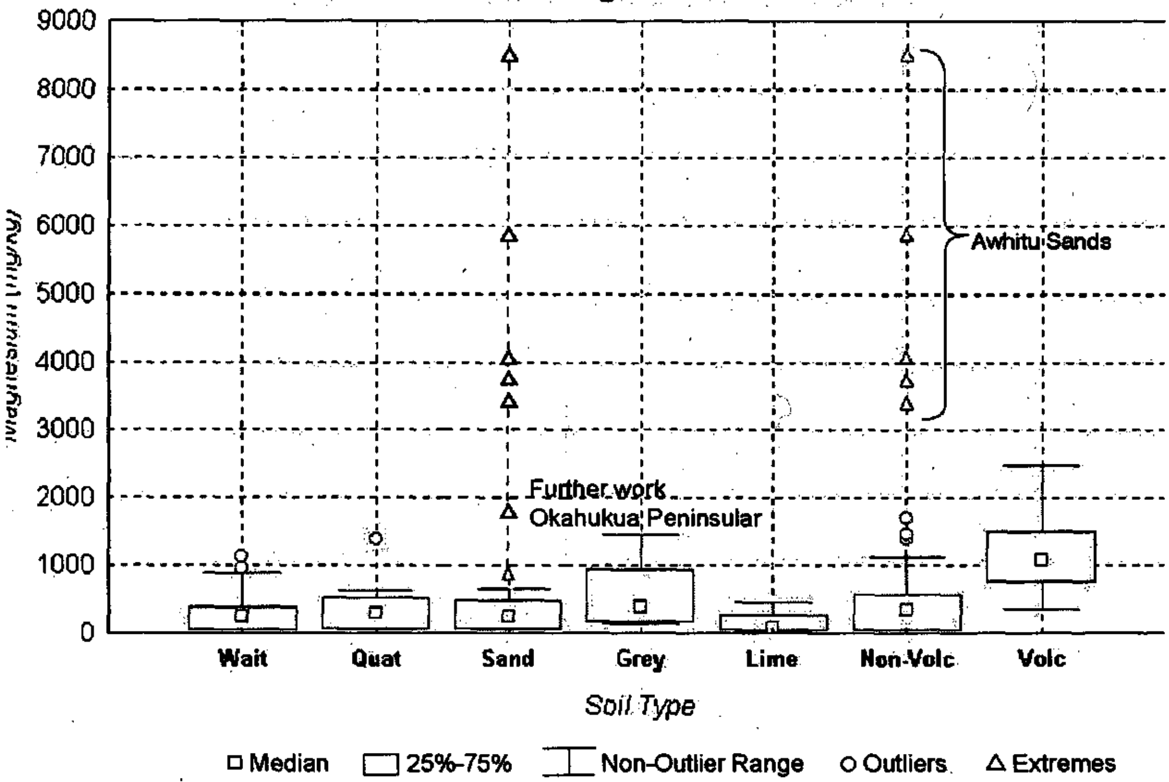
All values in mg/kg

Distribution (percentiles)

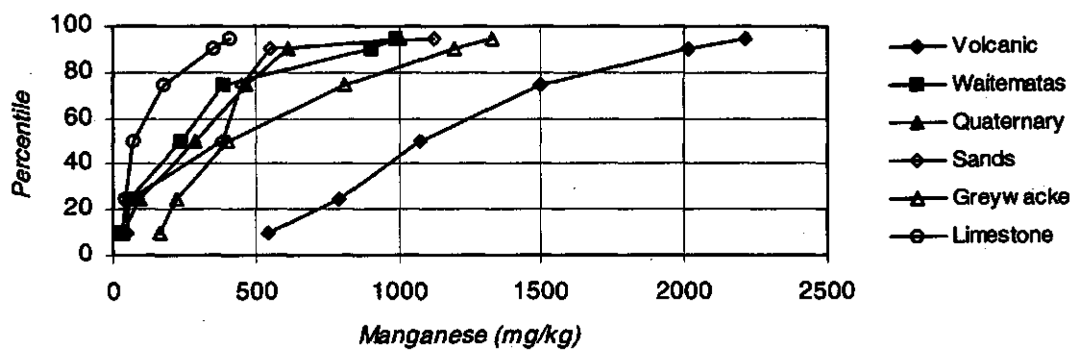
10	39	535	32	39	49	161	35		
25	60	787	57	90	60	219	45		
50	308	1075	233	284	376	395	68		
75	460	1501	382	459	446	806	180		
90	928	2010	903	612	544	1192	350		
95	1270	2214	989	1002	1124	1326	407		

*Specific lithology data removed for statistical analysis

Box & Whisker Plot for Manganese in Auckland Soils



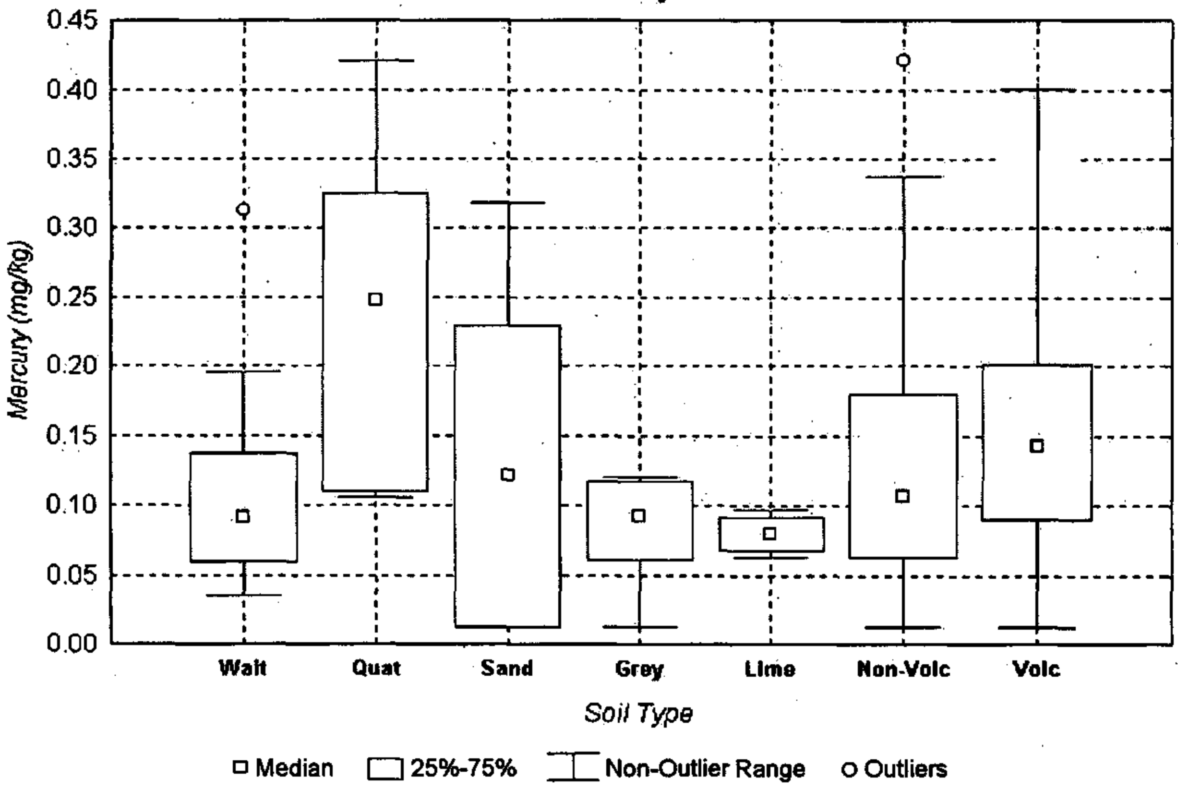
Cumulative Manganese Distribution in Auckland Soils



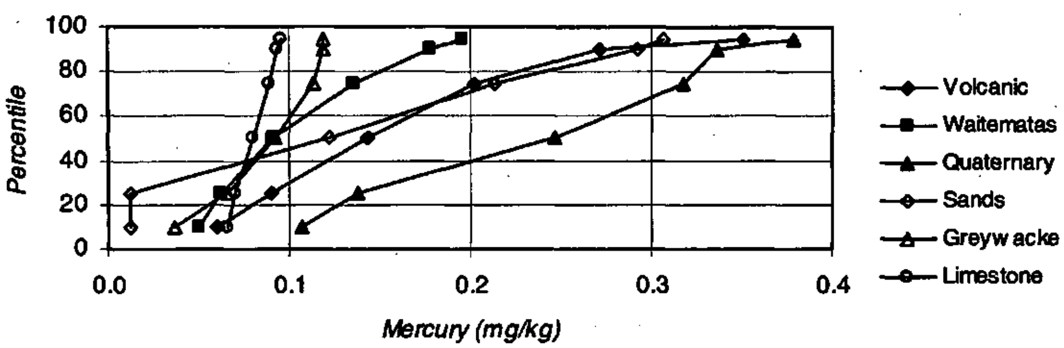
Mercury	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	55	41	22	11	12	6	4	2	2
Arithmetic mean	0.13	0.13	0.11	0.24	0.13	0.08	0.08		
Standard Deviation	0.10	NA	0.06	0.11	0.12	0.04	<0.03		
Geometric Mean	0.10	NA	0.09	0.21	0.07	0.07	0.08		
Median	0.107	0.143	0.091	0.247	0.122	0.093	0.08		
Minimum	<0.03	<0.03	0.035	0.106	<0.03	<0.03	0.063	0.091	0.114
Maximum	0.421	0.401	0.313	0.421	0.319	0.12	0.097	0.099	0.245
All values in mg/kg									
Distribution (percentiles)**									
10	0.040	0.060	0.050	0.107	0.013	0.037	0.066		
25	0.065	0.090	0.062	0.138	0.013	0.066	0.071		
50	0.107	0.143	0.091	0.247	0.122	0.093	0.080		
75	0.175	0.202	0.136	0.318	0.214	0.114	0.089		
90	0.307	0.271	0.177	0.337	0.292	0.119	0.094		
95	0.321	0.351	0.195	0.379	0.306	0.119	0.095		

**where values are less than the analytical detection limit of 0.03 mg/kg, a value of half that was used (0.015 mg/kg) for statistical purposes

Box & Whisker Plot for Mercury in Auckland Soils

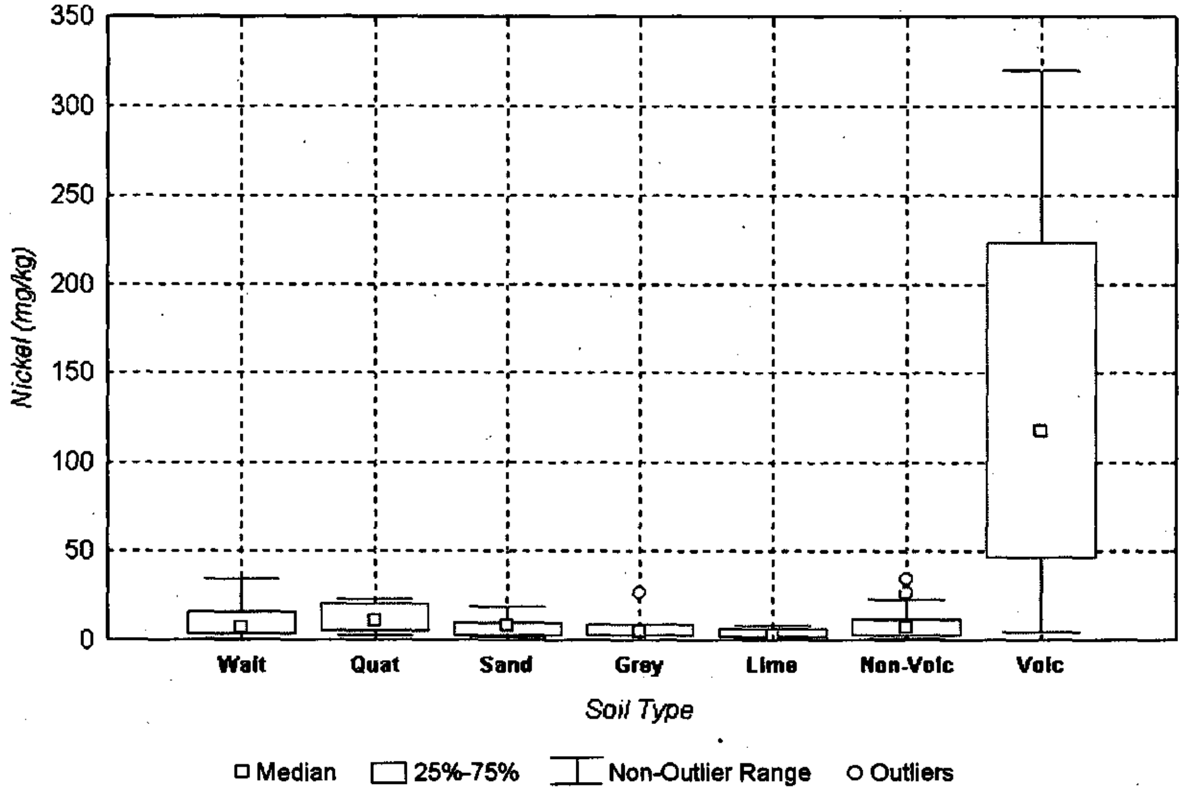


Cumulative Mercury Distribution of Auckland Soils

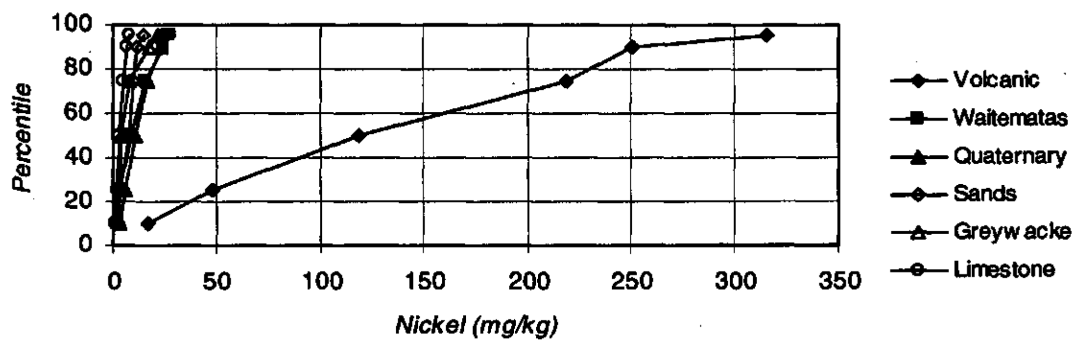


Nickel	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	38	18	11	12	6	4	2	2
Arithmetic mean	9.4	87.3	11.1	11.5	7.4	8.3	3.7		
Standard Deviation	7.9	NA	9.6	7.6	4.8	9.2	3.2		
Geometric Mean	6.5	73.9	7.2	9.1	5.9	5.6	2.7		
Median	7.1	118	9.2	10.7	8	4.3	2.7		
Minimum	0.9	4.6	0.9	2.7	1.9	2.7	0.9	2.5	4.96
Maximum	34.1	320	34.1	23.3	18.1	26.3	8.3	6.6	5.4
All values in mg/kg									
Distribution (percentiles)									
10	2.1	16.4	2.1	2.8	2.0	2.9	1.3		
25	3.0	47.7	3.3	5.7	3.1	3.0	1.8		
50	7.1	118	9.2	10.7	8.0	4.3	2.7		
75	11.9	219	15.5	16.4	9.5	8.1	4.6		
90	23.2	252	24.0	23.2	11.5	17.6	6.8		
95	24.6	315	27.0	23.3	14.6	22.0	7.5		

Box & Whisker Plot for Nickel in Auckland Soils

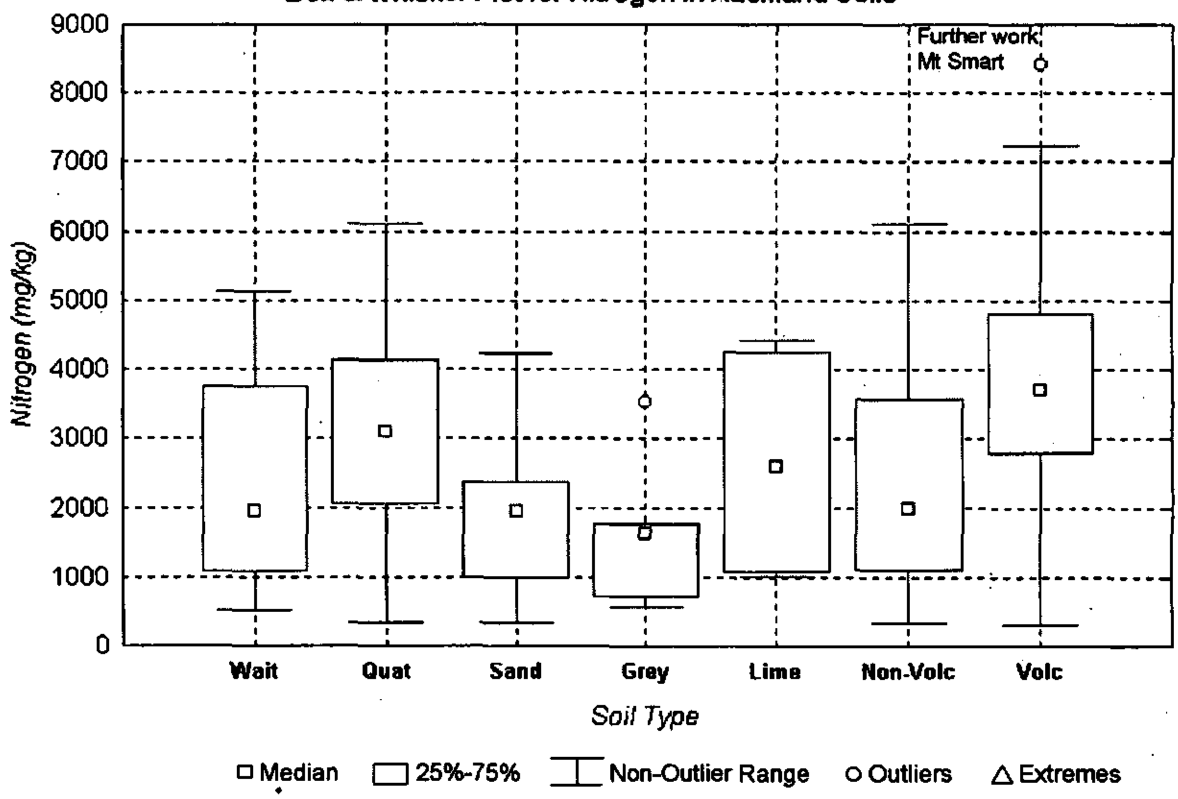


Cumulative Nickel Distribution in Auckland Soils

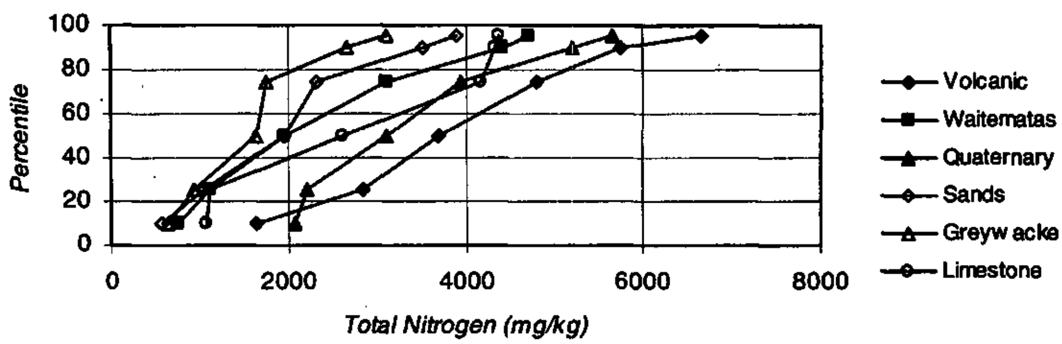


Nitrogen (Total)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	34	18	11	12	6	4	2	2
Arithmetic mean	2340.10	3745.18	2260.89	3203.64	1906.58	1641.50	2670.25		
Standard Deviation	1448.70	1769.17	1433.39	1592.94	1166.29	1059.50	1836.96		
Geometric Mean	1869.03	3198.08	1838.10	2668.79	1539.40	1374.85	2146.08		
Median	1982	3699.5	1939	3101	1952	1624	2613		
Minimum	336	324	532	346	336	558	1028	1495	1500
Maximum	6108	8422	5141	6108	4224	3535	4427	3392	3543
All values in mg/kg									
Distribution (percentiles)									
10	607	1633	746	2066	577	645	1062		
25	1112	2825	1104	2199	1033	940	1113		
50	1982	3700	1939	3101	1952	1624	2613		
75	3476	4796	3104	3938	2322	1753	4171		
90	4322	5760	4419	5202	3511	2656	4324		
95	4893	6671	4719	5655	3894	3095	4376		

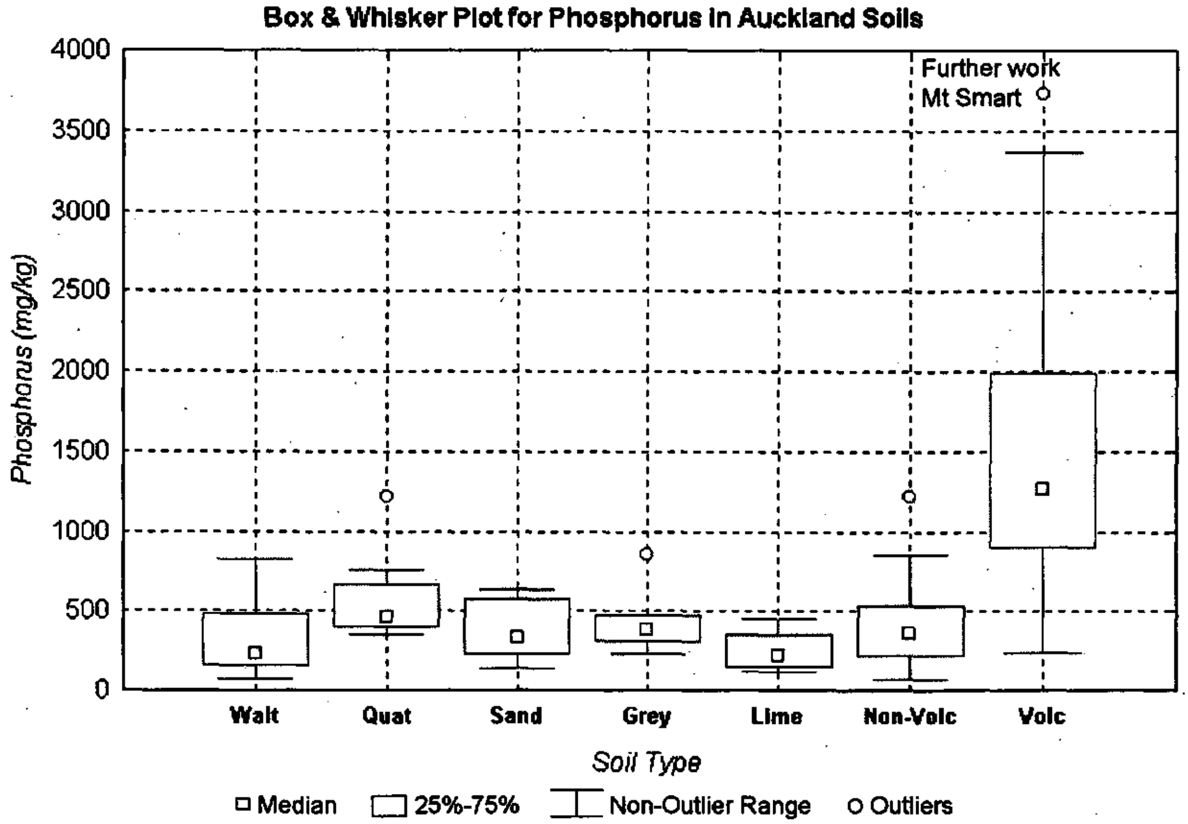
Box & Whisker Plot for Nitrogen in Auckland Soils

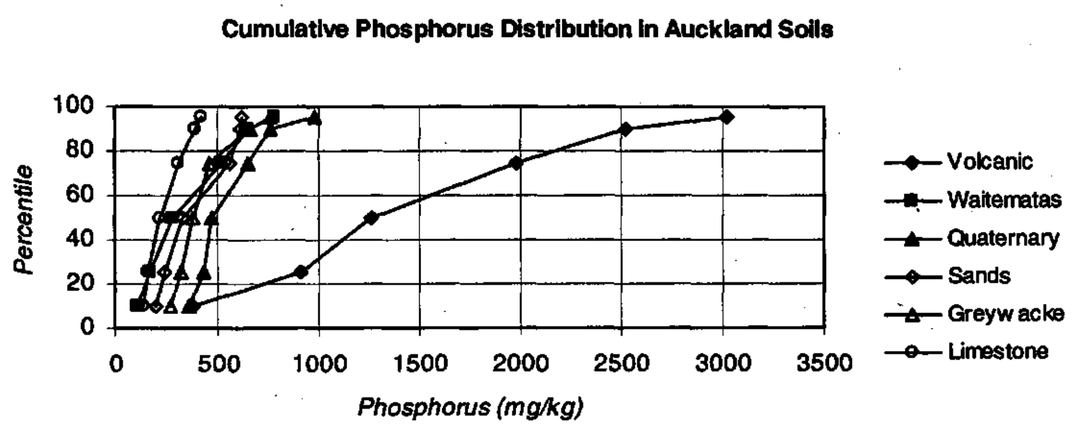


Cumulative Nitrogen Distribution in Auckland Soils



Phosphorus	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	34	18	11	12	6	4	2	2
Arithmetic mean	411	1180	358	568	386	439	251		
Standard Deviation	230	NA	233	250	181	222	144		
Geometric Mean	347	1141	284	530	345	401	222		
Median	401	1265	280	465	331	380	219		
Minimum	76	246	76	350	140	233	117	223	188
Maximum	1213	3729	824	1213	633	855	448	348	420
All values in mg/kg									
Distribution (percentiles)									
10	140	383	113	363	198	275	135		
25	235	914	166	428	235	317	162		
50	401	1264	280	465	331	380	219		
75	540	1978	519	649	561	463	307		
90	666	2513	649	756	610	663	392		
95	797	3007	778	985	621	759	420		



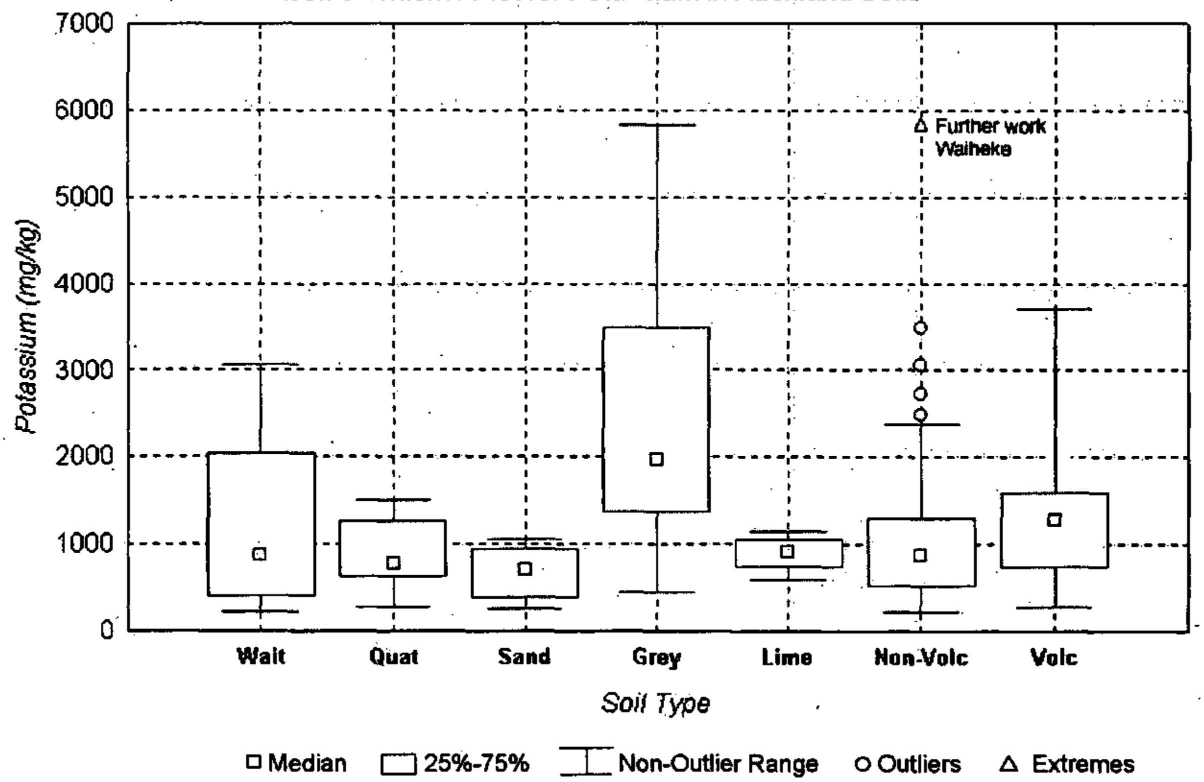


Potassium	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	34	18	11	12	6	4	2	2
Arithmetic mean	1137	1118	1204	855	683	2516	900		
Standard Deviation	1006	NA	918	388	298	1925	231		
Geometric Mean	865	1091	893	771	615	1897	875		
Median	867	1275	878	777	713	1965	919		
Minimum	226	275	226	281	259	448	601	1580	434
Maximum	5840	3660	3070	1510	1060	5840	1160	1890	1340

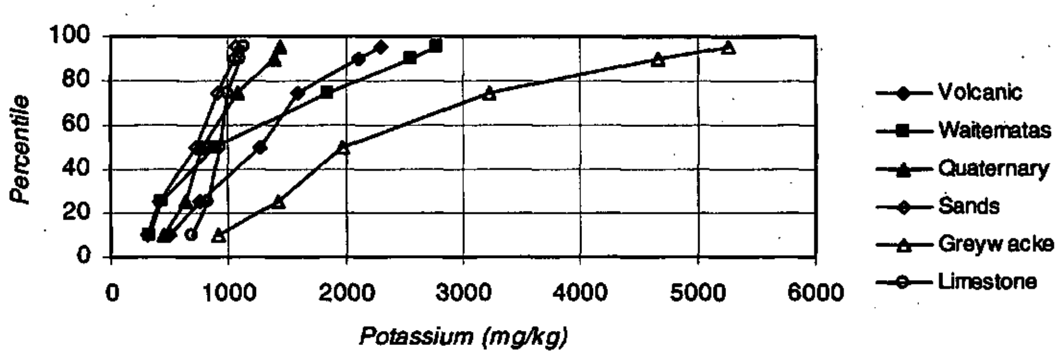
All values in mg/kg

Distribution (percentiles)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
10	348	494	326	447	312	914	687		
25	534	748	431	636	415	1423	816		
50	867	1275	878	777	713	1965	919		
75	1285	1595	1855	1088	910	3220	1002		
90	2380	2101	2562	1380	1047	4670	1097		
95	2900	2283	2781	1445	1055	5255	1128		

Box & Whisker Plot for Potassium in Auckland Soils



Cumulative Potassium Concentrations of Auckland Soils

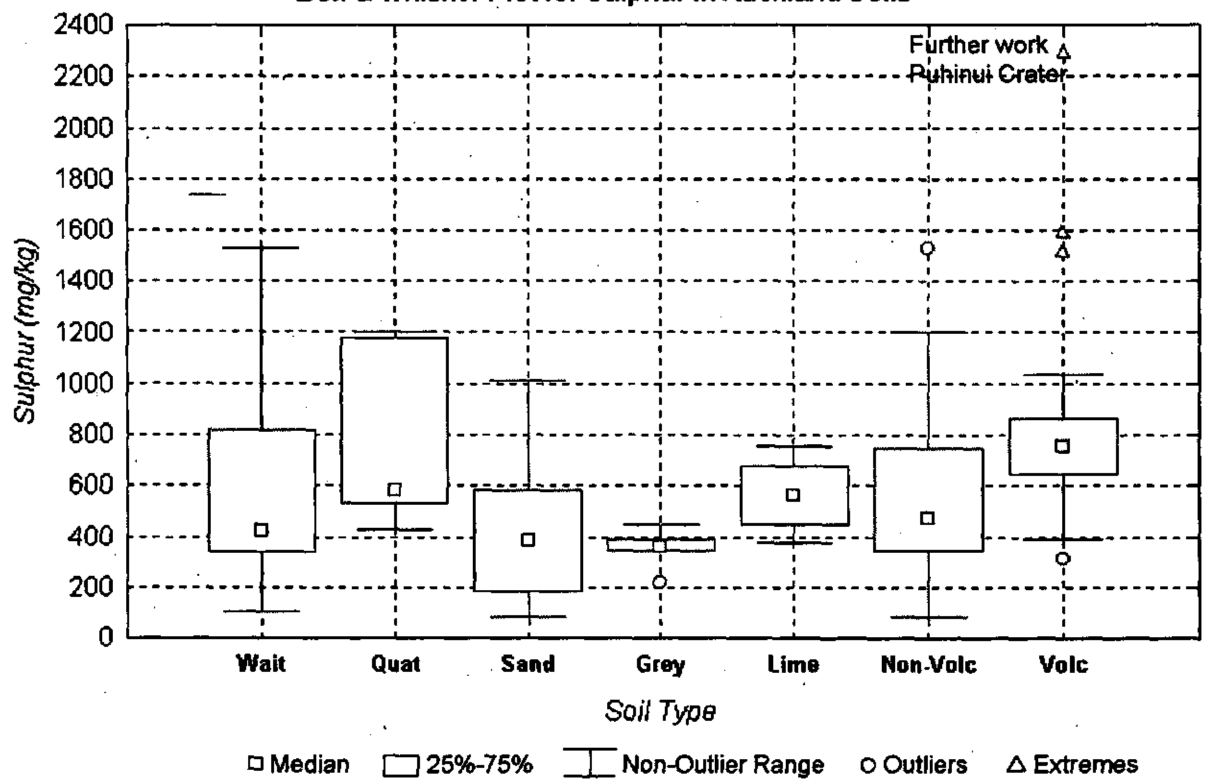


Sulphur	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	50	34	17	11	12	6	4	2	2
Arithmetic mean	565.74	740	621.88	749.27	424.00	353.83	565.50		
Standard Deviation	331.81	NA	401.11	301.64	281.51	75.98	158.71		
Geometric Mean	467.72	731	490.90	699.40	333.10	345.92	548.06		
Median	500	758	586	585	384.5	359.5	566		
Minimum	85	313	103	426	85	219	375	255	597
Maximum	1532	2288	1532	1202	1009	448	755	537	767

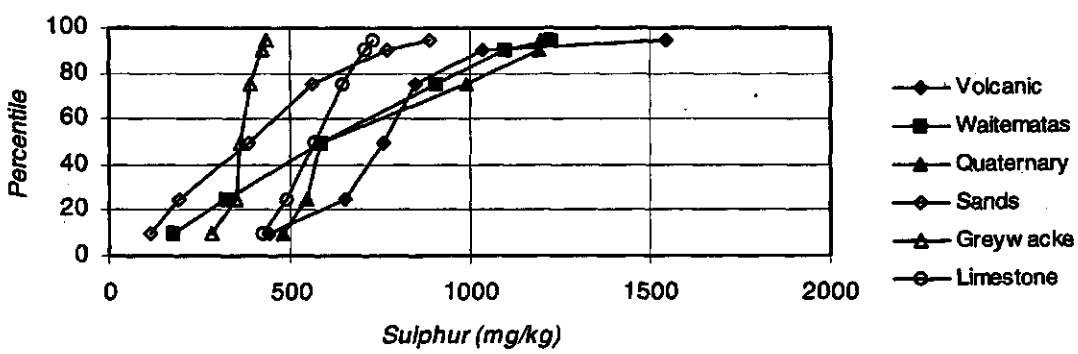
All values in mg/kg

Distribution (percentiles)	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
10	180	437	175.2	475	110.7	282	420		
25	346	654	322	545.5	192.75	346	487.5		
50	500	758	586	585	384.5	359.5	566		
75	753.25	848	902	990	563.25	386.5	644		
90	1072.1	1033	1096.4	1191	770.1	420	710.6		
95	1185.15	1545	1222.4	1196.5	886.9	434	732.8		

Box & Whisker Plot for Sulphur in Auckland Soils



Cumulative Sulphur Distribution in Auckland Soils

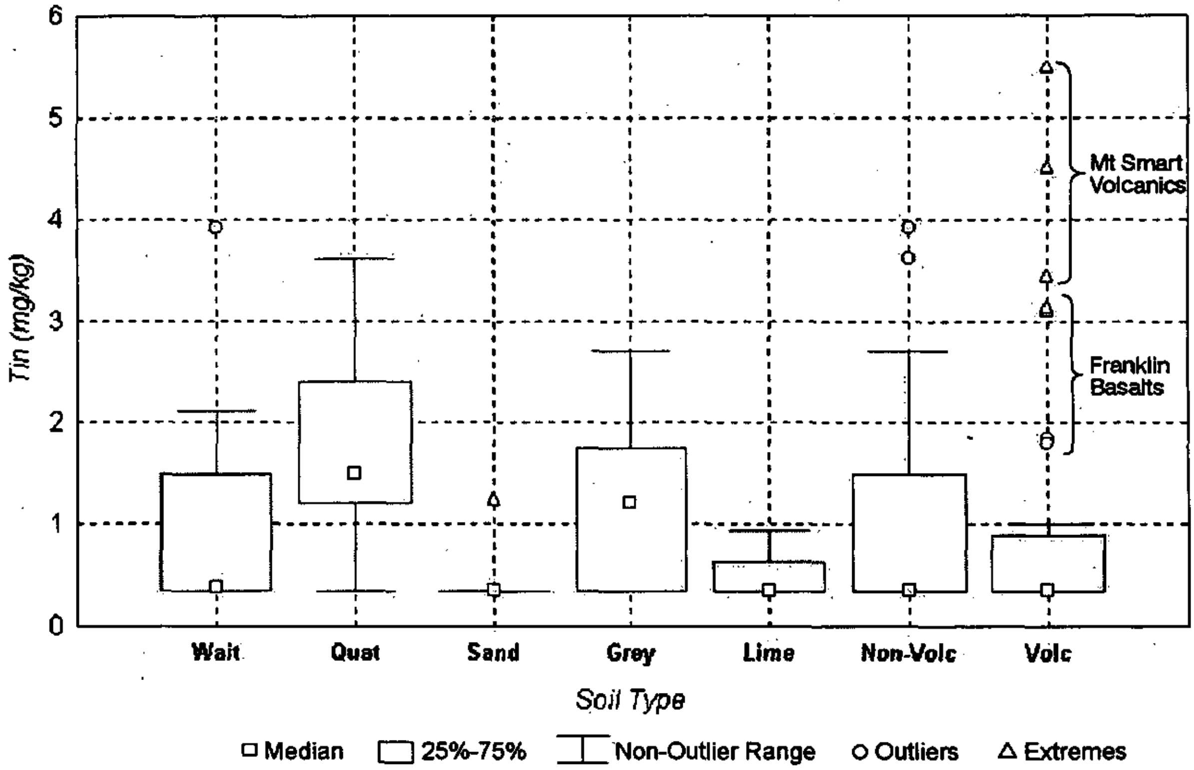


Tin	All Non-Volcanic Soils	Volcanic*	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	53	33	22	9	12	6	4	2	2
Arithmetic mean	0.94	0.42	0.89	1.73	0.42	1.26	0.50		
Standard Deviation	0.89	0.18	0.91	1.05	0.26	0.92	0.30		
Geometric Mean	0.65	0.39	0.62	1.35	0.39	0.96	0.45		
Median	0.35	0.35	0.375	1.5	0.35	1.205	0.35		
Minimum	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Maximum	3.91	1	3.91	3.61	1.24	2.71	0.94	2.16	3.69
All values in mg/kg									
Distribution (percentiles)**									
10	0.35	0.35	0.35	0.35	0.35	0.35	0.35		
25	0.35	0.35	0.35	1.21	0.35	0.49	0.35		
50	0.35	0.35	0.38	1.50	0.35	1.21	0.35		
75	1.49	0.35	1.41	2.41	0.35	1.70	0.4975		
90	2.16	1	1.86	2.67	0.35	2.24	0.763		
95	2.5	1	2.10	3.14	0.75	2.47	0.8515		

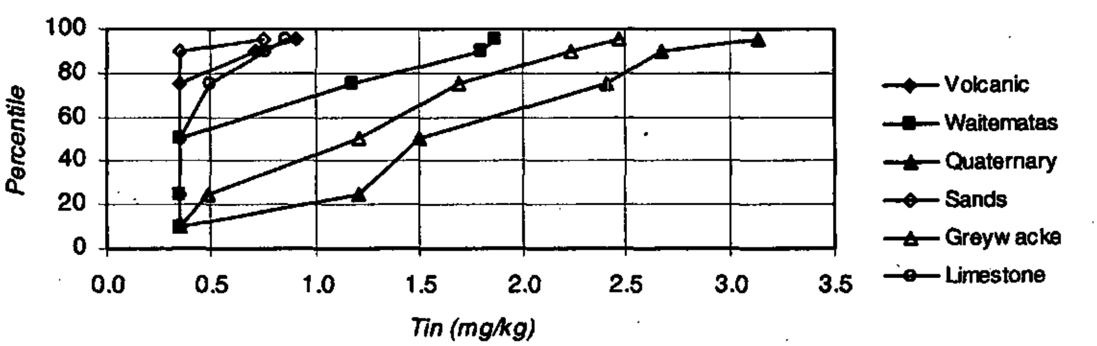
*Specific lithology data removed for statistical analysis

**where values are less than the analytical detection limit of 0.7 mg/kg, a value of half that was used (0.35 mg/kg) for statistical purposes

Box & Whisker Plot for Tin in Auckland Soils

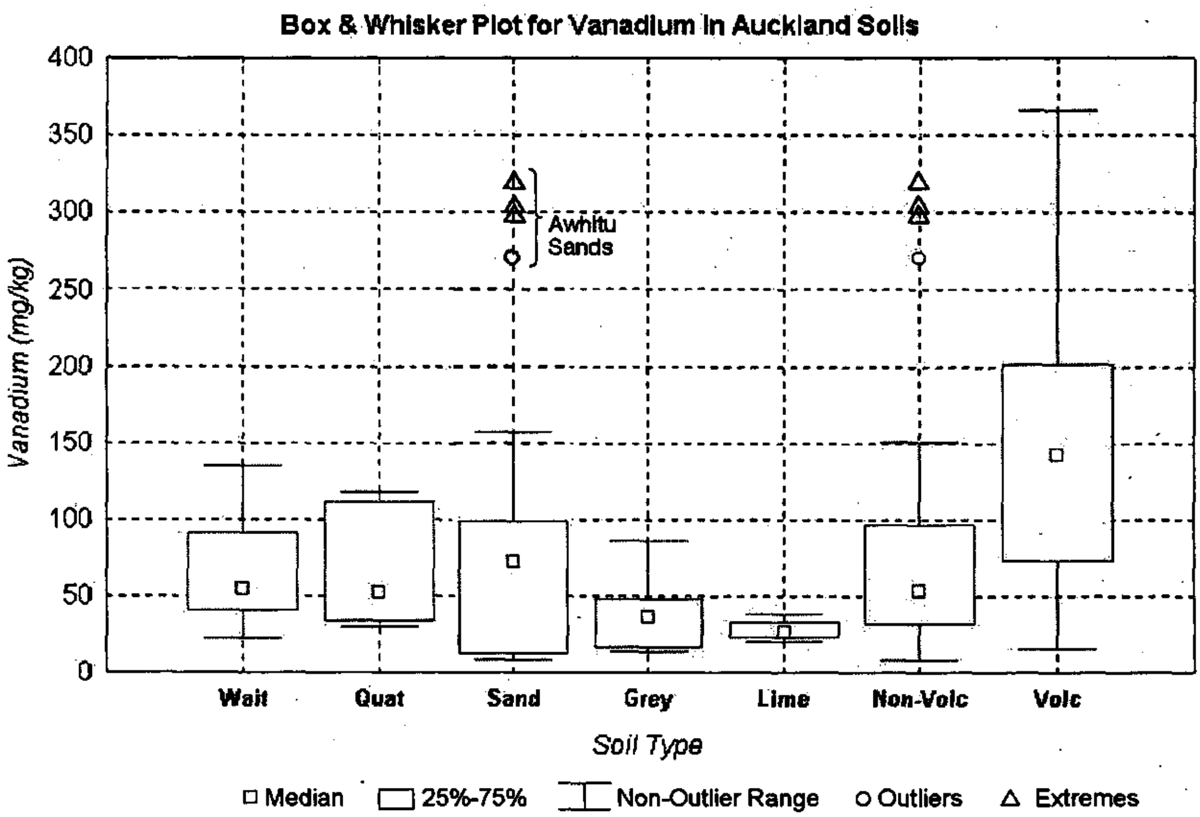


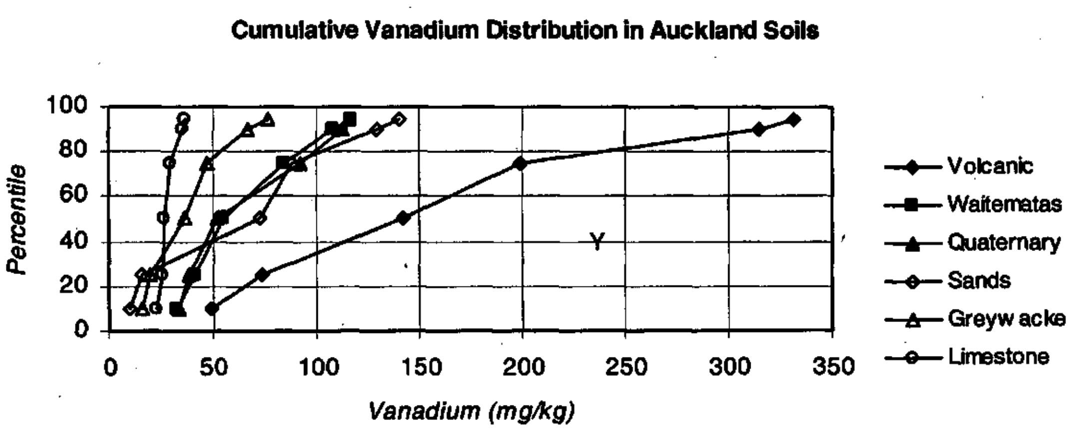
Cumulative Tin Distribution in Auckland Soils



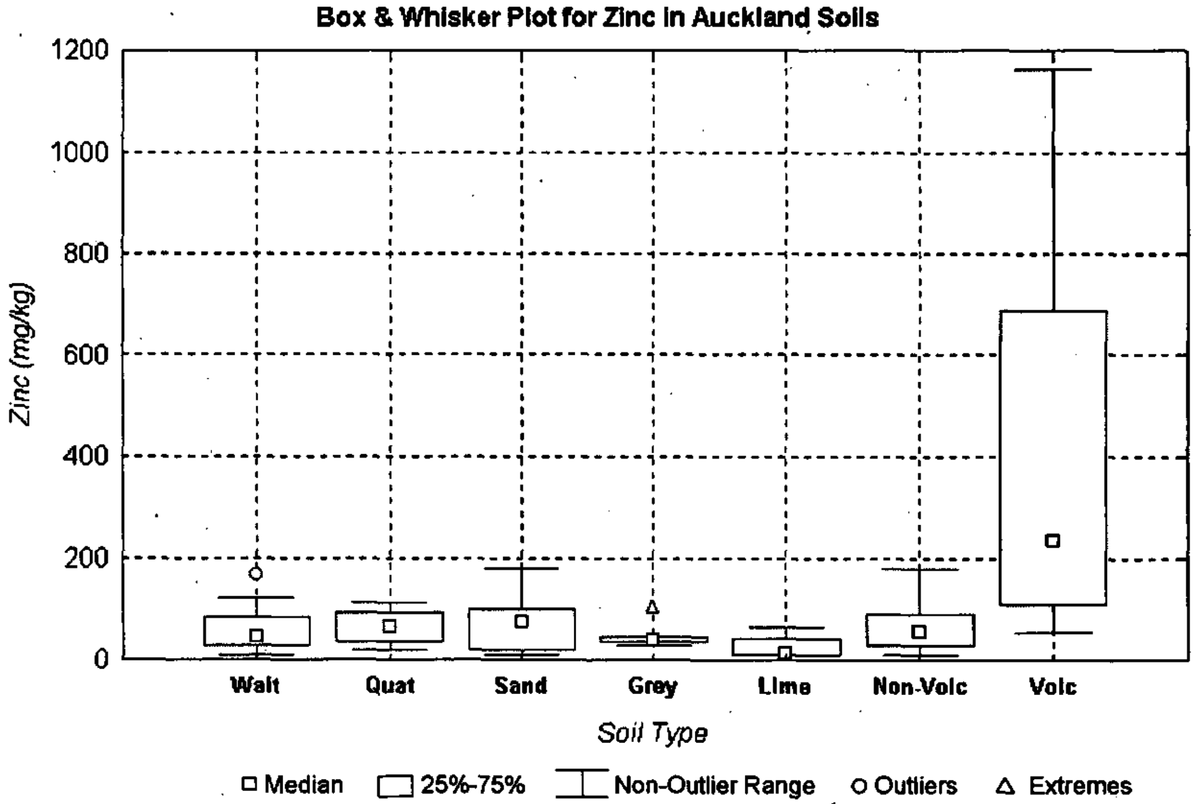
Vanadium	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands*	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	50	40	18	11	11	6	4	2	2
Arithmetic mean	58.7	123	63.6	64.9	66.1	39.6	28.1		
Standard Deviation	36.2	NA	31.9	34.2	49.1	26.9	7.4		
Geometric Mean	47.4	116	56.7	57.4	43.8	32.6	27.4		
Median	48.5	142	55.3	51.8	72.3	36.5	26.8		
Minimum	8.6	15.6	21.9	30.1	8.6	14	20.6	14.7	362
Maximum	151	366	135	118	151	86.1	38.4	37.4	506
All values in mg/kg									
Distribution (percentiles)									
10	18.8	49	32.2	33	9.6	15.5	22.4		
25	30.8	74	41.1	38	15.6	19.4	25.0		
50	48.5	142	55.3	51.8	72.3	36.5	26.8		
75	80.8	199	84.7	92.5	88.3	47.4	29.9		
90	113	314	108	113	129	66.9	35.0		
95	124	331	117	116	140	76.5	36.7		

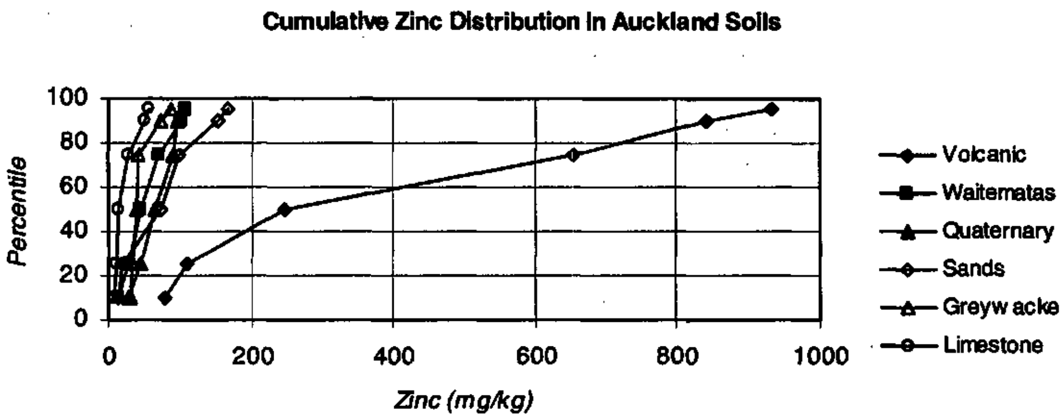
*Specific lithology data removed for statistical analysis





Zinc	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	38	18	11	12	6	4	2	2
Arithmetic mean	58.7	252	54.3	66.1	75.1	48.1	25.3		
Standard Deviation	39.1	NA	33.1	30.0	55.5	27.4	26.0		
Geometric Mean	45.3	233	43.7	58.7	52.3	43.7	18.2		
Median	52.1	247	45.8	63.9	74.3	39.2	14.1		
Minimum	9.2	54.5	9.6	21	10.7	29.8	9.2	27.2	143
Maximum	179	1160	123	111	179	103	63.9	36.5	333
All values in mg/kg									
Distribution (percentiles)									
10	12.8	80	14.9	28.2	13.2	31.9	9.6		
25	28.2	110	29.1	44.5	19.7	34.5	10.2		
50	52.1	246	45.8	63.9	74.3	39.2	14.1		
75	86.2	654	71.1	91.3	98.0	43.3	29.3		
90	106	840	100.6	96.6	152.8	73.4	50.0		
95	117	931	108.6	103.8	167.5	88.2	57.0		





Total Organic Carbon	All Non-Volcanic Soils	Volcanic	Waitematas	Quaternary	Sands	Greywacke	Limestone	Onerahi	Manukau Brec
Samples above detection	51	34	18	11	12	6	4	2	2
Arithmetic mean	3.66	5.20	3.69	5.33	2.65	2.72	3.32		
Standard Deviation	2.31	2.41	2.04	3.30	1.55	1.34	0.84		
Geometric Mean	3.05	4.60	3.08	4.66	2.24	2.42	3.25		
Median	3.2	4.74	3.53	3.89	2.175	2.375	3.025		
Minimum	0.63	0.85	0.63	2.14	0.85	0.96	2.68	2.47	2.91
Maximum	13.96	11.64	7.93	13.96	5.39	4.69	4.54	4.63	7.19
All values in % dry wt.									
Distribution (percentiles)									
10	1.21	2.118	1.442	2.65	1.057	1.51	2.731		
25	2.185	3.9725	2.3725	3.615	1.39	2.1275	2.8075		
50	3.2	4.74	3.53	3.89	2.175	2.375	3.025		
75	4.615	6.4325	4.875	6.33	3.695	3.5	3.535		
90	6.43	8.272	6.553	7.45	4.913	4.275	4.138		
95	7.145	9.8865	7.0035	10.705	5.1645	4.4825	4.339