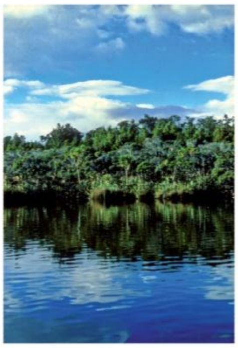

Determining background soil concentrations of contaminants for managing land

Envirolink Advice Grant 1251-MLDC83

Landcare Research
Manaaki Whenua

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Contents

Summary

Project and Client

- This report presents recommendations for a nationally consistent approach to the determination of background concentrations of contaminants in soil. It reviews international and national approaches, identifying data sources for New Zealand, and considers the regulatory context for applying of this information. This project was undertaken for Marlborough District Council between October 2012 and May 2013 with funding from Envirolink (Advice Grant 1251-MLDC83).

Objectives

- Review national and international approaches to determining background concentrations of inorganic and organic contaminants for use in the management of contaminated land.
- Provide an overview of the regulatory context in which background soil concentrations are applicable.
- Recommend methodologies for determining background soil concentrations of chemical substances, including for areas with disturbed soils.

Methods

- Review of the scientific and grey literature was undertaken using electronic database searches, and the Internet. In addition, regional council representatives provided data and comments on approaches used nationally.
- Two approaches to providing a nationally consistent approach were investigated: the use of predictive relationships for background concentrations of As, Cu, Pb, Ni, Zn that were suggested to be globally applicable; the use of spatial tools to extend the spatial relevance, and relate the data collected to additional information, e.g. soil properties and geological information.

Results

- There are various terms used to describe background soil concentrations of naturally occurring trace elements, and some organic compounds. These terms may be used interchangeably, or used differently in different contexts. Ambient (or ‘normal’) background, which is naturally occurring concentrations plus concentrations arising from diffuse pollution such as motor vehicles, is the predominant form of background used in the international regulatory context.
- The regulatory context for the use of ‘background’ concentrations, nationally and internationally, includes soil quality, and managing contaminated land and waste (e.g. disposal of clean fill, application of biosolids to land).
- In the last decade particularly in Europe, there has been a substantial effort placed in determining the ambient background concentrations of various trace elements for

managing land. These studies have typically involved large-scale systematic sampling, with detailed data analysis using spatial techniques.

- Data analysis can be broadly grouped into two approaches; descriptive and predictive. Descriptive data analysis approaches rely on statistical analysis to describe the distribution of the data, and generate ‘upper limits to background variation’. Predictive data analysis approaches relate the concentration of substances of interest to particular soil properties (e.g. clay, pH) or other elements (e.g. Fe, Total P).
- There is a relatively consistent approach used in the statistical analysis of the geochemical data for defined sampling ‘subsets’ of interest. These subsets of interest may be predefined, or determined through the use of more complex geostatistical analysis.
- In New Zealand, various approaches to determining background concentrations have been used, including sampling on a regional basis and compilation of data to develop national estimates of background concentrations. There are recognised gaps in spatial coverage.
- Investigation of previously published predictive relationships for determining background concentrations, using data from 106 regional council background sites, suggests these relationships developed internationally are not applicable to New Zealand soils.
- S-Map and LRIS could be useful tools to extend the spatial relevance of data and could also be used to identify key factors influencing background concentrations across New Zealand, although only the LRIS currently has national coverage.

Recommendations

- Further analysis of existing data, including the use of spatial tools to provide preliminary identification of key factors influencing trace element concentrations (recognising there are gaps in spatial coverage) and to identify whether predictive relationships can be developed.
- Collection and/or analysis of archived samples to ‘fill the gaps’ in spatial coverage based on a national systematic survey design is required. Nationally consistent site and sample information need to be recorded – at minimum soil order, land-use type, GPS location, soil parent material – for any new samples collected.
- A consistent sampling collection methodology should be used, and samples (archived or fresh) analysed for a consistent suite of analytes and soil parameters. A minimum of 20 samples is recommended for determining background concentrations for a defined group.
- Development of a spatial database to hold information that links or is part of existing spatial tools such as S-Map should be undertaken, to provide a central repository for data, and to allow ongoing data analysis. This spatial database should also allow for the inclusion of data from all land uses to maximise the value of the database and allow for the influence of land use on trace element concentrations to be assessed.

1 Introduction

Nationally and internationally there is an increased focus on how to determine ‘background’ concentrations of contaminants for the purposes of managing land. This focus has often been the result of legislative imperatives; for example, Johnson and Demetriades (2011) highlight nine European Commission (EC) Directives driving demand for harmonised geochemical baseline data across European political borders. These include the EC Sewage Sludge Directive (86/278/EEC), the proposed EC Soil Protection Directive, the EC Mine Waste Directive (2006/21/EC) and the EC Landfill Directive (1999/31/EC). Geochemical baseline data are required for the monitoring and modelling of impacts of activities on the environment or to provide a baseline against which any future changes can be measured.

In New Zealand, the National Environmental Standard for assessing and managing contaminants in soil to protect human health (the NES), which came into force on 1 January 2012, places an increased focus on ‘background’ soil concentrations, as the NES does not apply ‘if contaminants in or on the piece of land of interest are at, or below background concentrations’. In addition, in developing the soil contaminant standards (SCS) for these contaminants, consideration was given to background concentrations of arsenic and cadmium (MfE 2011a). For arsenic, the ‘background concentration’ (defined as the 99th percentile concentration in soils collected from around the country and thought not to have been affected by anthropogenic activities) was used as the SCS for the rural residential land-use scenario, as the derived value for this scenario was below this concentration.

For cadmium also, the background concentration (once again defined as the 99th percentile concentration of cadmium in soils collected from around the country and thought not to have been affected by anthropogenic activities) is used to define the first tier of the Tiered Fertiliser Management System for Cadmium (MAF 2011). From a soil quality perspective, knowing the variation in naturally occurring concentrations of trace elements including cadmium in agricultural land assists in determining the rate of accumulation, and identifying potential risks associated with anthropogenically applied trace elements such as fertiliser-derived cadmium. Similarly, understanding the variability and range of background concentrations of chemical substances may be of use in determining criteria for waste accepted at clean fills, and also for understanding the potential impacts from applying biosolids to land.

However, there is a lack of national guidance on how to determine background concentrations in soils, and how this should be considered in the context of managing land. Furthermore, there is confusion around the term ‘background’, which has a complex and varied usage in different areas of science or for different purposes (e.g. Matschullat et al. 2000; Reimann & Garrett 2005; Reimann et al. 2005). This includes background as being only naturally occurring concentrations, or being naturally occurring concentrations plus concentrations arising from diffuse anthropogenic contamination.

This report provides an overview of international and national approaches to determining background concentrations, identifies data sources for New Zealand, and provides the regulatory context for the application of this information. This is then used to provide recommendations for a nationally consistent approach to determining background concentrations. This project was undertaken for Marlborough District Council between October 2012 and May 2013 with funding from Envirolink (Advice Grant 1251-MLDC83).

2 Objectives

- Review national and international approaches to determining background concentrations of inorganic and organic contaminants for use in the management of contaminated land.
- Provide an overview of the regulatory context in which background soil concentrations are applicable.
- Recommend methodologies for determining background soil concentrations of chemical substances, including for areas with disturbed soils.

3 Methods

A review of national and international approaches to determining background concentrations of chemical substances in soil was undertaken using electronic databases to source journal publications and from general Internet searching. In addition, information on national approaches and existing data were provided directly by representatives from some regional councils.

Two approaches to providing a nationally consistent approach were investigated: the use of predictive relationships for background concentrations of arsenic (As), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) that were suggested to be applicable globally; and the use of spatial tools to extend the spatial relevance of existing data and to relate data collected to additional information (e.g. soil properties, geological information).

4 Definitions

Only naturally occurring substances are considered in the context of background concentrations. This includes the range of elements, but also applies to some organic compounds, in particular polycyclic aromatic hydrocarbons (PAH), which can have natural origins (e.g. bushfires). There are numerous terms used to define the ‘background’ concentrations of chemical substances in soil, including normal, typical, baseline, ambient, characteristic, natural, background and widespread. These terms are often used interchangeably or can be defined differently in different contexts (see Matschullat et al. (2000), Reimann & Garrett (2005) and Reimann et al. (2005) for more detailed discussion).

For the purposes of this report, the following definitions are used:

Natural background – The concentrations of naturally occurring elements derived/originating from natural processes in the environment as close as possible to natural conditions, exclusive of specific anthropogenic activities or sources. May also be referred to as the geochemical background. Attributable to mineral content derived from parent materials, and influence of soil-forming processes.

Ambient background – The concentrations of chemical substances in the environment that are representative of the area surrounding the site not attributable to a single identifiable source. This can include contaminants from historical activities and widespread diffuse impacts, e.g. fallout from motor vehicles. Referred to as 'normal' concentrations in the UK (DEFRA 2012).

Baseline – The soil concentrations of chemical substances in a specified location at a given point in time. Baseline concentrations are analogous to natural background concentrations where the specified locality is not influenced by diffuse anthropogenic sources, or ambient concentrations when the specified locality is influenced by diffuse anthropogenic sources. In contrast to ambient and natural background concentrations, baseline concentrations also include concentrations in locations known to be influenced by land use (e.g. agricultural land use).

Threshold – Upper limit of background variation (Reimann & Garrett 2005).

5 Regulatory context for the use of background soils information

There are three main contexts where background soil concentration of chemical substances is relevant in the regulatory management of land: ensuring soil quality, contaminated land management, and waste disposal.

5.1 Soil quality

There are two ways in which information on background soil concentrations is relevant to soil quality. The first is assessing the increase of contaminant concentrations over background to assess the anthropogenic input of chemical substances to soils through activities such as agriculture. The other is through the development of soil guideline values to protect ecological receptors. For the latter, some methodologies are based on the concept that the ecosystem is already adapted to the ambient background concentration (ABC) for the locality and that it is only adding contaminants over and above this background concentration that has an adverse effect on the environment (Crommentuijn et al. 1997; Verbruggen et al. 2001; SCEW 2010a). This approach is used in the Netherlands (Crommentuijn et al. 1997; Verbruggen et al. 2001), and has also been proposed for use in Australia (SCEW 2010b) for the protection of ecological receptors.

In New Zealand, soil quality monitoring by regional councils is typically undertaken for state of the environment reporting and has a number of objectives, including to:

- 'Provide an early-warning system to identify the negative effects of primary land uses on long-term soil productivity (physical, chemical, biological); and
- Track specific, identified issues relating to the effects of land use on long-term soil productivity (which may also be district/area specific)' (Land Monitoring Forum 2009).

Assessing the increase of contaminant concentrations over background concentrations and understanding the rate of accumulation of trace elements are means of assessing anthropogenic input and addressing those objectives (see also Kim and Taylor 2009 for discussion on trace elements in soil quality monitoring). Background concentrations have also been used as a trigger to invoke management actions; for example, defining the first tier of the Tiered Fertiliser Management System for Cadmium (MAF 2011). However, these approaches provide no indication of the potential effect arising from the concentrations present.

Soil guideline values for the protection of ecological receptors provide exactly that, an indication of potential effects. To this end, they can be used as long-term targets for soil quality, where there is a high level of protection (and minimal or no effects), or they could be used an indicators for concentrations of contaminants that might lead to adverse effects where there is a lower level of protection.

While the focus on background concentrations for the protection of soil quality is often on potentially toxic elements, there is also a role for understanding the concentrations of essential elements in soil as that may influence agricultural productivity (Hill & Sparling 2009). For this purpose boron (B), cobalt (Co), Cu, iodine (I), iron (Fe), manganese (Mn), selenium (Se), Zn, and possibly chloride and fluoride are considered to be a useful suite of analytes (Hill & Sparling 2009).

5.1.1 'Background concentrations' in managing soil quality internationally

GEMAS (geochemical mapping of agricultural soils and grazing land of Europe)

The use of background concentrations for managing soil quality has gained increasing momentum in Europe. For example, Johnson and Demetriades (2011) highlight nine EC directives driving demand for harmonised geochemical baseline data across European political borders. Of these, the REACH (Registration, Evaluation and Authorisation of Chemicals) legislation adopted in December 2006 (EC 2006a) and the proposed EC Soil Protection Directive (EC 2006b) have been key drivers for an extensive geochemical survey programme to provide harmonised geochemical data at the continental-Europe scale – the GEMAS project (geochemical mapping of agricultural soils and grazing land of Europe).

REACH specifies that industry must prove that it can produce and use its substances safely. This is complicated for industries that deal with natural resources as their 'product' occurs naturally and the natural background variation needs to be established, in addition to a methodology to differentiate the industrial impact from the natural geogenic background.

The GEMAS project commenced in 2008, and sampling has been undertaken in 34 European countries, covering an area of 5.6 million km^2, at a sample density of one site each of arable land (0–20 cm) and land under permanent grass cover (0–10 cm), per 2500 km^2 (Reimann et al. 2011. There were strict guidelines and training developed for sample collection and analysis to ensure consistency of the information provided (EuroGeoSurveys Geochemistry Working Group 2008; Reimann et al. 2011). These are discussed in more detail in section 6.1. Several recent publications discuss the results of this project and the implications for the use of such information (e.g. Reimann et al. 2010, 2012a, b; Tarvainen et al. 2013).

Sustainability of Canadian agriculture

An alternative use of background concentrations for managing soil qualities is illustrated in the development of an index for trace elements (TE) to enable the environmental sustainability of Canadian agriculture to be assessed (Sheppard et al. 2009, Agriculture and Agri-Food Canada 2010). The indicator considers six elements: As, cadmium (Cd), Cu, Pb, Se and Zn. The indicator is a soil balance indicator that estimates TE inputs based on the amounts of fertiliser, feed supplements and biosolids used per hectare on agricultural land and the TE loss from leaching, crop removal and volatilisation. The soil balance calculates what the concentration of TE in agricultural soils will be after 100 years of inputs and losses (century concentration) if current management practices are continued over that period. Given the risk is calculated for 100 years into the future, the indicator provides a means to identify those soil and management practices that require attention in advance of the development of a TE contaminant problem.

Information on ‘century concentrations’ is used in two ways. The first is through comparison with Canadian soil quality guidelines (SQG) (http://ceqg-rcqe.ccme.ca/) where a risk quotient (RQ) is calculated to indicate potential toxicity. The RQ is the estimated soil concentration of TE divided by the SQG concentration. This RQ can be summed across elements. If the RQ summed for the six elements is greater than 1, then the land area is classed as potentially at risk.

The second way is through assessment of the increase in concentrations over background. This is primarily applicable to locations where background concentrations of some soils exceed SQG, which were established to protect all soils, and can be overly protective. The results are presented in categories of <10%, 10–30%, 30–50%, 50–100% and >100% increase of century concentrations over background. It was considered that due to the range and variability of background concentrations, an increase above the background concentration of ~50% is statistically significant. Each of the six TEs is considered separately, and the highest level of increase above background among the six is used for the indicator. This class of increase above background concentrations also provides a more sensitive measure of the influence of management practices on the rate of TE accumulation in soil.

The indicator is developed on a spatial scale through georeferencing of data based on soil landscape classes (SLC) according to the national soil classification system (Soil Landscapes of Canada Working Group 2005 in Sheppard et al. 2009). Soil series is the primary land unit, with SLC being based on texture, pH, organic matter content, slope, stoniness, etc.

5.1.2 Soil guideline values for the protection of ecological receptors

The development of soil guideline values for the protection of ecological receptors is increasingly using an ‘added risk approach’ for naturally occurring elements. This approach was proposed by Crommentujin et al. (1997) and assumes that species are fully adapted to the natural background concentration and therefore only the anthropogenic added fraction should be regulated or controlled. This approach is used in the Netherlands in the development of intervention values for managing contaminated land, in REACH guidance (ECA 2008) on conducting a chemical safety assessment for a naturally occurring substances, and more recently in Australia for the development of Ecological Investigation Levels (EIL, SCEW 2010a).

The Australian methodology or an adaptation has been proposed for use in New Zealand to develop soil guideline values for cadmium (MPI 2012). This methodology suggests the use of the regression equations developed by Hamon et al. (2004) to assist in determining background concentration for use in the development of soil guideline values for the protection of ecological receptors. These authors developed a series of generic equations from Southeast Asian, including Australian, data that they indicated may be appropriate for deriving background concentrations of As, Cr, Co, Cu, Ni, Pb, and Zn globally.

More detail on the development of soil guideline values for the protection of ecological receptors is provided in Cavanagh & O'Halloran (2006) and MPI (2012).

5.2 Contaminated land management

In New Zealand, the *National Environmental Standard for assessing and managing contaminants in soil to protect human health* (the NES) came into force on 1 January 2012. This standard has imposed changes to how contaminated land is identified and assessed by local government. The NES specifies that:

> *'These regulations do not apply to a piece of land described in subclause (7) or (8) about which a detailed site investigation exists that demonstrates that any contaminants in or on the piece of land are at, or below, background concentrations.'*

No definition is provided in the NES as to what constitutes background concentrations, although the users' guide (MfE 2012) defines background concentrations as:

> *'Naturally occurring ambient concentrations of the element in the area local to the land.'*

The most extensive description of background concentrations is provided in CLMG No. 4 (MfE 2006), which states that background concentration is:

> *'An estimate of the natural concentration of a substance (element, compound or mixture) that would exist in the absence of any anthropogenic input, usually on a regional, sub-regional or catchment basis. For chemical elements in soils, the background concentration is expected to show some broad-scale variation depending on the nature of the geochemical parent materials. '*

This document further states that a site is considered to be above background concentration is concentrations are clearly higher than background, with the 95th upper confidence limit provided as an example for defining the upper limit for background concentrations (MfE (2006).

In MfE (2012), reference is given to CLMG No. 5 (MfE 2011b) for guidance on how to determine natural background concentrations.

However, there is limited guidance provided in CLMG No. 5, which states that background samples are collected in the area near the site that is not affected by the contaminant sources on the site… and if required by the DQOs, at least one background sample should be collected in addition to some other general information on background samples.

Some further guidance on collecting site-specific background soil samples is provided by Environment Canterbury (http://ecan.govt.nz/publications/Reports/EstablishingaLocalBackgroundConcentrationforyour2.pdf). In addition to guidance on site selection, this guidance suggests that samples should be collected from two sites with the same soil type as the site of interest, and a soil pit should be dug to 50 cm to confirm the soil type and that it has not been disturbed.

From a contaminated-land perspective the key naturally occurring contaminants of concern are As, Cd, Cu, Cr, Ni, Pb, Zn, mercury (Hg) and PAHs.

5.2.1 'Background concentrations' in managing contaminated land internationally

Background concentrations are widely used in international regulations and guidance for the management of contaminated land. Background in this context typically refers to ambient background (i.e. naturally occurring plus diffuse anthropogenic input). In the United States these may be used for establishing remediation targets (e.g. NREPC 2004; Diamond et al. 2009) or for assessing contaminated land, for example in Italy (Cicchella et al. 2005), Germany (BMU 1999), and Finland (Jarva et al. 2010).

In the United Kingdom, there have been recent changes to the statutory guidance for contaminated land to reduce uncertainties around when land does and does not require remediation (DEFRA 2012) A key part of this revision was to clarify that 'normal' background levels would not constitute contaminated land – thus the new statutory guidance states that the contaminated land legislation (called Part 2A) is *'not intended to apply to land with levels of contaminants in soil that are commonplace and widespread throughout England or parts of it, and for which in the very large majority of cases there is no reason to consider that there is an unacceptable risk'* (DEFRA 2012). The guidance further specifies 'normal' levels of contaminants being naturally occurring and arising from diffuse pollution sources such as vehicles (DEFRA 2012). The authors note that the work to determine 'normal' levels of contaminants in soil supports the English contaminated land regime rather than the planning regime. The difference being that the contaminated land regime requires developers to show that land is safe, suitable for use and, after remediation, cannot be determined as statutory contaminated land. For planning purposes, remediation is needed to ensure a site is suitable for its future intended use. Under the contaminated land regime, remediation is needed if the site, given its current use, is presenting such a high level of risk that if nothing is done, there is a significant possibility of significant harm such as death, disease or serious injury. Further details of the methodology used to determine normal concentrations are provided in section 6.2.1.

The phrase '… in the very large majority of cases there is no reason to consider that there is an unacceptable risk …' highlights an important point in relation to the use of ambient concentration for contaminated land assessment: that there may be situations where ambient concentrations pose a significant level of risk to human health. In the United Kingdom, historical mining activities are considered as part of the normal background (Cave et al. 2012). Such areas may be associated with naturally elevated concentrations of trace elements, which may pose human health risks. In Lavrion, Greece, for example, a legacy of lead mining resulted in extensive Pb contamination that gave rise to health concerns for the local residents, and required widespread remediation of the area (Demetriades 2011). For this reason, the risk associated with concentrations of elements associated with mining activities should be considered on a case-by-case basis.

Another point for consideration is that whereas for ecological receptors it is considered that the ecosystems are adapted to conditions associated with naturally elevated background concentrations and thus these concentrations pose no risk, the same is not true for protection of human health (Ernst 2012). For example, there are some areas that are naturally high in As (e.g. Bangladesh, India) but that show significant human health impacts due to elevation of As in groundwater used as drinking water (Ernst 2012).

5.3 Clean fills and biosolids application

A third application for the use of background soils concentration information is in the area of waste disposal, in particular disposal of material to clean fill and application of biosolids to land. Both of these activities can result in increases in contaminant loadings to soils that should be managed to ensure that no detrimental effects arise from the activities. Consideration of those loadings relative to background soil concentrations provides one way to manage those activities.

In fact, a draft memo from Waikato Regional Council proposes criteria for clean fill that take into account the background concentrations of trace elements in the region, as well as soil guideline values for the protection of ecological receptors. The proposed criteria are largely based on a mid-point between background concentrations for the region and soil guideline values for the protection of ecological receptors developed for Auckland Regional Council (Cavanagh & O’Halloran 2006).

Soil limits associated with the application of biosolids to land currently specified in New Zealand are based on effect concentrations (NZWWA 2003). However, in Europe, proposals for new soil limits of contaminants for sludge-amended agricultural soils are based on European background soil concentrations (DRG JRC 2006; EC 2010; Milleau et al. 2010).

6 Approaches to determining background concentrations

As highlighted in the previous section there are a number of recent international studies that have been undertaken to determine background concentrations in the context of managing land. Interest in the determination of background soils concentrations has also resulted in the development of an ISO standard for determining background concentrations (defined as content of a substance in a soil resulting from both natural geological and pedological processes including diffuse source inputs). This includes guidance on sample collection, completeness of datasets and statistical analysis of the data (ISO 2011).

There are two important steps in the determination of background concentrations:

1. Collection and chemical analysis of samples
2. Analysis of those data.

Standardised approaches to collection and analysis of samples reduce the variability associated with those factors. Approaches to data analysis can be broadly grouped as descriptive and predictive. Descriptive approaches rely on statistical analysis to determine ‘acceptable’ concentration ranges, thresholds and outliers, while predictive approaches rely on the development of relationships between trace elements and particular soil properties, including selected trace elements.

6.1 Sample collection and analysis

Recent European surveys to determine geochemical baselines have largely been systematic surveys, meaning that samples are collected on the basis of nominal samples per unit area. The density of sampling is dependent on the purpose – for example the GEMAS survey, which is determining background concentrations at a European scale, is based on collection of one sample per 2500 km^2, while determination of ‘normal’ concentrations in the United Kingdom is based on samples collected at scales ranging from one sample per 2500 km^2 (GEMAS data) to one site every 25 km^2 and including more detailed collection at urban (4 sites km^2), and rural (1 site 2 km^2) scales. Further discussion on the influence of scale is provided in Reimann (2005) and Reimann et al. 2009).

The number of samples required to develop a robust estimate of background concentrations depends on the variation of the data. While statistical equations can be used to determine sample numbers (if the expected variation is known), general guidance is that between 20 (NREPC 2004) and 30 samples (ISO 2011) are required to develop robust estimates of background concentrations.

Analyses are typically undertaken on composite samples collected using a scheme similar to that shown in Figure 1 – the distance for the square can vary. These samples may be collected from soil pits that also establish soil type and horizons – the pit can be dug to the second soil horizon – or soil cores. At least one soil pit should be dug at each location to establish soil type. The depth of sample collected may depend on the land use being assessed, for example, in GEMAS, agricultural land was sampled to 20 cm while grazing land was sampled to 10 cm. Often, the upper vegetated layer is removed although roots remain (EuroGeoSurveys Geochemistry Working Group 2008).

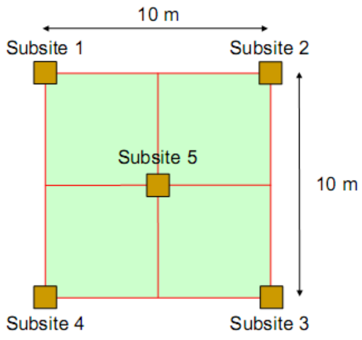

Figure 1 Composite soil sampling scheme used in GEMAS. Soil samples are composited from five subsites from a plot 10 × 10 m square according to the above scheme.

6.1.1 Quality control of studies

The GEMAS survey developed rigorous quality control and assurance processes to reduce variability introduced by sampling and analytical processes (Reimann et al. 2011). This included protocols for recording of site information, as well as:

1. the collection of a field duplicate sample at every 20th sample site,
2. randomising all samples prior to submitting them for analyses,
3. the use of a control reference sample (project standard), unknown to, and unrecognisable by, the laboratory at a rate of one standard per 10–30 samples, and
4. the insertion of analytical replicates or project samples at a rate of one in 10–20 samples.

6.1.2 Analytical considerations

There are differences in the results obtained from different analytical techniques; in particular it is known that *aqua regia* extraction of soils will give lower concentrations that those determined by X-ray fluorescence (XRF) (e.g. Tarvainen et al. 2009). Both techniques are commonly used, and some studies have developed relationships for relating the results obtained from both techniques to enable use of the data (Utermann et al. 2003, Ander et al. 2011).

6.2 Descriptive approaches to data analysis

There is a wealth of discussion and guidance on appropriate statistical analysis of geochemical data (e.g. Matschullat et al. 2000; Reimann et al. 2005, 2008; ISO 2011).

Statistical analysis for determining background concentrations usually follows a process of analysing the data distribution – using multiple approaches to provide a good representation of the data (Figure 2), followed by the determination of some upper limit of background concentration or threshold. In some cases, the initial data exploration may be used to identify regions that are geochemically different. For this, cumulative density functions have often been used – in these, points of inflection indicate different classes in a dataset (Figure 3), or more complex geostatistical analyses can be done to define ‘domains’ in which background concentrations are similar (see below for more discussion). Other techniques such as principal components analysis (e.g. Zhao et al. 2007) or factor analyses may also be undertaken at this point, although some authors urge caution with the use of such techniques due to concerns about validity of distributional assumptions (Reimann et al. 2011).

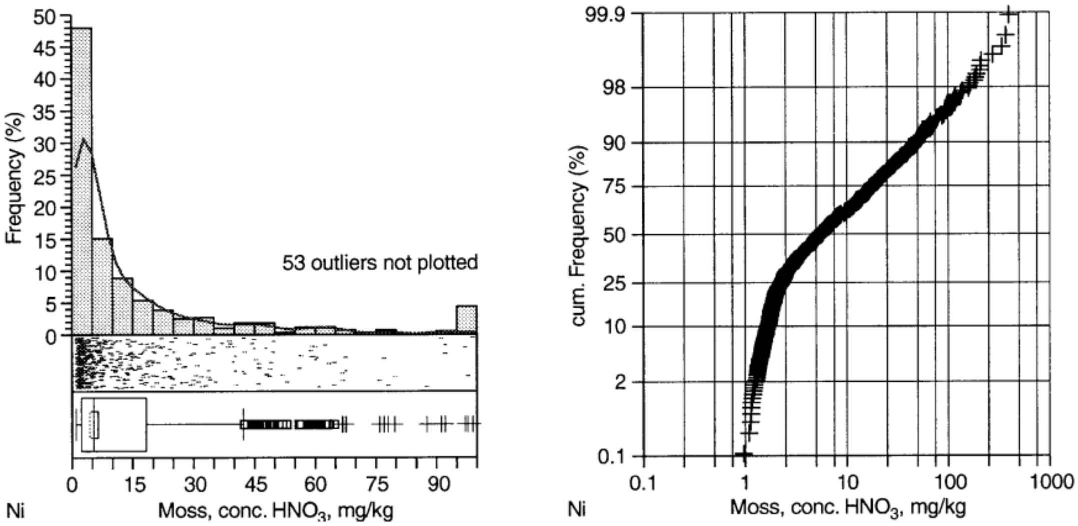

Figure 2 Combination of histogram, density trace, one-dimensional scatttergram and boxplot and a CDF diagram to give a fast graphical impression of the data distribution (from Reimann & Filzmoser 2000).

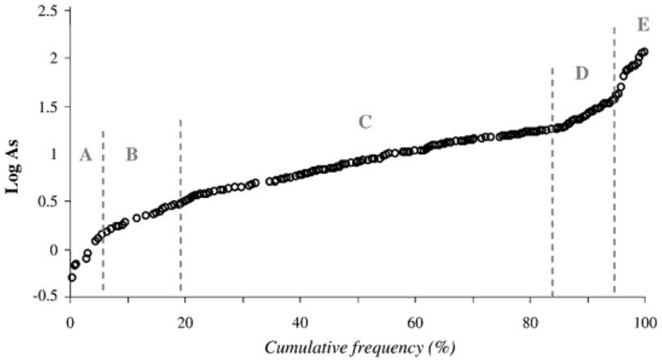

Figure 3 Cumulative frequency distribution curve of log-transformed data for arsenic, concentrations in Granada soils indicating the inflection points that separate the different classes (A, B, C, D and E) in the dataset Dashed lines indicate the inflection points (from Diez et al. 2009).

Boxplots are a common means to provide summary statistics for the data as they are not influenced by the distribution of data and have been shown to be most reliable in detecting outliers for up to 15% outliers in a population; thereafter, using median +2 MAD (median absolute deviations) are better (Reimann et al. 2005). Figure 4 shows a typical boxplot, where the whiskers are set at 1.5× the interquartile range (H) to identify outliers. Extreme outliers are typically identified as being more than 3× the interquartile range above or below the 75th and 25th percentile respectively.

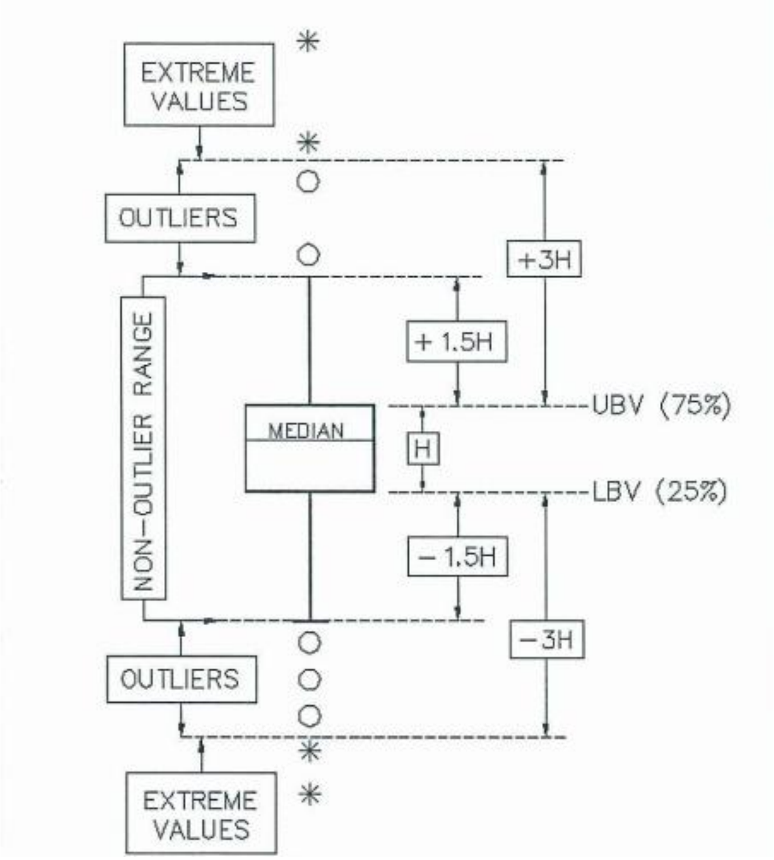

Figure 4 Typical properties of a box and whiskers plot (from Tonkin and Taylor 2006).

The upper limit for outliers using boxplots (upper limit = Q75 + 1.5H) has also been used to define the threshold for the upper limit for background variation (e.g. Jarva et al. 2010).

The upper confidence limit (UCL) for the 95th percentile is probably the most widely used threshold for determining upper limits for background concentrations (e.g. NREPC 2004; Cave et al. 2012), although the 99th percentile is also used if the dataset is sufficiently large (Diamond et al. 2009) with the observation that there is little difference between the UCLs of the 95th and 99th percentiles (Diamond et al. 2009). There are some statistical tools available to calculate the UCL of the 95th percentile, such as ProUCL developed by US Environment Protection Agency (US EPA 2010). Cave et al. (2012) also provide the code used for the statistical package R to determine the UCL of 95th percentiles.

In addition to determining upper limits, statistical analyses may also be undertaken to compare the difference in concentrations between different groups. Depending on data distribution these may be parametric (e.g. ANOVA) or non-parametric (e.g. Kolmogorov–Smirnov tests, Kruskal–Wallace ANOVA) techniques.

6.2.1 UK 'normal' background

The considerable work undertaken in the United Kingdom to establish 'normal' background concentrations (NBC) of selected contaminants to support contaminated land management (Ander et al. 2011, 2012; Cave et al. 2012; DEFRA 2012; Johnson et al. 2012) provides a useful case study to consider the determination of background concentrations.

These studies, based on the analysis of over 42 000 sampled points across England, resulted in the development of national soil contaminant maps for England for As, Pb, Cd, Cu, Ni, Hg and benzo(a)pyrene and technical guidance sheets for users.

Sample density ranges from one site in 2500 km^2 (GEMAS) to one site every 25 km^2 and more detailed collection at urban (4 sites km^2), and rural (1 site 2 km^2) scales. Variability in contaminant concentrations across England is attributed to the underlying parent material on which a soil has formed. This may simply be from the weathering of certain rock types enriched in a particular contaminant or from non-ferrous metalliferous mineralisation with which the contaminant is associated, either as the main ore mineral or an accessory. In these studies, anthropogenic activity associated with mining and associated processes (e.g. smelting) that has left a legacy of diffuse pollution in England is considered as part of the widespread and typical contaminant levels.

The data exploration was focused on contaminant distributions, both across England and statistically when plotted and mapped by a variety of techniques, with a key aim to identify the main factors controlling the concentration and distribution of the selected contaminants in soils. The UK studies use the term 'domain' to identify areas of England to which high concentrations of a contaminant can be attributed to be the result of readily distinguishable controlling factors. Such regions are defined by a boundary derived from a soil's underlying parent material, an urbanisation index, or an area of non-ferrous metalliferous mineralisation with associated mining activities. The area remaining outside domains defined by these controlling factors is referred to as the 'principal domain'. These domains were defined through the use of a k-means cluster approach (Hartigan & Wong 1979 in Ander et al. 2011) to prioritise higher concentration areas that may form separate natural background concentration domains, to reducing the data to a limited number of domains (Figure 5).

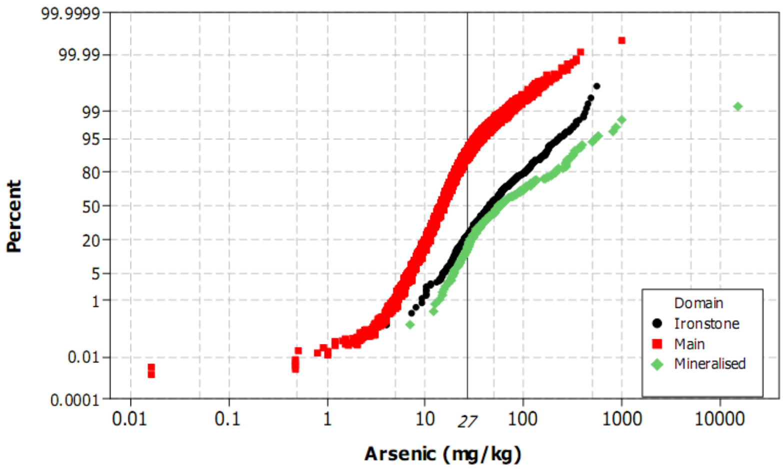

Figure 5 Probability plot of topsoil. Arsenic results categorised by potential domains. The k-means threshold of 27 mg/kg is shown by the vertical line. (Main = principal domain).

A minimum of 30 results are considered necessary to determine an NBC for a given domain. The NBCs are determined for each domain using the statistical process outlined in Figure 5, which includes initial distributional analysis (density distribution and histogram plots) and calculates the skewness coefficient (SC) and octile skewness coefficient (OS) to determine the method by which the 95th percentile upper confidence interval is calculated. The code used to undertake these analyses is available from the project website http://www.bgs.ac.uk/gbase/NBCDefraProject.html.

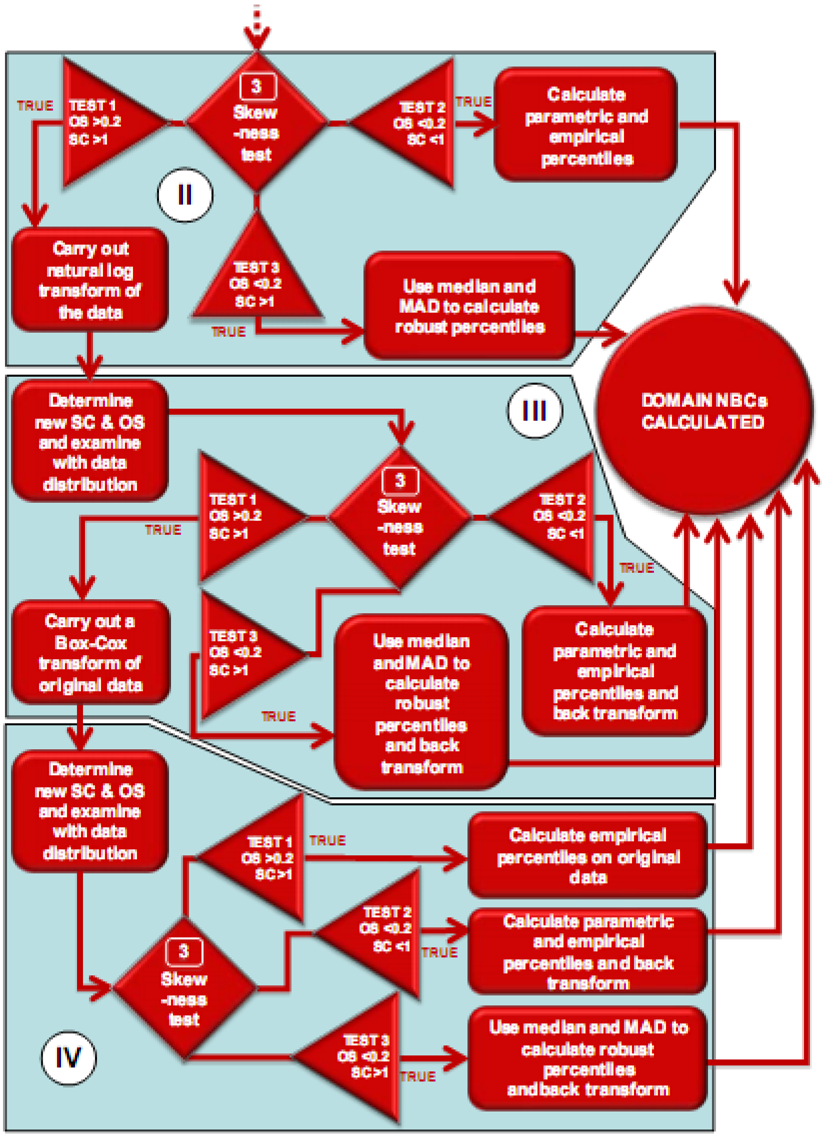

Figure 6 Statistical analysis outline used in Cave et al. (2012) to determine 'normal' background concentrations for defined domains.

6.3 Predictive approaches

An alternative approach for determining background concentrations is through the use of predictive relationships whereby the concentration of trace elements of interest are related to soil properties such as pH, clay content, organic matter content, or more conservative trace elements such as Fe, or Mn. Such techniques are arguably only applicable for determining naturally occurring background concentrations, since ambient background concentrations will be influenced by proximity to diffuse pollution sources in addition to natural occurring concentrations. However, this can be of benefit in determining the increase in concentrations over natural background.

6.3.1 Hamon et al.

Hamon et al. (2004) developed a series of generic equations from Southeast Asian, including Australian, data that they indicated may be appropriate for deriving background concentrations of As, Cr, Co, Cu, Ni, Pb, and Zn globally. These relationships have been recommended for use in the development of ecological investigations levels in Australia (SCEW 2010). The relationship is based on equation 1

$$\mathrm{Log}[M] = a \log[\mathrm{Fe}] + c. \qquad (1)$$

Regression relationships were determined from the linear correlations of the log-transformed dataset, following removal of 5% of observations with the highest positive residuals. The parameters describing these regressions are shown in Table 1.

Table 1 Regression parameters for heavy metals and %Fe concentrations in soil, including the constant for the 95th percentile, determined by Hamon et al. (2004)

	a	c	95th percentile	R^2
As	0.574	0.507	1.064	0.5
Co	0.894	−1.409		0.71
Cr	0.75	1.242	1.916	0.58
Cu	0.612	0.808	1.235	0.61
Ni	0.702	0.834	1.381	0.64
Pb	1.039	0.118	0.558	0.66
Zn	0.589	1.024	1.529	0.61

6.3.2 Canada

Sheppard et al. (2009) determined background soil concentrations for use in the Canadian TE index by collecting 200 soil samples from across the country, from projects that were designed to sample a cross section of soil properties in agricultural land. Trace element (As, Cd, Cu, Pb, Se, and Zn) concentrations were measured, and were found to be positively correlated with soil clay content ($P < 0.05$). Equations were developed by backward stepwise linear regression to predict background TE concentrations from soil, clay, sand, silt, and organic carbon contents and pH (water), and these equations were used to interpolate values for all soil landscape class (SLC) polygons. They noted that while the equations were highly significant, the R^2 values were typically <30%. However, the imprecision implied by the low R^2 value was not considered significant as the ranges of observed and predicted background soil concentrations were not large (Table 2).

Table 2 Background median and range of selected trace elements determined during development of the Canadian TE (trace elements) index. These are estimates based on soil texture, pH, and carbon content (from Sheppard et al. 2009)

Trace element	Median (mg/kg)	Range (mg/kg)
As	4.2	2.3–6.4
Cd	0.27	0.20–0.44
Cu	16	11–37
Pb	15	10–25
Se	0.64	0.25–1.7
Zn	62	42–140

6.3.3 The Netherlands

‘Reference lines’ for determining background concentrations in the Netherlands were developed by correlating the total concentrations in the soil-matrix to the percentage lutum (clay) and organic matter content and moving the regression line so that 90% of measurements fall under the regression line. The reference line is then used to determine the concentration for a standard soil (10% organic matter and 25% clay) (Crommentuijn et al. 1997). These reference lines were also used to relate to normalised ecotoxicity data in the development of soil guideline values for the protection of ecological receptors (Verbruggen et al. 2001).

Table 3 Predictive relationships for determining background soil concentrations in the Netherlands, and calculated background concentrations for a standard soil (10% organic matter, 25% clay) for selected trace elements

Trace element	Reference line	Calculated background soil concentration
As	15 +0.4(L+H)	29
Cd	0.4 +0.007 (L+3H)	0.8
Cr	50+2L	100
Cu	15+0.6(L+H)	36
Pb	50+L+H	85
Hg	0.2+0.0017(2L+H)	0.3
Ni	10+L	35
Zn	50+1.5(2L+H)	140

6.3.4 Miscellaneous

Other authors have also developed predictive relationships, using different approaches. Zhao et al. (2007) investigated predictive relationships for data from the United Kingdom. Principal components analysis was used initially and found association with Al, Fe, K, Mn, Cr, Co and Ni. These authors found the multiple regressions using Fe and Al were better than regression based on Fe or Al alone. Unlike Hamon et al. (2004), these authors found only weak associations between Zn, Cd, Cu or Pb and Fe (or Al, Mn), and that soil texture was better at explaining variation than major soil taxonomic group. Therefore, upper limits based on soil texture groups were used to define upper background limits.

Sterckeman et al. (2006) used the relationships between trace elements and Fe or Al concentrations in 52 surface soils developed from loess deposits in northern France to predict the 'pedo-geochemical background concentrations' of the former. Regression equations were presented for a range of trace elements including As, bismuth (Bi), Cu, molybdenum (Mo), Pb, antimony (Sb), tin (Sn), thallium (Tl), vanadium (V) and Zn, although the R^2 was typically <0.5.

7 Determining background soils concentration for New Zealand

Determination of background concentrations is dependent on the available data, as well as the methods used to derive the 'threshold' or upper limits of background concentrations that are the primary interest for land management. This section provides an overview of existing data, including methods used to determine background concentrations, and investigates two approaches that could be useful for providing a more robust basis for deriving background concentrations.

7.1 Existing data

7.1.1 Previous New Zealand studies

A number of studies have previously been undertaken in New Zealand either explicitly for the purpose of developing background soils concentrations of selected chemical substances on a regional or national basis, or that provide data that can be used for this purpose. These studies have largely been undertaken by regional councils, although some studies have also been undertaken by independent researchers. A brief description of the studies is provided below.

Regional council studies

Studies undertaken by regional councils have typically been either to determine background concentrations (typically for contaminated land management purposes) or to provide information on background concentrations (typically as part of soil quality monitoring programmes undertaken for state of the environment reporting; Table 4). These different purposes are reflected in the way sampling has been undertaken (Table 4). While both approaches provide representative samples, the variation in sampling will lead to some variation in the results. The difference in purpose also reflects a difference in the grouping or classification used to collect samples or report results. Contaminated land investigations are more likely to group soil types according to underlying geology and devise sampling strategies from that. Soil quality studies will report results according to soil type or land use and may also include additional soil analyses (e.g. pH, cation exchange capacity) that could be of use in developing predictive relationships. A further point of difference is that studies for contaminated land purposes have tended to group soils based on the old New Zealand genetic soil classification and/or geology (Table 4), whereas soil quality studies tended to identify the NZCS Soil Order of the samples, although results may be presented on the basis of different land use as opposed to soil order.

The most extensive work for determining background concentrations, including in urban areas, has been undertaken in the Canterbury Region and primarily for contaminated land purposes. For trace elements, it is acknowledged that further data are required if more robust estimates are to be developed by the establishment of two estimates of the upper limit on background concentrations (Tonkin and Taylor 2006). The first estimate is based on the maximum concentration measured (Level 1), while Level 2 is based on the maximum concentration plus half the interquartile range. Sufficient samples were deemed to have been collected for the urban study on PAH to allow the determination of background concentrations as the 95th percentile upper confidence limit (Tonkin and Taylor 2007b).

Table 4 Summary of existing regional council data relevant for determining background concentrations of chemical substances

Council	Study	Purpose	Method	Analytes	Analysis	Sample classification basis	Basis for reporting results
Bay of Plenty	Unpublished	Soil quality	Soil quality monitoring	Range	Total recoverable		NA
Environment Canterbury	Percival et al. (1996)	Contaminated land assessment	National Soils Database, literature review	Ba, Cr, Cd, Co, Cu, Pb, Ni, Zn, S,	Primarily XRF from National Soils Database	NZ soil series	NZ soils series
	URS (2005)	Contaminated land assessment	sampling methodology			Soil series, grouped with parent material	NA
	Tonkin and Taylor (2006)	Contaminated land assessment	(2006) 90 sites – 17 in urban, 73 across Canterbury. Four samples 0–150 mm, one from 400–550 80x80-m quadrat. Pit dug to 0.5m	As, Bo, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Zn	Total recoverable	Soil series, grouped with parent material	Soil series
	Tonkin and Taylor (2007a)	Contaminated land assessment		As, Bo, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Zn	Total recoverable	Soil series, grouped with parent material	Soil series
	Tonkin and Taylor (2007b)	Contaminated land assessment		PAH		PAH distribution assumed to be independent of soil type	
Marlborough District Council	Gray (2010)	Soil quality	25 sites, using soil quality monitoring techniques.	pH, Olsen P, Cu, Cr, Cd, As, Pb, Ni, Zn	Total recoverable	Soil order	Land use
	Gray (2011)	Soil quality	75 samples, using soil quality monitoring techniques	pH, Olsen P, Cu, Cr, Cd, As, Pb, Ni, Zn	Total recoverable	Soil order	Land use
Auckland Regional Council	ARC (2001)	Contaminated land	91 sites, 150-mm cubic monolith pit dug to 0.5 m, 15 sites	Bo, P, L, S, Sn, Ba, Cd, Co, Cr Cu, K, Mg, Mn, Ni, V, Zn,	Microwave digestion ICP-OES , AAS, total	Geological units	Geological units

Council	Study	Purpose	Method	Analytes	Analysis	Sample classification basis	Basis for reporting results
		assessment	resampled in 2001 with 4 samples collected at one location	As, Hg, Total N, TOC	recoverable		
	Curran-Cournane & Taylor (2012)	Soil quality	84 sites, soil quality monitoring		Total recoverable	Soil order	Land use
	ARC unpublished	Indigenous sites	Soil quality monitoring			Soil order	Unpublished
Greater Wellington Regional Council	URS (2003)	Contaminated land assessment	4 samples collected from each of the corners of a 15 m by 15 m square	As, soluble Bo, Cd, Cr, Cu, Pb, Hg, Ni, Zn, TPH, PAH	Total recoverable	Geological units, and soil maps	
	Sorenson (2012)	Soil quality	Soil quality monitoring	As, Cd,Cr, Cu, Pb, Ni, Zn	Total recoverable	Soil order	Land-use
Taranaki Regional Council	TRC (2005)	Soil quality	Not stated	Cd	Total recoverable	Soil series	Soil series, land-use
Waikato Regional Council	Taylor(2011)		29 sites, using soil quality monitoring techniques	Soil quality plus As, Cd, Cu, Cr, Pb, Hg, Ni, Zn, Fe	Total recoverable	Soil order	
	WRC unpublished		54 sites in 11 urban centres in Waikato, parks and schools	Inorganic suite, PAH	Total recoverable	Not reported	

*Soil quality monitoring technique: 25 soil cores to 10 cm depth at 2-m intervals along the 50-m transect using 2.5-cm-diameter auger (Hill & Sparling 2009).

Predictive studies

McDowell et al. (2013) investigated relationship between cadmium and soil properties with a view to determining background soil concentrations of Cd. The authors compiled existing data, and undertook reanalysis of archived soil samples collected during various studies. A summary of the data collated is shown in Table 5. While the study reports on Cd, samples were analysed for aluminium (Al), As, barium (Ba), B, calcium (Ca), Cd, Cu, Fe, potassium (K), Pb, magnesium (Mg), Mn, Mo, Ni, uranium (U), V and Zn using ICP-OES. The authors separated the samples into those collected from minimally disturbed sites (293, MD), and samples from various land uses (1043). One criterion for the minimally disturbed sites was that the Zn:Cd ratio was >400. A low Zn:Cd ratio is considered to be indicative of sites impacted by long-term superphosphate application (Roberts et al. 1994). However, recent research suggests that this relationship may be breaking down with addition of relatively clean zinc in recent years (Kim 2011).

Table 5 Summary of data used in McDowell et al. (2013)

Study	Notes	Number of samples from minimally disturbed locations
500 soils 1998–2000 (see Hill et al. 2003)	Data from published reports and reanalysis of some samples from Bay of Plenty, Waikato, Taranaki, and Marlborough and all samples from Northland, Auckland, Wellington and Canterbury regions.	62
McDowell & Stewart (2006)	Reanalysis of 5 topsoils (0–10 cm depth) from the Otago Region under pasture, production forestry and native land use	2
Zanders et al. (1999)	Data from fertilised pasture and native (broadleaved or podocarp forest) land use under two contrasting soil types. Soil depths of 0–3.5, 3.5–7.5, 7.5–15.0, and 15–30 cm.	2
ARC (2001)	Data from 105 minimally disturbed sites (0–10 cm depth) in the Auckland Region	105
Unpublished West Coast study	Twenty samples of topsoil (0–10 cm depth) taken from native (largely podocarp) bush sites	20
MAF database	Data were obtained from samples taken of the 0–10 cm depth of 50 dairy, 293 drystock, 272 arable, 54 forestry, 10 urban, and 85 native land use sites around New Zealand	85
Roberts et al. (1994), Longhurst et al. (2004)	398 soils As, Pb, Cd, Cu and P of 312 pastoral (drystock and dairy) and 86 non-pastoral sites. Sample depths 0–2.5cm, 2.5–7.5cm	86 (90% native bush)

McDowell et al. (2013) present some of the only data comparing the concentrations of a trace element (Cd) with different soil orders. There were some differences in Cd concentrations between soil orders, with Granular soils showing the highest concentrations, but these soils also had the most non-detectable concentrations.

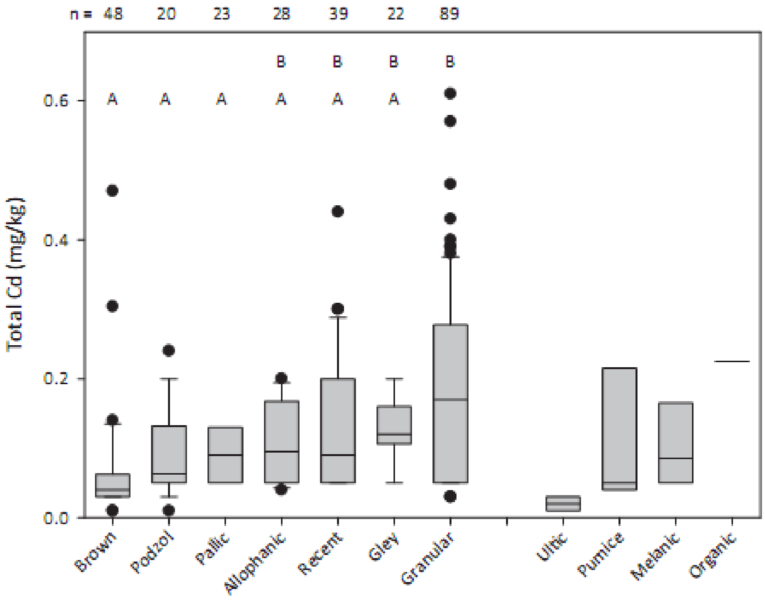

Figure 7 Cadmium concentration in soil orders in the dataset of minimally disturbed soils from McDowell et al. (2013).

The MD dataset was used to develop regression equations using total phosphorus (P), which showed the highest correlation with Cd, as the primary explanatory variable. The authors found no significant difference between the equations developed for different soil orders, and thus the general equation shown below was used to predict a background Cd concentration for each soil in the land use database with $R^2 = 0.58$. The regression approach was used to only predict background Cd in the land use dataset up to the 95th percentile of the MDC dataset (0.48 mg kg^{-1}).

Total Cd (mg kg^{-1}) = 0.000142 total P (mg kg^{-1}) + 0.042.

National surveys

To date the majority of national surveys of contaminants have been compilations of data from previous studies, although some studies have specifically set out to assess the concentrations of contaminants in soil on a national basis. A summary of available studies is provided below.

MfE – Ambient concentrations of selected organochlorines in soil

The study by Buckland et al. (1998) is the only systematic study that has been undertaken in New Zealand for the purposes of assessing selected baseline concentrations of organochlorine contaminants. To ensure wide geographical coverage, the country was divided into eight strata on the broad basis of climate and geology, while working generally within current geographical (regional council) boundaries. Samples were collected from six land-use types within each of the strata, with a total of 51 samples collected.

Each sample comprised a number of subsamples, 27 for the rural sampling, arranged at regular intervals in a triangle originating from the 'sampling station'. For some rural areas the results from two sampling stations were combined. For the urban areas either 36 (4 × 3 × 3) or 48 (4 × 4 × 3) subsamples were collected for each sample so that the results from four localities were combined, with each locality having 12 samples collected in a grid pattern. Urban-area sites were located (non-randomly) in parks and reserves that met appropriate clearly defined criteria.

This study established baseline concentrations for the selected organochlorines, for different land uses in New Zealand.

Cadmium studies

Longhurst et al. (2004) provide data on As, Cd, Cu, Pb and Zn from a national survey of 312 agricultural topsoils and pastures, and included 86 non-farmed, primarily indigenous forest sites undertaken in the early 1990s. Sites sampled covered the major soil groups throughout the North and South islands. Composite soil samples (16 cores, 2.5-cm diameter) were taken at two depths, 0–2.5 and 2.5–7.5 cm. although soils data were integrated to give a 0–7.5 cm depth estimate of heavy metal concentrations. Soil samples were analysed by atomic absorption spectroscopy.

Taylor et al. (2007) provided the first extensive compilation of available data for Cd in soils. Data from a total of 1794 topsoil samples were collated, 1649 were georeferenced and able to be mapped. The 372 samples from reserves, tussock, bush, indigenous forest and plantation forestry were used to derive background concentrations for Cd. Samples were mainly collected at two time periods: 1989–1995 and 2000–2006.

National Environmental Standard

During the development of the NES for assessing and managing contaminants in soil for the protection of human health, the Ministry for the Environment compiled information on As and Cd to assist in setting soil contaminant standards (MfE 2011a). On the basis of available data the 99th percentile for As was 17.4 mg/kg, and that for Cd was 0.65 mg/kg (MfE 2011a). For As, the background concentration (defined as the 99th percentile concentration in soils thought not to have been affected by anthropogenic activities collected from around the country) was used as the soil contaminant standard (SCS) for the rural residential land-use scenario. Selection of the 99th percentile was based on recommendations from the toxicological and technical advisory groups (MfE 2011a).

While a reasonable amount of data was compiled (372 datapoints for As and 486 for Cd), several data limitations were noted in MfE (2011a), including:

- Variation in the sampling and analytical methodologies used by different councils and Crown Research Institutes
- Poor land-use classification
- Representative data could not be obtained for large areas of New Zealand and sample density was concentrated in Auckland, Waikato, Wellington and Canterbury, while limited or no data were available from Gisborne, Manawatu-Wanganui, Marlborough, Nelson, Northland, Otago, Southland, Taranaki and Westland
- No data were available for locations that could result in the formation of hotspot areas of high As concentrations such as natural geological processes, geothermal activities and processing associated with gold mining.

7.1.2 National Soils Database

The National Soils Database (NSD) comprises soil profile data collected from soil pits throughout New Zealand and includes soil chemistry and soil physical properties where available. The NSD is considered to be the fundamental dataset that underpins soil knowledge of New Zealand, and the basis from which soil classifications, soil interpretation, land management models, and an understanding of how soil properties vary with geology, rainfall, vegetation, topography, have been developed (Hewitt et al. 2012). The NSD provides numerical data to assist in the development of S-Map and the land resource information system (LRIS).

In terms of the current project, the NSD includes XRF analyses for a suite of trace elements including Cr, Ni, Cu, Zn, and Pb for approximately 286 surface soil samples from a variety, although primarily agricultural, of land-uses.

7.2 Tools for extending spatial relevance of existing and future data

Internationally spatial tools are increasingly used to determine background soils information (e.g. Lado et al. 2008; Diez et al. 2009; Jarva et al. 2010; Cave et al. 2012) or to utilise background concentration information (e.g. Sheppard et al. 2009). Often geostatistical analyses are undertaken and used to define relevant ‘domains’ or groupings where background concentrations are similar. Such tools enable the extrapolation of collected data to areas where data have not been collected. Whether the tools are geologically based or soils-based appears to depend on what databases are available. For example, Ander et al. (2011) used a Soil-Parent Material Model (SPMM), and a mineralisation and historical mining database. In contrast, Sheppard et al. (2009) utilise a spatial system based on soil classifications (see also section 6.3.2). A number of spatial tools that are potentially of value in national determinations of background concentrations are available in New Zealand and are discussed below.

7.2.1 Land Resource Information System (LRIS)

The LRIS (http://lris.scinfo.org.nz/) is a means for the public to access environmental data held by Landcare Research. Data layers available include NZLRI soil fundamental data layers (FSLs), vegetation data layers, and land-cover database. The NZLRI (FSL) is a spatial database that describes land on the basis of five characteristics including rock type. The FSLs are based on 16 key attributes for soil selected through a consultation process with stakeholders. These attributes fall into three groups: soil fertility/toxicity, soil physical properties (particularly those related to soil moisture), and topography/climate. Rock type is a potentially useful parameter to investigate variation in trace element composition in different soils. Similarly, the vegetation attributes and/or landcover database could be useful mechanisms for linking some land-use to soil-concentration data in a broader context.

7.2.2 S-Map

S-Map is a spatial database for New Zealand soils that has been designed to provide quantitative soil information for modellers and to provide the best-available soil data for use by land managers and policy analysts (Lilburne et al. 2012). S-Map includes linkages to the National Soils Database and Q-Map, a geological spatial database developed by GNS (see below).

Soil classification in S-Map is based on the New Zealand Soil Classification System (Hewitt 2010). There are 15 soil orders defined in this system and a brief summary of the characteristics and distribution of the orders across New Zealand, and the relationship to a previous soil classification system, the New Zealand Genetic Soil Classification, is shown in Appendix 1. Trace element concentration in soils can be influenced by parent material, and as can be seen from Table A1 some soil orders can be derived from any parent material, thus a high variation in TE concentration might be expected for these soil orders. For other soil orders, the variation in composition of the parent material may also lead to variations in soil, although this is anticipated to be less than that arising from different parent materials. S-Map contains information on parent material, rock class of rock and of fines (<2 mm) for the defined soil siblings, which could be of use in explaining geochemical variations in different soil types.

The nominal mapping scale is 1:50 000 with more detailed mapping retained where possible. While current coverage across New Zealand is incomplete (Figure 8), there is ongoing work to extend coverage.

Figure 8 Map showing current S-Map coverage as at April 2013. Coverage is at 1:50 000 scale.

7.2.3 Q-Map

Q-Map is a national spatial database containing geological information and was developed by GNS over the period 1993–2012. It provides geological maps at 1:250 000 scale across New Zealand.

7.3 Testing the Hamon relationship

Predictive relationships developed by Hamon et al. (2004) have been recommended for use in the development of ecological investigations levels in Australia (SCEW 2010a). This methodology, or an adaptation of this methodology, has been proposed for use in New Zealand (MPI 2012). However, this requires validation of the relationships for New Zealand soils. Predictive relationships also provide a mechanism to estimate the background concentrations in areas that have not been extensively investigated, if the appropriately soil parameters have been measured, in this case %Fe.

Investigation was undertaken to determine whether these equations were useful for predicting background soil concentrations in New Zealand soils, using regional council data for 106 background sites from Auckland, Waikato, Bay of Plenty, Wellington, Marlborough, and Taranaki. The relationships between %Fe and As, Cr, Cu, Ni, Pb and Zn were examined, as these were the elements for which equations were developed by Hamon et al. (2004) and are of interest in land management.

For the New Zealand data, significant correlations were observed between log-transformed data for %Fe and the above elements, and regression analyses were performed (Table 6). All regressions were significant although they often only explained a small amount of variation in the data, as indicated by the R^2 values in Table 6. In contrast, the regression analyses by Hamon et al. (2004) yielded much higher R^2 values (Table 1).

Table 6 Regression parameters for the relationship between total metal and %Fe using New Zealand data

	Slope	Standard error	Intercept	Standard error	R^2
Arsenic	0.357	0.084	0.404	0.035	0.15
Chromium	0.929	0.100	0.366	0.042	0.45
Copper	0.358	0.08	0.923	0.033	0.16
Nickel	0.54	0.097	0.543	0.040	0.23
Lead	0.728	0.102	0.441	0.043	0.33
Zinc	0.364	0.056	1.34	0.023	0.29

The regression lines from Hamon et al. (2004) were plotted against the New Zealand data, and the regressions developed from that data (Figure 9). Visually, the regression lines from Hamon et al. (2004) were not a good fit for the majority of trace elements and given the low R^2 values, further analysis was not undertaken. Based on this dataset, the relationships developed by Hamon et al. (2004) do not appear to be appropriate for use in New Zealand. Further, given the low level of variability explained by the regression with %Fe, it would be appropriate to consider alternative regression analyses (e.g. based on texture, additional elements).

Zhao et al. (2007) found that the Hamon et al. (2004) relationships didn’t hold for soils collected from the United Kingdom. They found that multiple linear regression of Co, chromium (Cr) or Ni, and Al and Fe explained 65–85% of variability in the data.

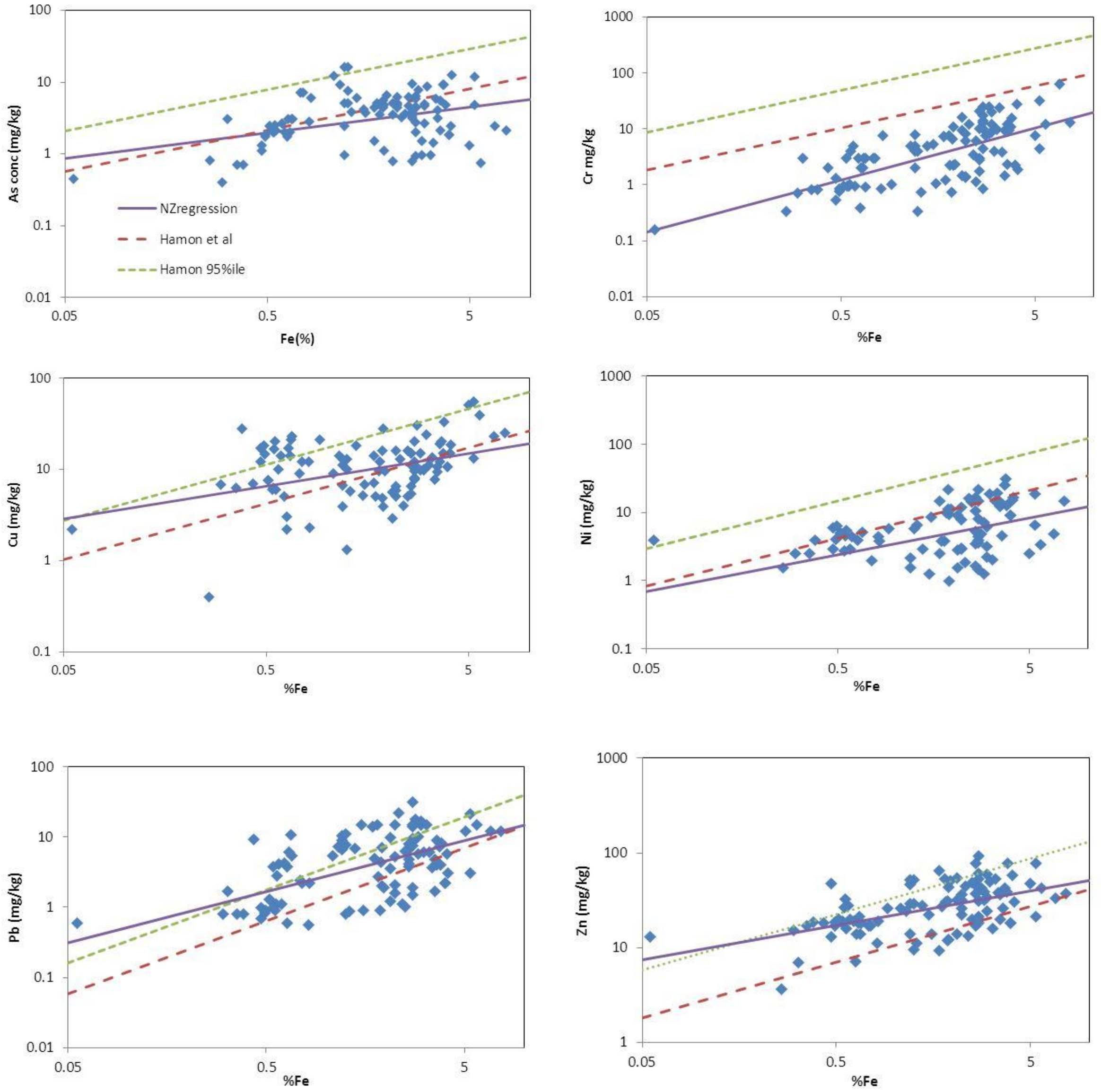

Figure 9 Plots of New Zealand data, and regression lines from Hamon et al. (2004) (short dash) including the 95th percentile line (long dash), as compared to the regression line developed for New Zealand data from background sites (solid line).

7.4 Assessing the use of spatial tools

Internationally, and particular in Europe, spatial tools are increasingly being used to determine geochemical baselines for managing land, particularly contaminated land (e.g. Reimann et al. 2008; Jarva et al. 2010; Cave et al. 2012). Spatial tools can extend the spatial relevance of data that has been collected, and can be used to identify relevant 'groupings' in which background concentrations are similar. Spatial tools may be based on geological or soil classifications, largely dependent on what data are available at the appropriate scale.

A challenge with the use of existing New Zealand data for providing national estimates of background concentrations, beyond simple percentiles, is that the basis for sample groupings and/or description of samples used is variable – some are geologically based (e.g. ARC 2001), some have a combined geology and soil basis (e.g. URS 2003; Tonkin and Taylor 2006), while others are soil-based (e.g. Percival et al. 1996). Additionally, there often appears to be greater variation within a defined group than between groups (e.g. URS 2003; Tonkin and Taylor 2007) suggesting there may be better ways of identifying appropriate groupings to explain variations in background concentrations.

Spatial tools such as S-Map and LRIS could be used to extract additional information about the sampling locations (within the constraints of mapping scales used by the respective systems) that would enable the consistent classification of samples (e.g. initially at soil order level) or that might help explain variation in trace element concentrations (e.g. rock-class of fines (<2 mm), parent material).

Data and locational information for some existing 'background' soil quality monitoring sites in Canterbury, Wellington, and Waikato were used to explore the potential utility of spatial information systems, S-Map and LRIS, for this purpose. Figure 3 shows the spatial distribution of the selected sites, while Table 7 shows the distribution of the sample sites across soil orders, and some of the information extracted. It was found that even though these general areas were mapped by S-Map (e.g. Canterbury), not all sampling locations in that region were covered by S-Map. Of the 118 locations, 45 had data available through S-Map, and the remainder had attributes extracted from LRIS.

It was hoped to be able to undertake a preliminary assessment of the variability of trace element concentrations; however, there were insufficient data (trace element data were only available for 62 of the 118 sites) across the different soil groupings to be able to undertake any meaningful analysis. Nonetheless, the process illustrated the potential for using these systems to extract additional information that could be used to develop relevant functional groupings for determining background concentrations.

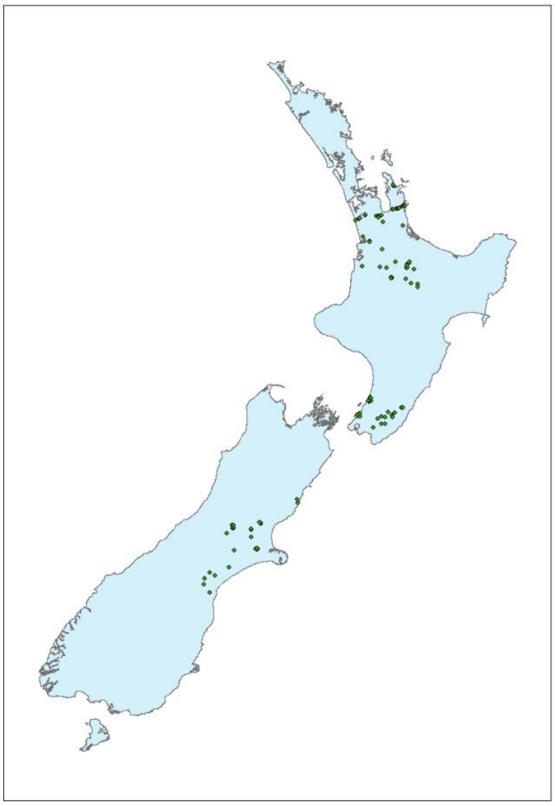

Figure 3 Location of selected regional council 'background' sample sites for which data were extracted from S-Map and LRIS.

Table 7 Soil order and rock classifications extracted from S-Map or LRIS for the 118 regional council background sites shown in Figure 3

Soil order	Number	'Rock-class of fine' (S-Map) (number of samples in S-Map)	Rock (LRIS)[1]
Brown	50	Andesite, rhyolite, greywacke (18)	Vo, Vu, Al, Gw, Ac, Ar
Gley	1	Greywacke (1)	
Melanic	1		Lo
Allophanic	7	Rhyolite (4)	Mo
Pumice	14	Rhyolite (9)	Us, Vo, Tp
Organic	1		Pt
Pallic	11	Greywacke, sandstone (5)	Lo
Granular	2	Andesite (2)	
Recent	6	Greywacke (4)	Al, Ar
Raw	2	Greywacke (1)	Wb
Podzol	5	Rhyolite	Kt, Mo

[1] Full names for the abbreviations are shown in Table A3.

7.5 Considerations in developing a nationally consistent approach

The key consideration in developing a nationally consistent approach for determining background concentrations is to use consistently classified samples to allow for more detailed analysis of the data at a national level. In the first instance this is simply recording GPS location and specifying the soil order of the collected sample, as currently the factors that significantly influence trace element concentrations in soils across New Zealand are unknown. Some are suspected, for example volcanic soils in Auckland have demonstrably higher concentrations of certain trace elements than non-volcanic soils. However, how this applies across New Zealand as a whole is unknown. An approach similar to that used in the United Kingdom, whereby background concentrations for individual contaminants are defined for a small number of ‘domains’, would seem to be a useful workable approach applicable for contaminated land management and soil quality purposes. The challenge lies with defining appropriate domains for New Zealand.

An extensive amount of data have been identified and collated in the course of this project; while some preliminary analyses were undertaken there was not the scope to undertake more extensive analysis. Further data exploration, which includes the use of spatial tools to provide linkage to other soil and geological parameters, could offer insight into some of these controlling factors. However, this is still likely to be incomplete as there are recognised gaps in spatial coverage and for locations suspected to have naturally elevated concentrations of trace elements.

Ideally, a well-planned systematic survey would be used to sample across New Zealand, although such an exercise is likely to be costly and therefore unlikely to be undertaken at the current time. However, as noted by Taylor et al. (2007), some potential may exist to analyse archived soil samples collected as part of previous systematic surveys (e.g. Carbon Monitoring System programme). Alternatively, or additionally, the potential exists to collect additional data through regional council soil quality monitoring programmes. In particular, a one-off intensive sampling of ‘background’ sites could be undertaken. Samples should be analysed for a suite of trace elements; this could include potentially toxic elements (As, Cu, Cd, Cr, Hg, Ni, Pb, Zn), as well as essential elements (B, Co, Cu, I, Fe, Mn, Se and Zn), and PAHs (fresh samples only). Additional soil parameters such as clay content, organic matter content, and pH could also be collected to enable the relationship of these variables with trace element concentrations to be determined to establish whether there are any predictive relationships that can be developed. If any new sampling sites are established, these should be located to most optimally ‘fill in the gaps’ in spatial coverage and ideally be selected to enable contribution to a national systematic survey.

There are some minor considerations around sampling techniques. Consistent sampling techniques could assist in reducing data variability. Current sampling in New Zealand has used different techniques (soil quality monitoring (25 cores of 10 cm depth along a 50-m transect (Hill and Sparling 2009) and conventional geochemical sampling (5 samples at the corner and in the centre of a square of dimension ranging from 15 to 80 m). It would be useful to undertake a comparative analysis of results obtained from sampling using these techniques to determine whether there is significant difference in the results obtained. Appropriate guidance on sampling could then be given.

Standardisation of analytical techniques also reduces variability in sample results. *Aqua regia* extraction (and typically with analysis by ICP-MS) is predominantly used for contaminated land and soil quality monitoring, and thus is most logical for use. However, it should be noted that relationships between XRF analyses and analyses using *aqua regia* extraction can be developed, which enables data collected by all methods to be used in subsequent analysis.

In terms of data analysis, there are relatively standard statistical techniques that are recommended for the analysis of data. Boxplots in particular are a useful tool to provide summary statistics and may also be used to define upper limits of background concentrations. These techniques have been used in New Zealand to provide summary statistics and to undertake some further statistical analyses such as comparison of concentrations between soil groups (e.g. URS 2003; Tonkin and Taylor 2006, 2007 a, b). The main limitation with existing studies that have been designed to determine background concentration is that there are only small samples numbers, and the analysis is undertaken on a priori defined groupings that differ between regions. International guidance suggests that 20–30 samples are the minimum required to develop robust estimates of the background concentration (NCERP 2004; ISO 2011).

Internationally, the 95th percentile UCL is the most commonly used method to define an upper limit for background concentrations. In New Zealand the 99th percentile has more frequently been used and, according to some authors, there is little difference between these values (Diamond et al. 2009). Upper limits have also been defined through the use of boxplots, with the upper limit defined as the 75th percentile + 1.5× the interquartile range. Selection of the relevant method for determining the upper limit is more a matter for agreement between stakeholders than there being a definitive correct answer.

Determining an upper limit for background concentrations has the most application for contaminated land management, and potentially also for soil quality purposes. Setting minimum limits for essential elements may also be relevant to consider. In the context of whether natural background or ambient background is most relevant, given the relative isolation of New Zealand and our lack of history of industrialisation, it is reasonable to expect that outside urban areas natural background concentrations do exist, and would be appropriate for use in these locations.

Finally, from a longer term perspective, development of a spatial database as a central repository for all current data, and data collected in the future, is a priority. It would be logical for this database to also house data from samples collected from different land uses to enable the analysis of that data alongside that from background sites. It is also essential that such a database links to other spatial tools such as S-Map to allow for linkage with the additional parameters held in these tools.

7.5.1 Urban soils

In urban areas, it is inevitable that there will be an urban background of contamination arising from diffuse sources. Internationally, ambient background concentration is referred to in contaminated land guidance or regulations (e.g. BMU 1999; Cicchella et al. 2005; FMfE 2007; Diamond et al. 2009; DEFRA 2012). In New Zealand, while background concentration are naturally occurring concentrations only, it would be unreasonable to expect a given site owner to remediate below ambient concentrations in urban areas. Of particular interest in the urban environment are PAH concentrations as these are derived from a number of diffuse anthropogenic combustion sources (e.g. vehicles, domestic woodburners). Lead is also of interest given historical use of leaded petrol.

Some regional councils have undertaken studies in towns and cities that provide some indication of concentrations of contaminants in urban areas (Table 8). Studies in Christchurch yielded an estimate for the upper ambient background concentrationt for BaP by using the upper confidence limit of the 95th percentile – 0.595 mg/kg (Tonkin and Taylor 2007b). These studies have appropriately targeted parks, reserves, schools or other areas expected to have been minimally disturbed. It should be noted that some international studies have found that large park areas may be relatively unimpacted from urban diffuse pollution sources, and suggest concentrations measured in these locations may be more representative of natural concentrations (BGS 2011).

Table 8 Summary of urban studies to determine background concentrations of trace elements and PAHs

City/town	Analytes	Number of samples	Source
Christchurch	PAH, B, Mn, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn	22	Tonkin and Taylor 2006, 2007a, b
Timaru	B, Mn, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn,	5	Tonkin and Taylor 2007b
Hamilton	PAH, suite of 33 inorganic elements	5	Waikato Regional Council unpublished
Waikato regional towns (10)	PAH, suite of 33 inorganic elements	4–5 per town	Waikato Regional Council

While determination of ambient PAH concentration is comparatively easy from the perspective that concentrations will largely be unaffected by soil type, determination of ambient concentrations of trace elements is more difficult as these will be influenced by soil type. However, a broader understanding of this variation from samples collected in non-urban areas would provide the context for the relative contribution from soil type variation. Analysis of PAH concentrations from non-urban areas would also provide some perspective on the degree of influence urbanisation has had on PAH concentrations in soil.

7.5.2 Soils disturbed by mining

It is recognised that across New Zealand there is a legacy of soil disturbance associated with historical mining activities – so much so that there is a specific soil order in the NZSC for such soils; Anthropic Soils (which also includes other soils that have been extensively disturbed). A challenge with these soils is that they may be elevated in one or more trace elements, thus even though these soils could be considered as ambient background if historical mining activities are considered as diffuse pollution sources (e.g. as in the United Kingdom), there is still a potential risk associated with any elevated concentrations – for example in Lavrion, Greece, a legacy of lead mining resulted in extensive lead contamination that gave rise to health concerns for the local residents, and widespread remediation was required (Demetriades 2011). Thus, it is appropriate to actually assess the risk to residents living at these locations. Similarly, it would be appropriate to assess the risk to residents living in areas with the same soils but that were undisturbed. Conversely, in the case of ecological receptors, if the elevated concentrations are due to historical mining activities, on the basis of the ‘added risk’ notion it would be reasonable to expect that the ecological community has adapted to these elevated concentrations, and thus there is minimal risk to these receptors.

7.6 Recommendations for a nationally consistent approach

Recommendations for developing a nationally consistent approach for determining background soil concentrations of chemical substances are:

- Consistent site and sample information should be recorded – at minimum soil order and land-type, GPS location.
- More extensive analysis (including the use of spatial tools such as S-Map) of existing data should be undertaken, to identify key factors influencing trace elements and to identify whether any predictive relationships can be developed.
- Consensus on the appropriate upper limit(s) (e.g. 99th percentile, 95th UCL, median) to be used for different land management purposes is required.
- A consistent sampling collection methodology, depth intervals, and analytical techniques should be used, and samples (archived or fresh) should be analysed for a consistent suite of analytes and soil parameters. This could include As, Cu, Cd, Hg, Ni, Pb, Zn, as well as essential elements (B, Co, Cu, I, Fe, Mn, Se and Zn), and PAHs. Soil parameters include: clay content, organic matter content, cation exchange capacity and pH. A minimum of 20 samples is recommended for determining background concentrations for a defined group.
- A national systematic survey should be designed and selection of any new sampling sites based on ‘filling the gaps’. Collection of samples from the same land-use type, for example the conservation estate, etc., would reduce the influence of land use on results. Analysis of archived samples from previous systematic surveys may provide a cost-effective means to ‘fill the gaps’.
- The ultimate goal is be able to determine background concentrations for 2–4 ‘domains’ for individual chemical substances that are applicable across New Zealand. Predictive relationships may also provide complementary or an alternative approach to determining concentrations of naturally occurring concentrations of trace elements, although these would not be able to be used for determining ambient concentrations, i.e. background concentrations in urban areas.

8 Conclusions

Internationally there has been considerable work over the last decade to determine background concentrations of contaminants for use in managing land to meet legislative requirements. Ambient concentration, i.e. natural plus diffuse anthropogenic contamination, is the primary background concentration referred to in international legislation or statutory guidance. In New Zealand, given our relative isolation and lack of history of industrialisation, it is reasonable to expect that natural concentrations do exist outside urban areas, and ability to obtain background concentrations based on naturally occurring concentrations is a reasonable presumption. However, in urban areas it is more appropriate that an ambient background concentration is used to manage land. For areas disturbed by mining and/or undisturbed areas with naturally elevated concentrations of elements the actual risk to human health should be assessed rather than assuming the concentrations have no effect. However, from an ecological perspective, it is reasonable to assume the community has adapted to the elevated concentrations.

Beyond data collation and statistical summary of existing data, and the development of one predictive relationship (for Cd), there have been no concerted efforts to determine background concentrations of chemical substances across New Zealand, and limited analysis has been undertaken of the factors influencing background concentrations at a national scale.

One approach investigated was using published relationships for predicting background concentrations based on Fe concentrations that were suggested to be globally applicable. However, preliminary analyses using a small amount of existing data found that these relationships did not hold for New Zealand soils, and that alternative predictive relationships may be more appropriate. Further, there are challenges in developing predictive relationship and/or assessing the influence of soil type or geology on background soil concentrations across New Zealand due to the variability in data collected and the variable classification of samples, partly due to data being collected at a regional level. Spatial tools such as S-Map and NZLRI provide the opportunity to be able provide consistent information on soil attributes (and hence classification of samples/sites) that would also be of use in identifying the key factors influencing background concentrations of trace elements across New Zealand. Identification of a small number of ‘domains’ for individual substances for which background concentrations can be determined potentially provides a practicable approach to determining background concentrations across New Zealand.

9 Recommendations

To progress the development of a consistent approach to determining background concentrations the following steps are recommended:

- Further analysis of existing data should be undertaken, including the use of spatial tools to provide preliminary identification of key factors influencing trace element concentrations (recognising there are gaps in spatial coverage) and to identify whether predictive relationships can be developed.
- Collection and/or analysis of additional samples, based on a national systematic survey design, is required to ‘fill the gaps’ in spatial coverage.
- A consistent sampling collection methodology should be used and samples (archived or fresh) analysed for a consistent suite of analytes and soil parameters. A minimum of 20 samples is recommended for determining background concentrations for a defined group.
- A spatial database to hold information that links or is part of existing spatial tools such as S-Map should be developed to provide a central repository for data, and to allow ongoing data analysis – this should also allow for the inclusion of data from all land uses to maximise the value of the database and allow for the influence of land use on trace element concentrations to be assessed.

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Appendix 1 – Soils classification

The original soils classification system used in New Zealand was the New Zealand Genetic Soils Classification (NZGSC) system developed in 1948. During the 1980s a new classification system, the New Zealand Soil Classification, was developed. This system grew out of the NZGSC and has soil order as the highest most generalised level of the classification. Table A1 shows the general correlation between NZSC, the NZGSC and those described in *Soils of the New Zealand Landscape* (Hewitt 1998). Fifteen soil orders cover the range of New Zealand soils and their distribution is shown in Figures A1 and A2, with some further details of order characteristics shown in Table A2.

Table A1 Correlation between the New Zealand Soil Classification system, New Zealand Genetic Soils Classification, and Hewitt (1998)

NZ Soil Classification	NZ Genetic Soil Classification	Soils in the New Zealand Landscape
Allophanic	Yellow Brown loams	Volcanic loams
Anthropic	Anthropic soils	
Brown	Yellow Brown earths (but excluding many northern yellow brown earths), Brown Granular loams and clays, Yellow Brown shallow and stony soils	Brown earths, coastal sands, volcanic clays, stony terrace soils
Gley	Gley soils, recently gley soils	Gley soils
Granular	Brown Granular loams or Brown Granular clays	Compact volcanic clays, volcanic loamy clays
Melanic	Rendzinas, rendzic, intergrades, or Brown Granular loams, or Brown Granular clays	Calcerous soils, black swelling clays
Organic	Organic soils	Organic soils
Oxidic	strongly weathered red loams, brown loams, Brown Granular loams or Brown Granular clays	Friable volcanic clays
Pallic	Yellow grey earths	Dense grey earths
Podzols	Podzols	podzols
Pumice	Yellow Brown pumic soils	Pumice soils
Raw	Unclassified or hydrothermal soils	Raw volcanic
Recent (alluvial and coastal)	Recent soils or lithosols	Recent alluvial soils, coastal sands
Semi-arid	Brown-grey earths or solonetz	Semiarid soils
Ultic	Northern Yellow Brown earths, Yellow Brown sands or podsols	Brown clays

Table A2 Summary of the characteristics and distribution of soil orders (adapted from MfE 2008)

Soil order	Region of New Zealand	Percentage cover in New Zealand (%)	Predominant land use	Description	Dominant parent material*	Expected variation in TE concentration across order
Allophanic	Central North Island	5	Pastoral farming, cropping, and horticulture	Allophanic Soils are dominated by allophane (and also imogolite or ferrihydrite) minerals.	Tephra	Low
Anthropic	Central Ōtago, Westland, urban environments	<1	Modified soils – extensive in urban areas and areas that have been mined	Anthropic Soils are constructed by, or drastically disturbed by people. They include soil materials formed by stripping of the natural soil, deposition of refuse or spoil, or by severe soil mixing. The original character of the soil and the normal soil properties are lost.	All	High
Brown	East Taranaki, Wanganui–Rangitīkei, east coast of North Island, Wellington, Marlborough, Nelson–Buller, Southland, and South Island high country	43	Intensive pastoral farming and forestry	Brown Soils have a brown or yellow-brown subsoil below a dark grey-brown topsoil.	Quartofeldsphatic, Quartz, feldspar, mica dominated Mafic, ultramafic,	High
Gley	Wetlands – low parts of the landscape prone to water logging	3	High-producing dairy farms (with drainage systems)	Gley Soils are strongly affected by waterlogging and have been chemically reduced. Waterlogging occurs in winter and spring, and some soils remain wet all year.	Potentially all	High
Granular	Northland, South Auckland, Waikato, and some areas in Wanganui	1	Pastoral farming, cropping, and forestry; horticulture in some areas	Granular Soils are clayey soils formed from material derived by strong weathering of volcanic rocks or ash.	Tephra	Low

Soil order	Region of New Zealand	Percentage cover in New Zealand (%)	Predominant land use	Description	Dominant parent material*	Expected variation in TE concentration across order
Melanic	Scattered locations throughout New Zealand	1	Pastoral farming, mixed cropping, and market gardening	Melanic Soils have black or dark grey topsoils that are well-structured. The subsoil either contains lime, or has well-developed structure and is neutral or only slightly acid.	Limestone or calcareous materials, basic volcanic rocks	High
Organic	Lowlands of Waikato, Bay of Plenty, Southland and West Coast wetlands	1	Vegetable growing and horticulture	Organic Soils are formed in the partly decomposed remains of wetland plants (peat) or forest litter. Some mineral material may be present but the soil is dominated by organic matter.	Organic	Low
Oxidic	Northland, and Auckland.	<1	Pastoral farming, forestry, and native bush	Oxidic Soils are clayey soils that have formed as a result of weathering over extensive periods of time in volcanic ash or dark volcanic rock. They contain appreciable amounts of iron and aluminium oxides.	Strongly weathered andesite, dolerite, and basalt	Low
Pallic	East coast of North Island and South Islands, and .Manawatū	12	Pastoral farming and mixed cropping	Pallic Soils have pale coloured subsoils, due to low contents of iron oxides. The soils have weak structure and high density in subsurface horizons.	Quartz, feldspar, mica dominated	Low
Podzols	Northland and Westland	13	Agriculture and forestry	Podzol soils are strongly acid soils that usually have a bleached horizon immediately beneath the topsoil.	Quartz, feldspar, mica dominated, tephra	Medium

Soil order	Region of New Zealand	Percentage cover in New Zealand (%)	Predominant land use	Description	Dominant parent material*	Expected variation in TE concentration across order
Pumice	Central North Island, Hawke's Bay, and Bay of Plenty	7	Pastoral farming, forestry, and native bush	Pumice Soils are sandy or gravelly soils dominated by pumice, or pumice sand with a high content of natural glass.	Tephra	Low
Raw	Scattered thoughout New Zealand	3	Vegetation is sparse, wildlife reseerves	Raw Soils are very young soils. They lack distinct topsoil development or are fluid at a shallow depth.	All	High
Recent	All districts (floodplains, lower terraces of rivers, and coastal areas)	6	Alluvial: dairy farming, arable crops, market gardening, horticulture, and sports fields Coastal: pastoral and exotic forestry	Recent Soils are weakly developed, showing limited signs of soil-forming processes.	All	High
Semiarid	Central Ōtago	1	Pastoral farming, pipfruit, tussock land, and mountains	Semiarid Soils are dry for most of the growing season. Rain is not sufficient to leach through the soil, so that lime and salts accumulate in the lower subsoil. Nutrient levels are relatively high, but the soils must be irrigated to produce a crop.	Quartz, feldspar, mica dominated	Low
Ultic	Northland, Auckland, Wellington, Marlborough and Nelson	3	Pastoral farming, native and production forestry, Urban	Ultic Soils are strongly weathered soils that have a well-structured, clay enriched subsoil horizon.	Quartz, feldspar, mica dominated	Low

*From Hewitt (1998) [1] based on range of parent materials included in order; doesn't consider variation within a given parent material.

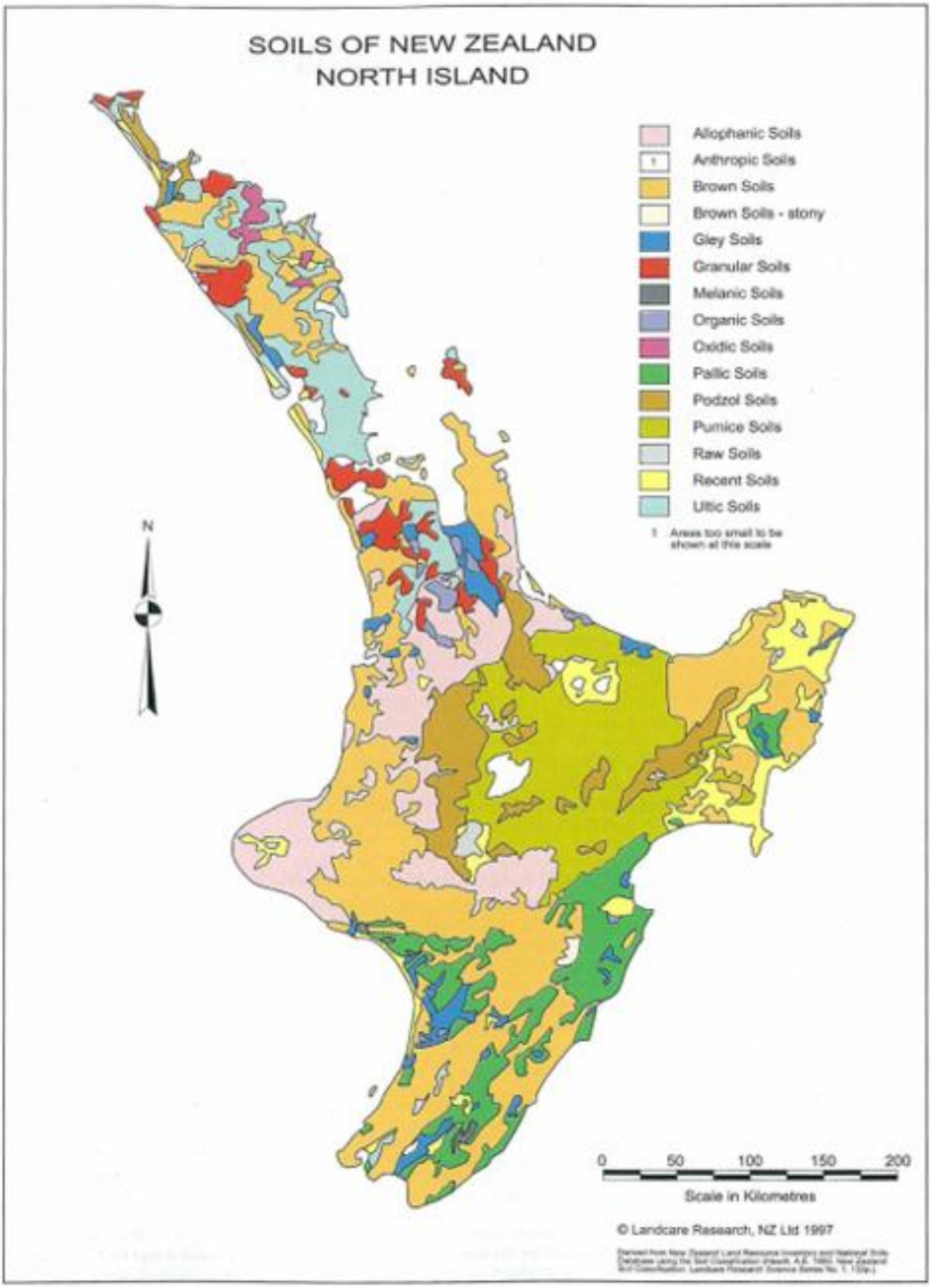

Figure A1 Distribution of soil orders across the North Island (from Hewitt 1998).

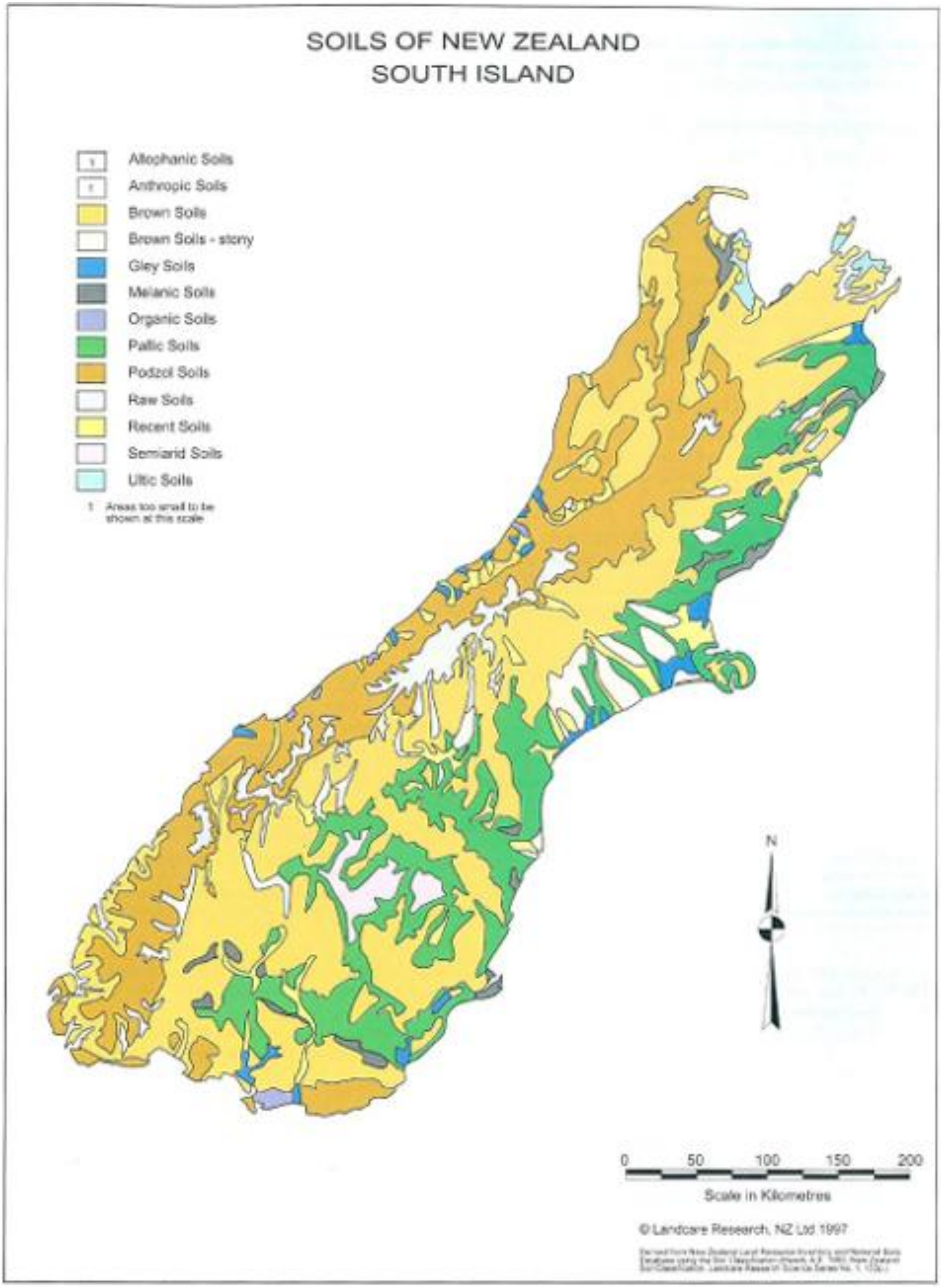

Figure A2 Distribution of soil orders across the South Island (from Hewitt 1998).

Appendix 2 – Rock classification used in LRIS

Table A3 Rock classification used in LRIS for North Island rock (from Newsome et al. 2008)

Item code	*Rock type class*	*Item code*	*Rock type class*
Igneous rocks			
Ng	Ngauruhoe ash	Rm	Rotomahana mud
Ta	Tarawera ash and lapilli	Sc[1]	Scoria
Lp	Lapilli	Kt	Kaharoa & Taupo ashes
Tp	Taupo & Kaharoa breccia & volcanic alluvium	Mo	Ashes older than Taupo pumice
Ft	Breccias older than Taupo breccia	La	Lahar deposits
Vu[1]	‘Soft’ volcanic rocks	Vo	Lavas, ignimbrite & other ‘hard’ volcanic rocks
Gn	Crystalline intrusive rocks	Um[1]	Ultramafics
Pt	Peat	Lo	Loess
Wb	Sands — windblown	Gr	Gravels
Al	Undifferentiated floodplain alluvium	Us	Unconsolidated to moderately consolidated clays, silts, sands, tephra & breccias
Mm	Mudstone or fine siltstone — massive	Mb	Mudstone or fine siltstone — banded
Mj	Mudstone or fine siltstone — jointed	Me	Mudstone — bentonitic
Sm	Sandstone or coarse siltstone — massive	Sb	Sandstone or coarse siltstone — banded
Cw	Weakly consolidated conglomerate	Mx	Sheared mixed lithologies
Cg	Conglomerate & breccia	Ac	Argillite — crushed
Ar	Argillite	Gw	Greywacke
Li	Limestone		
Other permitted values			
Estu	Estuary	Ice	Icefield
Lake	Lake	Rive	River
Quar	Quarry, mine, other earthworks	Town	Urban area, airport, oxidation pond

Table A4 Rock classifications used in LRIS for South Island rocks (from Newsome et al. 2008)

Item code	***Rock type class***	***Item code***	***Rock type class***
Surficial Rock Types			
Al	Alluvium, colluvium, glacial drift	Wb	Windblown sand
Lo	Loess	Pt	Peat
Sedimentary Rock Types: weakly indurated			
Ms	Mudstone	Ss	Sandstone
Fy	Interbedded sandstone & mudstone	Cw	Conglomerate
Sedimentary Rock Types: strongly indurated			
Ar	Argillite	Hs	Sandstone
Gw	Greywacke	Cg	Conglomerate
Ls	Limestone		
Igneous Rock Types			
Tb	Pyroclastics (ash & lapilli)	Vo	Lavas
In	Ancient volcanoes, minor intrusives (dikes & sills)	Gn	Plutonics
Um	Ultramafics		
Metamorphic Rock Types			
St1	Semi-schist	St2	Schist
Gs	Gneiss	Ma	Marble
Other permitted values			
estu	Estuary	Ice	Icefield
lake	Lake	Rive	River
quar	Quarry, mine, other earthworks	Town	Urban area, airport, oxidation pond