Determination and use of background concentrations of trace elements in soil in Otago and Southland

Envirolink Grant: 2518-ORC17

October 2025

Jo Cavanagh, Hadee Thompson-Morrison, Stephen McNeill

Manaaki Whenua – Landcare Research, a group of the Bioeconomy Science Institute

Dave Bull

HAIL Environmental

Simon Beardmore

e3Scientific

Contract Report registration number: 2526-0042

Prepared for: Otago Regional Council and Environment Southland

---

Reviewed by:	*Approved for release by:*
John Drewry	Sam Carrick
Senior Researcher	Portfolio Leader – Land Resources & Climate Change
Manaaki Whenua – Landcare Research	Manaaki Whenua – Landcare Research

Contents

Summary

Project and client

This project was undertaken for Otago Regional Council and Environment Southland under Envirolink Large Advice Grant 2518-ORC17. The aim of the project was to develop a region-specific data set of natural and ambient concentrations of trace elements in soil for use in contaminated land assessment and the determination of clean fill acceptance criteria.

Objectives

- To compare and critique the background concentrations of selected trace elements (arsenic, boron, cadmium, chromium, copper, mercury, nickel, lead, and zinc) for the Otago and Southland regions that have been determined using different approaches for different applications:
    - clean fill criteria
    - ecological soil guideline values
    - soil contaminant standards (SCS) for the protection of human health (i.e. when naturally occurring background concentrations are higher than SCS for certain land uses).
- To identify the range of additional contaminants for which it would be useful to have numeric criteria for waste acceptance, and, where possible, to recommend relevant numeric criteria and/or provide a rationale for any other criteria.

Methods

- Background concentrations of the selected trace elements for the Otago and Southland regions were determined using the following approaches:
    - national modelling, using a spatial mixed model (spaMM)
    - regional modelling, using the same modelling approach as for the national modelling but limited to regional-scale input data from Otago and Southland
    - geostatistical approaches, to determine background concentrations based on alternative pedological and/or geological groupings.
- An in-person workshop was held on 15 July with Otago Regional Council and Environment Southland contaminated land, soil quality, and policy and planning staff, along with selected environmental consultants, to discuss issues relating to, and options for the use of, background concentrations for regulatory purposes, including contaminated land management and clean fills.
- We prepared an overview of the approaches used in other regions of New Zealand, building on the workshop discussions to provide a critique of different approaches and the use of background concentrations in the context of different applications for the Otago and Southland regions.
- Additional contaminants for which it was considered useful to have waste acceptance or soil re-use criteria were identified, and, where possible, relevant numeric criteria were identified.
- Options for delineating areas of differing background concentrations, data sources and handling, and approaches used in other regions in New Zealand were discussed at a virtual

workshop on 25 August and informed the final report. The workshop again included Otago Regional Council and Environment Southland contaminated land, soil quality, and policy and planning staff, and selected environmental consultants.

Results and conclusions

- Four data sets comprising data from surveys undertaken by GNS Science (now Earth Sciences New Zealand), Manaaki Whenua – Landcare Research (a group of the Bioeconomy Science Institute), and regional councils were used to determine background concentrations, yielding over 2,400 data points nationally and over 800 data points regionally.
- Median concentrations based on national and regional statistical modelling were similar to median values based on the measured values. For the upper percentile values, modelled results were generally lower than the underpinning data, particularly for chromium and nickel, which reflects the presence of soils with naturally very high concentrations of these elements.
- To help determine relevant background concentrations for Otago and Southland, a set of principles were developed, as follows.
    - Soil is a valuable resource, and opportunities to minimise removal and enable beneficial re-use should be encouraged.
    - Risks associated with anthropogenic contamination should be negligible.
    - Risks associated with naturally elevated concentrations should be identified and managed appropriately.
    - When applied as criteria for clean fill, an adequate margin for error should be allowed so that exceeding a clean fill threshold by a minor margin will not inadvertently create contaminated land.
    - In general, the unrestricted re-use of soil should be allowed.
- A further principle was that criteria should be readily implementable (i.e. spatially simple).
- We compared the 95th and 99th percentile concentrations of the following data sets:
    - measured data - national: all land use, national – ambient sites only
    - measured data - Otago–Southland: all land use, Otago–Southland – ambient sites only, Otago–Southland: elevated and non-elevated areas
    - modelled data and
    - measured urban data set (95th percentile only).
- Also, ecological soil guideline values (Eco-SGVs) and the rural residential soil contaminant standards were used to develop risk-based background concentrations, which are concentrations equidistant from the 95th percentile background concentration and the lower of the Eco-SGV or SCS (i.e. the most sensitive receptor).
- Considering the principles listed above, and comparison with the background concentrations determined using different approaches, we suggest using the criteria shown in Table S1, which we collectively term ‘risk-based background concentrations’.
- Also shown in Table S1 are additional contaminants for which it was considered useful to have waste acceptance or soil re-use criteria. Criteria for additional contaminants are provided to enable comparison of any measured results for acceptance for soil re-use or clean fill, rather than indicating the range of contaminants soil should be tested for.

Table S1. Proposed risk-based background concentrations or soil re-use criteria for the management of contaminated land and soil relocation in Otago and Southland

Element	Criterion (mg/kg)	Basis
Arsenic	12	National 95th %ile ambient, which is below the derived value of 13 mg/kg for rural residential in MfE 2011c[a]
Boron	9	Otago–Southland 99th %ile, all land use
Cadmium	0.6	Equidistant between national 95th %ile and rural residential SCS
Chromium (elevated)	630[b]	Otago–Southland 99th %ile elevated, all land use
Chromium (non-elevated)	120[b]	Equidistant between Otago–Southland 95th %ile and Eco-SGV
Copper	80	Equidistant between national 95th %ile and typical Eco-SGV
Mercury	0.3	National 99th %ile all land use
Nickel (elevated)	890[b]	Otago–Southland 99th %ile, elevated, all land use
Nickel (non-elevated)	30[b]	Equidistant between Otago–Southland 95th %ile and CCME SQG$_e$
Lead	95 150	Equidistant between national 95th %ile and rural residential SCS 95th%ile urban ambient [d]
Zinc	150 180	Equidistant between national 95th %ile and typical Eco-SGV 95th%ile urban ambient [e]
Additional contaminants		
TPH C7–C9	110	Derived from MfE Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand 1999, revised 2011. Table 4.15 (WasteMINZ 2023b)
TPH C10–C14	58	Derived from MfE Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand 1999, revised 2011. Table 4.2 (WasteMINZ 2023b)
TPH C15–C34	150 (coarse soil[f]) 650 (fine soil[g])	Half Eco-SGV (Cavanagh & Harmsworth 2022)
PAH – BaP-eq	1	Empirical limit indicative of the presence of roading coal tar (WasteMINZ 2023a)
∑DDTs	0.5	Soil concentration above which DDTs in milk solids increase (Fonterra 2024)
Asbestos, fines, and fibrous asbestos	<0.001%	Quantification limit for respirable fibre risk; asbestos fibres may be present (BRANZ 2024)
PFOS and PFHxS	0.003	Human health investigation level for residential with garden / accessible soil (HEPA 2025)

[a] See Appendix A1 and A6 in MfE 2011c. The 95thile estimate for As in areas identified as naturally elevated is 28 mg/kg.

[b] Naturally elevated areas includes areas 'downstream' of mafic/ultramafic areas that may be influenced by eroded mafic/ultramafic material. Elevated Cr and Ni concentrations in the absence of marked elevated concentrations of other trace elements is likely indicative of naturally elevated concentrations.

[c] SQG$_e$ – soil quality guideline for environmental health (CCME 2015).

[d] Calculated excluding sites that were above the rural residential SCS; the 95th percentile value excluding sites above the residential SCS is 160 mg/kg.

[e] Calculated excluding sites that were above the 95% protection level Eco-SGV.

[f] Coarse-grained soils are those that contain more than 50% by mass of particles greater than 75 µm (mean diameter).

[g] Fine-grained soils are those that contain more than 50% by mass of particles less than 75 µm (mean diameter).

TPH = total petroleum hydrocarbons; PAH = polycyclic aromatic hydrocarbons; DDTs = dichlorodiphenyltrichloroethanes; PFOS = perfluorooctanesulfonate; PFHxS = perfluorohexanesulfonic acid.

- For contaminants that are not listed, the approach of providing a 'buffer'' ensures that exceeding these values by a minor margin does not inadvertently create a risk to ecological receptors or human health, and should be used. This could include the use of half the value of the lowest risk-based soil guideline level appropriate to the New Zealand environment and regulatory settings, or, where the contaminant is naturally occurring, the average of the background concentration and the lowest risk-based soil guideline level.
- Different sampling regimes and different statistical approaches are required to determine whether a site is above or below background concentrations (e.g. as per clause 5[9] in the National Environmental Standard for Managing Contaminants in Soil for the Protection of Human Health [NES-CS]), as opposed to characterising soil for 'disposal'. Reports received by councils should be critically reviewed for their adequacy in undertaking the appropriate comparisons.
- We suggest that these risk-based background concentrations could also be used as soil re-use criteria and allow for the unrestricted re-use of soils. Soils with higher concentrations should still be acceptable for re-use where it can be demonstrated that the added soil does not elevate concentrations at the recipient site, and that the concentrations at the site are suitable for its use.
- Evaluation of the use of background soil concentration information in existing policy and regulatory settings, and in clean fill definitions, is required to determine whether the intended or optimal outcomes are being achieved (e.g. Is the use of background concentrations appropriate for clean fill waste acceptance criteria? Is clause 5[9] of the NES-SC achieving its intended purpose, and what is that purpose?).

Recommendations

Following are the key recommendations based on this report.

- Greater recognition should be given to soil as a valuable resource, and opportunities to minimise removal and enable beneficial re-use should be encouraged.
- The proposed risk-based background concentrations should also be considered to be soil re-use criteria that enable the unrestricted re-use of soils.
- The 95th percentile modelled concentrations should be used to identify areas in which arsenic, chromium and nickel are likely to be naturally elevated, to assist in the management of soils and, where relevant, human health risk in these areas.
- Consideration should be given to using urban ambient concentrations of lead (excluding sites with concentrations above soil contaminant standards) and zinc (excluding sites with concentrations above the Eco-SGV) as background concentrations in urban areas.
- Greater tracking of soil relocation – by both the 'donor' and the recipient of the soil – should be implemented to provide assurance to councils that soils are being re-used appropriately, and that contaminated soils are not being placed in clean fills.
- When use of these risk-based background concentrations is confirmed, 'user-friendly' guidance should be developed to provide clarity on their application for contaminated land assessment and clean fill acceptance criteria.
- Given the upcoming resource management reforms, opportunities should be sought to ensure that economic and environmental outcomes arising from the current use of 'background' concentrations in the NES-CS, and waste management and clean fill definitions, are clarified and evaluated to ascertain whether these outcomes are being realised. If not, changes should be advocated.

1 Introduction

The unique geology of Otago and Southland has resulted in naturally elevated concentrations of certain trace elements. In some cases, soil may appear contaminated by human activity when compared with existing national-scale data, even though the elements present are geogenic in their source and below soil guideline values for the protection of human health and the environment.

Otago Regional Council recently proposed including the predicted background concentrations developed by Manaaki Whenua – Landcare Research in 2023 in its proposed Land and Water Regional Plan. The predicted background concentrations data set was to be used to establish acceptance criteria for clean fill sites and to enable assessment of site contamination.

However, wider discussions with the Otago Regional Council compliance team and contaminated land consultants working in the Otago region highlighted that adopting values from the predicted background concentrations would make the permitted activity pathway unrealistic and had the potential to direct large volumes of low-risk and uncontaminated materials soils to landfill. This is because they would not be identified as 'clean' even though they posed low to negligible risk and might not be 'contaminated' at all.

Environment Southland requires more regionally robust and consistent data sets of natural and ambient background concentrations of trace elements in rural and urban soils for a range of uses, including contaminated land assessments under the NES-SC, disposal of surplus soils, clean fill acceptance criteria, application of WasteMINZ landfill guidelines, as well as future use for regional planning, support for territorial authorities, and improving the classification of contaminated land. Areas of naturally elevated chromium, nickel, and asbestos are of particular interest.

More broadly, the disposal of large volumes of low-risk and uncontaminated materials – often termed 'surplus soils', because they can be surplus to on-site requirements – to landfills is being recognised as a significant issue that needs to be addressed at a national level (Cavanagh, Harmsworth et al. 2023; PCE 2024; WasteMINZ 2024a; Napp 2025). Most recently, WasteMINZ has started to develop a nationwide soil surplus framework, with funding from the Ministry for the Environment.[1]

This project aims to develop a region-specific data set of natural and ambient concentrations of trace elements in soil for contaminated land assessment and the determination of appropriate clean fill acceptance criteria. Developing a regional data set may allow for better and more consistent management of soils and fill material, which will ensure that human health and the environment are protected while enabling the beneficial re-use of low-risk (low-level contamination) material.

---

[1] https://www.wasteminz.org.nz/soil-surplus-project

2 Background

2.1 Definitions

Numerous terms are 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 2005 for a more detailed discussion).

For the purposes of this report the following definitions are used.

- *Ambient background:* the concentrations of chemical substances in the environment that are representative of the area surrounding the site and are not attributable to a single identifiable source. This can include contaminants from historical activities and widespread diffuse impacts (e.g. fallout from motor vehicles). This is referred to as ‘normal’ concentrations in the UK (DEFRA 2012).
- *Natural background:* the concentrations of naturally occurring elements derived/originating from natural processes in the environment as close as possible to natural conditions, and excluding specific anthropogenic activities or sources. This may also be referred to as the ‘geochemical background’, attributable to mineral content derived from parent materials, other natural processes such as volcanic ash dispersal and geothermal inputs, and the influence of soil-forming processes. This is also the definition of ‘background’ used in *Contaminated Land Management Guideline No. 5* (MfE 2021).
- *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:* the upper limit of background variation (Reimann & Garrett 2005).

2.2 Previous determination of background concentrations

Spatial tools are increasingly used internationally to determine background soil concentrations (e.g. Lado et al. 2008; Diez et al. 2009; Jarva et al. 2010; Cave et al. 2012). Often geostatistical analyses are used to define relevant ‘domains’ or groupings to indicate where background concentrations are similar. Such tools enable spatial extrapolation to areas with little or no soil sampling. Whether the extrapolations are based on geological or soil data appears to depend more on what databases are available as opposed to a rigorous assessment of the factors controlling background concentrations.

For example, in the UK a Soil-Parent Material Model (SPMM) has been developed (Lawley 2009), based on the origin of the parent materials, dominant mineralogy, and texture. This is available at a 1:50,000 scale and was used by Ander et al. (2011), along with mineralisation and historical mining databases, to determine ‘normal’ (background concentrations) across the UK for the purposes of managing contaminated land. In contrast, Sheppard et al. (2009) used a spatial system based on soil classifications to provide a trace element index to assess the sustainability of Canadian agriculture. Lado et al. (2008) used a geological database – along with various other databases, including land cover, nightlights (as a measure of urbanisation), and infrastructure – to explain heavy metal concentrations across 26 European countries.

Cavanagh (2013b) reviewed various approaches to determining background concentrations and considered that in the context of available data in New Zealand. Cavanagh et al. (2015) built upon this report, and provided a first attempt to develop nationally consistent estimates of concentrations of selected naturally occurring trace elements (arsenic, boron, cadmium, chromium, copper, lead, nickel, and zinc) concentrations in New Zealand using existing data collated from different sources. Their study evaluated the use of geologically related parameters from several spatial databases and statistical modelling to develop consistent national estimates of naturally occurring concentrations across New Zealand. The purpose of the study was to develop background concentrations suitable for use in the development of added-risk ecological soil guideline values (Eco-SGVs, see section 2.3.2).

Naturally occurring concentrations were based on a rock-type parameter, 'Chemical4', which provided the ability to predict likely concentrations in locations for which no data were available. Chemical4 was based on rock-group from QMAP,[2] which is a database of geological maps developed by GNS Science over the period 1993–2012 (Rattenbury & Isaac 2012). Chemical4 subdivided the Miocene and younger sedimentary rocks and sediments (Maui and Pakihi supergroups, Mortimer et al. 2014) of rock group, forming 72 categories. Chemical4 was used as the basis for generating preliminary background concentration distribution (described by the effective median, and the 5th and 95th percentile estimates) for the individual trace elements for the individual Chemical4 subgroups across most of New Zealand.

Subsequently, Cavanagh, McNeill et al. (2023) used a more spatially representative extended data set and a different modelling approach to provide updated estimates of selected naturally occurring trace elements (arsenic, boron, cadmium, chromium, copper, lead, nickel, and zinc) across New Zealand. Modelling used over 2,000 data points to assess the influence of land use and three explanatory data layers – parent material, soil order, and Land Environments of New Zealand level 1 categories – on the concentration of the key trace elements.

From this model, estimates of the rural ambient concentrations (i.e. including sites where anthropogenic activities might occur, although there is expected to be minimal anthropogenic additions of trace elements to the soil and no difference from naturally occurring concentrations) across New Zealand were made, providing a nationally consistent approach to determining background concentrations. In this report the predicted concentrations are displayed as filled contour plots to enable visualisation of the variation in concentrations across the country. Contours delineated areas within the median, 90th, 95th, and 99th percentiles of the predicted concentrations. Areas identified as being at or above the 95th percentile of predicted concentrations are considered to be areas that may contain naturally elevated concentrations, which may also vary significantly at smaller scales than captured in the current study and may warrant site-specific investigations to better determine background concentrations. This information was used to develop updated Eco-

---

[2] http://www.gns.cri.nz/qmap

SGVs, including consideration of the influence of variation in background concentrations for modifying Eco-SGVs (see section 2.3.2).

2.3 Use of background concentrations

2.3.1 Management of contaminated land

In the National Environmental Standard for Managing Contaminants in Soil for the Protection of Human Health (NES-CS), background concentrations are used in Clause 5(9), which states, 'These regulations do not apply to a piece of land … 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'. For this clause to apply, there is the requirement that the land must have been identified as having, having had, or is more likely than not to have had, a HAIL (Hazardous Activities and Industries List) activity on it.

However, this clause often appears to be interpreted as indicating that a HAIL activity must have occurred, and that the NES-CS does apply to land with soil concentrations considered to be *above* background (i.e.), even if below any applicable human health criteria (i.e. soil contaminant standard, SCS) or environmental guideline. Under the RMA 1991, 'contaminated land' means land that has a hazardous substance in or on it that (a) has significant adverse effects on the environment; or (b) is reasonably likely to have significant adverse effects on the environment. For soils with contaminant concentrations below applicable human health criteria (i.e. the SCS) or environmental guideline (e.g. Eco-SGVs; Cavanagh & Harmsworth 2023), it cannot be said that a significant adverse effect is occurring or is likely to occur; therefore the land should not be considered contaminated land.

In a different context, the now-repealed Natural and Built Environment Act 2023 included a definition of a natural hazard as being 'soil that contains concentrations of naturally occurring contaminants that pose an ongoing risk to human health.' Logically, 'naturally occurring contaminants' in this context is intended to mean background concentrations, and, in particular, naturally elevated background concentrations. Therefore, clause 5(9) of the NES-CS is contradictory to the purpose of the NES-CS (protection of human health), because excluding land at or below background concentration doesn't necessarily ensure protection of human health, particularly where those concentrations are naturally elevated.

2.3.2 Ecological soil guideline values

Soil guideline values for the protection of ecological receptors (microbes, invertebrates, plants, wildlife, livestock, i.e. Eco-SGVs) provide a first assessment of the potential negative environmental effects associated with contaminants (Cavanagh & Munir 2019). Eco-SGVs for naturally occurring contaminants (i.e. metals and metalloids) have been developed using the 'added-risk' approach (Cavanagh & Munir 2019). This approach considers that soil biota are adapted to the naturally occurring concentrations of potential contaminants, and that it is the 'added' anthropogenic component that drives toxicity responses. The magnitude of the acceptable 'added' concentration is determined by assessing toxicity data, with the 'added concentration limit' added to the background concentration (see Cavanagh & Munir 2019 for further details). The added-risk approach allows for variation in the Eco-SGVs based on variation in naturally occurring background concentrations. Cavanagh and Harmsworth (2022) further evaluated the application of Eco-SGVs and outlined their use based on three levels of protection: 95%, 80%, and 60% of species (based on chronic toxicity data).

Subsequently, Cavanagh and Harmsworth (2023) reassessed the implementation of Eco-SGVs using updated background concentration estimates from Cavanagh, McNeill et al. 2023, and taking into account the variation in background concentrations for modifying Eco-SGVs. Initially the median background concentration is used to determine the Eco-SGVs (Cavanagh & Munir 2019). Some pragmatism is then required to determine when it is appropriate to modify the Eco-SGVs based on background concentrations to avoid overly complex application, and to ensure they still afford an appropriate level of protection.

Cavanagh and Harmsworth (2023) considered both the percentile range and the proportional contribution of the natural background concentration to the Eco-SGV, and also the relevance of allowing further adjustment for lower levels of protection. These authors recommended that background concentration adjustment should only be done for the 95% protection values, partly because background concentrations generally comprise only a small proportion of the 80% and 60% protection values, but also because it was not considered appropriate to enable further adjustment of values associated with lower levels of protection. For the 95% protection values, background adjustment was only considered relevant for those contaminants where the difference between median concentration and the upper percentiles was >10 mg/kg, and where the background concentration comprised >10% of the Eco-SGV.

2.3.3 Waste acceptance criteria

The *Technical Guidelines for Disposal to Land* (WasteMINZ 2023) provide technical guidance on siting, design, construction, operation, and monitoring for disposal to land, and classify landfills into five types:

- Class 1 Landfill – municipal solid waste landfill or industrial waste landfill
- Class 2 Landfill – construction & demolition landfill or industrial waste landfill
- Class 3 Landfill – managed fill
- Class 4 Landfill – controlled fill
- Class 5 Landfill – clean fill.

In the context of background soil concentrations, Class 5 clean fill is most relevant. It is intended that materials placed in a Class 5 clean fill will to be inert, and it is recommended that the regional soil background levels for trace elements be adopted as the basis for accepting materials for these sites. The waste acceptance criteria for a Class 5 clean fill are based on the accepted background concentrations for inorganic elements in the intended catchment of the site and provide for trace concentrations of a limited range of organic compounds.

It should also be noted that approaches used by regional councils for clean fill criteria have been variable, based either on background concentrations alone, or on a combination of background concentrations and Eco-SGVs and protecting human health (e.g. Cavanagh 2013a, 2021), or on concentrations that are not lower than the 95th percentile of the regional background and do not exceed the lower of the protective thresholds for the most sensitive receptor (i.e. the lower of human health or ecological thresholds) (WRC 2022). See also section 5.3.

3 Objectives

- To compare and critique the background concentrations of selected trace elements (arsenic, boron, cadmium, chromium, copper, mercury, nickel, lead, and zinc) for the Otago and Southland regions that have been determined using different approaches for different applications:
  - clean fill criteria
  - ecological soil guideline values
  - soil contaminant standards (SCS) for the protection of human health (i.e. when naturally occurring background concentrations are higher than SCS for certain land uses).
- To identify the range of additional contaminants for which it would be useful to have numeric criteria for waste acceptance, and, where possible, to recommend relevant numeric criteria and/or provide a rationale for any other criteria.

4 Methods

4.1 Overview

Background concentrations of selected trace elements for the Otago and Southland regions were determined using three different approaches:

- national modelling, based on predictive modelling using a spatial mixed model (spaMM)
- regional modelling, using the same approach as for national modelling but using only regional-scale input data from Otago and Southland
- geostatistical approaches, to determine background concentrations based on alternative pedological and/or geological groupings.

An in-person workshop was held on 15 July with Otago Regional Council and Environment Southland contaminated land, soil quality, and policy and planning staff, along with selected environmental consultants, to discuss issues related to, and options for the use of, background concentrations for regulatory purposes, including contaminated land management and clean fills.

We provide an overview of the approaches used to develop background concentrations and/or clean fill criteria in other regions in New Zealand. Drawing on the workshop discussions, we critique the different approaches and uses of background concentrations in the context of different applications for the Otago and Southland regions. We also identify additional contaminants, and relevant numeric criteria where possible, for which it would be useful to have numeric criteria for waste acceptance criteria. Options for delineating areas of differing background concentrations, data sources and handling, and approaches used in other regions in New Zealand were discussed at a virtual workshop on 25 August. This workshop again included Otago Regional Council and Environment Southland contaminated land, soil quality, and policy and planning staff, and selected environmental consultants.

We also provide a short discussion on determining site-specific background concentrations. The recommended background concentrations have been provided as spatial layers for councils.

4.2 Data

Four data sets were used to develop estimates of background concentrations:

- the New Zealand geochemical baseline data set
- regional geochemical surveys
- regional council state of the environment soil quality data
- regional background studies.

These are described further below. For convenience the data sets are referred to as GNS, RGS, RC, and ACWB.

4.2.1 New Zealand soil geochemical baseline data set (GNS)

This data set combines soil samples from pre-existing surveys undertaken by GNS Science or Manaaki Whenua – Landcare Research (Martin, Turnbull et al. 2023). Over 95% of the samples were collected after 2011; the remaining samples, collected between 1960 and 2011, were included from otherwise under-represented regions of the country.

Samples in this data set were all collected by hand, typically using soil corers, augers, or hand trowels to collect a near-surface sample. Sample depths varied between surveys, but 10 of 20 surveys sampled the top 10 cm, nine sampled the top 20 cm, and one sampled the top 30 cm. Samples were oven dried at 40°C and sieved to retain the sub-2 mm portion.

The surveys determined element concentrations in order to map their variation across the country. A single instrument was used to acquire a suite of 65 elements: inductively coupled plasma mass spectrometry (ICP-MS) on an aqua regia solution were undertaken by Bureau Veritas Minerals Laboratories in Vancouver (further details are provided in Martin, Turnbull et al. 2023). Only the data for arsenic (As), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) are considered here.

4.2.2 Regional geochemical surveys (RGS)

Geochemical data based on grid-based sampling from several regional studies undertaken by GNS Science were also analysed. These were from Auckland (Martin, Lim et al. 2023), Marlborough/Tasman (Turnbull, Martin, Rattenbury 2017), northern Otago (Martin et al. 2017), and southern New Zealand (Martin et al. 2015). The surveys collected samples at 0–20 or 0–30 and 50–70-cm depths, spaced on an 8 km grid, with some additional sampling undertaken on 4 km or 2 km grids. These samples were analysed for all major and trace elements using aqua regia partial digest ICP-MS and whole-sample XRF. Data from the surface samples (2–30 cm samples for southern New Zealand, 2–20 cm for the remaining studies) were used in the current study.

4.2.3 Regional council state of the environment soil quality monitoring (RC)

Data from regional council SoE soil quality monitoring programmes were used as an additional data set. These data were compiled for national reporting in 2020, and Cavanagh et al. (2020) provide a detailed description of the data collation. Briefly, samples were typically collected following Hill & Sparling 2009, whereby approximately 25 subsamples (0–10 cm) are collected along a 50 m transect to form a single composite sample. Samples were typically extracted using nitric and hydrochloric acid, followed by analysis by inductively coupled optical emission spectroscopy (ICP-OES) or inductively coupled plasma mass spectroscopy (ICP-MS).

4.2.4 Regional studies on background concentrations (ACWB)

Data from studies to determine background soil concentrations in Auckland (ARC 2001), Wellington (URS 2003), and Canterbury (Tonkin & Taylor 2006, 2007) were used as the final data set. Sampling included single point samples, or composite samples comprising subsamples collected from the centre and points of a grid around a 10–20 m square. Samples were typically extracted using nitric and hydrochloric acid, followed by analysis by ICP-OES, ICP-MS or atomic absorption spectroscopy. Further detail on these studies is provided in section 5.3 which provides an overview of background concentrations in other regions. In addition, data from three regional transects undertaken by Waikato Regional Council over 1998–2013 were used. Sampling and analysis were undertaken as described for regional council state of the environment (SoE) soil quality monitoring (section 4.2.3).

4.2.5 Data processing

Data from the four data sets were combined and processed to ensure consistent land-use classifications. Sites with no land-use or location information were removed from the data set. Any left-censored values (e.g. those below analytical detection limits) were replaced by half that value. Any right-censored values (e.g. those defined as greater than any value) were left as they were (this was quite rare). Where multiple data were provided for the same location, these were filtered so that only data from the most recent sampling event were retained. If there were multiple values in the most recently sampled year, the mean of those values was used. Any negative or zero concentration values were removed from the data, as were any rows of data that contained no trace element concentration data (e.g. SoE monitoring sites where trace elements had not been measured) or missing explanatory variable information (i.e. rows that had no information recorded for soil order, LENZ class or parent material – discussed in section 4.3). After processing, the four combined data sets resulted in 2,941 rows of data for further analysis. A summary of the contribution of the different data sets is shown in Table 1, with the distribution of sample locations shown in Figure 1. These data were used in national modelling.

Table 1. Number of data points, by land use and data source

Land use	ACWB	GNS	RGS	RC	All sources
Background*	188	342	591	99	1,220
Exotic forest	2	31	139	76	248
Grazing	3	314	451	355	1123
Mine	0	0	1	0	1
Perennial cropping	0	32	4	89	125
Short-rotation cropping	0	81	6	102	189
Urban	0	2	14	10	26
Wetland	0	6	3	0	9
All NZ	**193**	**808**	**1,209**	**731**	**2,941**

* Conservation estate or other land with no or minimal land-use activity

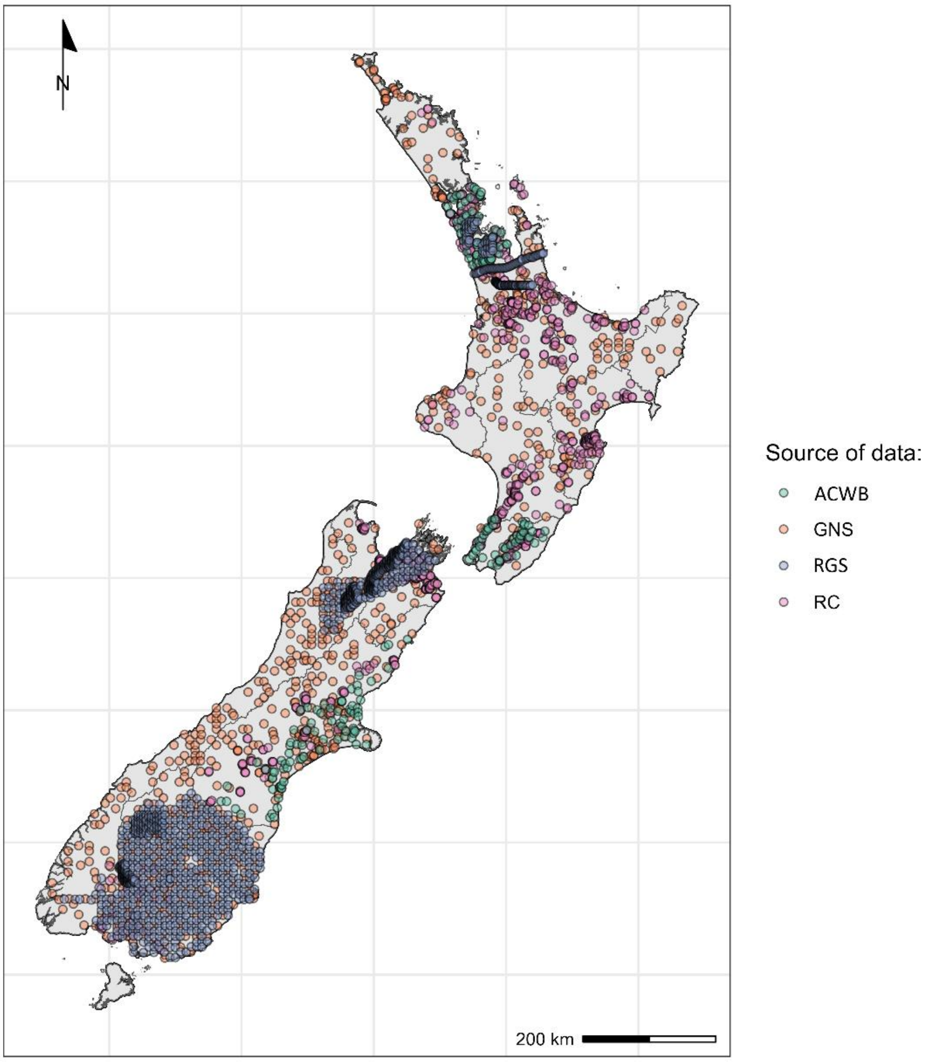


Figure 1. Locations of all data, shown by source of the data. ACWB refers to the combined regional background concentration and council transect studies dataset, GNS is the extended national data set, RGS is the regional geochemical studies dataset, and RC is the collated SoE soil quality monitoring data set.

For the analysis, land uses in Table 1 were further consolidated via spatial analysis to provide a rural ambient class, which combined 'Background,' 'Forestry', and 'Grazing' that was not 'High Producing Exotic Grassland', based on the Land Cover Database version 5 land-use class. A rural ambient concentration was used to recognise the extent of anthropogenic activities across New Zealand, but the land uses included are anticipated to have minimal anthropogenic trace element inputs, so these rural ambient concentrations are not expected to differ much from naturally occurring concentrations. In an urban environment, ambient trace element concentrations – primarily lead from the historical use of leaded petrol, and, rarely, other trace elements associated with industrial emission – might reasonably be expected.

Using this approach, 1,513 sites are rural ambient, which is 62.2% of the total number of sites. Figure 2 shows a plot of the rural ambient points alongside sampling points from other land uses. These modified land-use classes were used within the spaMM model as an explanatory variable, in addition to those described in section 4.3.

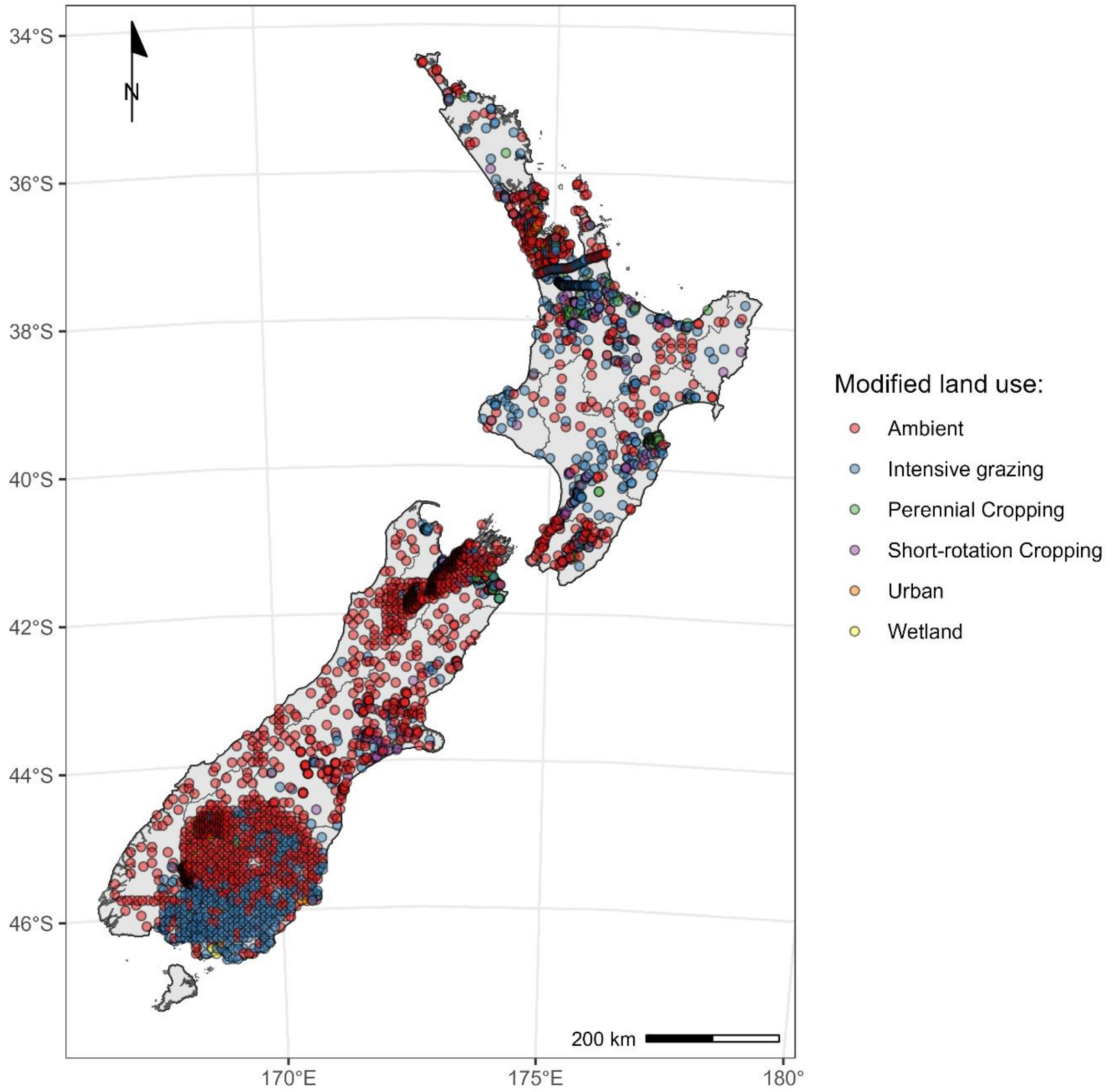


Figure 2. Distribution of sampling sites based on land-use category.

Data trimming for regional modelling

A regional model was developed using only input data from within the Otago and Southland regions. The data set described above was therefore trimmed to contain only sites that fell within the boundaries of these regions. This resulted in a data set with 834 rows of data. There were no ACWB sites remaining in this data set because these were collected from around the Auckland, Wellington, and Canterbury regions only. The Otago and Southland sites contained all of the same modified land-use categories as the national data set (3).

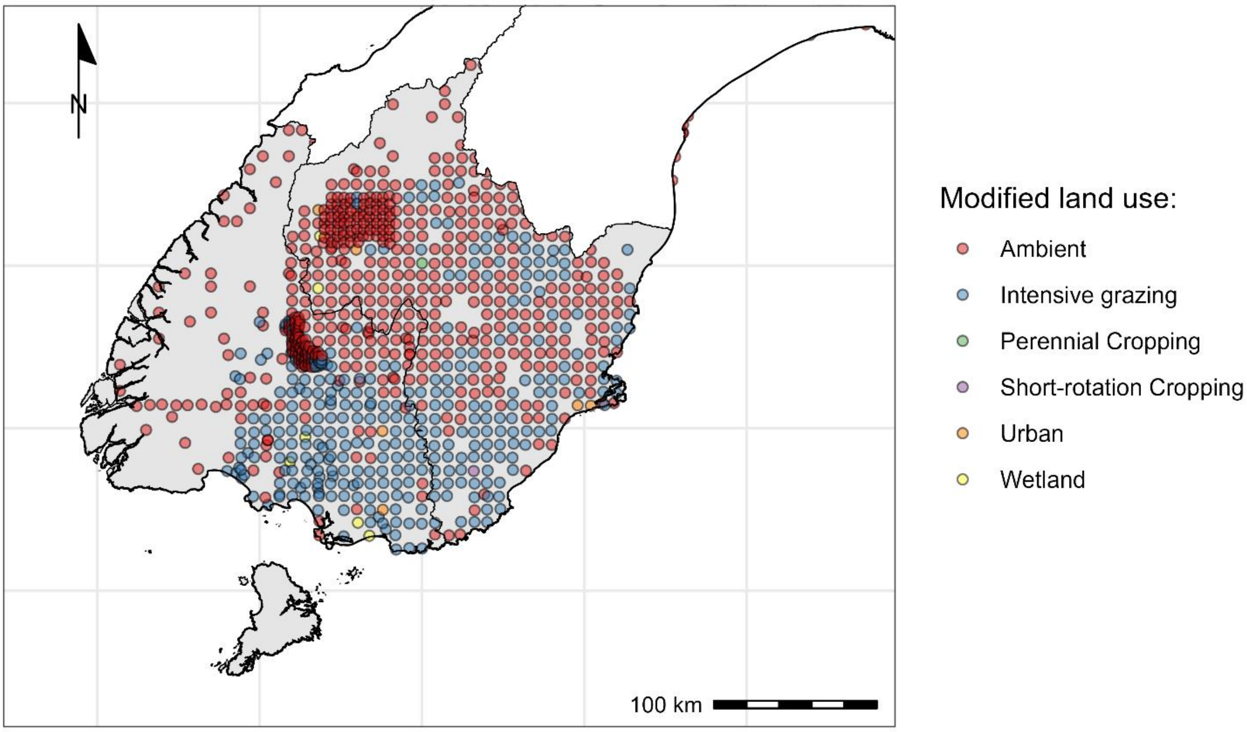


Figure 3. Distribution of sampling sites in Otago and Southland regions based on land-use category.

4.3 Explanatory variables

The site-based trace element data were complemented by data from three GIS-based polygon spatial databases that regionally and/or nationally delineate areas that are interpreted as having distinct common pedological and/or geological properties. These were:

- parent material
- soil order
- LENZ class.

4.3.1 Parent material layer

The parent material map was generated using a combination of sources. The geological survey of New Zealand (QMAP) was used as a main parent material baseline, using its ROCKCLASS attribute. QMAP[3] is a database of geological maps developed by GNS Science over the period 1993–2012 (Rattenbury & Isaac 2012). This includes a national seamless GIS component based on the 21 published geological maps at 1:250,000 (Heron 2014).

ROCKCLASS information was combined with additional information from the New Zealand Land Resource Inventory (NZLRI)[4] in order to add information about peat, loess, and volcanic ash deposits, which are critical to soil formation but typically not included in QMAP. Some ROCKCLASS attributes were grouped to generalise the parent material classes, with grouped attributes expected to have similar trace element distributions. The parent material classes and descriptions are as follows.

- The ‘Ultramafic Igneous’ class groups the ‘Volcanic’, ‘Ultramafic Intrusive’, and ‘Tectonic’ classes of QMAP.
- The ‘Limestone’ class groups the ‘Limestone’ and ‘Chemical Sediment’ classes of QMAP.
- The ‘Felsic Igneous’ class groups the ‘Intermediate Intrusive’, ‘Intermediate Extrusive’, ‘Felsic Intrusive’, and ‘Felsic Extrusive’ classes of QMAP. Tephra was also included by the different volcanic ash classes mapped as part of the NZLRI.
- The ‘Mafic Igneous’ class groups the ‘Mafic Intrusive’ and ‘Mafic Extrusive’ classes of QMAP.
- The ‘Gneiss’ class was renamed from the ‘Metamorphic’ class in QMAP.
- The ‘Sediment’ class was renamed from the ‘Clastic Sediment’ class in QMAP.
- The ‘Loess’ class was sourced from the NZLRI.
- The ‘Peat’ class was created from a combination of S-map (see below) and the NZLRI.
- The ‘Schist’ class was sourced from the ‘Schist’ class in QMAP.

The distribution of parent material classes across New Zealand is shown in Figure 4.

---

[3] http://www.gns.cri.nz/qmap

[4] http://lris.scinfo.org.nz/

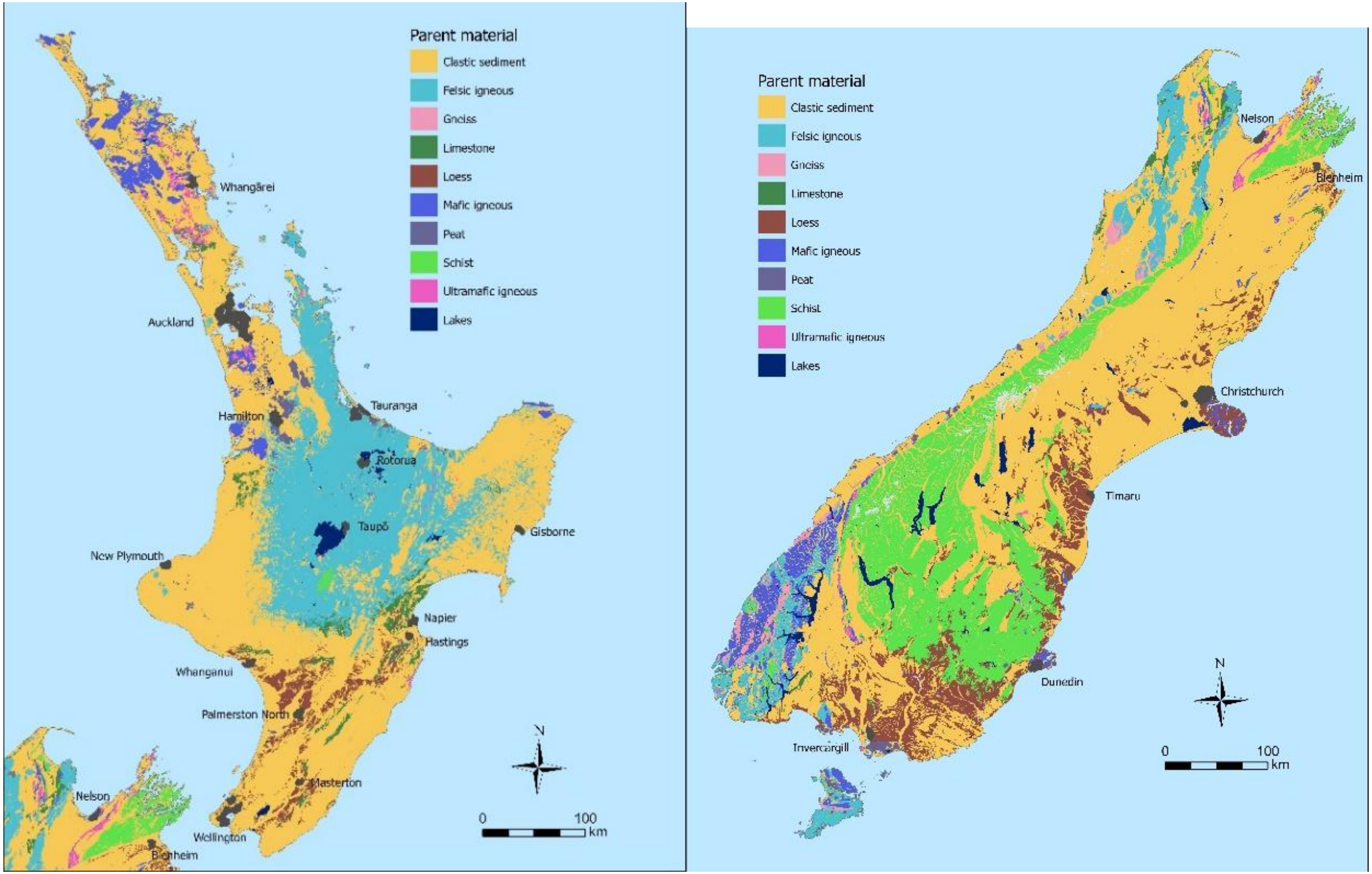


Figure 4. Distribution of parent materials across New Zealand.

4.3.2 Soil order

Soil order was determined by combining information from S-map and the Fundamental Soil Layers (FSL) for areas where S-map was not available. S-map[5] is a spatial database for New Zealand soils designed to provide quantitative soil information for modellers, and it includes links to the National Soils Database and QMAP (Lilburne et al. 2012). Data are mapped at a 1:50,000 scale, or finer in some locations.

The FSL is housed within the Land Resource Information System[6], which allows the public to access environmental data held by Manaaki Whenua – Landcare Research. The FSL describes land on the basis of five characteristics (including soil order) and is also mapped at a 1:50 000 scale. The distribution of soil orders nationally is shown in Figure 5.

---

[5] http://smap.landcareresearch.co.nz/home

[6] http://lris.scinfo.org.nz/

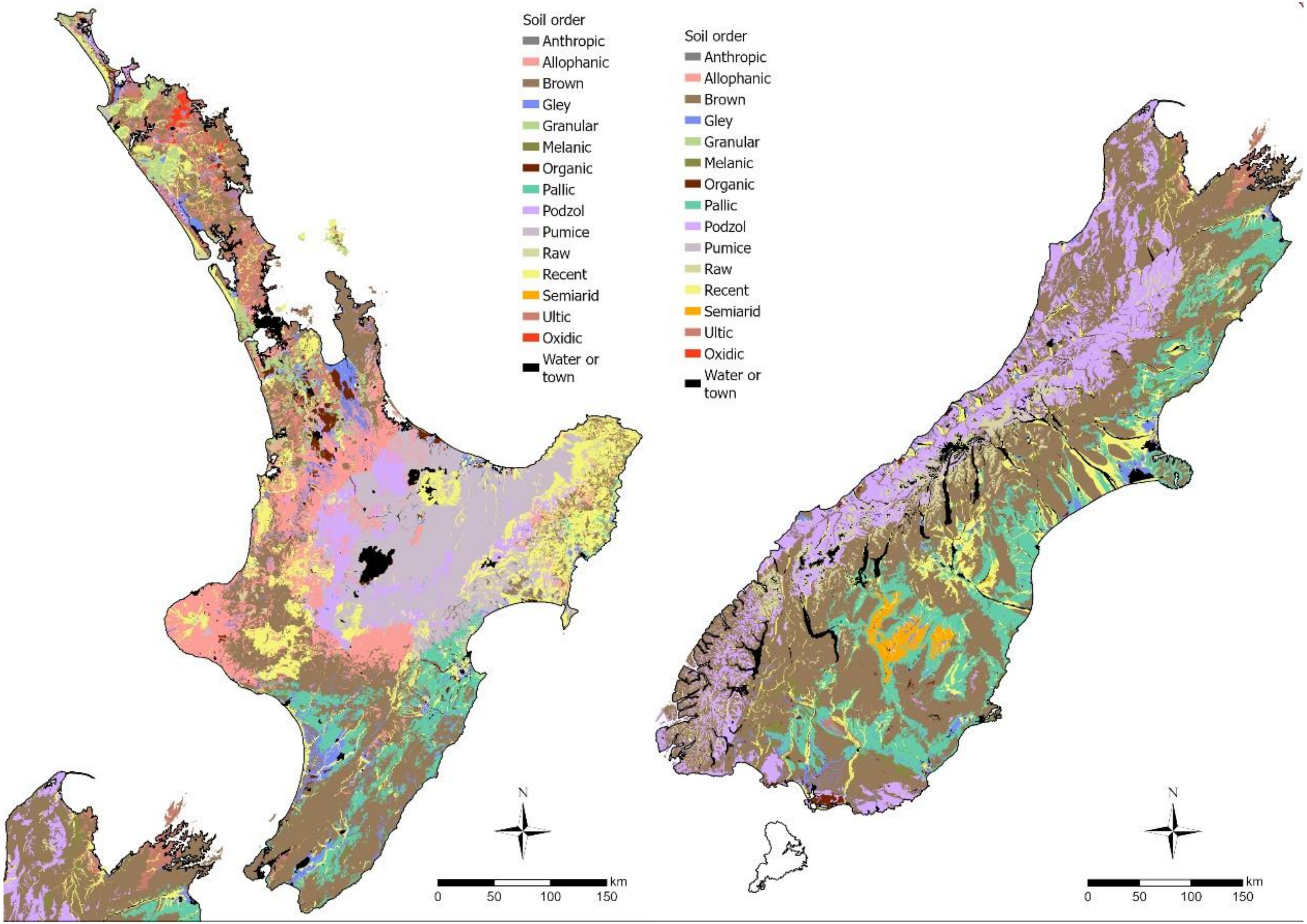


Figure 5. Distribution of soil orders across the North and South Island of New Zealand.

4.3.3 Land Environments of New Zealand

Soil formation (and hence trace element concentrations) can be influenced by climatic conditions. Land Environments of New Zealand (LENZ)[7] provides a different perspective for considering baseline concentrations of trace elements in soil, describing ecosystems as a function of various aspects of New Zealand's climate, landforms, and soils (Leathwick et al. 2002). Some LENZ classes are associated with distinct soil types and geologies in particular Ultramafic soils. At a finer scale many rare ecosystems[8] are also associated with distinct geologies, including geothermal areas, and inland and alpine areas with skeletal or poorly developed soils, including boulderfields of calcareous rock, granitic sand plains, and ultrabasic hills (Wiser et al. 2013). The distribution of Level 1 LENZ classes across New Zealand is shown in Figure 6.

---

[7] https://www.landcareresearch.co.nz/tools-and-resources/mapping/lenz/

[8] https://www.landcareresearch.co.nz/publications/naturally-uncommon-ecosystems/

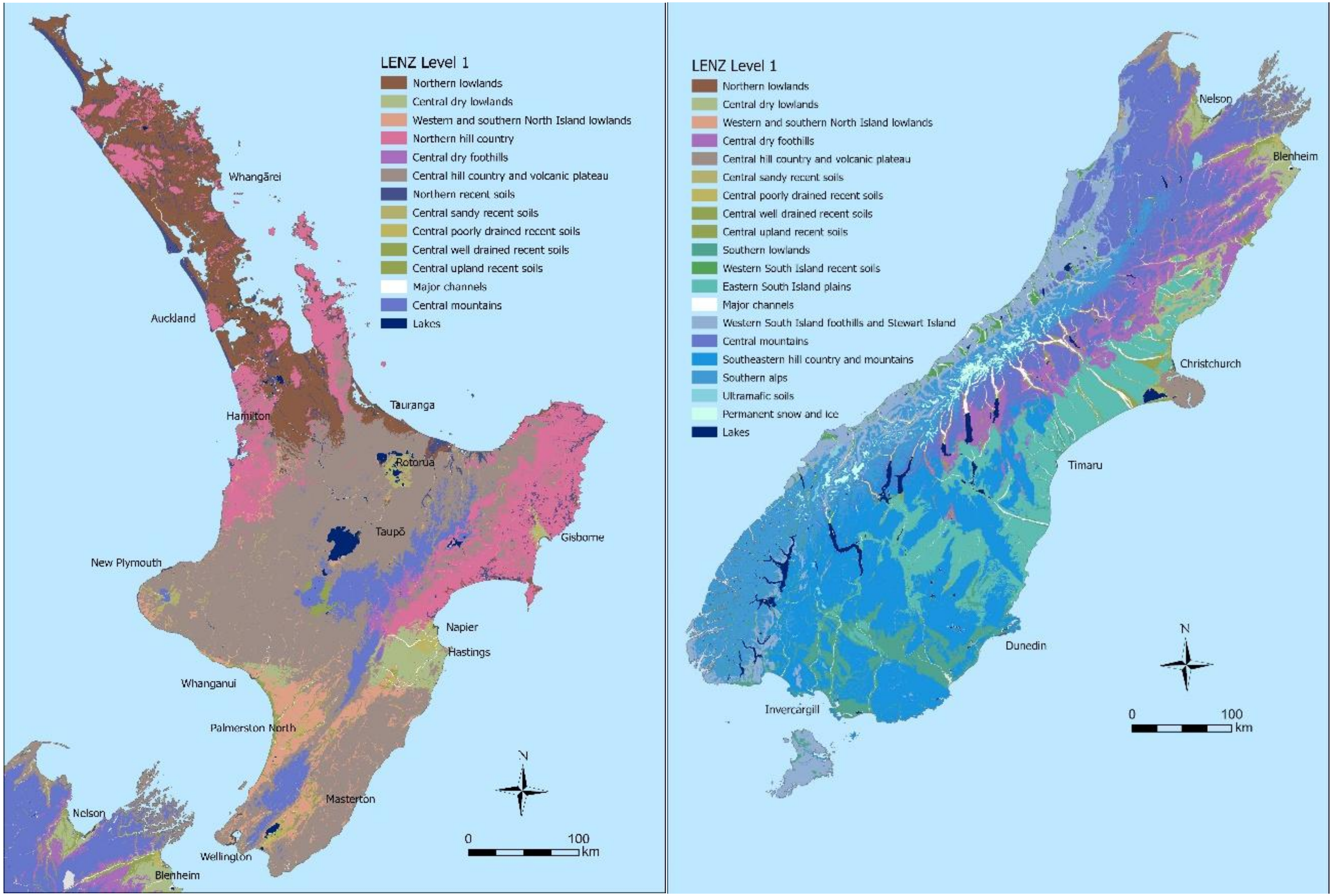


Figure 6. The distribution of Level 1 LENZ classes across the North and South Island of New Zealand.

4.4 Statistical modelling

The statistical modelling used in this project builds on the modelling approach described in Cavanagh, McNeill et al. 2023 but using a newer approach that allows for spatial effects to be included in the model. Specifically, they used a spatial mixed model (spaMM), using the spaMM R package (Rousset & Ferdy 2014), for this analysis. A spaMM is a mixed-effects model, with or without spatial random effects, in which the response variable (here, the trace element concentration) depends on a combination of covariates. The model we used included the fixed effects of LENZ, soil order, parent material, and land use, plus a Matern (covariance function) spatial random effect, using location to account for spatial correlation in the data. The modelled response used a gamma distribution with a log link function. All statistical analysis was undertaken using R version 4.3.2 (R Core Team 2023).

The following general process was used in both the national and regional modelling for all trace elements.

1. Outliers were identified and removed from the data set, either by using the Cook’s distance measure in previous Generalised Additive Model (GAM) iterations (see Cavanagh, McNeill et al. 2023), or by expert opinion removal of exceedingly high values considered most likely to have arisen from anthropogenic contamination.
2. Data were split randomly into training and validation subsets using a 70:30 split ratio, with the training subset used to fit the model and the validation subset used to test the fit.
3. A spaMM was fitted as described above.
4. Goodness of fit was assessed for the fitted models, using the metrics of mean error, root mean square error (RMSE), and R^2. These metrics are presented in the following subsection. Generally, the fit was slightly better for the training subset than for the validation data set, suggesting mild over-fitting.
5. Measured-versus-fitted plots were generated, both in linear- and log-scaled form (the log-scaled form is shown for each trace element in the following subsections).
6. There are few diagnostics available for spaMM models owing to their relative newness in the literature compared with other methods. The diagnostics we used included the following (data not presented).

- We employed residual tests using the DHARMa package (Hartig 2022), and quantile-quantile normal plots and residual versus fitted plots from the DHARMa package to detect unusual behaviour. Some subjective judgement is required in interpreting these plots as to what constitutes ‘unusual behaviour’, because no model is perfect. Measured-versus-fitted plots were used for each individual factor level: soil order, parent material, and LENZ class.
- To indicate how predicted responses (i.e. trace element concentrations) vary using specific explanatory variables, partial effect plots were generated to show the effect on the predicted response for different levels of each explanatory variable after the effect of other variables is taken into account.
- Exogenous variable-effect plots were generated to determine any likely influence on the data of variables not included in the model, including slope, elevation, map coordinates, data source, and alternative geochemical grouping variables that could plausibly be expected to

have some influence on the data, including Chemical4, Chemical6 (see section 5.2.2 for more detail), lithology, and rock class.

4.4.1 Model diagnostics

Goodness-of-fit metrics

The goodness-of-fit results for each trace element are shown on the linear and log scales in Figure 7 (national model) and Figure 8 (regional model). Note that the linear and log scale plots should not be directly compared. The different metrics have different measures; i.e. error measures close to zero indicate better alignment between a model's predictions and data, while higher R^2 values indicate lower variance between measured and modelled data.

Generally, the model fit is slightly better for the training subset compared to the validation data set in both the national and regional models, suggesting mild over-fitting. The metrics for the national and regional models are generally similar, although with regional values indicating slightly better fit. For example, the R^2 value for As is higher in the regional model than in the national model, which potentially reflects the higher relative contribution of As-containing schist material in Otago (see Figure 4), creating a better fit for this element in the regional model compared with the national model. The R^2 for B is lower than for the other elements for both the regional and national models, and this probably reflects the lower number of observations in the model input data compared to other elements.

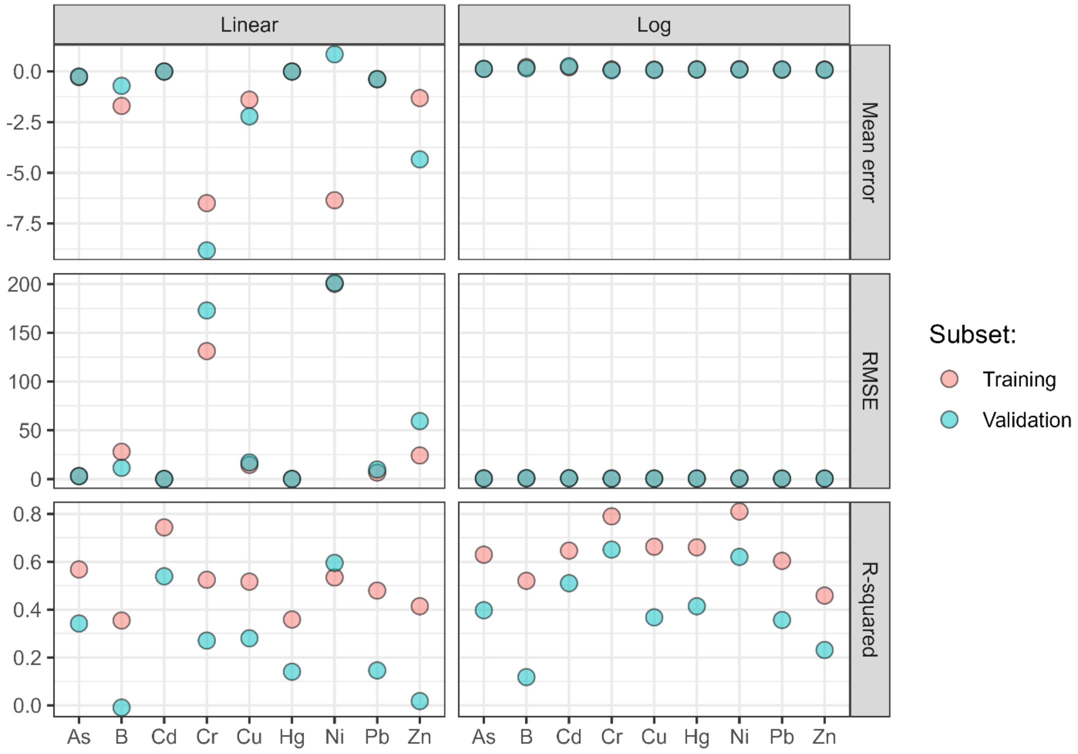


Figure 7. Plots of mean error, RMSE, and R^2 for all elements and all models, using both the linear and log-transformed values of the trace element concentration and fit from the national modelling.

Note: The linear and log values should not be directly compared.

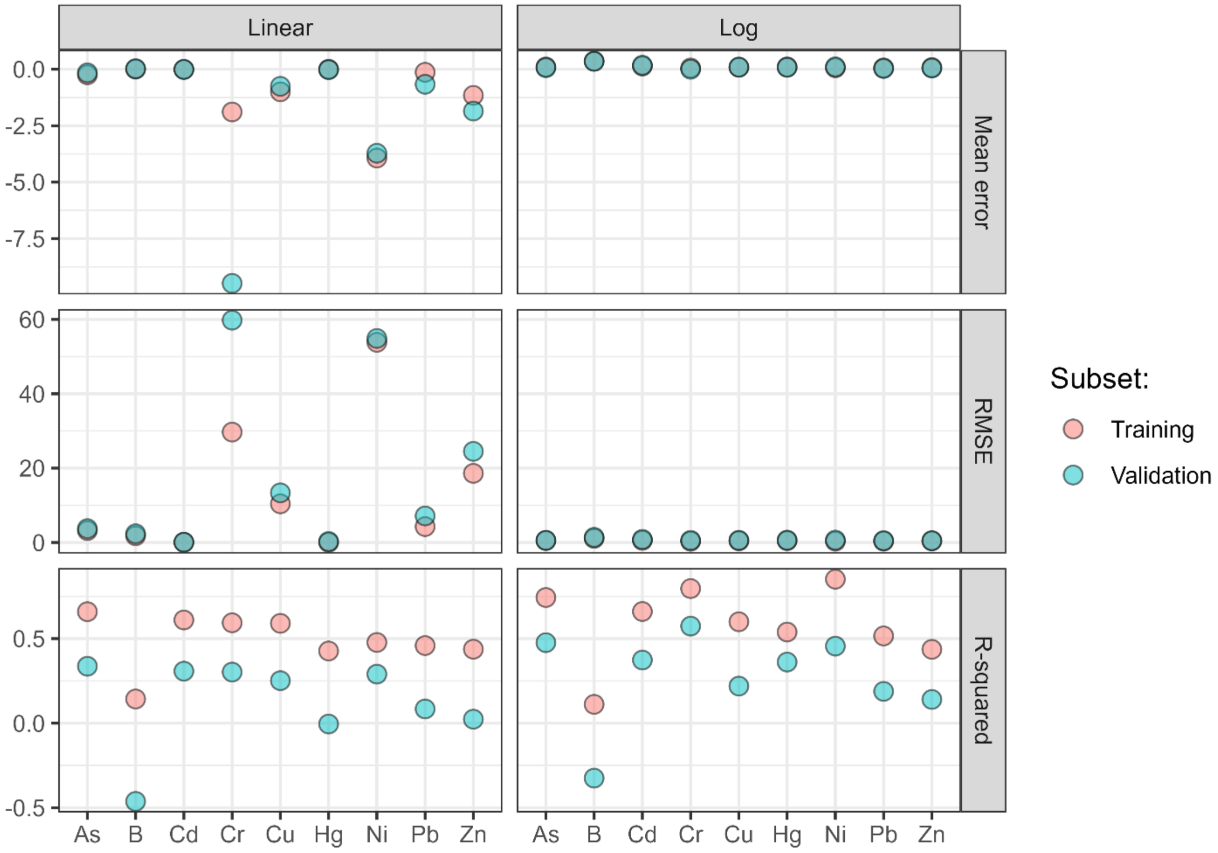


Figure 8. Plots of mean error, RMSE, and R^2 for all elements and all models, using both the linear and log-transformed values of the trace element concentration and fit from the regional modelling.

Note: The linear and log values should not be directly compared.

Measured-versus-fitted diagnostics

Measured-versus-fitted values for each trace element are shown in Figure 9 (national model) and Figure 10 (regional model). The pattern is similar for most trace elements, with a good fit throughout the mid-range of measured values, while low-end and high-end values tend to be over- and under-predicted, respectively. The regional model for B had a particularly poor fit, probably due to the relatively low number of data points for B in the regional model (n = 187).

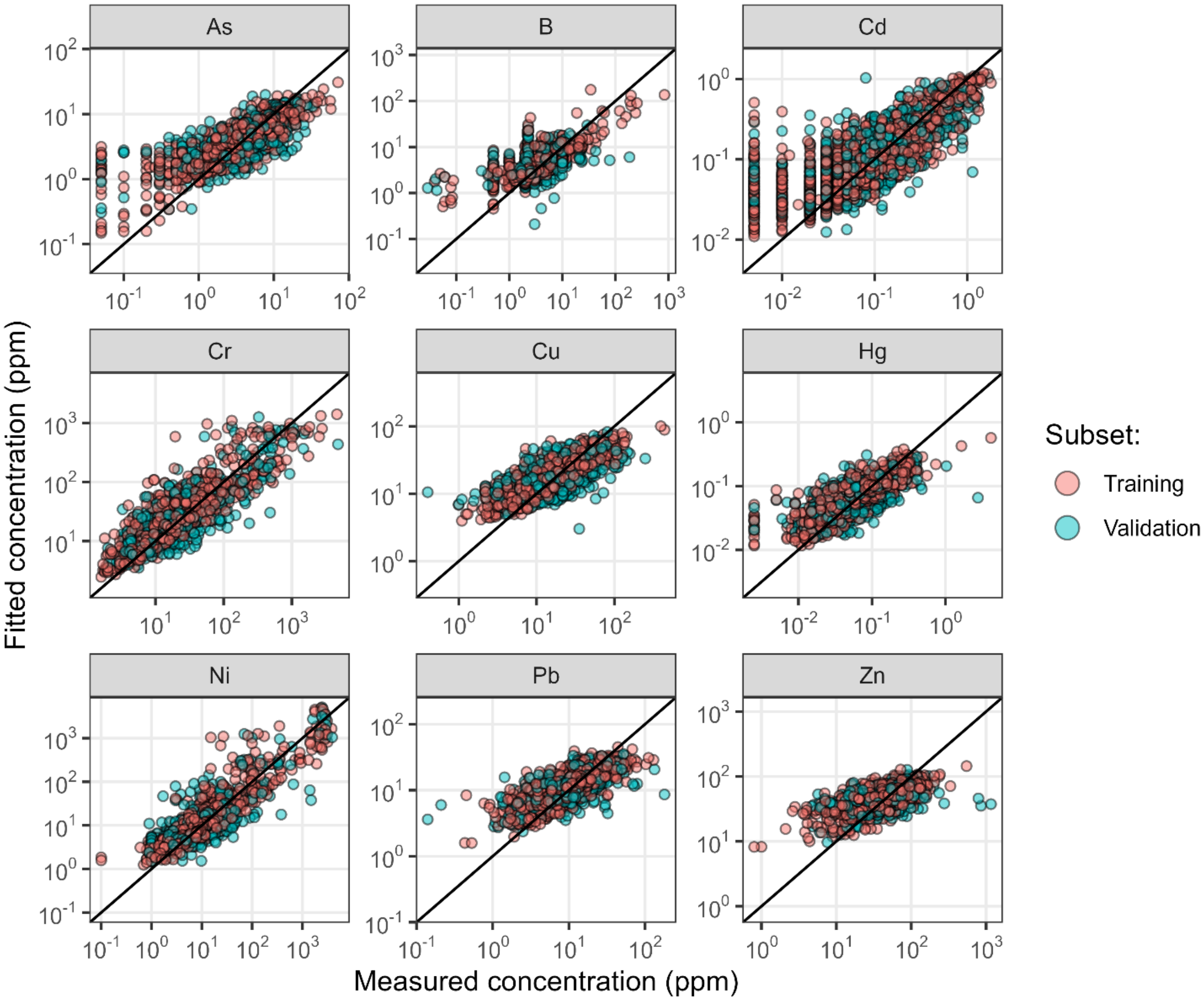


Figure 9. National model measured-versus-fitted plot for all elements, with concentration on a logarithmic scale. The points are coloured according to whether they come from the training or validation subset.

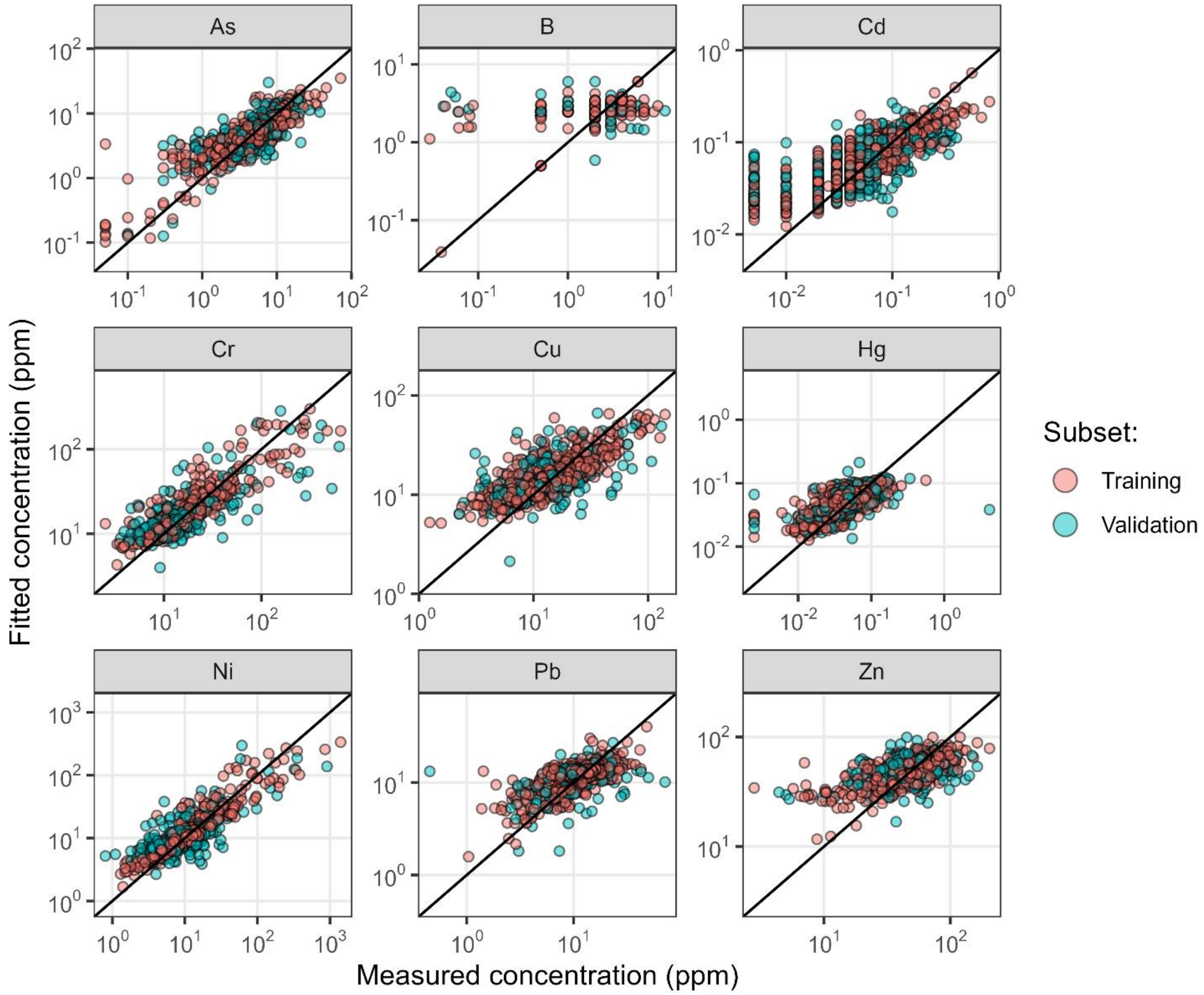


Figure 10. Regional model measured-versus-fitted plot for all elements, with concentration on a logarithmic scale. The points are coloured according to whether they come from the training or validation subset.

4.4.2 Model outputs

The predicted concentrations of each trace element for the ambient land use across New Zealand are presented at a 1 km × 1 km resolution. To help apply the predicted estimates for the management of contaminated land or other purposes, the information on predicted concentrations is also presented as contour plots, with contours at the 50th, 90th, 95th, and 99th percentiles of the predicted values. Thus, within each 'band', the concentration is anticipated to fall within, for example, minimum to 50th percentile, or 50th to 90th percentile.

A table in the contour maps presents the specific concentrations for each percentile cut-off. As shown in Figure 10 and explored more in the subsections below, the relationship between modelled and measured values is not a perfect 1:1. Therefore these contour plots are useful as a means of delineating areas likely to contain ambient elevated concentrations, more so than defining absolute concentrations that are likely to occur at the upper end of ambient concentration ranges.

National model

National maps are shown in Appendix, 1 and regional maps (developed by clipping the national maps) for Otago and Southland shown in sections 5.1.1 to 5.1.7. Note that the scale on the continuous plots represents the concentration range present on the visible map area, and therefore total ranges and their representations differ between the national (Appendix 1) and clipped-to-regional figures, despite using the same national spaMM model. However, the contour plots generated from the national model for the Otago and Southland regions show quantile delineations based on national predictions (i.e. relative to national ranges).

Regional model

The same regional continuous concentration plots and contour plots were produced from the regional spaMM model for Otago and Southland and are presented alongside the national model-derived plots for comparison. The scales and concentration ranges presented on these regional plots are specific to the Otago and Southland regions.

4.5 Distribution and risk-based background concentrations

In addition to the modelled results, we also determined background concentrations based on the distribution of measured trace element concentration using both the national and Otago–Southland regional data sets, for all land uses and ambient land use. We also determined urban ambient distributions for Dunedin using data from Turnbull, Martin, Rattenbury et al. 2017. This study used sampling methodology modified from that described for the regional geochemical studies in section 4.2.2.

Sampling was 1 km-spaced across Dunedin City, with 83 sites collected on this grid. A further 30 sites were collected within the grid-based sampling to collect soil from most Dunedin City schools. Samples were collected from three standardised depths: a surface O-depth (0–2 cm), a near-surface A-depth (2–20 cm), and a deeper B-depth sample (50–70 cm. These samples were analysed for all major and trace elements using aqua regia partial digest ICP-MS and whole-sample XRF. Data from the surface samples (0–20 cm) were used in the current study

Specifically, we used sites identified as urban residential, schools or urban greenspace to determine the 95th percentile concentrations. For Pb we calculated the 95th percentile distribution, excluding sites that had concentrations higher than the residential SCS and separately excluding sites that had concentrations higher than the rural residential SCS. For Cu and Zn we calculated the 95th percentile distribution, excluding sites that had concentrations higher than the 95% protection Eco-SGV.

Finally, we also determined risk-based background concentrations as being those that are equidistant between the 95th percentile background concentrations and the lower of Eco-SGVs or human health soil contaminant standards.

5 Determination of background concentrations

5.1 Modelled background concentrations

Tables 2 and 3 provide summaries of results for modelled trace elements from both models. The median values are generally similar for all trace elements, while the national model typically predicts higher upper-end concentrations compared to the regional model. The exceptions here are As and Cu, which may be due to areas of natural elevation of these trace elements in Otago and Southland, resulting in a higher relative influence of higher concentrations in the regional model compared with the national model. Elements are presented here first in order of interest (As, Cr, and Ni, due to their known elevation across areas of Otago and Southland), followed by the remaining trace elements in alphabetical order of the element name.

Table 2. Distribution of the fitted values (mg/kg) for each element for the national spaMM model

Element	Min.	5%	Median	90%	95%	99%	Max.
As	0.051	1.14	3.55	6.13	7.36	10.5	30.9
Cr	2.15	6.46	14.5	25.3	34.1	83.7	1377
Ni	0.773	3.89	8.67	14.2	17.1	47.3	5828
B	0.40	1.70	4.12	7.98	9.73	15.3	224
Cd	0.0081	0.026	0.075	0.16	0.23	0.37	0.84
Cu	3.06	8.12	13.6	21.1	24.4	33.6	101
Pb	1.46	4.63	11.0	17.4	19.1	22.7	40.2
Hg	0.010	0.026	0.060	0.10	0.13	0.18	0.50
Zn	8.24	24.1	47.3	65.1	70.3	79.8	131

Table 3. Distribution of the fitted values (mg/kg) for each element for the regional spaMM model

Element	Min	5%	Median	90%	95%	99%	Max
As	0.036	0.103	3.69	7.83	9.72	15.9	39.6
Cr	3.91	8.59	14	26	31.3	49.4	360
Ni	2.04	4.93	8.68	14.8	17.7	29.1	321
B	0.017	1.34	2.58	4.13	6.00	7.06	8.62
Cd	0.0067	0.021	0.048	0.080	0.095	0.15	0.62
Cu	1.48	7.63	13.6	22.2	27.4	48.2	118
Pb	1.51	3.16	12.0	15.3	16.8	20.7	28.6
Hg	0.0097	0.022	0.057	0.086	0.097	0.12	0.36
Zn	8.82	27.3	45.1	60.8	66.2	77.8	109

Comparisons between modelled and measured (ambient) data distributions are summarised in Table 4 for the national model and Table 5 for the regional model. All data are presented in mg/kg, or ppm in the case of the figures. There is generally good agreement between the median of the actual data and the modelled value for the individual trace elements, although there is under-prediction of the upper percentile values. This is particularly so for Cr and Ni, for which the 95th and 99th percentiles from the ambient data are markedly higher than for the modelled data, and reflect the presence of soils with ultramafic or mafic parent material, which can have naturally very high concentrations (see also sections 5.1.2 and 5.2.2).

Table 4. Comparison of modelled estimates and percentiles of trace element concentrations (mg/kg) from the national ambient data set

Element	Ambient data					Modelled			
	n	Median	95th %ile	99th %ile	Max.	Median	95th %ile	99th %ile	Max.
As	1,646	3.5	11.9	22	72	3.6	7.4	10.5	30.9
Cr	1,644	15.9	286	1,013	4,758	14.5	34.1	83.7	1,377
Ni	1,645	10.0	155	2,473	3,898	8.7	17.1	47.3	5,828
B	634	3.0	23	149	255	4.1	9.7	15.3	224
Cd	1,699	0.1	0.25	0.52	1.33	0.1	0.2	0.4	0.84
Cu	1,647	14.6	54	98	439	13.6	24.4	33.6	101
Pb	1,643	11.5	26	49	180	11.0	19.1	22.7	40.2
Hg	1,511	0.1	0.2	0.3	180	0.1	0.1	0.2	0.5
Zn	1,650	48.3	99	138	1,160	47.3	70.3	79.8	131

Table 5. Comparison of modelled estimates and percentiles of trace element concentrations (mg/kg) from the regional ambient data set

Element	Ambient data					Modelled			
	n	Median	95th %ile	99th %ile	Max.	Median	95th %ile	99th %ile	Max.
As	540	5	16	33	72	3.69	9.72	15.9	39.6
Cr	540	13	124	360	651	14	31.3	49.4	360
Ni	540	9	70	347	1,403	8.68	17.7	29.1	321
B	125	2	7	9	12	2.58	6.00	7.06	8.62
Cd	537	0.04	0.15	0.30	0.69	0.048	0.095	0.15	0.62
Cu	540	14	52	98	141	13.6	27.4	48.2	118
Pb	539	13	22	28	34	12.0	16.8	20.7	28.6
Hg	530	0.04	0.12	0.19	4.16	0.057	0.097	0.12	0.36
Zn	540	49	91	113	152	45.1	66.2	77.8	109

Generally, there are small differences in the concentration ranges predicted, and in the spatial delineation of elevated areas, between the national and regional models for most trace elements.

5.1.1 Arsenic

Overall there is a reasonable fit of the data, as shown by the measured vs fitted model (Figures 9 & 10) and goodness-of-fit parameters (shown in Appendix 1), with the under-prediction at higher concentrations observed in previous modelling (Cavanagh, McNeill et al. 2023) less pronounced. However, compared to the underlying ambient data, some under-prediction in concentrations is evident, particularly for the 99th percentile (Table 4).

The regional model predictions (Figure 12) have a wider range than the national model (Figure 11), but the median concentration is similar. The higher upper end predicted concentrations in the regional model probably reflect the greater relative area of schist parent material, known to include elevated As concentrations (see also Appendix 2), in the modelled data. The main difference between the national and regional modelling for As is that the regional contour plot does not delineate some areas highlighted in the national contour plot as elevated, including around Macraes goldmine (inland from Moeraki) and around Berwick Forest and Waipori Falls in eastern Otago. This is probably an artefact of the higher upper-end concentrations observed for the regional model, which results in correspondingly higher percentile values (Figures 13 and 14).

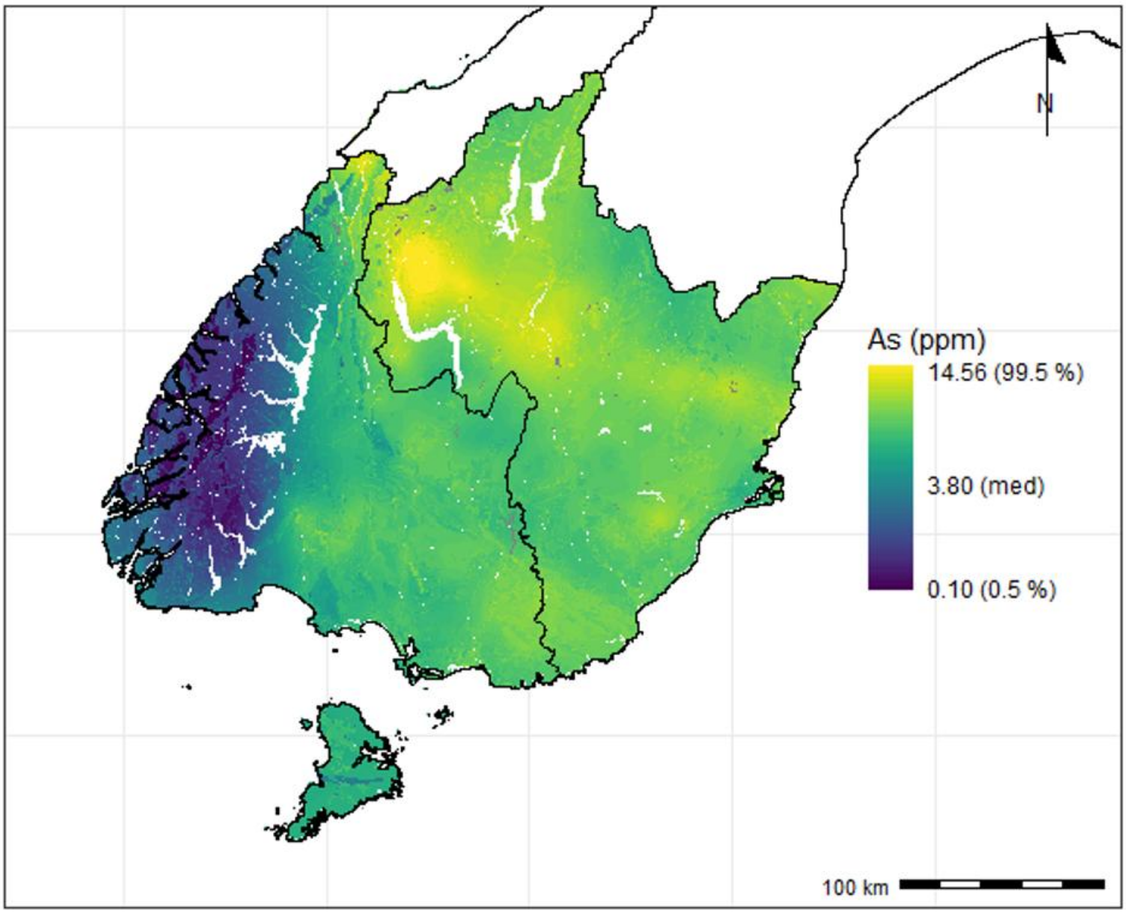


Figure 11. Estimate of arsenic concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

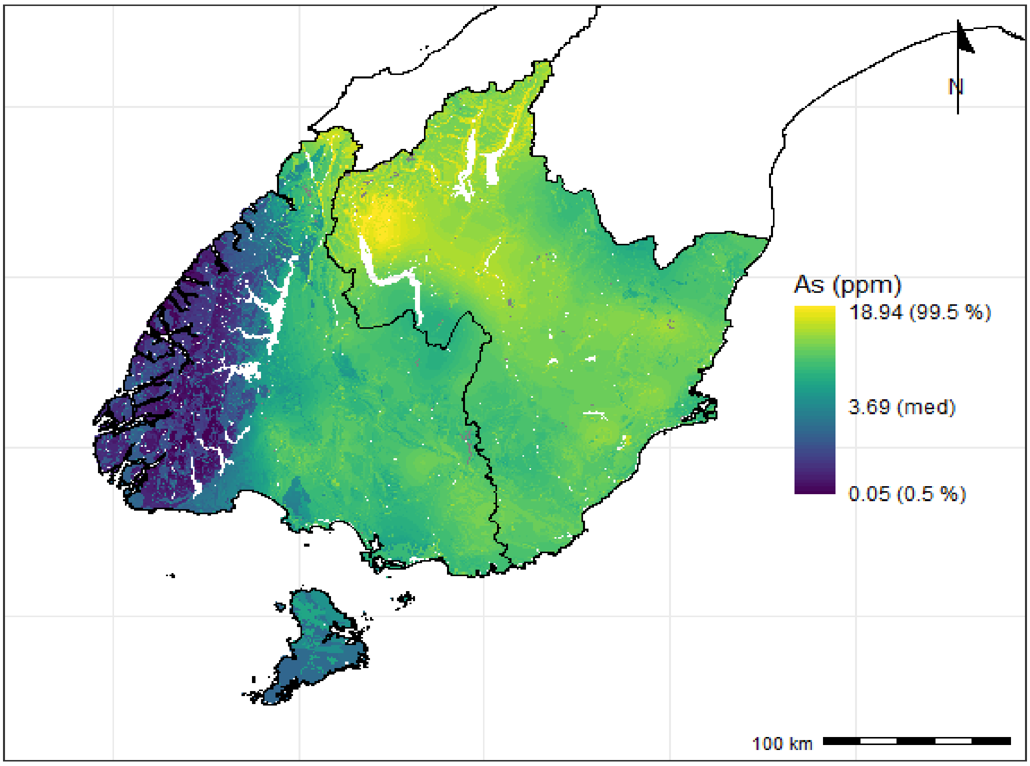
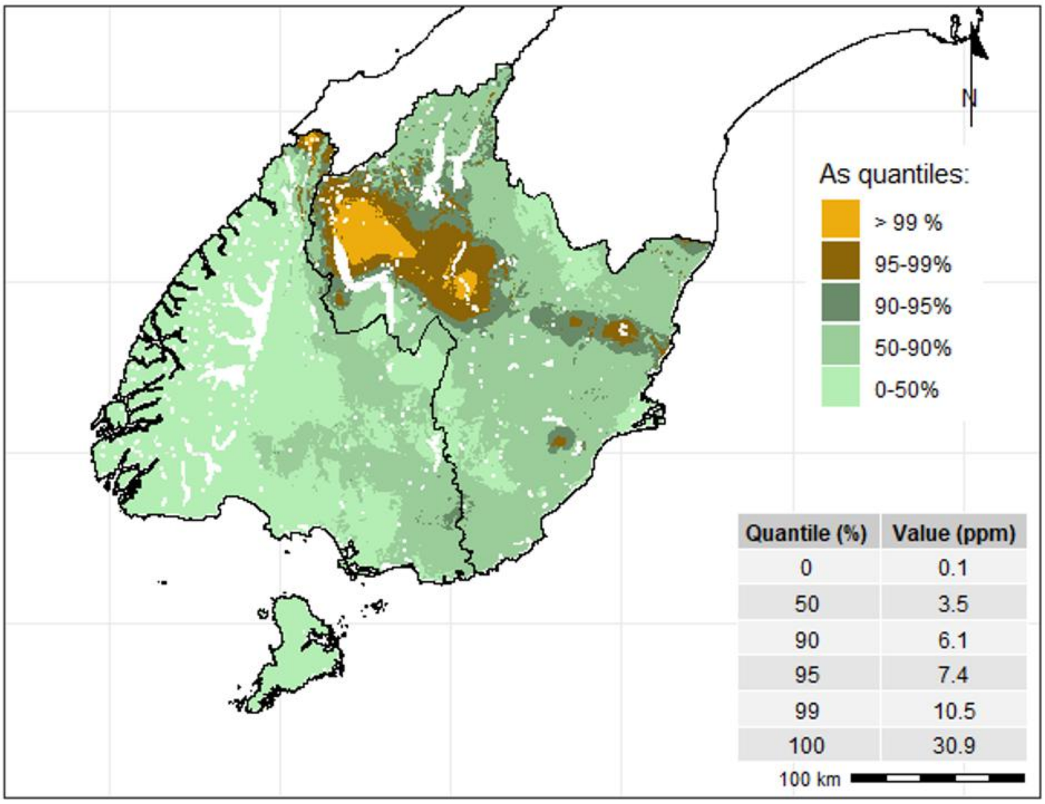


Figure 12. Estimate of arsenic concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	0.1
50	3.5
90	6.1
95	7.4
99	10.5
100	30.9

Figure 13. Contour plot of As quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).

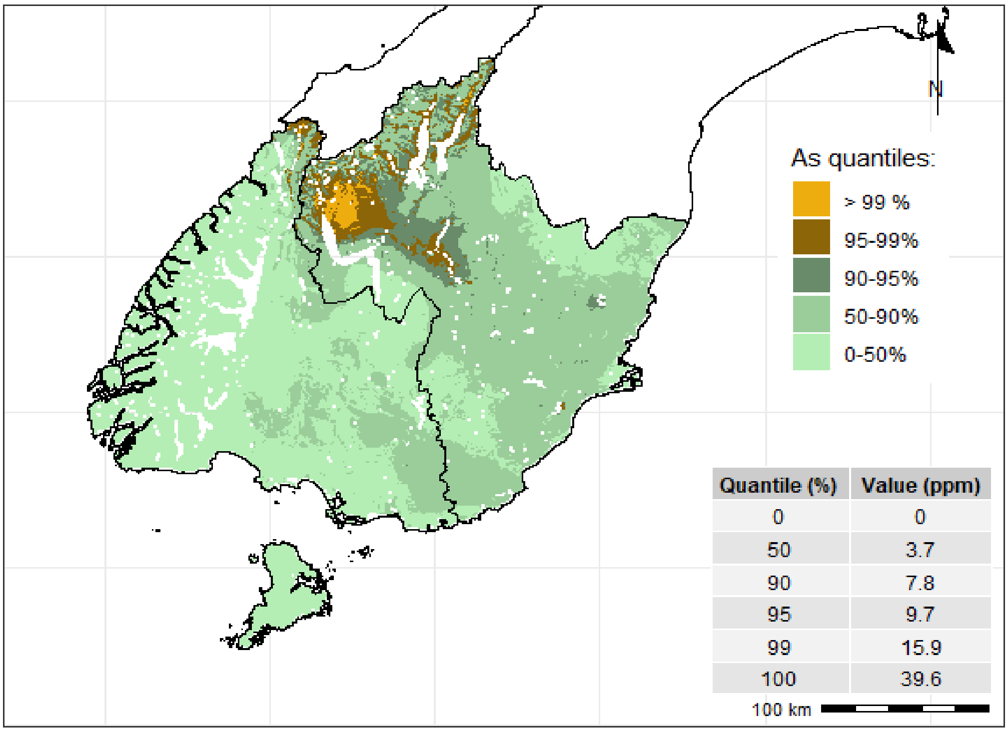


Figure 14. Contour plot of As quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.2 Chromium and nickel

Maps for Cr and Ni are presented together, because naturally occurring concentrations are strongly driven by the distribution of ultramafic rocks. Also, evaluation of data for ≥95th percentile distribution indicates that gravels in the Otago and Southland regions may contain elevations in Cr and Ni (Appendix 2, see also section 5.2.2), which is probably a result of ‘downstream’ movement of ultramafic parent materials.

Overall there is a reasonable fit of the data for both Cr and Ni, as shown by the measured vs fitted models (Figures 9 & 10). While predicted values for the upper percentile estimates for Cr and Ni are markedly lower than those for the underlying data set (Table 4), the underlying measured data are skewed by the markedly elevated concentrations present in soils with mafic and ultramafic parent material (see also section 5.2).

The national model for Cr has a wider range and higher upper-end concentrations than the regional model, although the median values are similar. This is also the case for Ni. Generally similar areas are delineated as elevated in the regional and national models. The exceptions here are the area around Jamestown, north of Milford Sound, with the national model showing a delineated area of Ni elevation here that is less distinct in the regional model outputs; and the western part of Fiordland, with the regional model showing some elevations in both Cr and Ni that are not highlighted by the national model.

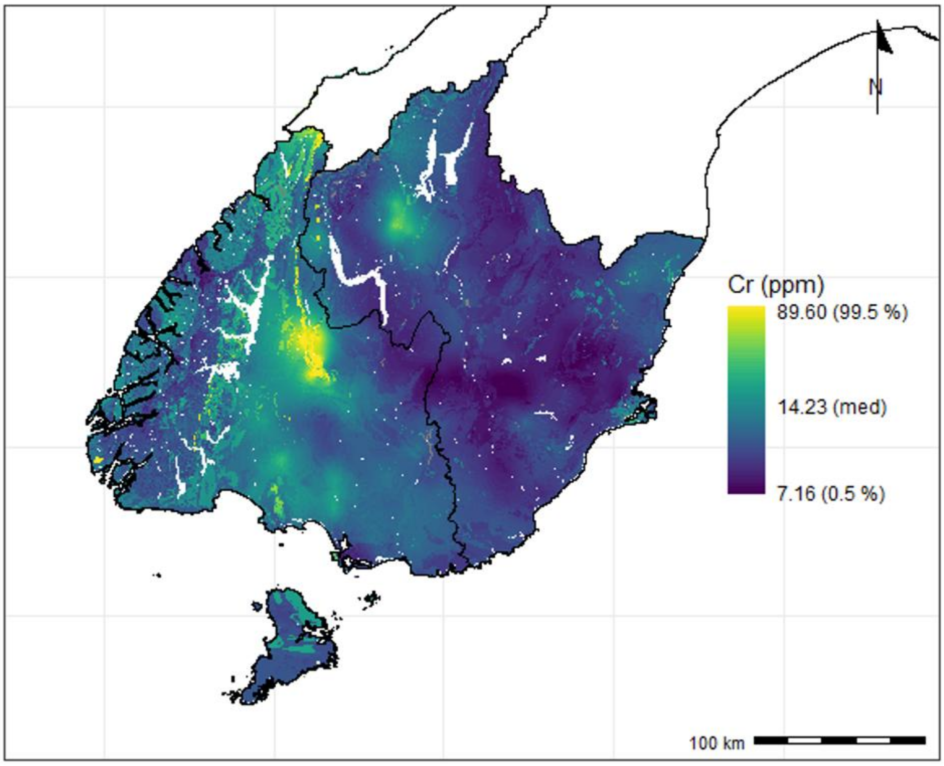


Figure 15. Estimate of chromium concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

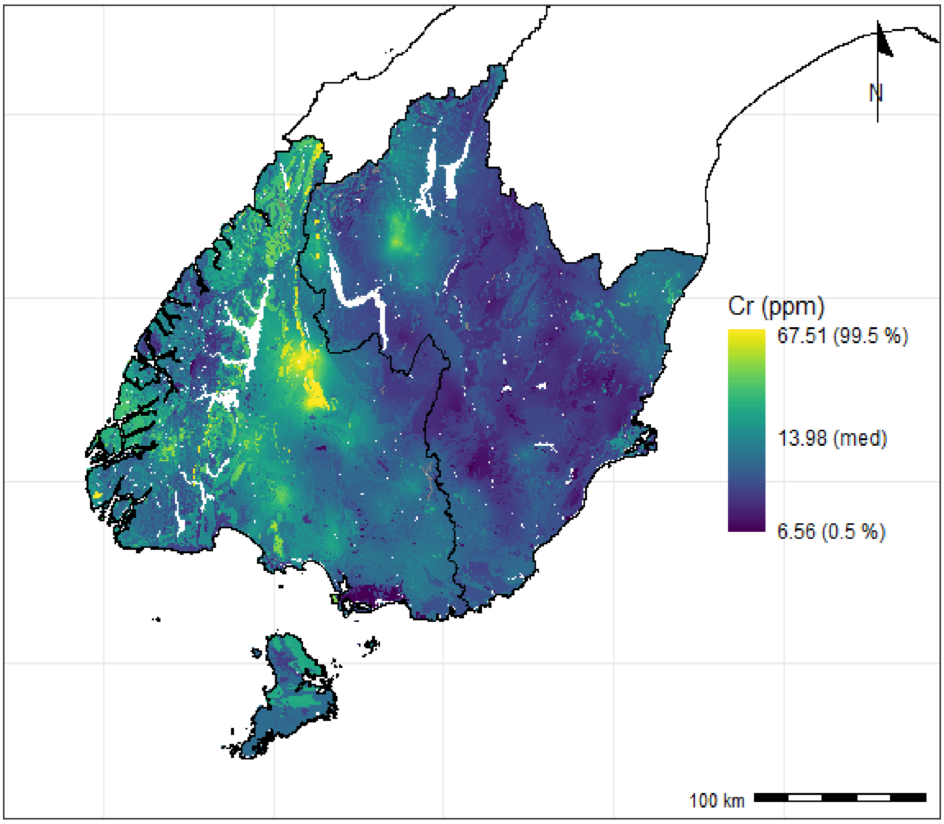
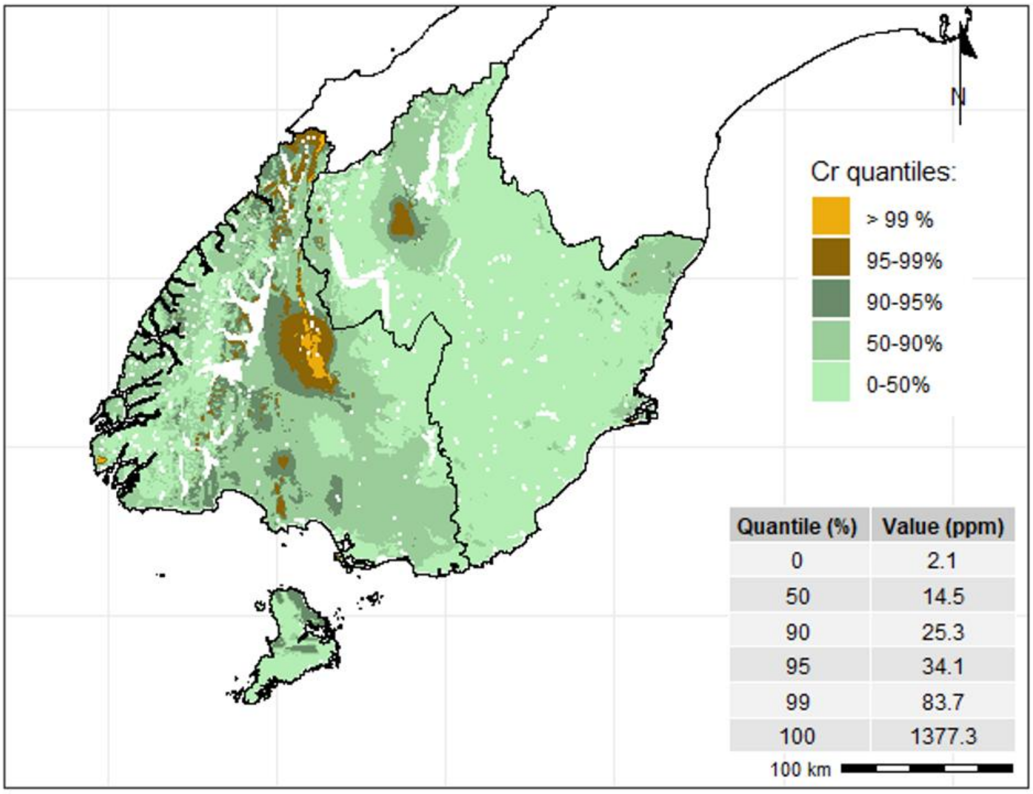


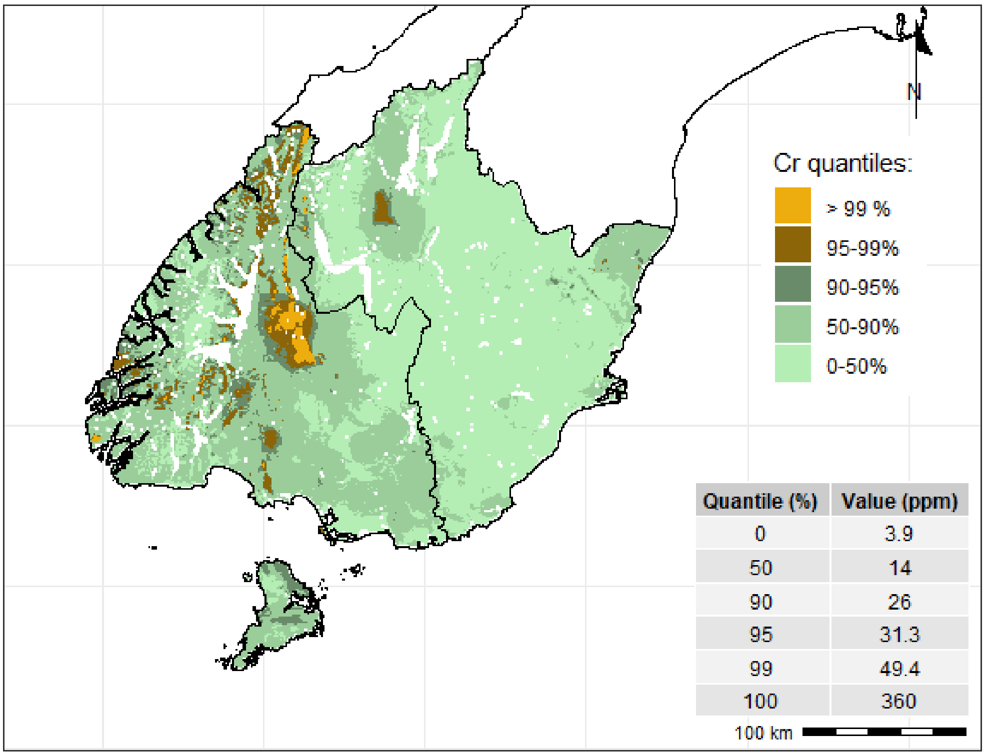
Figure 16. Estimate of chromium concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	2.1
50	14.5
90	25.3
95	34.1
99	83.7
100	1377.3

Figure 17. Contour plot of chromium quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).



Quantile (%)	Value (ppm)
0	3.9
50	14
90	26
95	31.3
99	49.4
100	360

Figure 18. Contour plot of chromium quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

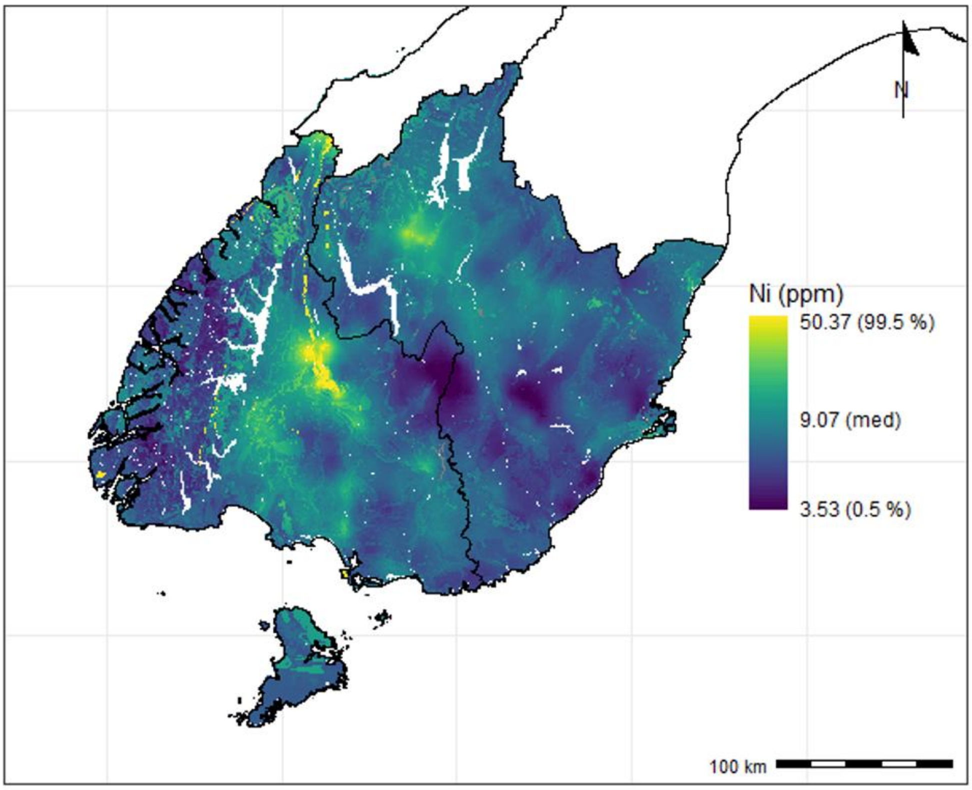


Figure 19. Estimate of nickel concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

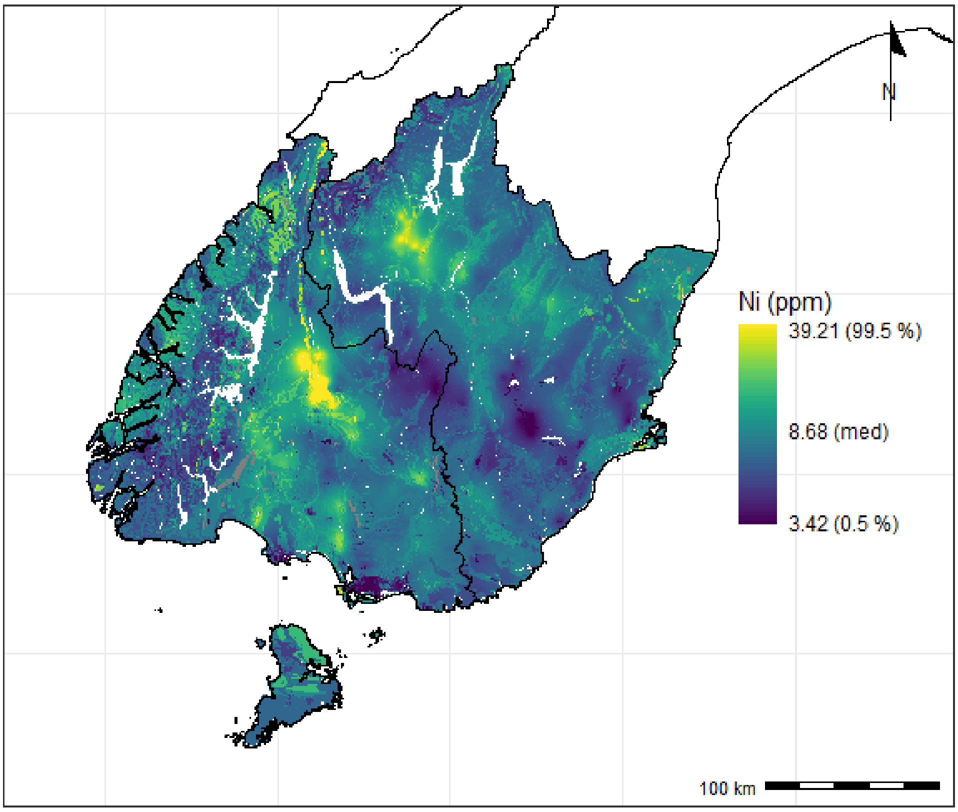
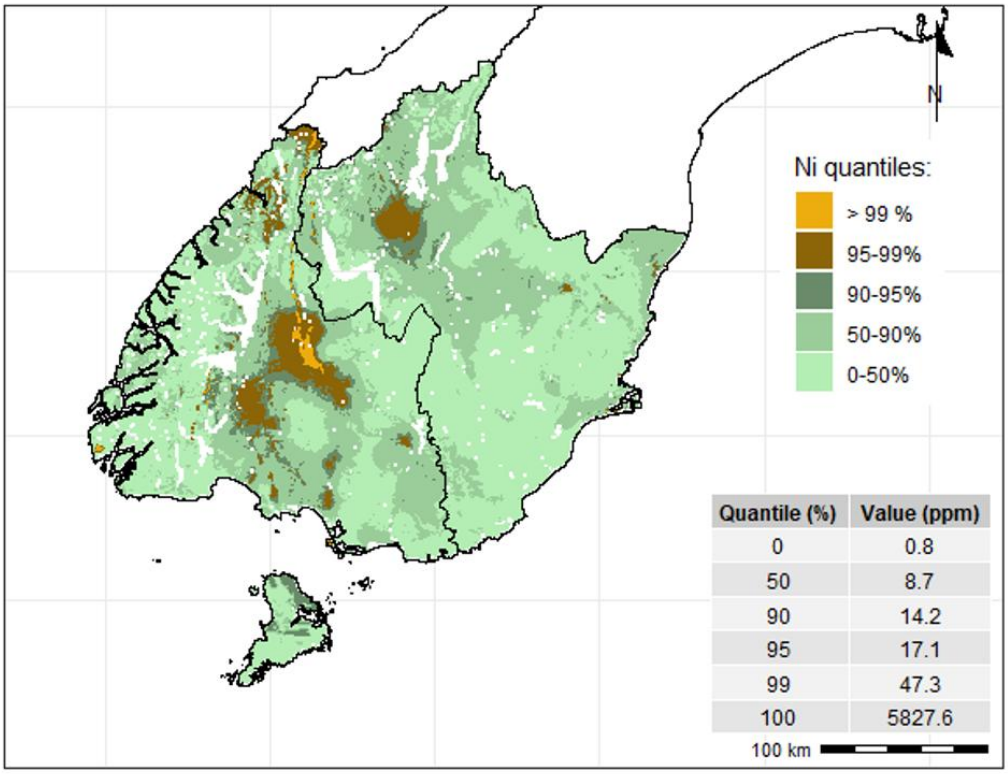


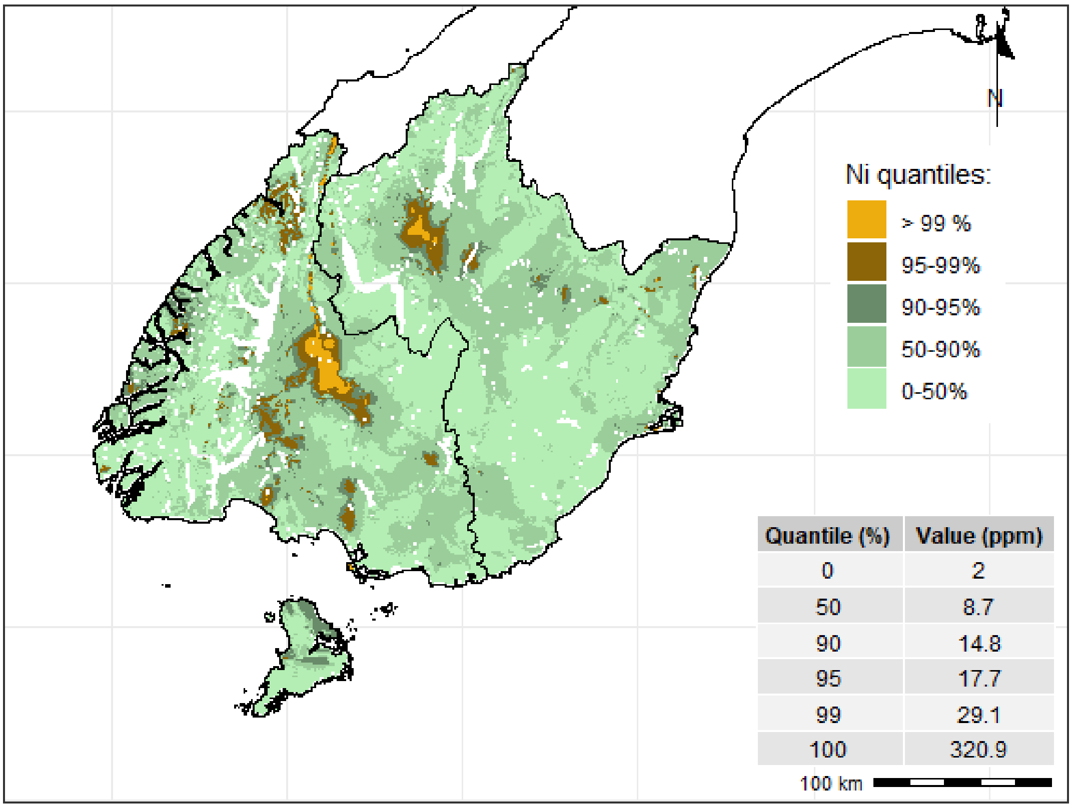
Figure 20. Estimate of nickel concentration throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	0.8
50	8.7
90	14.2
95	17.1
99	47.3
100	5827.6

Figure 21. Contour plot of nickel quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).



Quantile (%)	Value (ppm)
0	2
50	8.7
90	14.8
95	17.7
99	29.1
100	320.9

Figure 22. Contour plot of nickel quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.3 Boron

There is a reasonable fit with measured values for the nationally modelled B concentrations, as shown in Figure 9. Some overfitting is evident, as the training subset adheres more to the 1:1 line than the validation subset. The national model does over-predict at the lower-end and under-predict at the higher-end concentrations (Figure 9 and Table 4). The model fit for B in the regional model was particularly poor, with lower-end concentrations drastically over-predicted and upper-end concentrations under-predicted (Figure 10). This poor model fit was supported by the model diagnostics, particularly the exogenous variable effect plots, which indicated a greater influence of exogenous variables on the data than would be expected. The poor fit is probably a product of the relatively low number of data points for B in the regional model (n = 187).

There are marked differences between the national and regional continuous concentration plots for B. These differences are attributed to the poor fit of the regional model, and the resulting narrower range of predicted concentrations compared to the national model. The regionally predicted concentrations for Fiordland and Stewart Island / Rakiura follow an almost inverse trend compared to the nationally predicted concentrations, which we expect are likely to be more accurate.

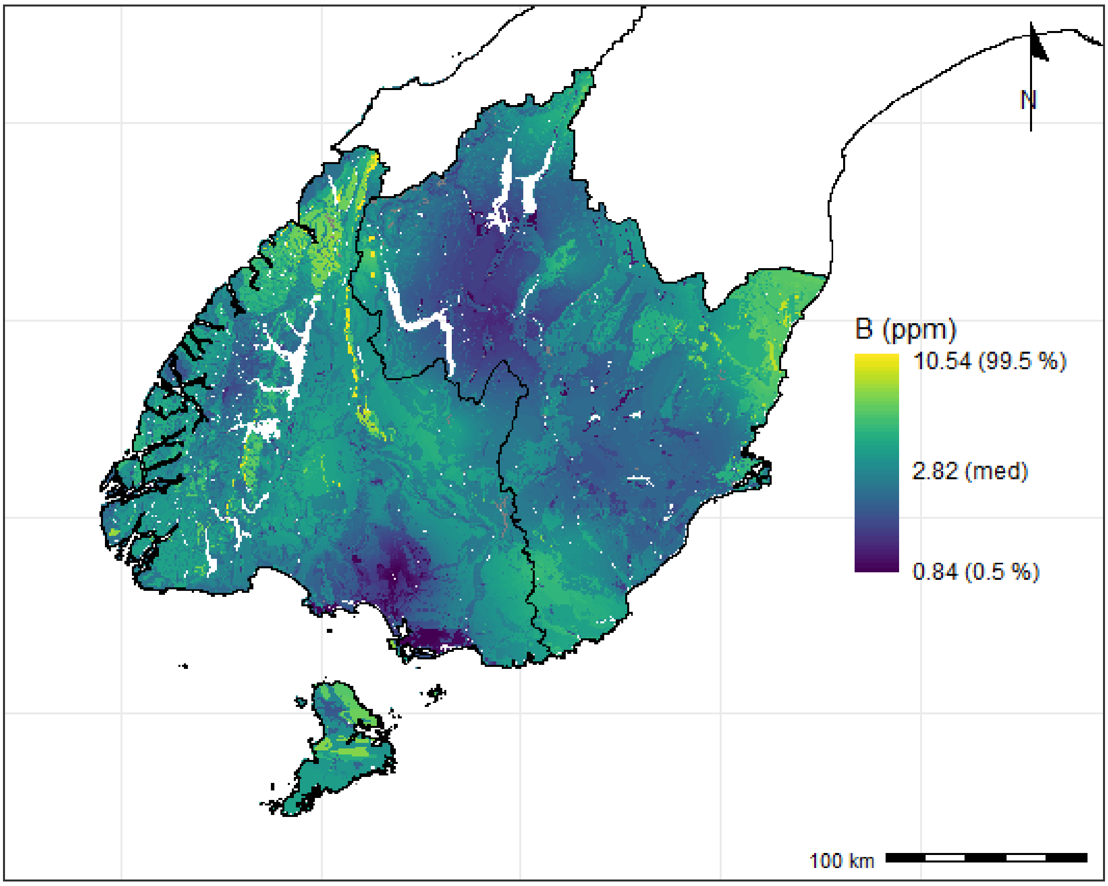


Figure 23. Estimate of boron concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

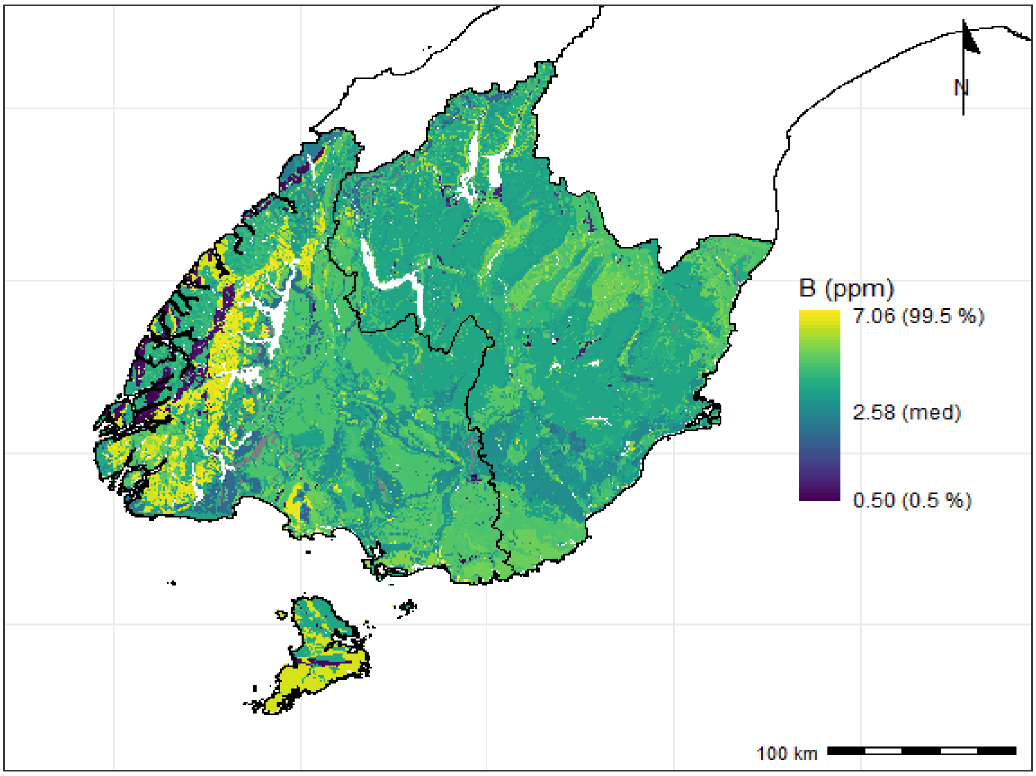
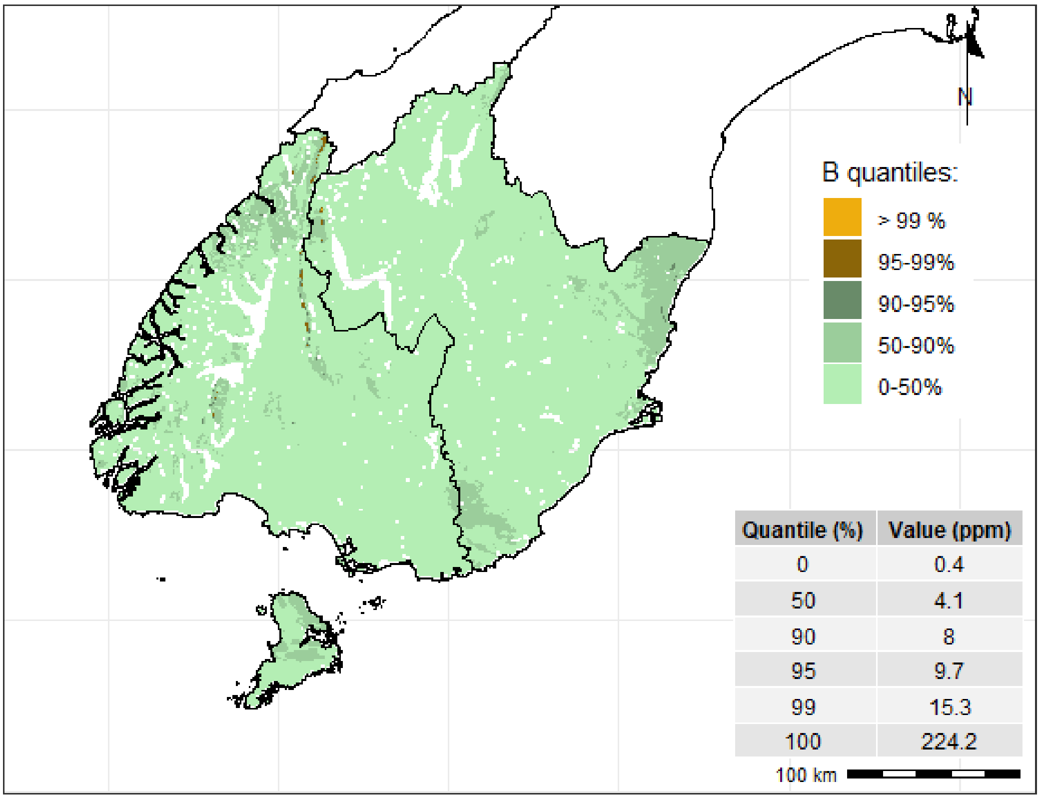


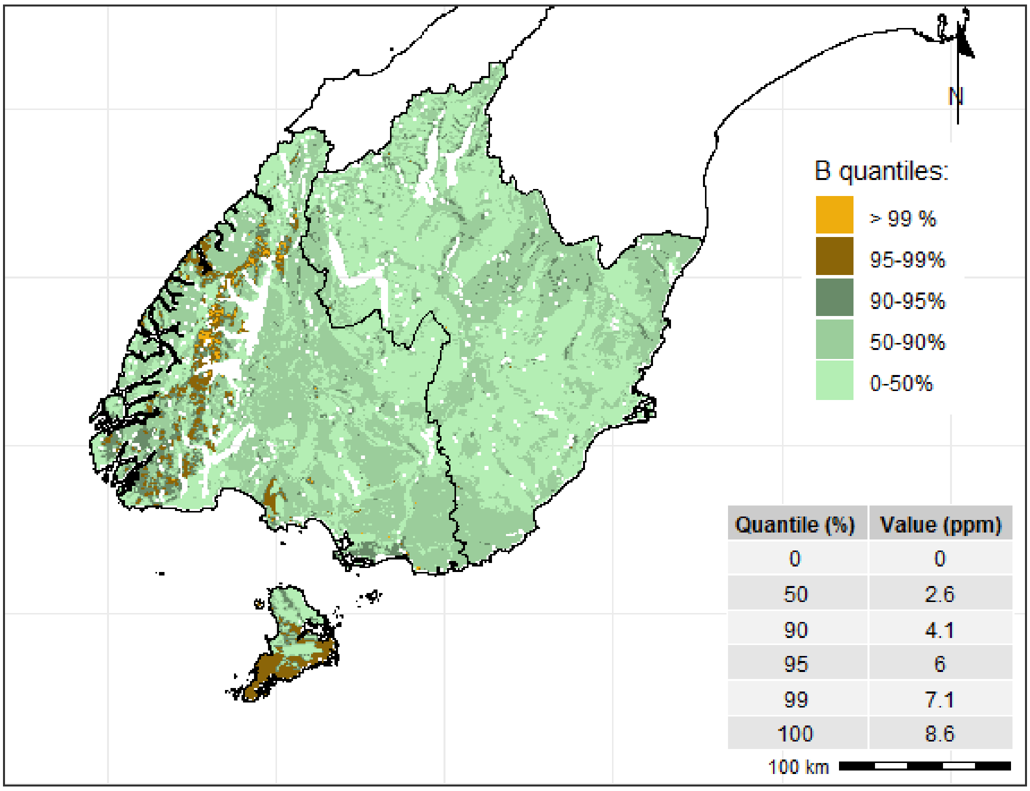
Figure 24. Estimate of boron concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	0.4
50	4.1
90	8
95	9.7
99	15.3
100	224.2

Figure 25. Contour plot of boron quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).



Quantile (%)	Value (ppm)
0	0
50	2.6
90	4.1
95	6
99	7.1
100	8.6

Figure 26. Contour plot of boron quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.4 Cadmium

The model fit for Cd was similar to that for As, in that lower-end and upper-end concentrations tended to be over- and under-predicted, respectively (Figures 9 & 10, Table 4). The regional model over-predicts to a lesser degree than the national model, but potentially under-predicts to a worse degree than the national model.

The continuous concentration plot using the national model for Cd (Figure 27) shows some higher concentrations across the bottom of the South Island and Stewart Island / Rakiura that are not shown by the regional model (Figure 28). This is likely to be attributable to the slightly higher upper-end concentrations for the regional model.

The difference between the national and regional modelled contour plots reflects the narrower range of the regional predicted quantiles (Figure 30) compared to the national-level quantiles shown in Figure 29. For example, the 99th percentile for the regional predicted concentrations is 0.1 mg/kg, compared to 0.4 mg/kg for the predicted national concentrations. Therefore, the regional model has delineated areas that may be elevated relative to regional concentrations but are not markedly elevated compared to the national range of concentrations.

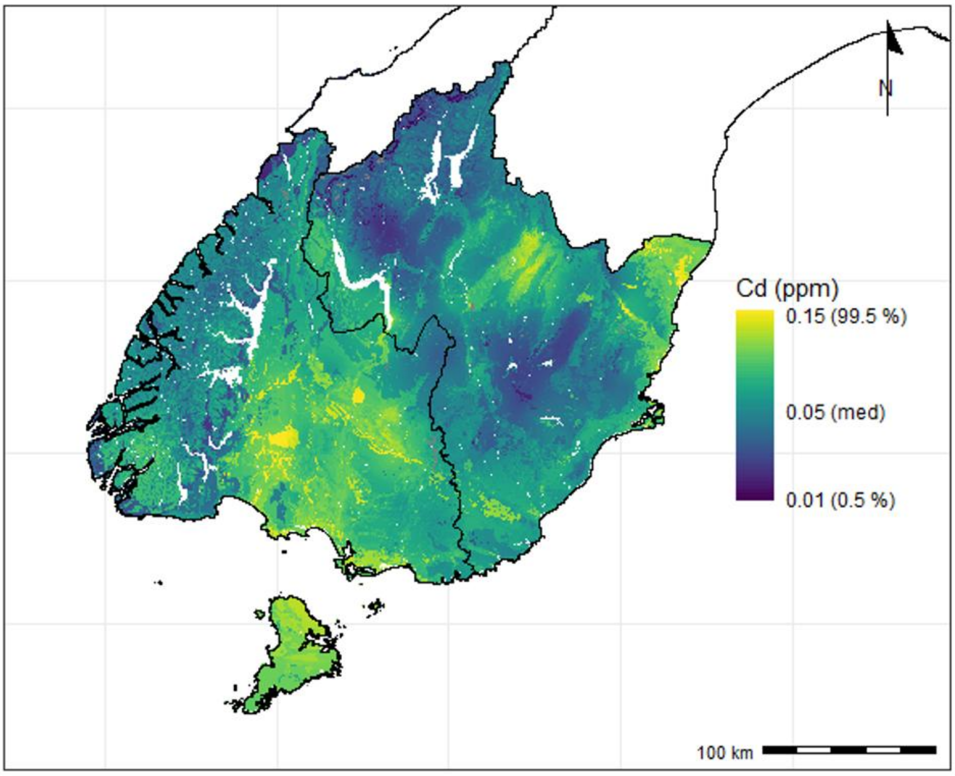


Figure 27. Estimate of cadmium concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

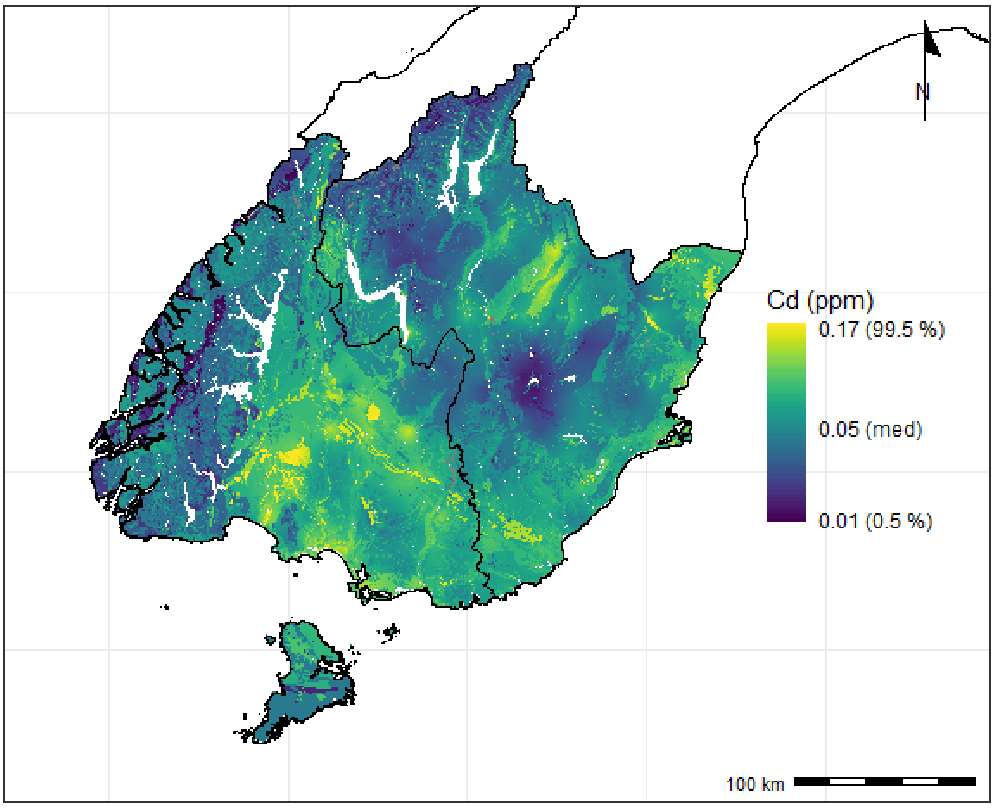
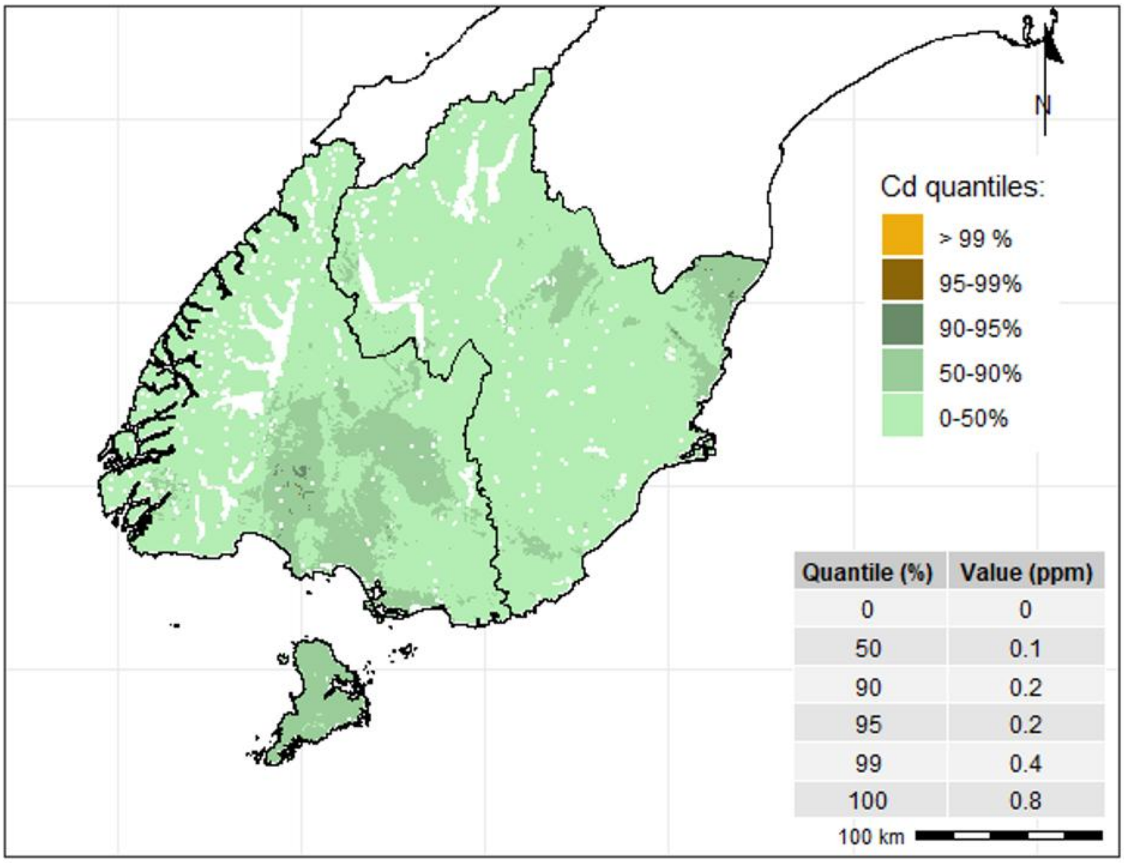


Figure 28. Estimate of cadmium concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	0
50	0.1
90	0.2
95	0.2
99	0.4
100	0.8

Figure 29. Contour plot of cadmium quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).

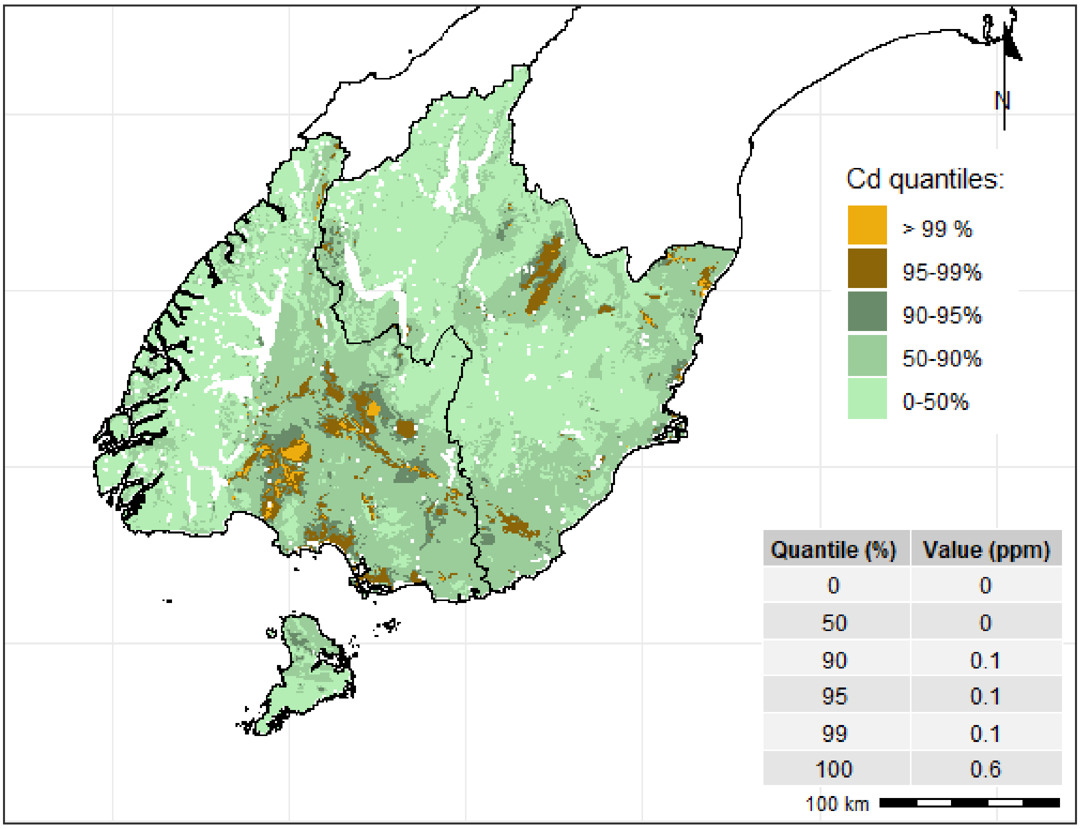


Figure 30. Contour plot of cadmium quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.5 Copper

The model fit for Cu is reasonable, and median concentrations for both models are similar to that for the ambient data (Table 4), but both models do show under-predictions at high-end concentrations and over-predictions at low-end concentrations. In both models some mild overfitting is evident, as the training subset data adheres more to the 1:1 line than the validation subset data, with validation data more likely to be under-predicted (Figures 9 & 10).

The comparison between national and regional model outputs for Cu concentrations (Figures 31 & 32) is similar to that for As, in that the regional model has a wider range, with higher upper-end concentrations, and does not highlight some areas that are more clearly delineated in the national model, particularly south of Lake Wānaka and around and north of the Milford Sound area.

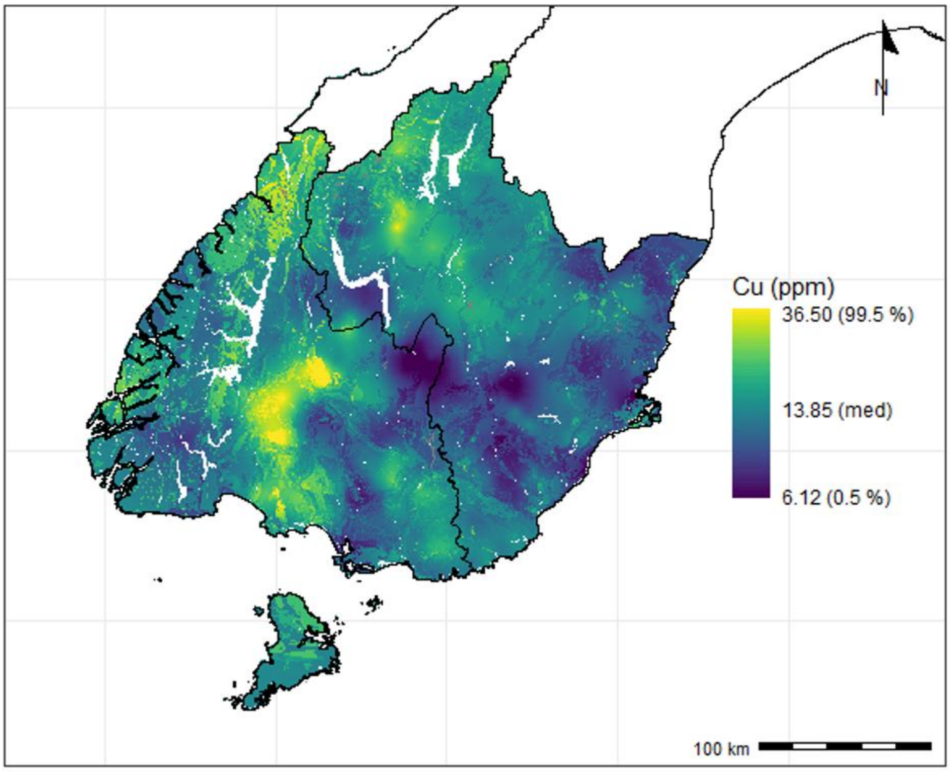


Figure 31. Estimate of copper concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

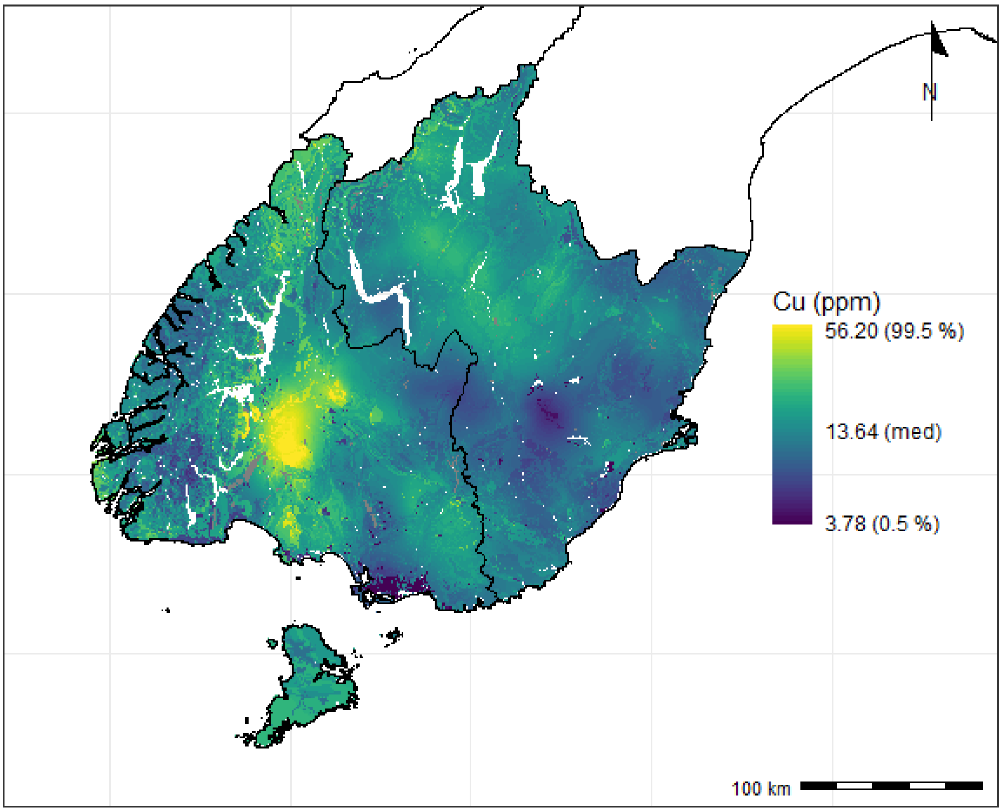
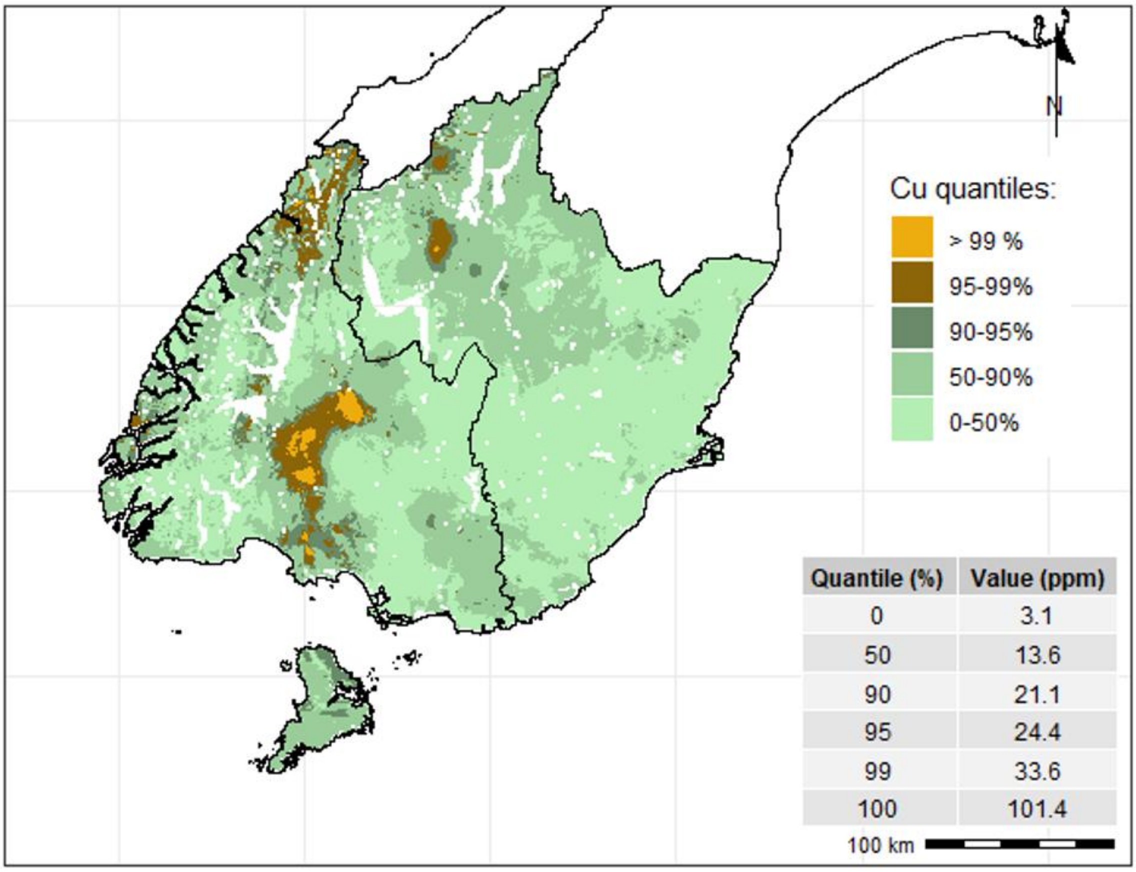


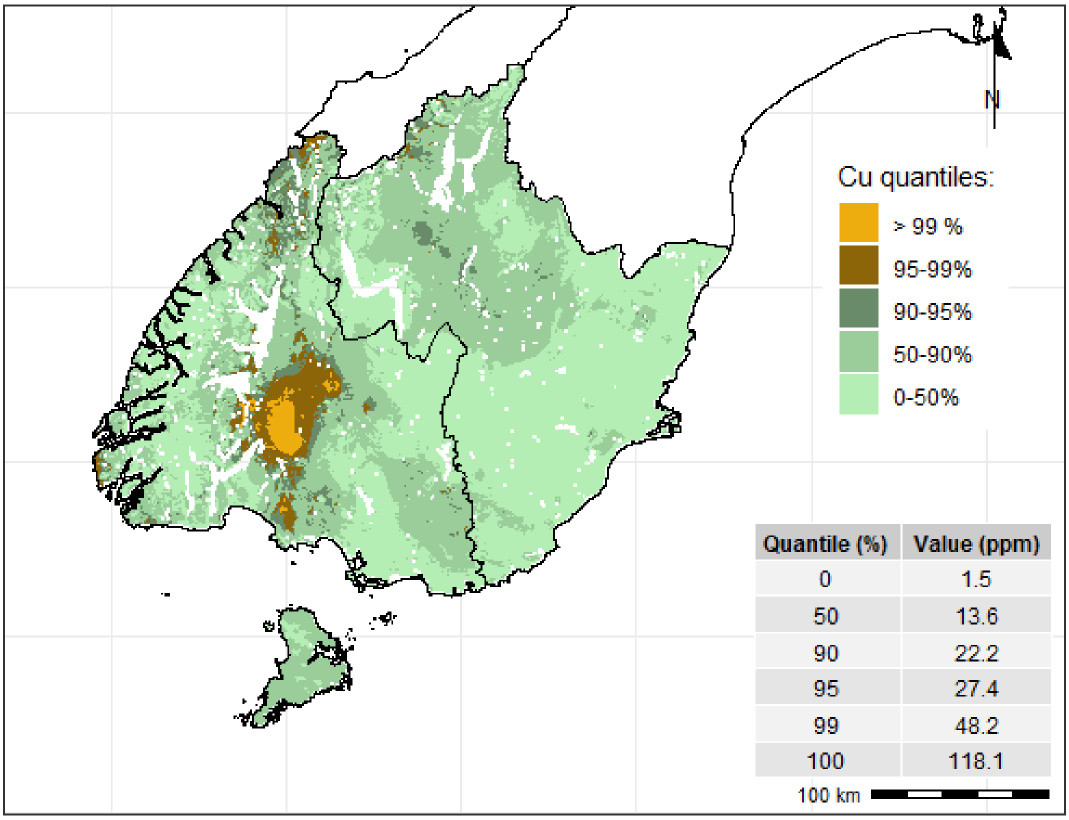
Figure 32. Estimate of copper concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	3.1
50	13.6
90	21.1
95	24.4
99	33.6
100	101.4

Figure 33. Contour plot of copper quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).



Quantile (%)	Value (ppm)
0	1.5
50	13.6
90	22.2
95	27.4
99	48.2
100	118.1

Figure 34. Contour plot of copper quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.6 Lead

The model fit for Pb is very similar to that for Cu, as shown in the measured-versus-fitted plots (Figures 9 & 10). The national model shows a slightly better fit than the regional model, with marginally more adherence to the 1:1 line. As with most trace elements, there is evident over- and under-prediction at low-end and upper-end concentrations, respectively. The modelled maximum concentrations are an order of magnitude lower than measured ambient concentrations in both models (Tables 4 & 5).

As with most other trace elements there is some difference in the spatial delineation of areas of elevated Pb concentrations between the national and regional models (Figures 35 & 36), although the concentration range is low. The predicted concentration range is similar, but the regional model shows a more uniform spatial distribution, while the national model highlights areas of elevation in east Otago around Glenavy, and around the Taieri Plains. The regional model shows a larger area of elevation above the 95th percentile around and to the north of Lake Wānaka, and areas of elevation above the 90th percentile both north and south of Lake Wakatipu.

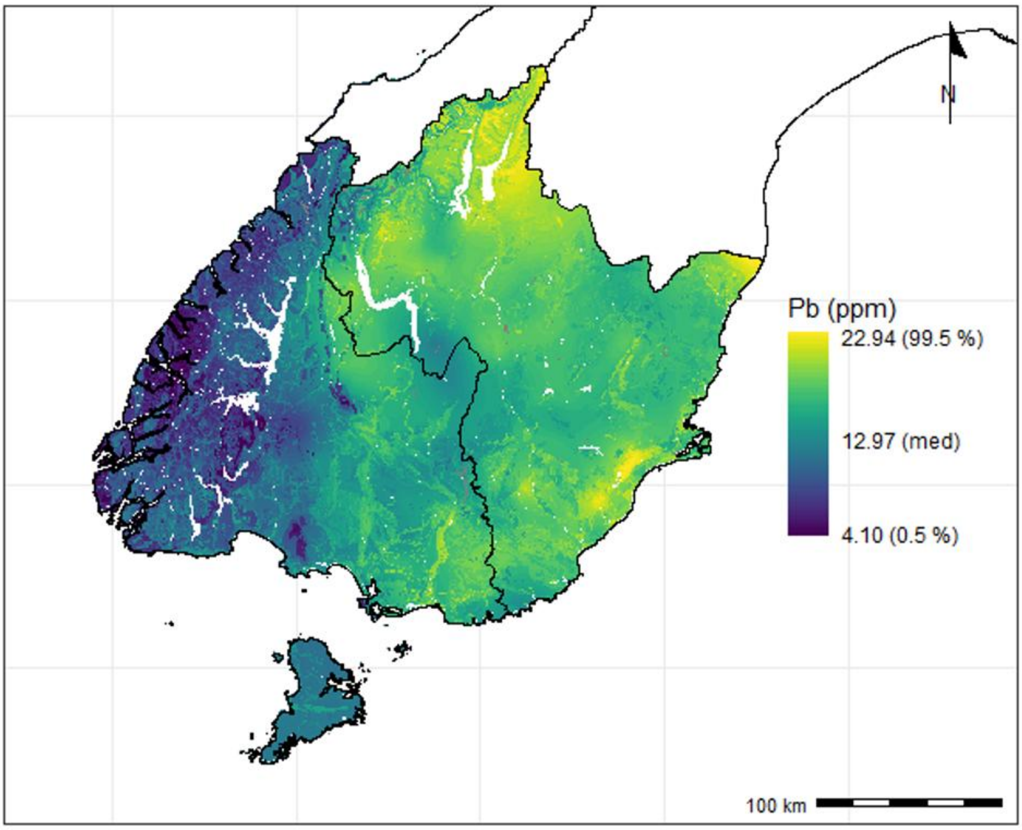


Figure 35. Estimate of lead concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

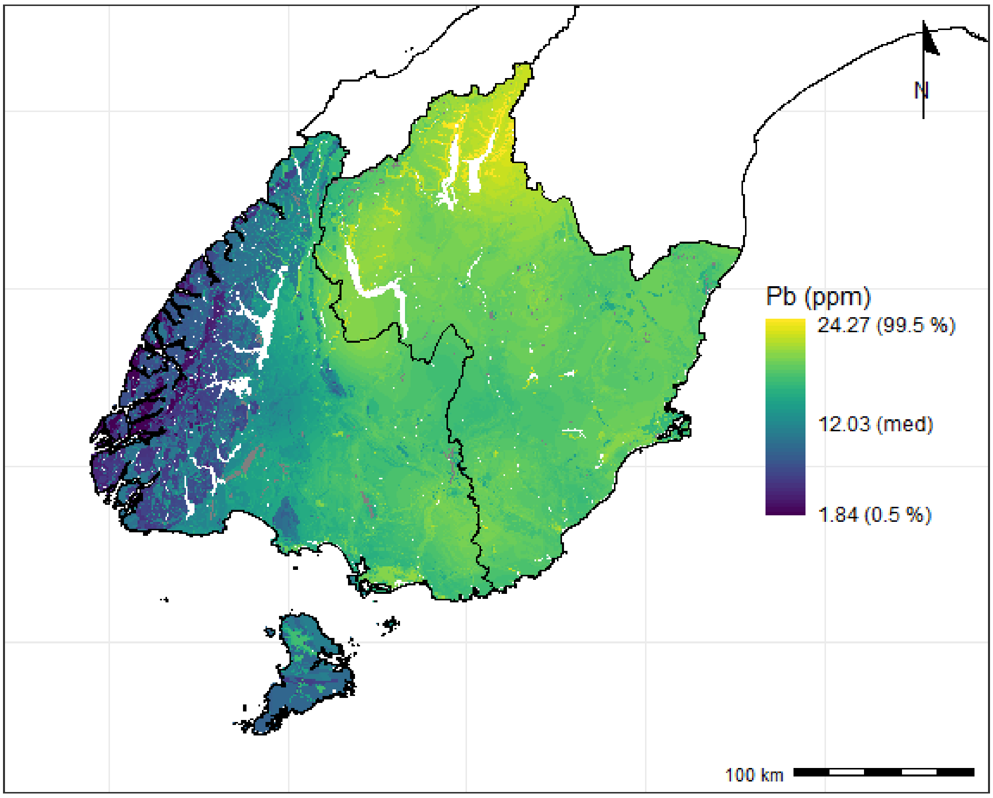
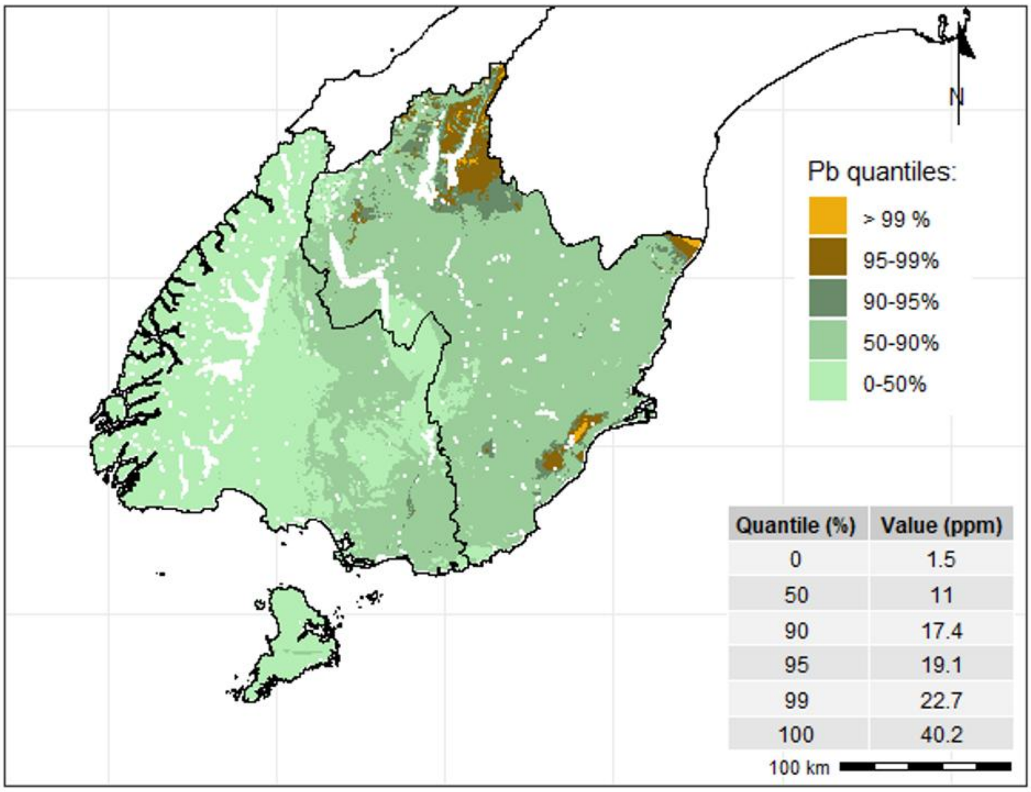


Figure 36. Estimate of lead concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	1.5
50	11
90	17.4
95	19.1
99	22.7
100	40.2

Figure 37. Contour plot of lead quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).

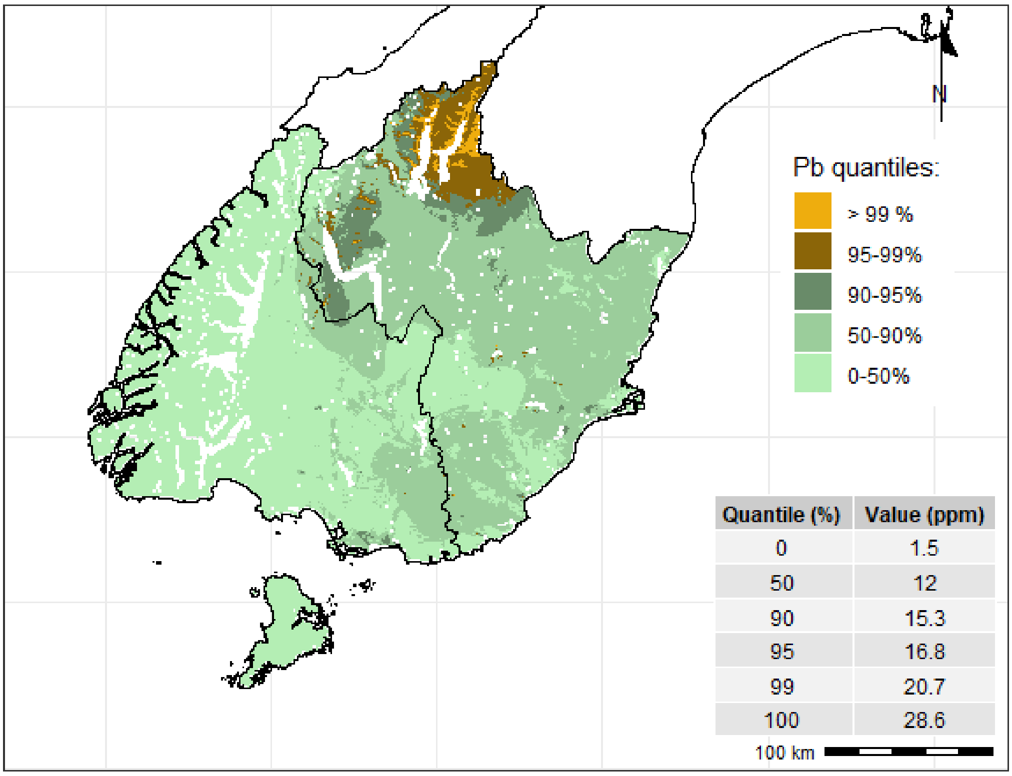


Figure 38. Contour plot of lead quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

5.1.7 Mercury

The model fit for Hg is similar to that for Cu and Pb. The national model shows a closer fit between measured and modelled values compared to the regional model (Figures 9 & 10), which predicts a narrower concentration range overall (Table 5).

There is a clear difference in areas delineated as elevated above the 90th percentile for Hg concentrations between the different models (Figures 39 & 40), with the exception of the area around the Catlins, which is highlighted in both. The regional predicted concentrations have a wider range but are more spatially uniform.

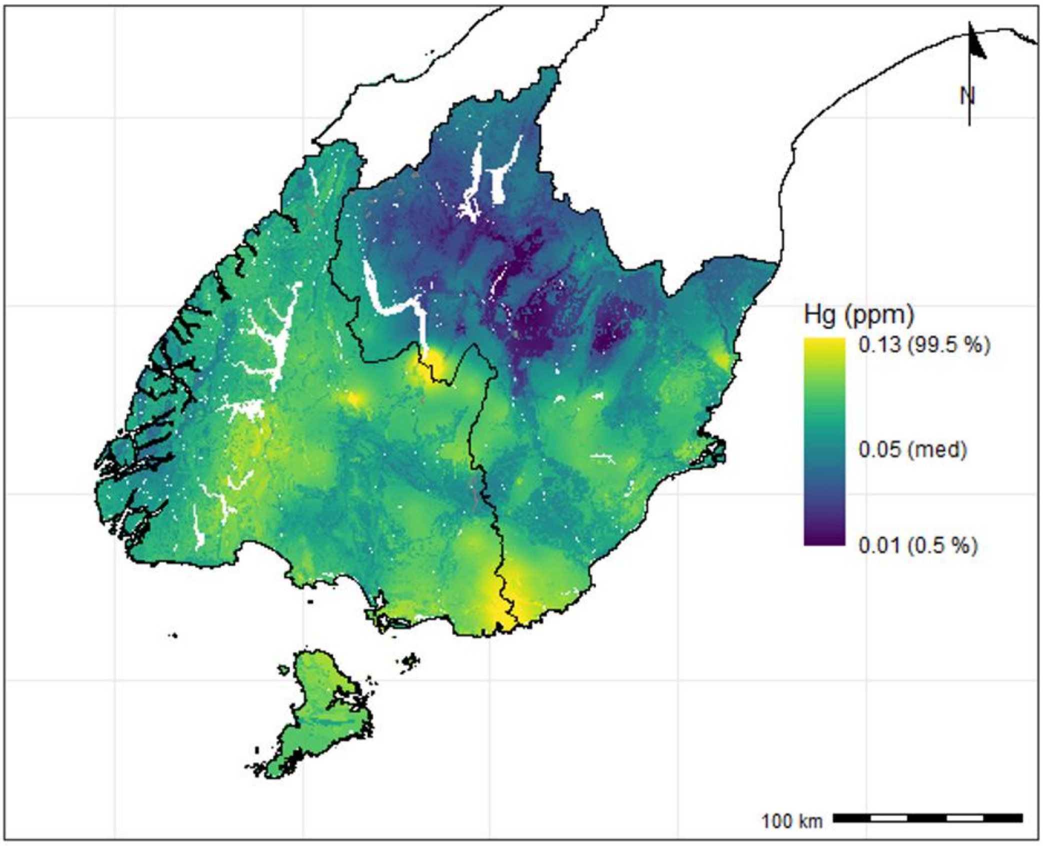


Figure 39. Estimate of mercury concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

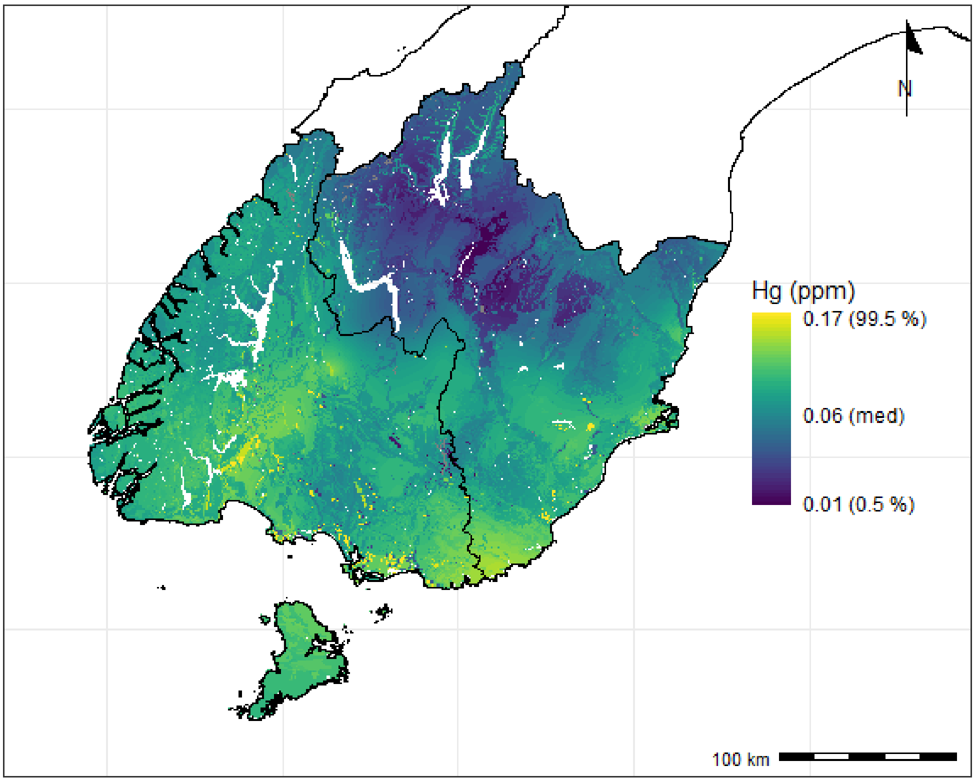
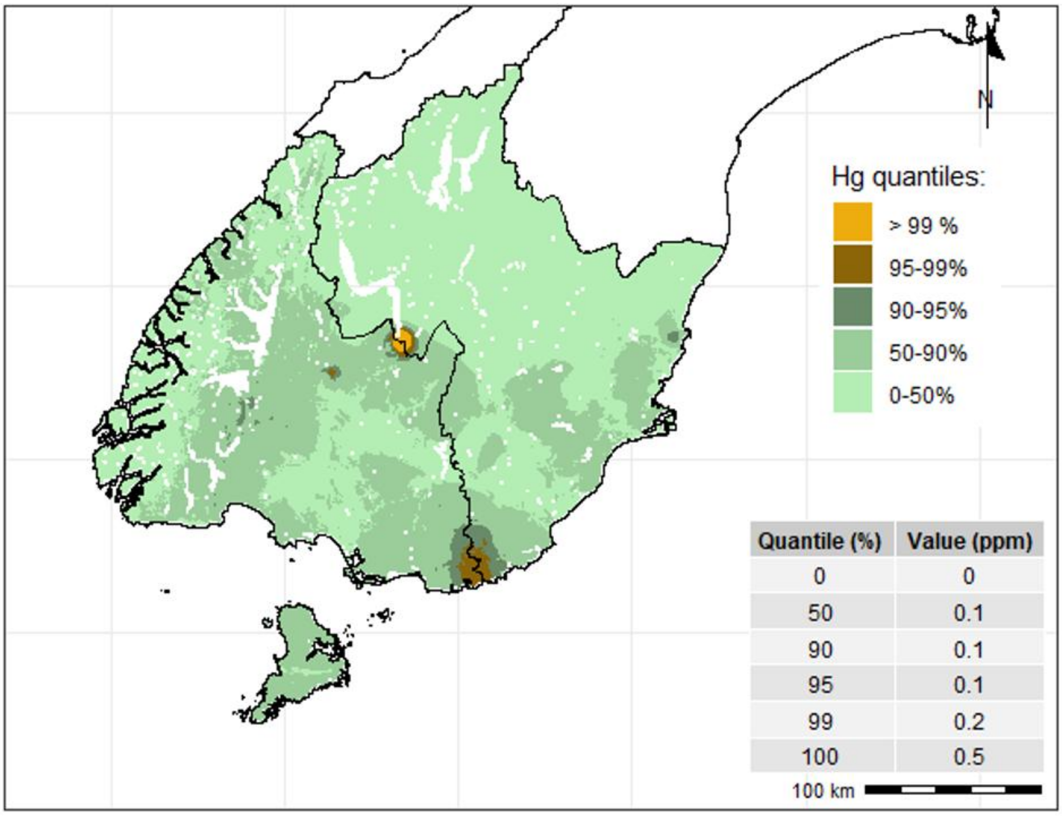


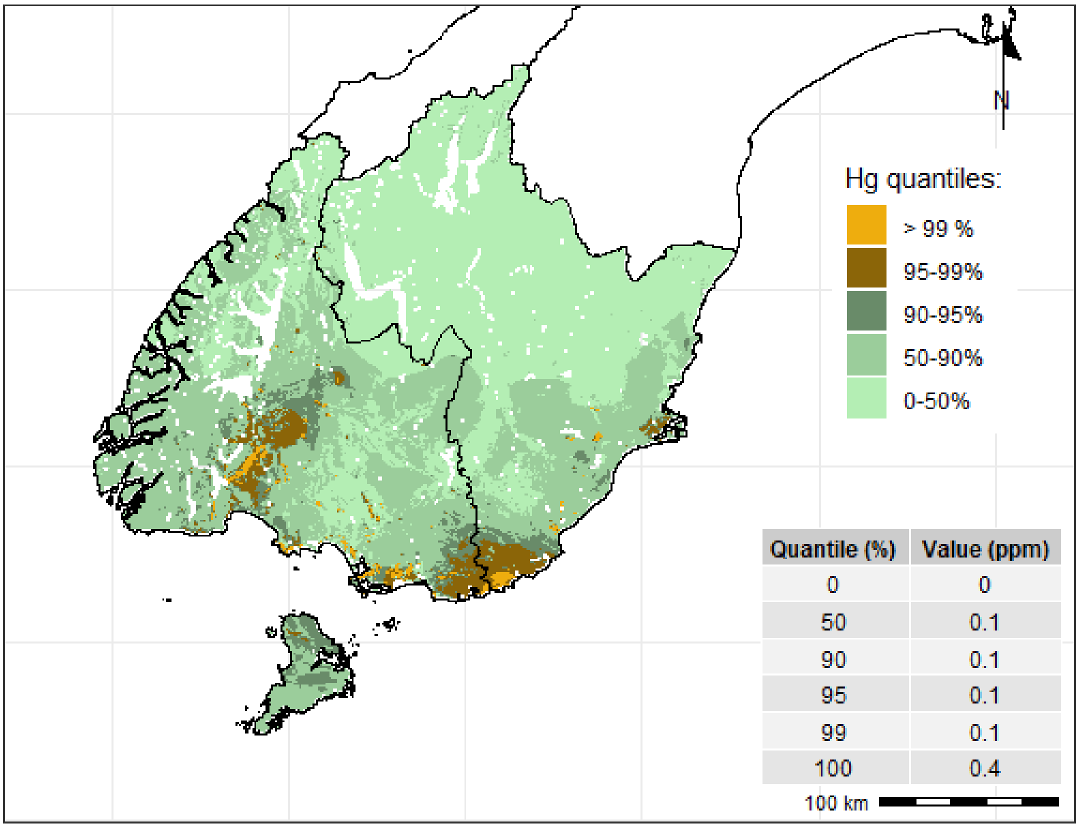
Figure 40. Estimate of mercury concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	0
50	0.1
90	0.1
95	0.1
99	0.2
100	0.5

Figure 41. Contour plot of mercury quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).



Quantile (%)	Value (ppm)
0	0
50	0.1
90	0.1
95	0.1
99	0.1
100	0.4

Figure 42. Contour plot of mercury quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.1.8 Zinc

The national model fit for Zn has improved from that reported in Cavanagh, McNeill et al. 2023, albeit with the under-prediction at upper-end concentrations less pronounced. The regional model fit is inferior to that for the national model, and remains similar to the results from Cavanagh, McNeill et al. 2023. Lower-end concentrations remain slightly over-predicted, and this is more apparent in the regional model (Figures 9 & 10). Overall, the spaMM model fit for Zn is reasonable, but inferior compared to most other trace elements.

The regional model for Zn has a slightly higher upper-end concentration than the national model (Figures 43 & 44). Also, the regional contour plot highlights some areas of elevation above the 90th percentile throughout Southland that are not shown in the national plot (Figures 45 & 46).

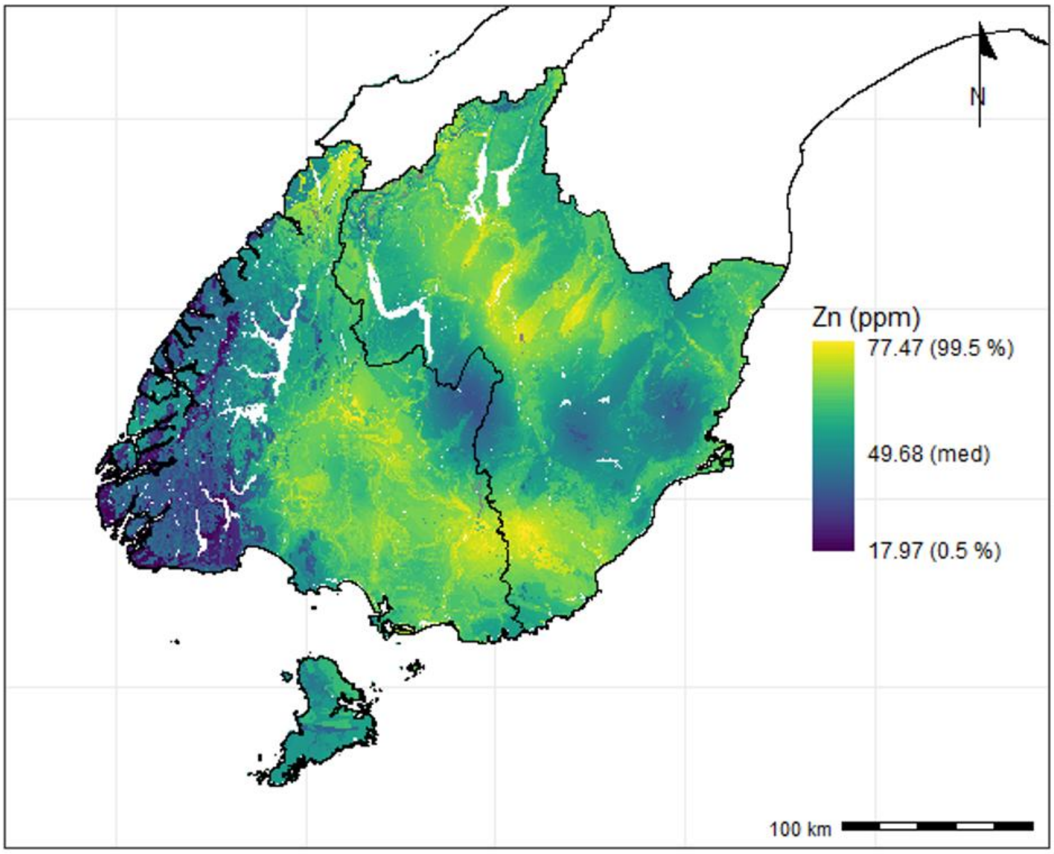


Figure 43. Estimate of zinc concentrations throughout the Otago and Southland regions using the national spaMM model.

Note that the concentration scale is regionally specific and differs from the scale used for national mapping (Appendix 1).

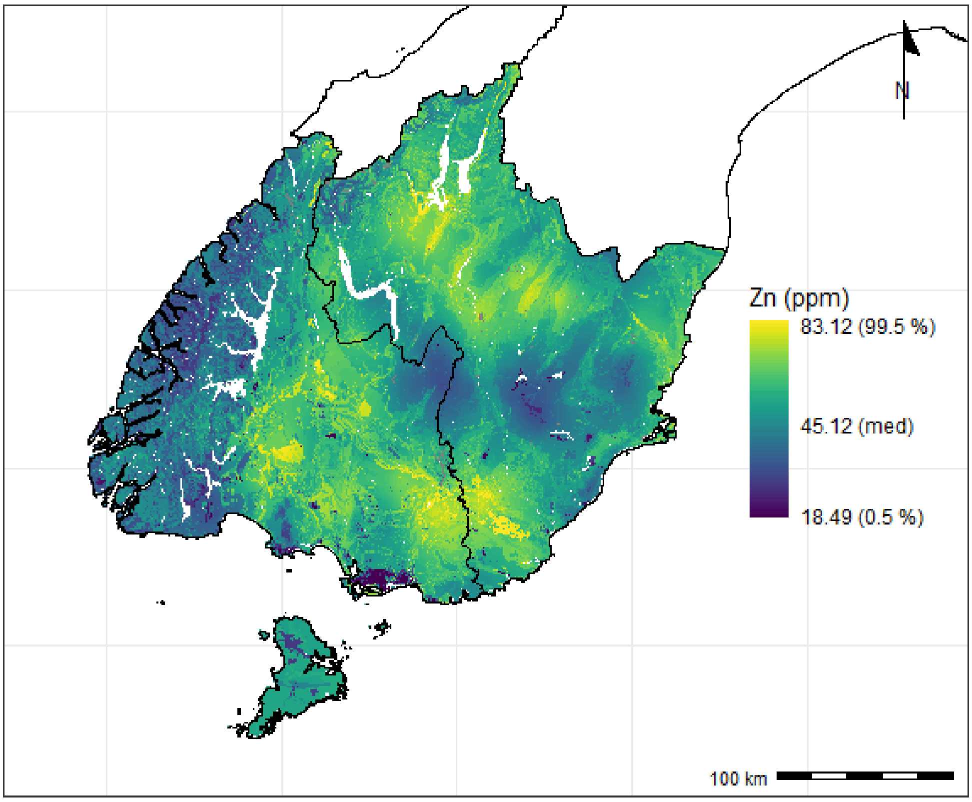
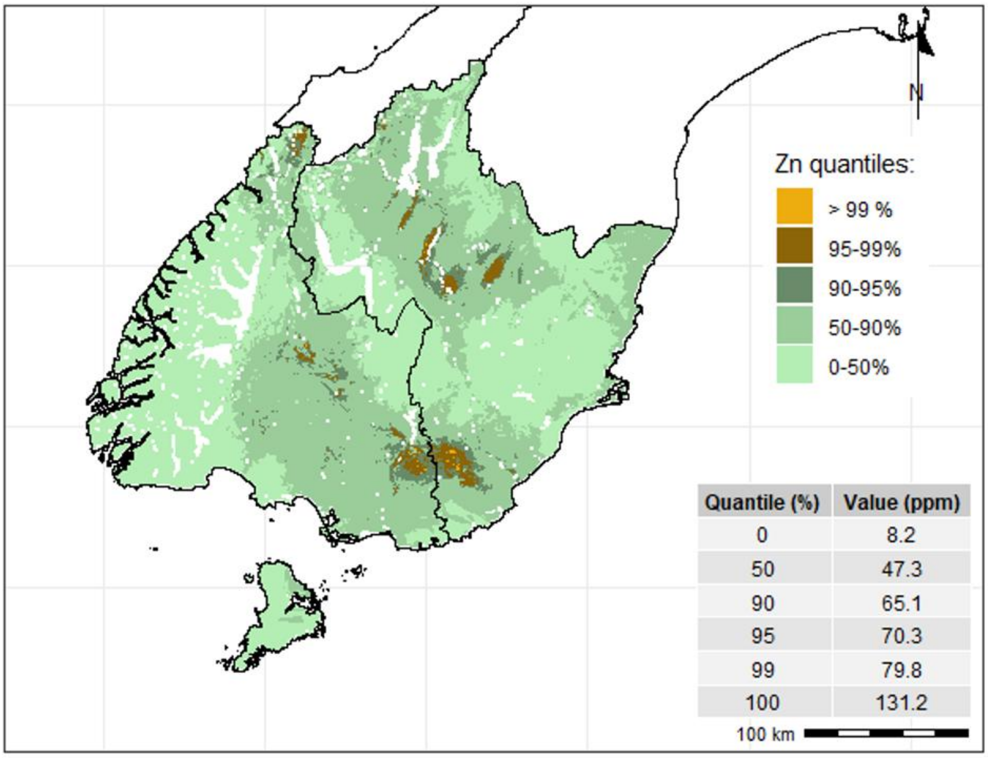


Figure 44. Estimate of zinc concentrations throughout the Otago and Southland regions using the regional spaMM model.



Quantile (%)	Value (ppm)
0	8.2
50	47.3
90	65.1
95	70.3
99	79.8
100	131.2

Figure 45. Contour plot of zinc quantile concentrations throughout the Otago and Southland regions using the national spaMM model.

Note: Quantile values are the same as those used for national mapping (Appendix 1).

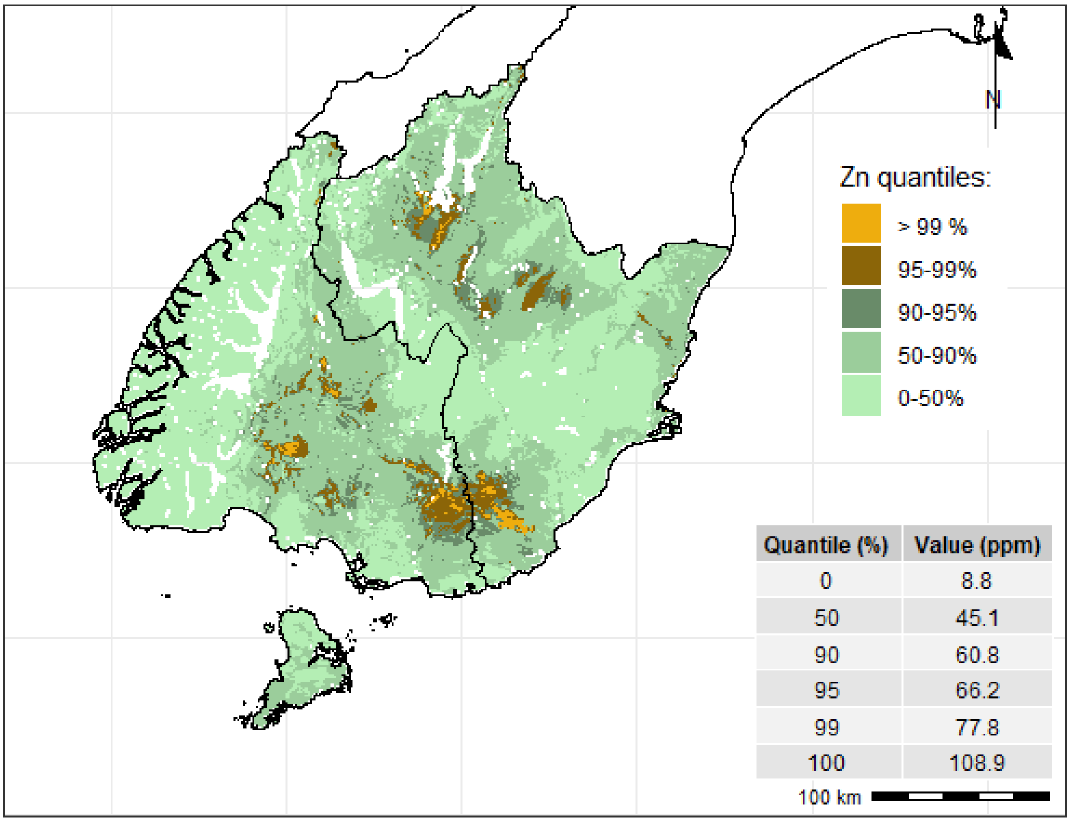


Figure 46. Contour plot of zinc quantile concentrations throughout the Otago and Southland regions using the regional spaMM model.

5.2 Distribution-based measured background concentrations

5.2.1 National and regional

The distribution of measured trace element concentrations using the national data set and the regional data sets are shown in Tables 6 and 7, respectively. The regional data set includes values determined from sampling across Dunedin City as the urban data set. Given the known elevation of Cr and Ni in mafic, and particularly ultramafic parent materials, we also calculated percentile distributions for soils with mafic and ultramafic parent materials, and other soils, in addition to all data.

For the national data set there was little difference between the 95th and 99th percentile values determined for the all-land use and rural ambient data sets for As, Cu, Hg, Cr (mafic/ultramafic), and Pb, while the 95th and 99th percentile values for Cd were higher in the total land-use data set, which is likely to be due to the widespread use of phosphate fertilisers containing Cd as a contaminant (Abraham 2020; Gray & Cavanagh 2023). For all other trace elements or groupings the rural ambient data set had higher concentrations, which suggests that areas that are naturally elevated in these trace elements comprise a greater proportion of the data set, and hence shift the upper percentile concentrations. This was initially surprising for Zn, which has been suggested to be elevated in pastoral soils due to the use of Zn as a treatment of facial eczema in livestock. However, this elevation may be attributable to the markedly higher Zn concentrations of background sites, particularly in the Auckland region (see next section).

For the Otago and Southland regions, the 95th and 99th percentile values for Cd were higher for the total land-use data set compared to the rural ambient data set. For all others there was minimal difference or slightly higher values for the rural ambient data set. The most marked difference when also considering the urban data set is the higher 95% percentile concentrations in the urban data set for Pb and Zn, noting that these 95% percentile values were calculated excluding sites where Pb exceeded the rural residential or residential SCS, and where Zn exceeded the Eco-SGV.

Comparing the regional data set to the national data set shows that the 95th and 99th percentile values for As are marginally higher in the Otago–Southland data set, while the 95th and 99th percentile values for all other trace elements are marginally or markedly lower for the Otago–Southland regional data set.

Table 6. Distribution of trace element concentrations using the national data set for all land uses, and for rural ambient land-use grouping

	Total data set					Rural ambient data set				
Element	***n***	**Median**	**95th %ile**	**99th %ile**	**Max.**	***n***	**Median**	**95th %ile**	**99th %ile**	**Max.**
As	3,042	4	11	21	440	1,781	3.5	12	22	440
B	1,245	4	22	160	839	697	3	35	196	839
Cd	3,133	0.10	0.69	1.15	29	1,835	0.05	0.28	0.66	1.33
Cr (all) *	*3,038*	*16*	*139*	*645*	*4,758*	*1,778*	*16*	*274*	*1,001*	*4,758*
Cr (mafic/ultramafic)	278	71	1031	2691	4758	209	105	1,214	2,766	4,758
Cr (non -mafic/ultramafic)	2,760	15	74	277	1,755	1,569	15	92	386	1755
Cu	3,041	15	54	99	465	1,780	15	54	98	439
Hg	2,617	0.06	0.21	0.38	4	1,648	0.05	0.20	0.34	4.1
Ni (all)*	*3,037*	*10*	*96*	*1,912*	*3,898*	*1,779*	*10*	*174*	*2,455*	*3,898*
Ni (mafic/ultramafic)	274	59	2582	3,099	3,898	207	96	2,814	3,110	3,898
Ni (non mafic/ultramafic)	2,763	9	32	159	3,163	1,572	9	34	231	3,163
Pb	3,061	12	34	85	1,280	1,783	12	32	79	1,280
Zn	3,068	53	111	207	1,160	1784	49	108	281	1,160

* Includes very high concentrations from soils with mafic/ultramafic parent material

Table 7. Distribution of trace element concentrations using the Otago–Southland regional data for all land uses, and for rural ambient land-use grouping, with data from Dunedin (Turnbull et al. 2017) providing the basis for the urban-specific estimates

	All land use					Ambient					Urban	
Element	***n***	**Median**	**95th %ile**	**99th %ile**	**Max.**	***n***	**Median**	**95th %ile**	**99th %ile**	**Max.**	***n***	**95th %ile**
As	886	4	13	26	72	549	5	16	33	72	69	11
B	207	2	6	9	12	131	2	7	8	12	69	8
Cd	886	0.06	0.26	0.48	1.31	549	0.04	0.16	0.38	1.04	67	0.6
*Cr (all)**	*886*	*14*	*75*	*286*	*651*	*549*	*13*	*122*	*354*	*651*	*69*	*78.3*
Cr (mafic/ultramafic)	55	51	432	640	651	50	51	447	641	651	-	-
Cr (non-mafic/ultramafic)	831	14	48	172	530	499	14	52	191	530	-	-
Cu	886	14	47	91	170	549	14	52	98	141	65	40
Hg	849	0.05	0.12	0.19	4.16	540	0.04	0.12	0.19	4.16	69	0.7
*Ni (all)**	*886*	*9*	*50*	*259*	*1,403*	*549*	*9*	*78*	*346*	*1,403*	*69*	*42*
Ni (mafic/ultramafic)	55	37	504	1,137	1,403	50	37	629	1161	1,403	-	-
Ni (non-mafic/ultramafic)	831	9	31	135	380	499	9	31	148	380	-	-
Pb	886	12	23	42	449	549	12	22	29	61	57	150 (220)
Zn	886	50	95	132	361	549	49	90	112	152	57	180

* Includes very high concentrations from soils with mafic/ultramafic parent material

5.2.2 Pedo-geological groupings

As noted in section 2.2, Cavanagh et al. 2015 used a geologically based 'Chemical4' grouping to model naturally occurring trace element concentrations across New Zealand. One problem with this approach was the high number of individual groups (72), which meant that for many groups there was an insufficient number of samples for background concentrations to be robustly determined. Also, the spatial distribution of the groups is complex, providing challenges for the comparison of measured results.

A different modelling approach was used by Cavanagh, McNeill et al. 2023, which allowed pedological and climatic influences to be incorporated alongside geological parent material. Also, the number of parent material classes was reduced to nine (see section 4.4.1), in contrast to the 72 Chemical4 groupings. An extended version of Chemical4, called Chemical6*,* was used in the *Geochemical Atlas for New Zealand* developed by Martin, Turnbull et al. 2023. Here the 26 poorly consolidated to unconsolidated sediments and volcanic rocks are further divided based on 15 regions, resulting in 230 Chemical6 groups in total. The rationale was that the bulk of the sediments in each region have significant input from eroded rock in the region, which therefore has its own geochemical characteristics.

Rather than attempt to determine trace element concentrations for the multiple individual different pedo-geological groupings, we looked at the distribution of sites that had concentrations that were equal to or greater than the 95th percentile concentration (Appendix 2). In this regard, Chemical6 was a particularly useful categorisation because it provides a regional breakdown of the clastic sediment class of parent material, into which the largest number of sites (1,963, Appendix 2) fall. This allowed for a qualitative assessment of the finer spatial-scale geological drivers of elevated concentrations. For example, gravels of Tasman–Nelson include many sites with an elevated concentration of Cr and Ni, probably as a result of contribution from ultramafic parent material. Similarly, gravels in Otago include sites with elevated As, probably as a result of being derived from schist parent material, which has elevated As (Appendix 2).

5.3 Determination of background concentrations in other regions

Background concentrations and/or clean fill criteria have been developed in a number of regions over time. These estimates vary because they have been developed for different locations, geographical extents, and pedo-geological units, and with varying sample numbers.

5.3.1 Auckland

Investigations to determine background concentrations in the Auckland region were carried out over 1999–2001 and are reported in ARC 2001. Soil samples (0–15 cm) were collected as a single point sample from 91 locations in May 1999 on soil derived from the major lithological units (eight) of the region. Fifteen sites were revisited in October 2001 to confirm the validity of outlier data obtained during the 1999 survey. The location of the individual sampling sites and the approximate extent of key lithological units used are shown in Figure 47.

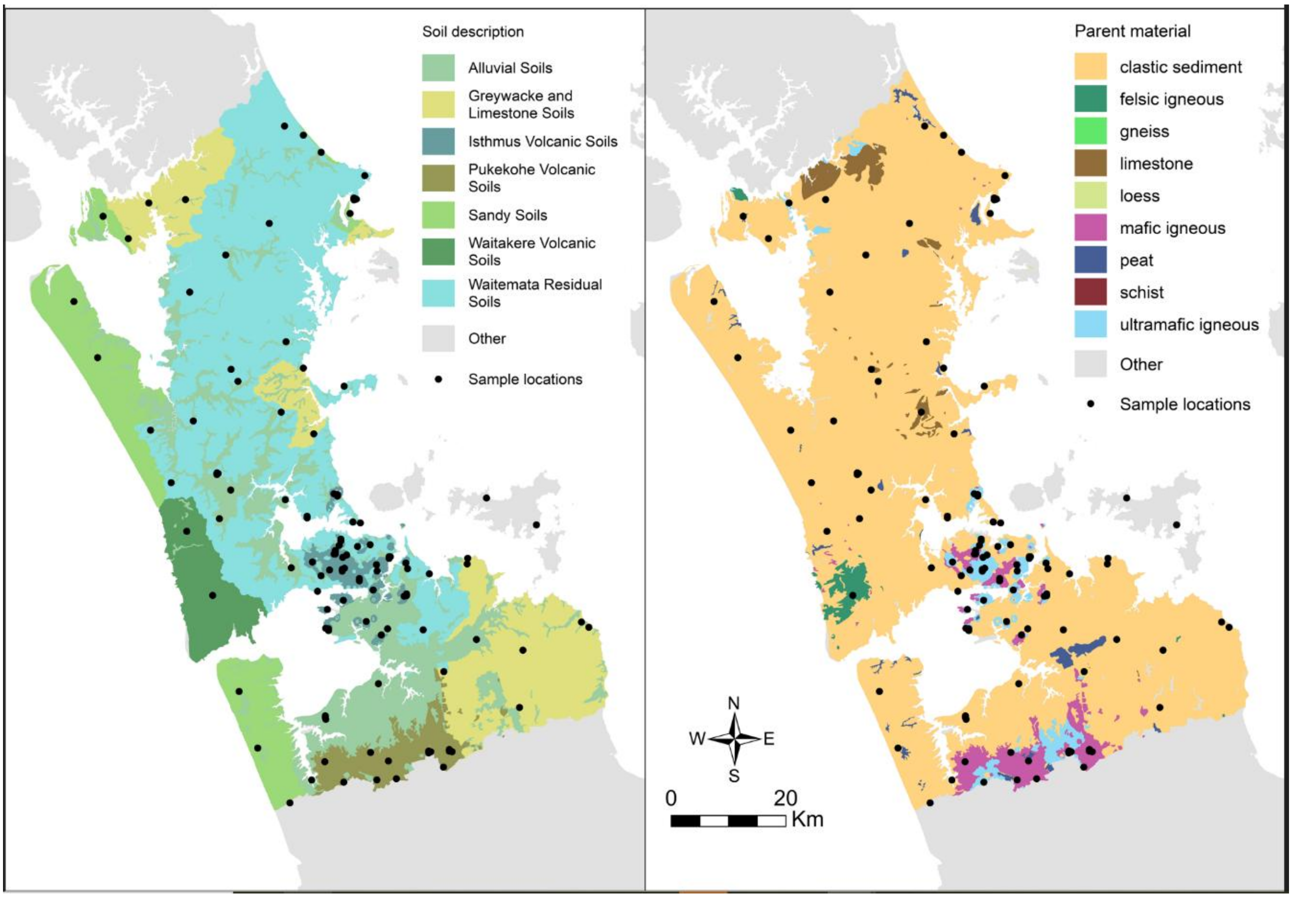


Figure 47. Location of samples used to determine background concentrations in Auckland in ARC 2001. Left: the base layer is the 'Soil types' layer provided by Auckland Council, which approximates the lithological groupings used in ARC 2001. Right: the distribution of the parent material groupings used in the current study for the same region.

Soils were grouped to provide trace element concentration ranges for volcanics and non-volcanics (Table 8), although it was recognised that individual soil types within the groups may be geochemically different (ARC 2001). For As, Cd, and Pb no difference was observed for background concentrations for volcanic and non-volcanic soils, although it was noted for Pb that some specific lithologies (Mt Smart volcanics) may require additional analyses to confirm background concentrations. For all other elements, concentration ranges are overlapping, although higher for soils derived from volcanic geologies than from non-volcanic origins (Table 8).

The Auckland Unitary Plan, section E30.6.1.4, covers conditions for the discharge of contaminants onto or into land from land not used for rural production activities. Under this section, the concentrations of contaminants (relevant to the site's history) in soil or fill material must not exceed (a) the criteria specified in Table E30.6.1.4.1 'Permitted activity soil acceptance criteria' or the background concentration ranges of trace elements specified in Table 3 of TP153 (ARC 2001). Permitted activity criteria are based on the protection of freshwater, and are based on the ISQG (interim sediment quality guideline)-Low criteria from the ANZECC (2000) guidelines, but multiplied by 4 for all basic contaminants except Zn, for which the relevant criterion was multiplied by 2 (Andrew Kalbarczyk, Auckland Council, pers. comm.). The only organic contaminants included under the permitted activity criteria are polycyclic aromatic hydrocarbons (PAH), as benzo(a)pyrene (equivalent) and total DDT. For other hydrocarbon contaminants, section E30.6.1.4 identifies that the criteria outlined in Table 4.20 'Soil acceptance criteria for protection of groundwater quality' in the *Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (MfE 2011b) need to be considered. Additional documents are specified in the Auckland Unitary Plan, section E30.6.1.4, for other contaminants present.

Table 8. Background concentration ranges (mg/kg) for volcanic and non-volcanic soils (from ARC 2001) and permitted activity criteria

Trace element	Non-volcanic	Volcanic	Permitted activity criteria
n	51–54[a]	38–42[a]	NA
As	0.4–12[b]		100
B	2–45	<2–260	Na
Cd	<0.1–0.65[b]		7.5
Cr	2–55	3–125	400
Cu	1–45	20–90	325
Ni	0.9–35	4–320	105
Pb	<1.5–65[b]		250
Zn	9–180	54–1,160	400

[a] The number of samples varied slightly for different elements.

[b] There was no difference in concentrations between non-volcanic and volcanic soils

NA – not applicable, Na – Not available

(Source: ARC 2001)

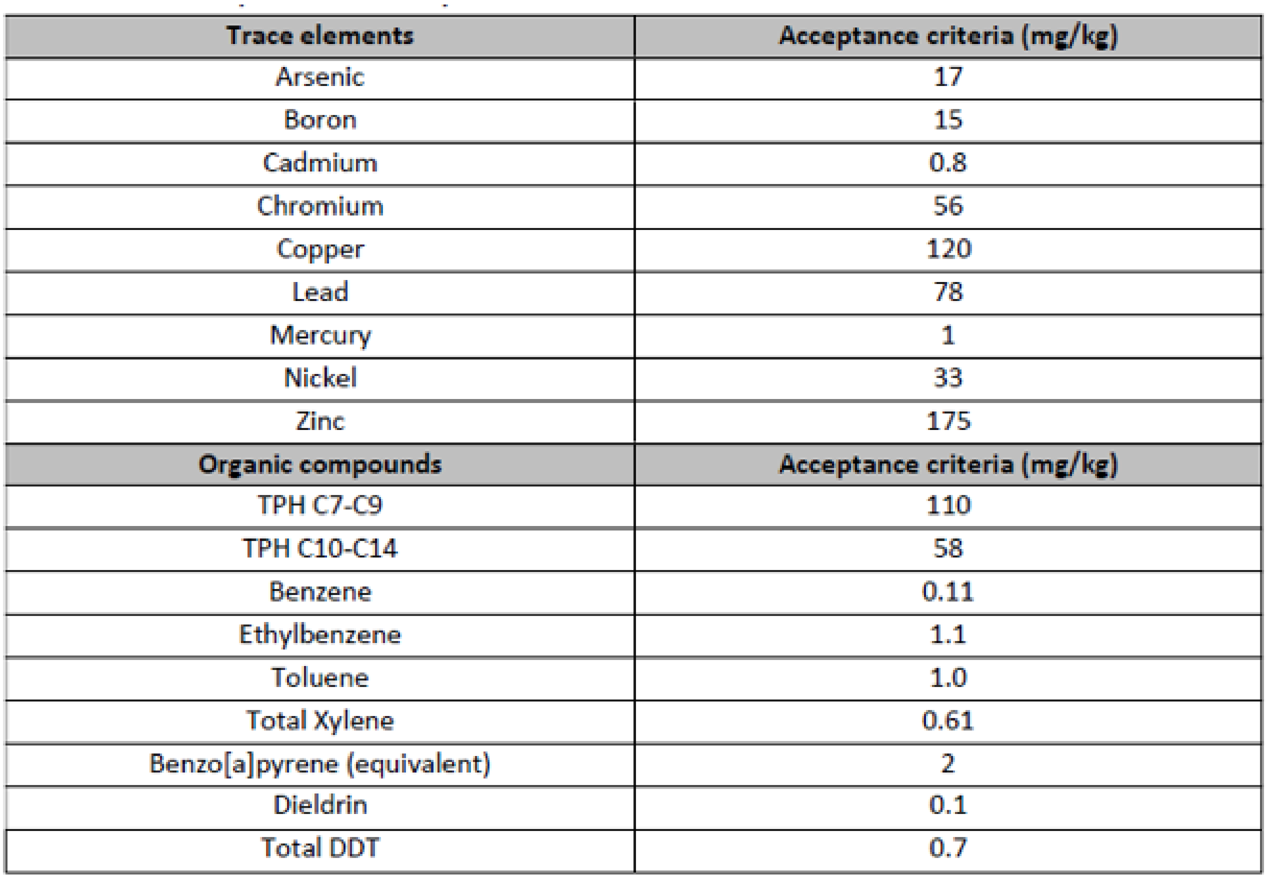
5.3.2 Waikato

Waikato Regional Council has a standard operating procedure that outlines their development of clean fill acceptance criteria (WRC 2022). This includes 95th percentile background concentrations updated in 2017 for natural background, forestry, pastoral and agricultural/arable land uses. This standard operating procedure updated clean fill criteria that were originally developed in 2006.

Different approaches were used to develop the clean fill criteria for trace elements. For example, criteria for As and Cd are based on the rural residential Soil Contaminant Standards (SCS), while others are based on 95th percentile background concentrations, or equidistance between the 95th percentile value for Waikato of surface soils and the serious risk Eco-SGV developed by Cavanagh & O'Halloran 2006) or Eco-SGVs developed by Cavanagh and Munir (2016). Where only minor changes arose as a result of updating, the original values were maintained to provide consistency with acceptance criteria used by operating clean fills.

The clean fill acceptance criteria for permitted activities for nine trace elements and a suite of organic compounds are shown in Table 9. Criteria for consented activities are similar but allow for higher concentrations of BTEX and Benzo(a)pyrene and total DDTs.

Table 9. Clean fill acceptance criteria for trace elements and organic compounds in the Waikato Region under a permitted activity scenario



Trace elements	Acceptance criteria (mg/kg)
Arsenic	17
Boron	15
Cadmium	0.8
Chromium	56
Copper	120
Lead	78
Mercury	1
Nickel	33
Zinc	175
Organic compounds	**Acceptance criteria (mg/kg)**
TPH C7-C9	110
TPH C10-C14	58
Benzene	0.11
Ethylbenzene	1.1
Toluene	1.0
Total Xylene	0.61
Benzo[a]pyrene (equivalent)	2
Dieldrin	0.1
Total DDT	0.7

BTEX = Benzene, Ethylene, Toluene, Xylene; DDTs = dichlorodiphenyltrichloroethanes

Source: WRC 2022.

5.3.3 Wellington

The development of estimates for background soil concentrations in the Wellington Region is described in URS 2003 and briefly summarised here.

Five main soil types were identified based on a review of the major parent rock formation soils information using the 1:250,000 Geological Maps of New Zealand, the 1:1,000,000 North Island Soil Map of New Zealand, and the Regional Soil Plan for the Wellington Region. In each of these main soil type areas (Figure 48), specific sample sites were chosen to gain a relatively even spatial distribution of soils best representing background (non-anthropogenically influenced) soils, and for ease of access included some sites that had been previously sampled through the SoE monitoring programme.

Surficial (0–150 mm depth) soil samples were collected from 40 locations during June 2003. The collected samples were analysed for As, soluble B, Cd, Cr, Cu, Pb, Hg, Ni, Zn, total petroleum hydrocarbons (TPHs), and polycyclic aromatic hydrocarbons (PAHs). URS (2003) noted that further soil sampling was required to improve statistical robustness before the data could be considered fully representative of background soil quality for the Wellington Region. Only trace element concentrations are discussed further here.

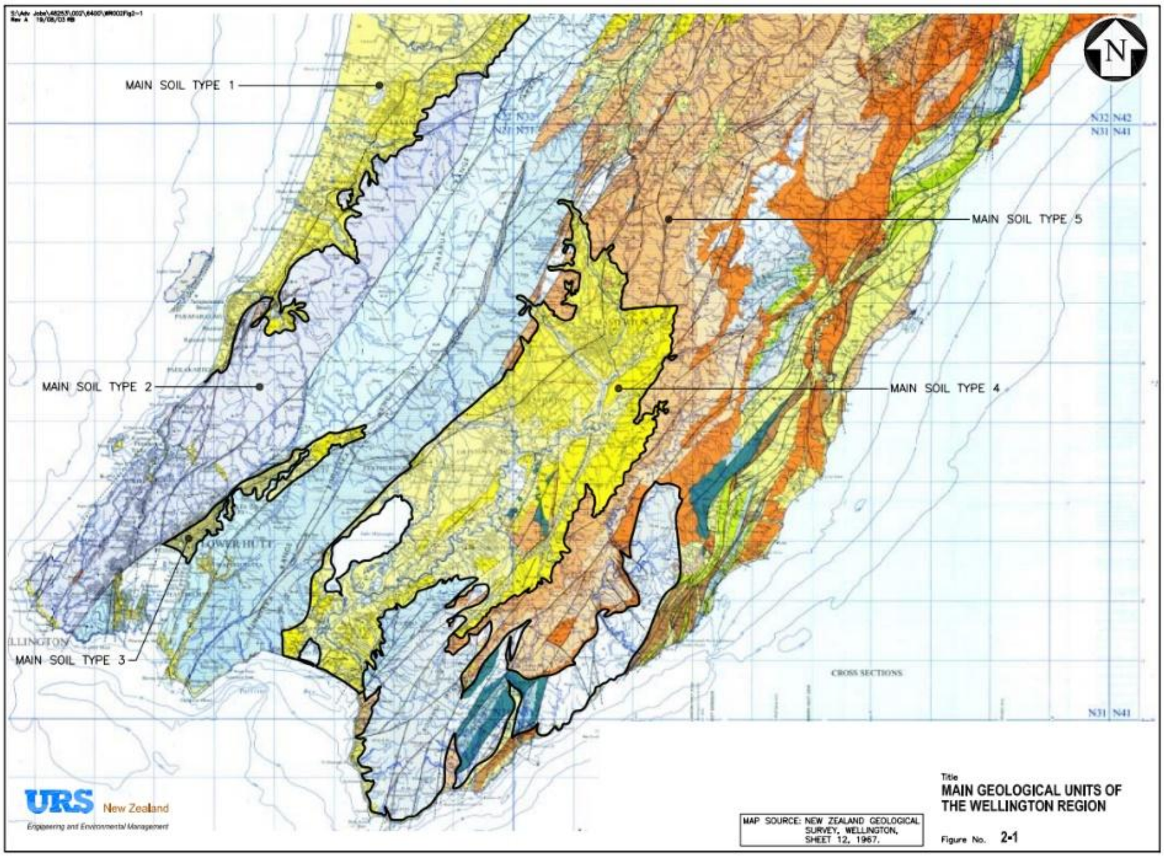


Figure 48. Approximate location of the main five soil types identified for determining background concentrations in the Wellington Region: type 1 – sandy soils, type 2 – greywacke soils, type 3 – Hutt alluvium, type 4 – Wairarapa alluvium, type 5 – mudstone/siltstone. (Source: URS 2003)

A summary of the background concentration ranges for trace elements in the main soil types in the Wellington Region, as determined by URS (2003), is shown in Table 10.

Table 10. Background concentration ranges (mg/kg) in the main soil types in the Wellington Region, as determined by URS 2003

Soil type (main soil type)	As	Cd	Cr	Cu	Ni	Pb	Zn
Sand (1)	<2–7	<0.1–0.1	7–12	4–10	4–9	4.5–180.0	28–79
Greywacke (2)	<2–7	<0.1–0.1	6–16	3–25	4–13	5.9–78.6	24–105
Hutt alluvium (3)	2–7	<0.1–0.2	9–18	5–19	5–14	16.7–73.3	38–201
Wairarapa alluvium (4)	2–7	<0.1–0.2	11–21	7–19	6–21	9.4–34.0	44–121
Mudstone/siltstone (5)	<2–4	<0.1–0.2	8–15	6–19	5–13	10.8–38.1	31–72

More recently a geochemical baseline survey that included 151 sites across urban, and some natural, areas of Wellington City, the Hutt Valley, the Wainuiomata basin, Johnsonville, and Porirua and outlying suburbs was undertaken by Morgenstern et al. 2024. In contrast to previous studies undertaken by GNS Science, and due to the relatively uniform geology of the area, the site locations were land-use targeted, ensuring sufficiently even spacing for interpolation of data, as opposed to the grid-based sampling used by Martin et al. (2015, 2017) and Turnbull et al. (2017). A total of 65 elements were measured by ICP-MS analysis of aqua regia extracts. Median values reported for the main trace elements generally fell within the range shown in Table 10; upper percentile data were not reported.

5.3.4 Canterbury

Background concentrations of selected trace elements were determined in Canterbury's major soil groups in studies in 2006 and 2007 (Tonkin & Taylor 2006, 2007) and are available online.[9] Soils were classified using the New Zealand Genetic Soil Classification System, which is no longer used, because this was the prevalent classification scheme available in the electronic data sets available at the time: the Land Resource Inventory and the Canterbury Soils data sets. A total of 90 sample sites were distributed across these soil groups: 17 in the Christchurch urban area and 73 throughout the rest of Canterbury (Figure 49). From these samples, concentrations of As, B, Cd, Cr, Cu, Pb, Mn, Hg, Ni, and Zn were measured in mg/kg.

The classification system had two levels. Level 1 gives the maximum concentration values of the above trace elements measured in each soil group. Level 2 concentrations are also available, which provide the maximum concentration values of the above trace elements measured in each soil group, plus half the interquartile range (buffer). A two-tiered approach was recommended to account for the limited data used to determine the background concentrations (Tonkin & Taylor 2006). The intent was for the approach to enable sites clearly below background to be designated as not contaminated, while retaining some flexibility in assessing sites within the upper limits of the proposed background concentrations.

---

[9] https://opendata.canterburymaps.govt.nz/datasets/593db381b6b04bcf8b6f01dc53d91954/about

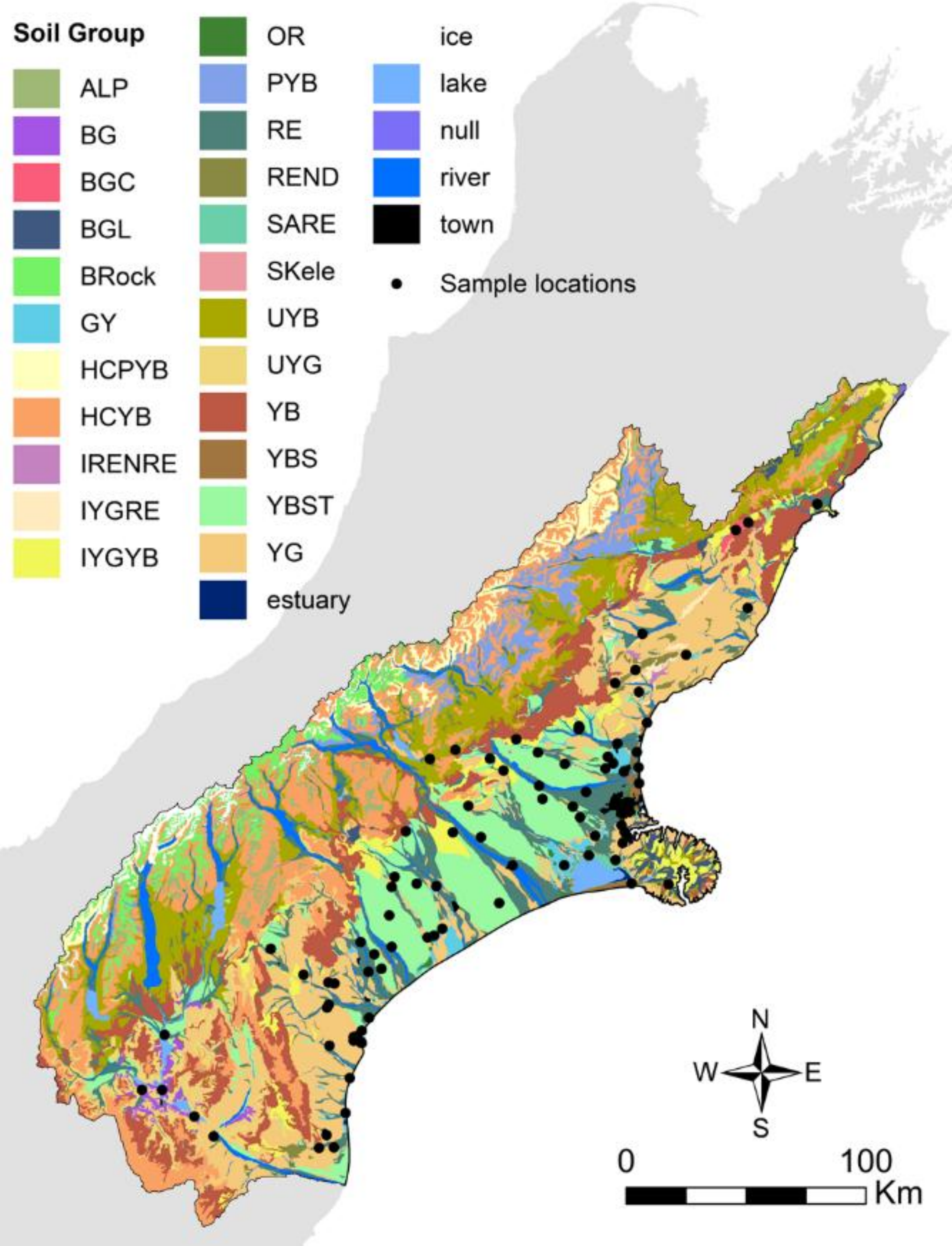


Figure 49. Sample site locations for background concentration studies, and the distribution of soil groups across Canterbury.

The reported maximum background concentrations are shown in Table 11.

Table 11. Reported maximum background concentrations for soils from the Canterbury region (all in mg/kg)

Area	Soil group	*n*	As	Cd	Cr	Cu	Ni	Pb	Zn
Regional	BG/BGL	4	5.1	0.20	22.5	27.3	20.7	17.2	116.0
	Gley	6	8.7	0.24	16.8	15.5	13.4	17.8	65.6
	Intergrade	8	6.1	0.12	24.5	15.2	15.3	27.5	69.8
	Organic	3	2.9	0.34	13.8	18.4	7.2	25.9	53.5
	Recent	18	11.5	0.18	20.8	18.8	19.0	37.4	86.5
	Rendzina	4	36.9	0.31	26.4	9.5	15.9	16.7	57.4
	Saline Gley Recent	4	6.8	0.09	13.2	12.2	9.6	44.4	47.3
	Yellow Brown Sand	4	3.4	0.06	11.0	7.1	8.7	31.9	50.7
	Yellow Brown Stony	14	5.8	0.10	18.3	10.2	12.8	18.7	64.0
	Yellow Grey Earth	15	4.6	0.11	15.6	11.5	11.6	18.8	62.4
	Yellow Brown Earth	2	4.2	0.04	18.9	10.1	16.1	11.9	43.1
Christchurch urban	Gley	6	10.6	0.20	18.5	23.3	15.6	34.9	138.0
	Organic	2	13.2	0.11	12.4	13.3	11.7	40.9	63.3
	Recent	8	15.3	0.20	19.0	17.7	16.6	101.0	149.0
	Saline Gley Recent	2	7.5	0.06	22.1	10.2	14.1	31.2	87.7
	Yellow Brown Sand	4	5.6	0.10	15.4	8.8	11.7	22.3	54.9
Timaru urban	Yellow Grey Earth	5	3.3	0.11	12.4	13.1	8.6	56.0	122.0

Source: Tonkin & Taylor 2007

5.3.5 Marlborough

Background concentrations and proposed clean fill criteria for Marlborough District Council were developed by Cavanagh (2013a). Background concentrations were based on data from 195 sites across Marlborough. Analysis of existing soil monitoring data showed that elevated concentrations of Cr and Ni occurred at some sites, typically in Recent Soils. These sites were clustered in alluvial valley fill draining regions associated with quartz reef mineralisation in schist, and ultramafic rocks (e.g. in the Pelorus, Wakamarina, Linkwater, and Fabians Creek areas). The identification of a cluster of sites with elevated concentrations of Cr suggests this general area should be treated differently when determining background soil concentrations, and consequently clean fill criteria.

Clean fill criteria were developed for the non-elevated region of Marlborough using the SCS, and added risk Eco-SGVs were derived by the addition of median background concentrations and ecological serious-risk guideline values developed by Cavanagh and O'Halloran (2006) and Cavanagh (2006). These criteria are shown in Table 12.

Table 12. Recommended clean fill criteria for the Marlborough region

Element	Recommended interim clean fill criteria (mg/kg)
As	12
Cd	0.9
Cr	88
Cu	147
Ni	75
Pb	92
Zn	260

Source: Cavanagh 2013a

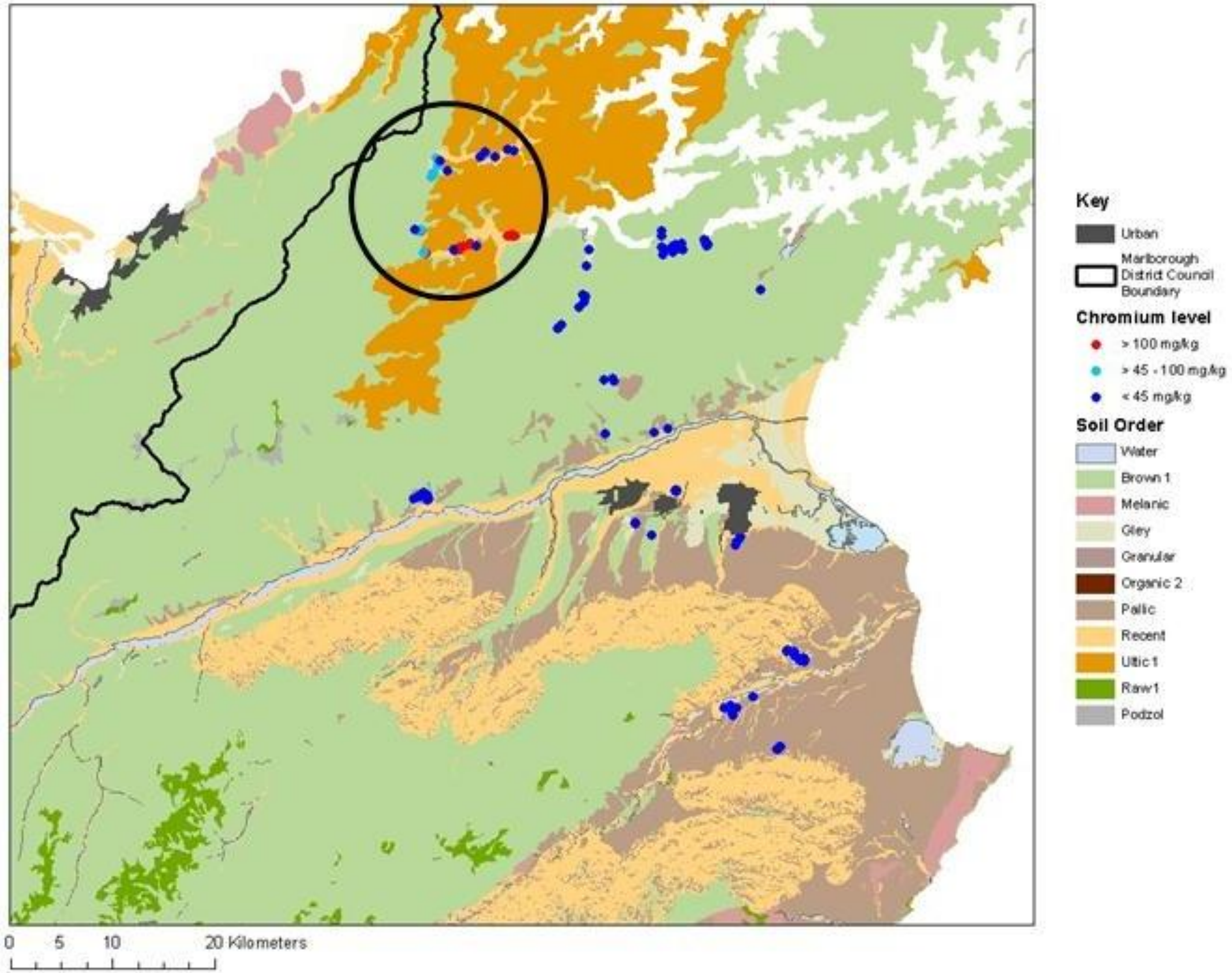


Figure 50. Map showing clustering of sites with elevated (>45–100 mg/kg) or highly elevated (>100 mg/kg) concentrations of chromium.
(Source: Cavanagh 2013b)

5.3.6 Tasman

Background concentrations in the Tasman region were originally determined through the analysis of trace element concentration data provided by Tasman Council using R version 3.0.2, to determine the 95th and 99th percentiles. A bootstrapping technique was used by Cavanagh (2015) to determine the upper confidence limit of the 95th percentile. This study also identified a sub-group of sites as having elevated Cr and Ni. Clean fill criteria were developed following the same approach as Cavanagh 2013a. Background concentrations and proposed clean fill criteria were updated in 2021 (Cavanagh 2021) using modelling undertaken by Cavanagh et al. 2015, data from geochemical surveys undertaken by GNS Science in 2017, and Eco-SGVs developed by Cavanagh and Munir (2019). Cavanagh (2021) also provided median and 95th percentile concentrations for the Dun Mountain mineral belt, which includes mafic and ultramafic materials (Table 13).

Table 13. Median and 95th percentile trace element concentrations for samples representative of the Dun Mountain mineral belt (identified lithologies of Dun Mountain ophiolite, mafic, and ultramafic materials)

Parameter	**Trace element**					
	As	**Cu**	**Cr**	**Pb**	**Ni**	**Zn**
Median	1	25.4	486.2	2.4	1938	48.7
95th percentile	4.6	105	1673	13.8	3053	70.3

Source: Cavanagh 2021.

Cavanagh (2021) presented a range of options for developing appropriate revised clean fill criteria (Table 14), depending on the policy and planning context in which they were intended to be used by Tasman District Council.

Table 14. Options for revised clean fill criteriaa proposed by Cavanagh (2021)

Element	Median[b] (mg/kg)	95th percentile[b] (mg/kg)	Revised Eco-SGV criteria[c] (mg/kg)	Regional median[d] (mg/kg)	Regional 95th percentile[d] (mg/kg)	Regional Eco-SGV[e] (mg/kg)	Human health[f] (mg/kg)
As	2.1	8.9	17 (18)	1.1–3.6	7.4–9.5	16 (17)	17
Cd	0.05	0.05	1.5 (1.5)	ND	ND	1.5 (1.5)	0.8
Cr	6.7	29	190 (300)	50-84	203–290	220 (355)	290
Cu	8.6	41	100 (220)	12-20	32–55	105 (225)	NL
Pb	6.8	25	280 (530)	7.9-12.4	16–20	280 (530)	160
Ni	4.4	25	ND	10-17	26–154	ND	130
Zn	25	102	170 (190)	34-48	72–92	180 (200)	NL
DDT residues	NA	NA	1.1 (1.9)	NA	NA	1.1 (1.9)	45

[a] Criteria could be based on the upper limits for background concentrations or the lowest of the relevant Eco-SGV and human health criteria.

[b] Based on the lowest median and lowest 95th percentile concentrations (i.e. more conservative values) determined by Cavanagh et al. (2015).

[c] Based on 95% protection for all receptors and the lowest median background concentration determined by Cavanagh et al. (2015). Criteria shown in brackets are the agricultural criteria, which provide 95% protection for plants and 80% for microbes and invertebrates.

[d] Based on preliminary analysis: the range is for the dominant geological groups underlying the existing land use shown in Table 4 of Cavanagh 2021. Further analysis is still required to develop more robust estimates, particularly for delineating areas with naturally elevated concentrations.

[e] Based on the lowest regional median concentration. Criteria shown in brackets are the agricultural criteria, which provide 95% protection for plants and 80% for microbes and invertebrates.

[f] The Soil Contaminant Standard for rural residential land use.

ND = not determined; NL = not limiting; NA = not applicable as not a naturally occurring substance, but ambient concentrations are often specified as being 0.48 mg/kg based on Gaw 2003.

5.3.7 Hawke’s Bay

Background concentrations for the Hawke’s Bay Region were determined in 2014 based on existing soil quality monitoring data (Cavanagh 2014). Upper limits for background concentrations were based on the 95th and 99th percentile distributions, and a statistical bootstrapping technique was used to determine the 95th percentile upper confidence limit of the 95th percentile. These estimates are shown in Table 15 and are thought to be used by consultants, although use of WasteMINZ Class 5 criteria could be more common (Kurt Barichievy, Hawke’s Bay Regional Council, pers. comm.).

Table 15. Summary of concentrations (mg/kg) of individual trace elements, and various estimates of upper limits for nominal background concentrations

Element	*n*	Max.	Min.	Median	95th %ile	95UCL	99th %ile
As	69	10.2	<2	3	7.0	9.0	10.1
Cd	69	0.79	<0.1	0.27	0.67	0.69	0.72
Cu	67	53	3	10.0	27.7	32	39.1
Cr	69	25.0	4	13.0	22.7	24.8	24.9
Hg	69	0.23	<0.1	<0.1	ND	ND	ND
Ni	69	20.0	2	8	16.9	17.6	18.6
Pb	69	36.5	2.6	9.1	24.2	27	30
U	69	3.6	0.4	1.0	1.6	2.8	3.1
Zn	69	122	24	51.0	99.8	107	112

UCL – upper confidence limit; ND – Not determined as only two samples were present at concentrations >0.1 mg/kg. (Source: Cavanagh 2014)

5.4 Ease of use of information on background concentrations

One aspect not often considered when determining background concentrations is how easy it is to use the information provided. As shown in the preceding section, the upper thresholds of background concentrations currently used vary, and include the maximum of the range in specific studies (ARC 2001; Tonkin & Taylor 2007; URS 2003), the 99th percentile concentrations of collated data sets (MfE 2011c), and the maximum concentration plus half the interquartile range for a given data set (Level 2 background, Tonkin & Taylor 2007). These estimates also vary because they have been developed for different locations, geographical extents, pedo-geological units, and sample numbers.

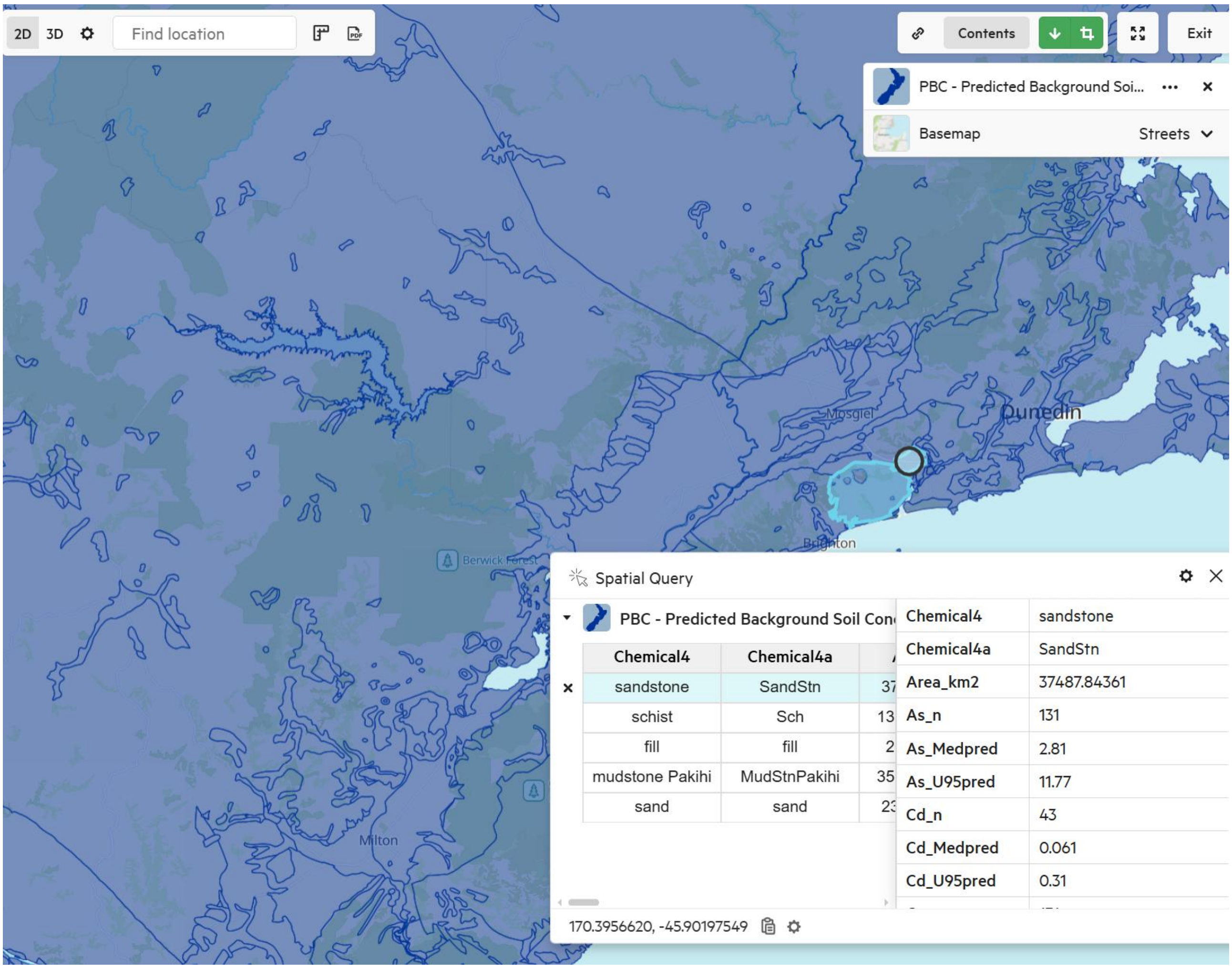
The different geographical extents and pedo-geological units used provide greater or lesser complexity – and relevance – when using this information for contaminated land assessments, or when determining soil re-use or waste acceptance criteria for clean fills. For example, background concentrations in Auckland (section 5.3.1) are delineated on the basis of whether the soils have volcanic or non-volcanic parent materials for some concentrations, which are notably different for Zn in particular. Canterbury delineates background concentrations on the basis of a dated soil classification (section 5.3.4), while Waikato uses a single 95th percentile for natural soils[10] or all land uses (WRC 2022) across the region. Similarly, a single upper estimate (99th percentile) of As and Cd background concentrations was developed in MfE (2011c) for comparing derived soil contaminant standards.

Cavanagh et al. (2015) used the geologically based Chemical4 parameter, which yields a spatially complex delineation of background concentrations, as shown in Figure 51. To provide a simpler approach to using predicted background concentrations for managing contaminated land or other purposes, Cavanagh, McNeill et al. (2023) presented information on these estimates as contour

---

[10] https://www.waikatoregion.govt.nz/services/waste-hazardous-substances-and-contaminated-sites/contaminated-sites/natural-background-concentrations/

plots, showing the 50th, 90th, 95th, and 99th percentiles of the predicted values (Figure 52). A table in the contour maps presents the specific concentrations for each percentile cut-off. This information can be accessed through the LRIS portal.[11] The Discrete Global Grid System was used to provide multi-element information for a given spatial location. However, mainly because the underlying model estimates are produced at a 1 × 1 km spatial resolution, the spatial outputs remain complex (Figure 53).



Chemical4	Chemical4a	
sandstone	SandStn	37
schist	Sch	13
fill	fill	2
mudstone Pakihi	MudStnPakihi	35
sand	sand	23

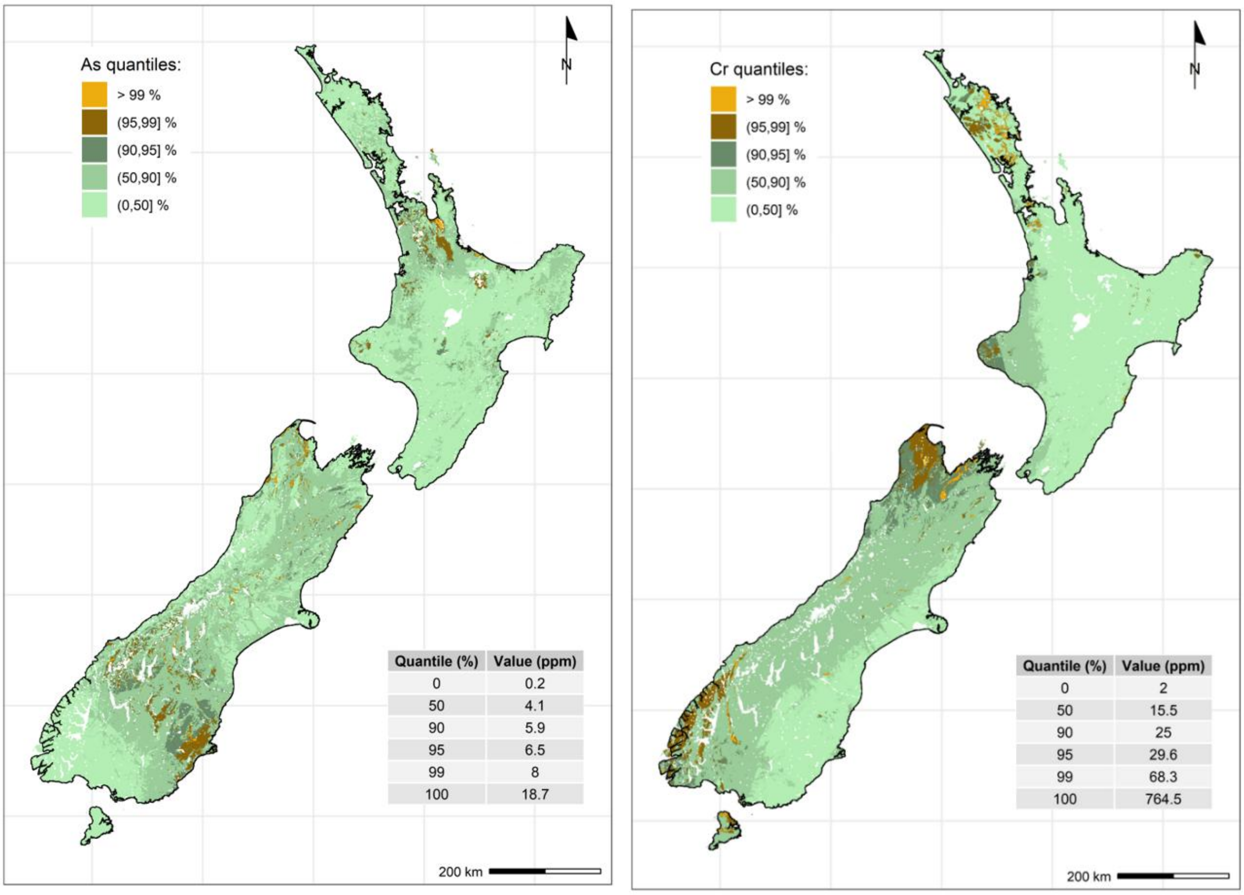
Chemical4	sandstone
Chemical4a	SandStn
Area_km2	37487.84361
As_n	131
As_Medpred	2.81
As_U95pred	11.77
Cd_n	43
Cd_Medpred	0.061
Cd_U95pred	0.31

170.3956620, -45.90197549

Figure 51. Example of areas delineated by Chemical4 mapping: the blue lines show the boundaries of different Chemical4 polygons; the light blue area indicates the polygon associated with a specific location, and the table provides information specific to that polygon.

---

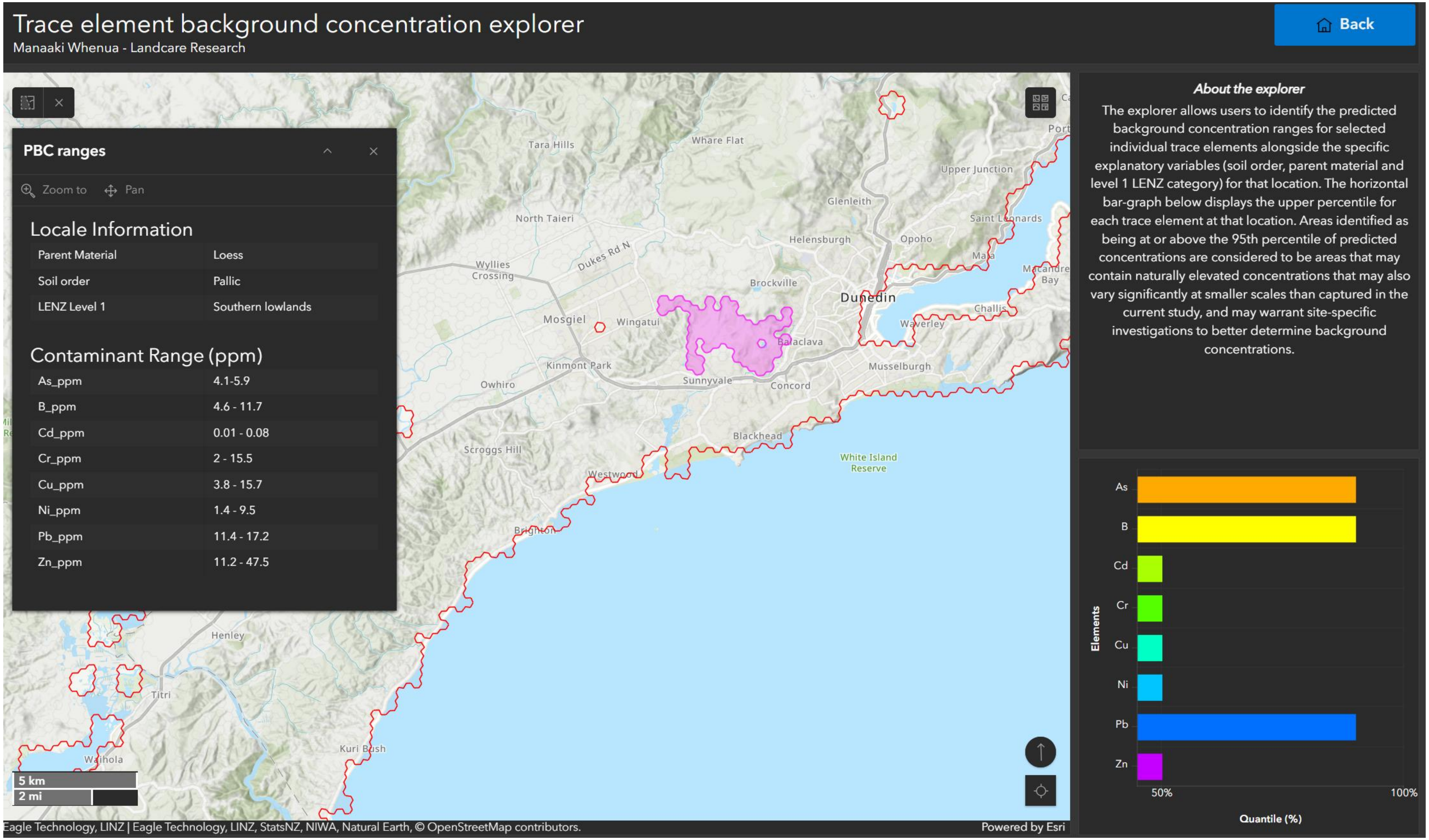
[11] PBC - Predicted Background Soil Concentrations, New Zealand (H3 resolution 9) | LRIS Portal



Quantile (%)	Value (ppm)
0	0.2
50	4.1
90	5.9
95	6.5
99	8
100	18.7

Quantile (%)	Value (ppm)
0	2
50	15.5
90	25
95	29.6
99	68.3
100	764.5

Figure 52. Examples of the individual trace element percentile maps developed by Cavanagh, McNeill et al. (2023) intended to simplify the use of predicted background concentrations in the management of contaminated land or other purposes.



Trace element background concentration explorer

Manaaki Whenua - Landcare Research

Locale Information

Parent Material	Loess
Soil order	Pallic
LENZ Level 1	Southern lowlands

Contaminant Range (ppm)

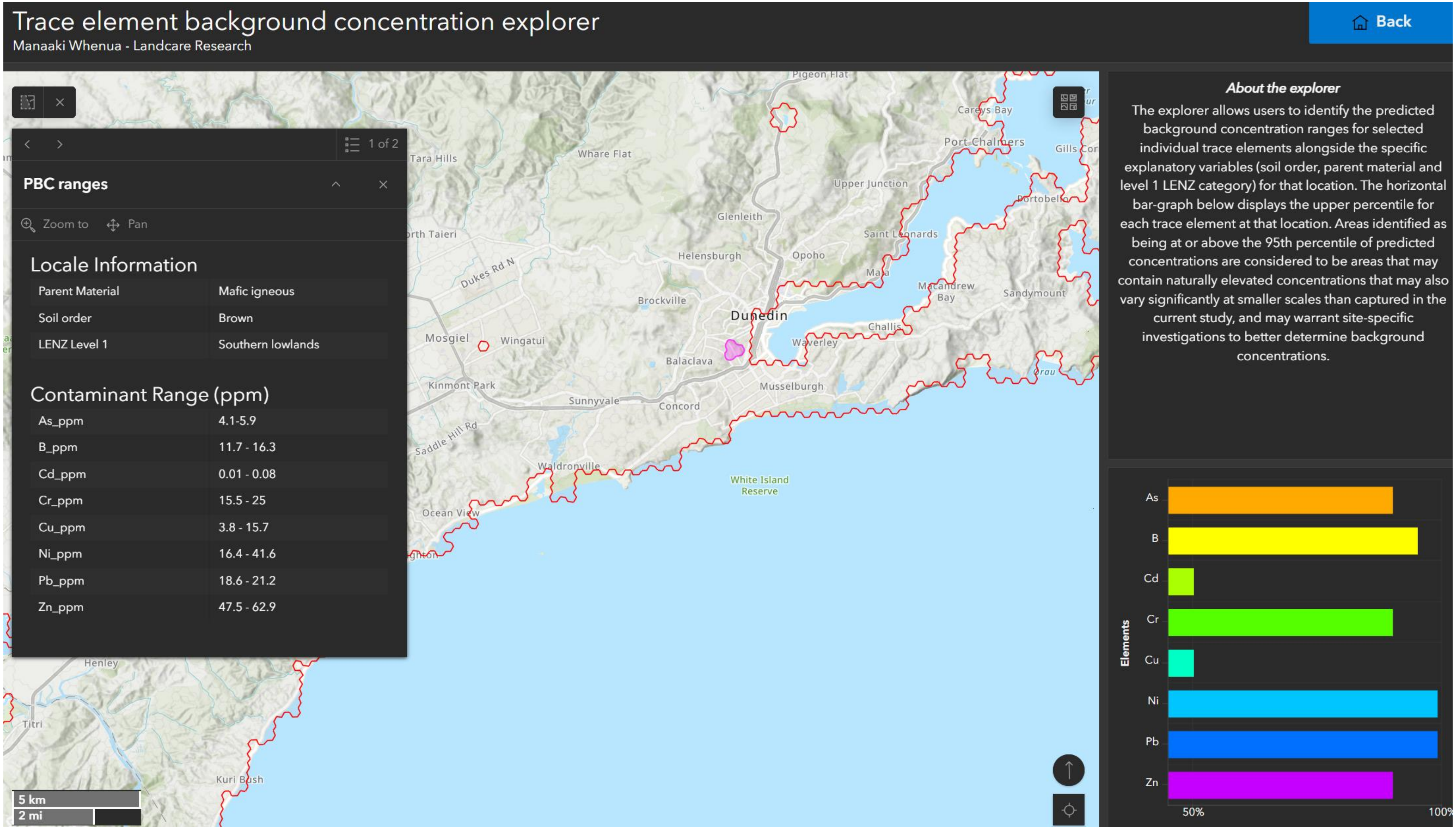
As_ppm	4.1-5.9
B_ppm	4.6 - 11.7
Cd_ppm	0.01 - 0.08
Cr_ppm	2 - 15.5
Cu_ppm	3.8 - 15.7
Ni_ppm	1.4 - 9.5
Pb_ppm	11.4 - 17.2
Zn_ppm	11.2 - 47.5

About the explorer

The explorer allows users to identify the predicted background concentration ranges for selected individual trace elements alongside the specific explanatory variables (soil order, parent material and level 1 LENZ category) for that location. The horizontal bar-graph below displays the upper percentile for each trace element at that location. Areas identified as being at or above the 95th percentile of predicted concentrations are considered to be areas that may contain naturally elevated concentrations that may also vary significantly at smaller scales than captured in the current study, and may warrant site-specific investigations to better determine background concentrations.

Eagle Technology, LINZ | Eagle Technology, LINZ, StatsNZ, NIWA, Natural Earth, © OpenStreetMap contributors.

Figure 53 (continued on next page). Screenshots from the trace element background concentration explorer, illustrating the fine-scale spatial variation of trace element concentrations that arises from this presentation of data.



Trace element background concentration explorer

Manaaki Whenua - Landcare Research

PBC ranges

Locale Information

Parent Material	Mafic igneous
Soil order	Brown
LENZ Level 1	Southern lowlands

Contaminant Range (ppm)

As_ppm	4.1-5.9
B_ppm	11.7 - 16.3
Cd_ppm	0.01 - 0.08
Cr_ppm	15.5 - 25
Cu_ppm	3.8 - 15.7
Ni_ppm	16.4 - 41.6
Pb_ppm	18.6 - 21.2
Zn_ppm	47.5 - 62.9

About the explorer

The explorer allows users to identify the predicted background concentration ranges for selected individual trace elements alongside the specific explanatory variables (soil order, parent material and level 1 LENZ category) for that location. The horizontal bar-graph below displays the upper percentile for each trace element at that location. Areas identified as being at or above the 95th percentile of predicted concentrations are considered to be areas that may contain naturally elevated concentrations that may also vary significantly at smaller scales than captured in the current study, and may warrant site-specific investigations to better determine background concentrations.

Figure 53(continued from previous page).

Although fine-scale spatial variation in concentrations is interesting from a research perspective, in a policy or regulatory setting this variation may be meaningless and add unnecessary complexity. For example, Cavanagh, McNeill et al. (2023) recommended that background concentrations should only be considered when they are *greater* than any risk-based human health or ecological values, while noting that investigations at a finer spatial scale may be required to better delineate areas of these natural elevated concentrations and to understand the associated risk to human health or the influence on ecological integrity. Similarly, US guidance background concentrations only become relevant after it has been determined that soil concentrations are greater than risk-based screening values. If concentrations are below any background concentration, then no further action (i.e. remediation) is required.[12] Background concentrations may be used to set remedial goals when they *are greater than* risk-based remedial goals. The rationale is that it is not reasonable to expect remediation to achieve concentrations less than soil background.

5.5 Background concentrations and ecological soil guideline values

As discussed in section 2.3.2, Eco-SGVs for naturally occurring contaminants (i.e. metals and metalloids) are developed using the 'added-risk' approach, with the median background concentration used to develop default Eco-SGVs (Cavanagh & Munir 2019). Cavanagh and Harmsworth (2023) updated default Eco-SGVs based on the background concentrations determined in Cavanagh, McNeill et al. 2023. Given the closeness of median values determined from the previous and current models, and median concentrations determined from the data (Table 16), we retain the default Eco-SGVs developed in Cavanagh & Harmsworth 2023 (Tables 17 & 18. However, some modifications are made to Eco-SGVs for upper percentiles (shown in Appendix 3).

Table 16. Comparison of median concentrations determined through modelling in Cavanagh, McNeill et al. 2023 and this study, and from the different data sets used in this study

Element	National model estimates		Otago–Southland data		National data	
	Cavanagh, McNeill et al. 2023	This study	Ambient	Total	Ambient	Total
As	4.1	3.6	5	**4**	3.5	**4**
B	4.6	4.1	2	**2**	3	**4**
Cd	0.08	0.1	0.04	**0.06**	0.05	**0.10**
Cr	16	14.5	13	**14**	16	**16**
Cu	16	13.6	14	**14**	15	**15**
Hg	NA	0.1	0.04	**0.05**	0.05	**0.06**
Ni	9	8.7	9	**9**	10	**10**
Pb	11	11.0	12	**12**	12	**12**
Zn	48	47.3	49	**50**	49	**53**

---

[12] https://sbr-1.itrcweb.org/using-soil-background-in-risk-assessment/#4_1

Table 17. Eco-SGVs (mg/kg) developed for selected contaminants based on the estimated median ambient concentration from Cavanagh, McNeill et al. 2023

% protection	As Eco-SGV (mg/kg)	B Eco-SGV (mg/kg)	B-HWS Eco-SGV (mg/kg)	Cd Eco-SGV (mg/kg)	Cd Eco-SGV$_{BM}$* (mg/kg)	Cr Eco-SGV (mg/kg)	Pb Eco-SGV (mg/kg)	Pb Eco-SGVBM* (mg/kg)
95%	20	14	7	5	1.5	200	290	290
80%	60	22	15	17	12	400	1290	900[1]
60%	150	25	17	40	35	660	3060	2,500[1]

* An extra 5% protection applied to each land use to provide protection against secondary poisoning.

Notes: BM = biomagnification; B-HWS = boron – hot-water soluble.

Table 18. Eco-SGVs (mg/kg) developed for copper and zinc contamination in the three New Zealand reference soils, based on the estimated median ambient concentration from Cavanagh, McNeill et al. 2023

% protection	Cu Eco-SGV typical soil	Cu Eco-SGV sensitive soil*	Cu Eco-SGV tolerant soil	Zn Eco-SGV typical soil	Zn Eco-SGV sensitive soil*	Zn Eco-SGV tolerant soil
95%	110	**95**	135	200	**180**	250
80%	245	**190**	350	320	**285**	410
60%	430	**330**	640	510	**450**	645

* Suggested default Eco-SGV. See Cavanagh and Harmsworth (2023) for adjustment based on soil pH, C, CEC.

Note: Eco-SGVs may be adjusted based on the background concentrations as described in Appendix 3.

5.6 Clean fills

As noted in section 2.3.3, one use of background concentrations for inorganic elements is as waste acceptance criteria for a Class 5 clean fill. Aside from variable criteria being used across the country (see sections 2.3.3. and 5.3), there are also variable definitions of clean fill used in existing policies, plans, and documents, with some definitions harking back to the MfE 2002 guidelines. These latter guidelines are suggested to have been superseded by WasteMINZ guidelines[13] for disposal to land (WasteMINZ 2023), which are currently under review. The following definition, which is similar to earlier definitions of 'clean fill' (e.g. MfE 2002), is provided in the National Planning Standards (MfE 2019):

> **Cleanfill:** means virgin natural materials such as clay, gravel, soil and rock that are free of:
>
> a combustible, putrescible, degradable leachable components
>
> b hazardous substances and materials
>
> c products or materials derived from hazardous waste treatment, stabilisation or disposal practices

---

[13] https://environment.govt.nz/news/revised-technical-guidelines-on-how-landfills-are-managed-published-by-wasteminz/

- d medical and veterinary waste, asbestos, or radioactive substances
- e contaminated soil or other contaminated materials and
- f liquid wastes

where hazardous substances has the same meaning as that in Section 2 of the Resource Management Act (1991) and section 2 of the Hazardous Substances and New Organisms Act 1996 for which a hazardous substance means:

unless expressly provided otherwise by regulations or an EPA notice, any substance—

- a with 1 or more of the following intrinsic properties:
    - i explosiveness;
    - ii flammability;
    - iii a capacity to oxidise;
    - iv corrosiveness;
    - v toxicity (including chronic toxicity);
    - vi ecotoxicity, with or without bioaccumulation; or
- b which on contact with air or water (other than air or water where the temperature or pressure has been artificially increased or decreased) generates a substance with any 1 or more of the properties specified in paragraph (a).

The Waste Minimisation (Information Requirements) Regulations (2021) further define a clean fill or Class 5 facility as being one that accepts only virgin excavated natural material (such as clay, soil, or rock) for disposal. 'Virgin' is not defined.

A strict interpretation of these definitions would suggest that very few materials would meet these definitions. For example, many naturally occurring trace elements (e.g. As) can be considered a hazardous substance because at higher concentrations they can elicit toxicity or ecotoxicity. All soils include organic matter as a natural and desirable component, particularly in surface soils, but organic matter could be considered putrescible or degradable. Similarly, organic compounds such as hydrocarbons, which can also be naturally occurring, are also considered degradable components. Finally, the use of 'virgin' is problematic because it suggests the exclusion of soils or material excavated from any site on which some land use activity has occurred.

We offer an alternative definition for clean fill that allows for low concentrations of trace elements or ubiquitous natural or synthetic organic contaminants, but constrains the level of risk:

> *Excavated natural material, such as clay, gravel, sand, soil rock or crushed rock, that is mostly* free of combustible, putrescible, degradable or leachable components and poses negligible risk to human health or the environment. When discharged to the environment, clean fill material will not have a detectable effect and, from a contaminant perspective, the fill site will be able to be utilised for an unrestricted purpose on closure.*

(We note that soils include organic matter as a natural and desirable component of soil, but which could be considered as putrescible, degradable or leachable. Similarly, organic compounds such as hydrocarbons can also be considered as degradable components.)*

MfE 2002 (p. 29) allows for clean fill criteria greater than background concentrations to be set through the regional plan process or as a condition of a specific resource consent for a clean fill. Safe contaminant levels for the intended future use of the land, the potential for contaminants to leach from the soil, and the potential adverse effect of the resulting leachate on the environment need to be considered in setting these criteria.

Given the upcoming resource management reforms, there may be opportunities to better evaluate these definitions in the context of the anticipated economic and environmental outcomes arising from their use.

5.7 Determination of background concentrations of trace elements for Otago and Southland

As highlighted above, there are multiple ways in which 'background' concentrations can be determined. With the exception of the use of background concentrations for the development of Eco-SGVs, the use of background concentrations fundamentally revolves around determining some upper level of concentration, either nationally, regionally, or for specific purposes (e.g. landfill waste acceptance criteria).

However, as noted in the Introduction, this project was driven by concern that the adoption of predicted background concentrations developed by Cavanagh et al. (2023) in the Otago Region's proposed Land and Water Regional Plan (pLWRP) would make the permitted activity pathway in the NES-SC unrealistic, and had the potential to require large volumes of low-risk and uncontaminated material to be disposed to landfill. Further, Cavanagh, Harmsworth et al. (2023) noted that moving from a heavy reliance on background concentrations for determining management requirements to a more risk-based approach would be beneficial in terms of facilitating greater soil re-use while ensuring protection of human health and the environment.

To help determine relevant background trace element concentrations for Otago and Southland, we developed a set of principles:

- Soil is a valuable resource, and opportunities to minimise its removal and enable beneficial re-use should be encouraged.
- Risks associated with anthropogenic contamination should be negligible.
- Risks associated with naturally elevated concentrations should be identified and managed appropriately.
- When applied as criteria for clean fill, an adequate margin of error should be allowed, so that exceeding a clean fill threshold by a minor margin will not inadvertently create contaminated land.
- In general, unrestricted re-use of soil should be allowed.

A further factor used to determine the criteria was that they need to be readily implementable (i.e. spatially simplistic).

We also undertook a qualitative evaluation of the advantages and disadvantages of different approaches for determining background concentrations of trace elements to help determine relevant criteria (Table 19).

Table 19. Pros and cons of different approaches for determining background concentrations of trace elements

Method	Advantages	Disadvantages
National modelling (section 5.1) (*n* = 2,941)	Provides spatially explicit estimates of the variation of rural ambient trace element concentrations across New Zealand.	The estimates appear to under-estimate upper concentrations, providing conservative measures. The output is highly spatially variable, and so difficult to easily implement at a broader scale.
Regional modelling (section 5.1) (*n* = 834)	Provides spatially explicit estimates of the variation of rural ambient trace element concentrations across Otago–Southland, based on regionally specific data.	The reduced data set used to develop the models means it is less powerful. Plus, the same disadvantages as for national modelling.
Distribution-based – national data set, all land use (section 5.2) (*n* = 3,133/278 mafic ultramafic)	Provides a spatially simplified approach, and is thus easier to implement	Doesn't provide information on the spatial variation in concentration. Includes higher-intensity land-use sites that potentially have elevated concentrations, and sites with natural elevated concentrations.
Distribution-based – national data set, ambient rural (section 5.2) (*n* = 1,835/209 mafic ultramafic)	Provides a spatially simplified approach; excludes higher-intensity land-use sites that potentially have elevated concentrations.	Doesn't provide information on the spatial variation in concentration. Potentially includes sites with naturally elevated concentrations.
Distribution-based – Otago–Southland data set, all land use (section 5.2) (*n* = 886/55 mafic ultramafic)	Provides a spatially simplified approach that is regionally specific.	Doesn't provide information on the spatial variation in concentration. Reduced number of sites compared to national. Includes higher-intensity land-use sites that potentially have elevated concentrations, and sites with naturally elevated concentrations.
Distribution-based – Otago–Southland data set, rural ambient (section 5.2) (*n* = 549/50 mafic/ultramafic)	Provides a spatially simplified approach that is specific for regional data. Excludes higher-intensity land-use sites that potentially have elevated concentrations.	Doesn't provide information on the spatial variation in concentration Reduced number of sites compared to national. Potentially includes sites with naturally elevated concentrations.
Distribution-based – parent material (*n* is variable for different parent materials) (Appendix 2)	Gives an indication of the spatial variation associated with parent material.	Very broad delineation of area to which concentrations applies. Assumes that spatial variation of trace elements is consistent within each parent material (cf. allowing for parent materials to be grouped where trace element concentrations are similar). Potentially includes sites with elevated anthropogenic concentrations.

Method	Advantages	Disadvantages
Distribution based – finer-resolution pedo-geological grouping (*n* is variable for different groupings)	Gives an indication of spatial variation associated with pedo-geological grouping.	Fine-scale delineation of area to which concentrations applies. Assumes that spatial variation of trace elements is consistent within each parent material (cf. allowing for groupings to be aggregated where trace element concentrations are similar). Potentially includes sites with elevated anthropogenic concentrations.
Distribution-based – urban data set, Dunedin (*n* =65)	Provides representation of urban ambient background.	Less conservative (i.e. higher) than non-urban background concentrations.

n = number of sample locations

We compared the 95th and 99th percentile concentrations of the different data sets: national – all land use, national – ambient sites only, Otago–Southland – all land use, Otago–Southland – ambient sites only, and the urban data set (95th percentile only) (Tables 20 & 21). Additionally, for As, Cr and Ni, which show clear indications of markedly elevated naturally occurring concentrations in Otago and Southland, we defined elevated areas as being those where concentrations were equal to or above the 95th%ile of modelled results, and non-elevated areas as being those areas with concentrations below the 95th%ile of modelled results. For each of these areas we extracted the datapoints from the underpinning dataset and determined the 95th and 99th percentiles (Table 20 & 21). Eco-SGVs and the rural residential soil contaminant standard shown in Table 20 were used to develop risk-based background concentrations, which are concentrations equidistant from the 95th percentile background concentration and the lower of the Eco-SGV or SCS (i.e. the most sensitive receptor).

Table 20. Summary of 95th percentile estimates for trace element concentrations, determined using different data sets: urban; national and regional (all land use and rural ambient); modelled data; ecological soil guideline values (Tables 17 &18); human health Soil Contaminant Standards for rural residential land use; and derived risk-based background concentrations

	Urban	National		Otago–Southland		Model estimates	Guideline values		Risk-based background[a]	
Element	**95th %ile**	**95th %ile all land use**	**95th %ile ambient**	**95th %ile all land use**	**95th %ile ambient**	**95th %ile**	**Eco-SGV**	**SCS rural residential[b]**	**Otago–Southland**	**National**
As	11	11	12	13	16	7.4	20	17	16	14
B	8	22	35	6	7	9.7	14	NA	*10*	*25*
Cd	0.6	0.69	0.28	0.26	0.16	0.2	1.5	0.8	0.48	0.54
Cr (all)	78.3	*139*	*274*	*75*	*122*	*34.1*	*200*	*>10,000*	*Na*	*Na*
Cr (mafic/ultramafic)	ND	1031	1214	432	447	ND	Na	Na	ND	ND
Cr (non-mafic/ultramafic)	ND	74	92	48	52	ND	200	>10,000	126	146
Cr (elevated)[c]	ND	ND	ND	388	ND	ND	Na	Na	ND	ND
Cr (non-elevated)[c]	ND	ND	ND	32	ND	ND	200	>10,000	116	ND
Cu	40	54	54	47	52	24.4	110 (95)	>10,000	74	82
Hg	0.7	0.21	0.20	0.12	0.12	0.1	0.7	NA	0.4	0.4
Ni (all)	*42*	*96*	*174*	*50*	*78*	*17.1*	*45*[d]	*NA*	*Na*	*Na*
Ni (mafic/ultramafic)	ND	2582	2814	504	629	ND	Na	NA	ND	ND
Ni (non- mafic/ultramafic)	ND	32	34	31	31	ND	45[d]	NA	38	40
Ni (elevated)[c]	ND	ND	ND	344	ND	ND	Na	ND	ND	ND
Ni (non-elevated)[c]	ND	ND	ND	18	ND	ND	45[d]	ND	32	ND
Pb	160 (150)	34	32	23	22	19.1	290	160	91	96
Zn	180	111	108	95	90	70.3	200 (180)	>10,000	145	154

[a] Equidistant between the 95th percentile ambient (regional or national) concentration and the lowest of SCS and Eco-SGV; [b] MfE (2011c); [c] Based on areas identified as having concentrations equal to or above (elevated) or below (non-elevated) modelled 95thile concentrations; [d] soil quality guideline for environmental health (SQG_e, CCME 2015).

NA = Not available, Na = not applicable, ND = not determined

Table 21. Summary of the 99th percentile estimates for trace element concentrations, determined using different data sets and modelled data

Element	National		Regional		Model
	99th %ile all land use	99th %ile ambient	99th %ile all land use	99th%ile ambient	99th %ile
As	21	22	26	33	10.5
B	160	196	9	8	15.3
Cd	1.15	0.66	0.48	0.38	0.4
Cr (all)	645	1,001	286	354	83.7
Cr (mafic/ultramafic)	2,691	2,766	640	641	ND
Cr (non-mafic/ultramafic)	277	386	172	191	ND
Cr (elevated)	ND	ND	630	ND	ND
Cr (non-elevated)	ND	ND	52	ND	ND
Cu	99	98	91	98	33.6
Hg	0.38	0.34	0.19	0.19	0.2
Ni (all)	1,912	2,455	259	346	47.3
Ni (mafic/ultramafic)	3,099	3,110	1,137	1,161	ND
Ni (non-mafic/ultramafic)	159	231	135	148	ND
Ni (elevated)	ND	ND	892	ND	ND
Ni (non-elevated)	ND	ND	25	ND	ND
Pb	85	79	42	29	22.7
Zn	207	281	132	112	79.8

ND = not determined.

Considering the principles listed above, the information in Table 19, and the results shown in Tables 20 & 21), we suggest the criteria shown in Table 22, which we collectively term ‘risk-based background concentrations’. An alternative framing of these criteria is that they are soil re-use criteria that enable unrestricted re-use of soils.

Table 22. Proposed risk-based background concentrations or soil re-use criteria for the management of contaminated land and soil relocation

Element	Criterion (mg/kg)	Basis
As	12	National 95th %ile ambient, which is below the derived value of 13 mg/kg for rural residential in MfE 2011c[a]
B	9	Otago–Southland 99th %ile, all land use
Cd	0.6	Equidistant between national 95th %ile and rural residential SCS
Cr (elevated)	630[b]	Otago–Southland 99th %ile elevated, all land use
Cr (non-elevated)	120[b]	Equidistant between Otago–Southland 95th %ile and Eco-SGV
Cu	80	Equidistant between national 95th %ile and typical Eco-SGV
Hg	0.3	National 99th %ile, all land use
Ni (elevated)	890[b]	Otago–Southland 99th %ile ultramafic, all land use
Ni (non-elevated)	30[b]	Equidistant between Otago-Southland 95th %ile and CCME SQG_e [c]
Pb	95	Equidistant between national 95th %ile and rural residential SCS
	150	95th%ile urban ambient [d]
Zn	150	Equidistant between national 95th %ile and typical Eco-SGV
	180	95th%ile urban ambient [d]

[a] See Appendices A1 and A6 in MfE 2011c. The 95thile estimate for As in areas identified as naturally elevated is 28 mg/kg.

[b] It is anticipated that concentrations will be highly variable in areas identified as being naturally elevated, which includes areas ‘downstream’ of mafic/ultramafic areas that may be influenced by eroded mafic/ultramafic material. Elevated Cr and Ni concentrations in the absence of marked elevated concentrations of other trace elements is indicative of naturally elevated concentrations.

[c] SQG_e – soil quality guideline for environmental health (CCME 2015).

[d] Calculated excluding sites that were above the rural residential SCS; the 95th percentile value excluding sites above the residential SCS is 160 mg/kg.

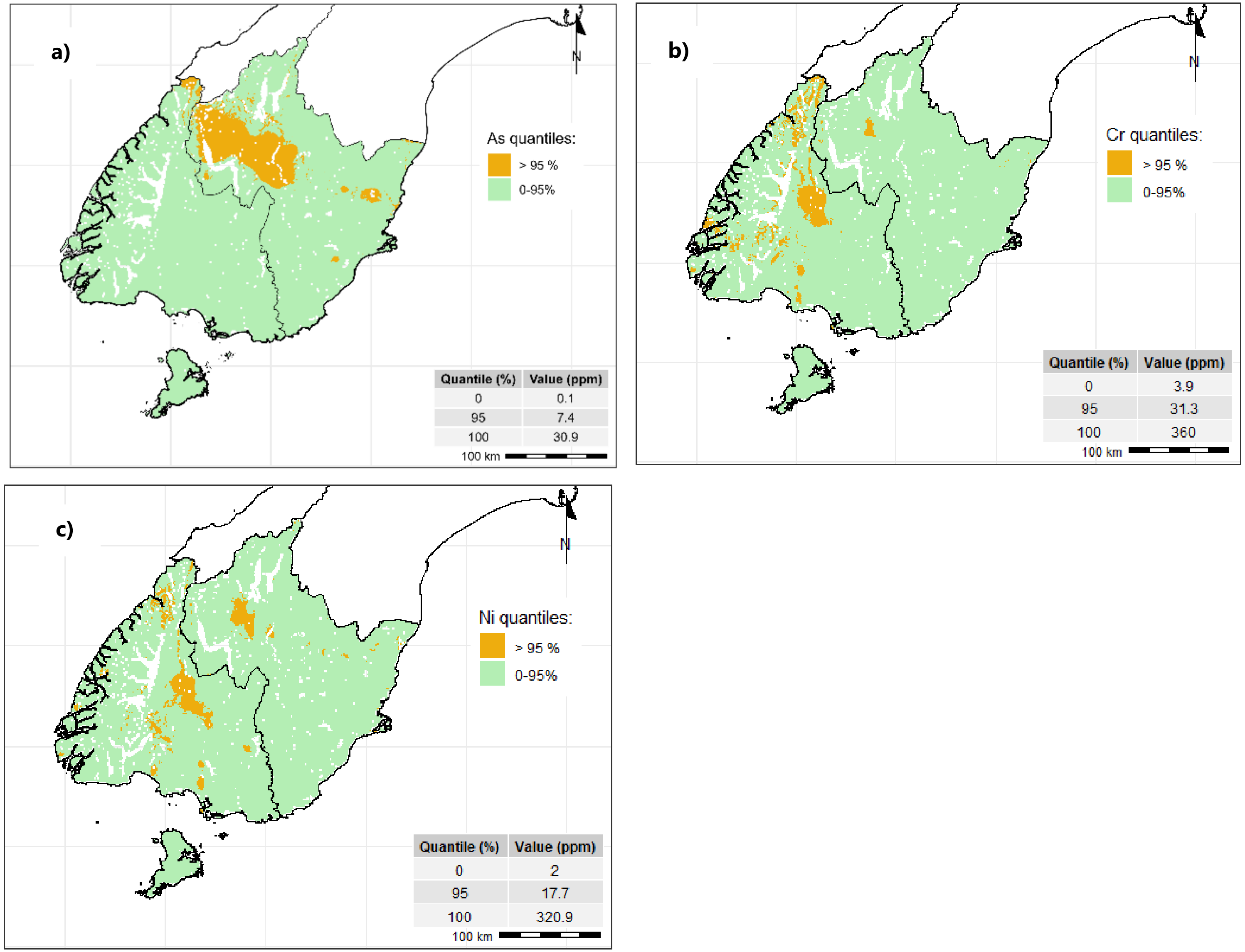
A more-specific principle used in selecting these criteria was that national estimates were used unless regional estimates were obviously different. This was particularly relevant for Cr and Ni, given the presence of ultramafic parent material in the region. Also, where risk-based background concentrations based on the SCS or Eco-SGV were lower than the 99th percentile estimates, these were used as the final criteria.

For Pb there is a marked difference between urban concentrations and broader concentrations (see Table 20). To enable unrestricted movement of urban soil that may contain low concentrations of Pb, the ‘re-use’ criterion is based on the risk-based background concentrations (150 mg/kg, Table 20) using the rural residential SCS (160 mg/kg). A marginally higher urban ambient risk-based background concentration of 160 mg/kg is obtained if the residential SCS of 210 mg/kg is used.

These proposed values are generally higher than the predicted background concentrations previously developed (Cavanagh, McNeill et al. 2023; Cavanagh et al. 2015) but still provide a ‘buffer’ to ensure that exceeding these values by a minor margin does not inadvertently create a risk to ecological receptors or human health. In other words, they are more conservative (i.e. lower) than criteria that might be used for the protection of ecological receptors or human health (NES-CS). These criteria are similar in approach to those used in the Waikato Region (WRC 2022) and developed previously for Marlborough District Council for clean fill criteria (Cavanagh 2013a).

As, Cr, and Ni all have naturally elevated concentrations in some areas that warrant additional consideration. The now-repealed Natural and Built Environment Act 2023 defined a natural hazard as including ‘soil that contains concentrations of naturally occurring contaminants that pose an ongoing risk to human health’. This, on its own, places greater emphasis on identifying areas with naturally elevated concentrations (particularly for As) and then assessing the risk these concentrations may pose to human health. Assessment of risk should include consideration of the bioavailability of As, which is expected to be generally lower for geogenic sources (e.g. Vandeuren et al. 2023; Bull 2017).

From an ecological perspective, areas with naturally elevated concentrations can have unique ecosystems that have adapted to these elevated concentrations. Initially, areas predicted to have modelled concentrations >95th percentile in the current study should be target locations to commence further evaluation (Figure 54). These could be ‘informative’ zones (i.e. to indicate where concentrations might be expected to be elevated in the specific contaminants), or ‘hard’ zones (to restrict movement of soil to within or between similar zones). For the latter, further ground-truthing of the modelled results would be useful. A similar approach could be used to delineate areas for urban ambient Pb.



a)

Quantile (%)	Value (ppm)
0	0.1
95	7.4
100	30.9

b)

Quantile (%)	Value (ppm)
0	3.9
95	31.3
100	360

c)

Quantile (%)	Value (ppm)
0	2
95	17.7
100	320.9

Figure 54. 'Informative' zones for area of naturally elevated concentrations of a) arsenic, b) chromium, and c) nickel.

It should be noted that for Cr and Ni, beyond a few specific industrial activities (e.g. electroplating, tanneries, timber treatment) the observed elevated concentrations of these elements in other locations is likely to be a result of 'downstream' movement of eroded mafic, and particularly ultramafic parent material. As an example, this is illustrated by the presence of samples above the 95th percentile of the distribution being located in the gravels of Southland (and also Marlborough, Tasman, and Nelson, where mafic and ultramafic parent rocks are known to occur).

The toxicity of Cr is dependent on its oxidation state, with Cr VI considered to be much more toxic than Cr III (MfE 2011d; Cavanagh & Munir 2019), which is the dominant form in the environment (Reijonen & Hartikainen 2016). For Cr III the human health risk is negligible, and a 95% protection level Eco-SGV is 200 mg/kg (Table 18); this is for soils not naturally elevated in Cr. The bioavailability of naturally occurring elevated concentrations is expected to be much lower than for anthropogenically derived contamination, which reduces the associated risk (Vandeuren et al. 2023).

Some verification of the expected lower bioavailability of naturally derived elevated concentrations of Cr and Ni would be useful to provide assurance that the occurrence of elevated Cr and Ni outside of areas with recognised naturally elevated concentrations is indeed a low risk. A useful initial assessment would be comparison of plant-available (i.e. weak acid extract, such as 0.01M $Ca(NO_3)_2$ and use that for comparison with the Australian ecological investigation levels based on 'fresh' (i.e. highly bioavailable) Ni (National Environment Protection (Assessment of Site Contamination) Measure 1999 as amended in 2013, volume 8).[14]

5.8 Additional contaminants

Several other contaminants have a relatively ubiquitous presence in trace amounts or may be naturally occurring. These include naturally occurring contaminants such as hydrocarbons (TPH and PAH), asbestos, and synthetic compounds such as DDT and its residues, DDE and DDD. Criteria for additional contaminants are provided here to enable comparison of any measured results for acceptance for soil re-use or clean fill, rather than indicating the range of contaminants that soil should be tested for.

Proposed criteria for TPH (which do also occur naturally) have been drawn from Table H-2 *Class 5 WAC for Organic Elements Contaminant* in WasteMINZ 2023 (for TPH C7–C9 and C10–C14) and from the Eco-SGVs provided in Cavanagh & Harmsworth 2022 (for TPH C16–C34). Criteria for PAHs are based on a toxicity-weighted criterion, BaP_{eq}, which is used in WasteMINZ 2023b to indicate the presence of coal tar. This is lower than both the Eco-SGV for BaP of 2.8 mg/kg (Cavanagh & Harmsworth 2023) and the soil contaminant standard for rural residential land use of 6 mg/kg.

DDT was widely used in New Zealand to control grass-grub before being phased out in the late 1970s. DDT is a persistent pesticide, so detection of DDT residues (including degradation products DDE and DDD and collectively referred to as ∑DDTs) in soils is still relatively common. The presence of DDTs in milk solids is arguably the greatest risk associated with soil-associated DDTs. Fonterra

---

[14] NEPM volume 8: Schedule B5c – Guideline on Ecological Investigation Levels for arsenic, chromium (III), copper, DDT, lead, naphthalene, nickel and zinc https://www.legislation.gov.au/F2008B00713/latest/text/21

(2024) suggest that DDT concentrations above 0.5 mg/kg potentially give rise to elevated DDTs in milk solids. This value is below the Eco-SGV of 2.4 mg/kg (Cavanagh & Harmsworth 2023), and also below the CCME value of 0.7 mg/kg (CCME 1999), which is commonly used in New Zealand. This value is above the 0.35 mg/kg previously proposed as an interim 'de minimis' threshold for enforcement in 'Regional Plan: Waste cleanfill compliance and discharges to land' (Otago Regional Council 2017).

Per- and polyfluoroalkyl substances (PFAS) comprise a large class of thousands of synthetic chemicals that are currently the focus of considerable attention internationally, as well as New Zealand, given their widespread use and persistence in the environment. The PFAS National Environmental Management Plan (PFAS NEMP) has been jointly developed by the Commonwealth, State, Territory, and New Zealand governments through the Heads of EPA Australia and New Zealand (HEPA), and is intended to provide nationally consistent guidance. The third version of the PFAS NEMP was published in December 2024 and includes new guideline values for investigation and risk assessment, including in soils. These changes largely arise from the inclusion of new data on plant uptake of these compounds. Manning (2025) suggests this has been done in a way that is considered to be inconsistent with the standard methodology, resulting in new guideline values that are considered overly conservative.

It should also be recognised that greater ongoing biodegradation of organic contaminants is more likely to occur if soil is kept out of landfills and the biological activity of the soils is enhanced.

For asbestos, the 0.001% w/w limit is based on a method that combines the standard accredited AS 4964-2004 method (which has a detection limit of 0.01%) with a fibre counting method currently used in the United Kingdom (BRANZ 2024). This combined method helps practitioners assess potential respirable fibre risk and means they can calculate the asbestos percentage to a higher degree of accuracy. Currently no New Zealand laboratories are accredited for this method, although several laboratories can undertake the analysis. This value was also previously proposed as an interim 'de minimis' threshold for enforcement in 'Regional Plan: Waste cleanfill compliance and discharges to land' (Otago Regional Council 2017). Importantly, we do not propose that asbestos should be completely absent from clean fill, because it is a naturally occurring substance; merely that it should be below the semi-quantitative method detection limit.

For other contaminants the general principle of applying a buffer when setting criteria applies. This could include the use of half the value of the lowest risk-based soil guideline level appropriate to the New Zealand environment and regulatory settings (identified following MfE 2011b), or, where the contaminant is naturally occurring, the average of background concentration and the lowest risk-based soil guideline level.

For pesticides, information sources include environmental exposure limits set by the EPA[15] and nominal concentrations of concern identified by Thompson-Morrison and Cavanagh (2024) for a range of pesticides present in the Wellington Region. An example is glyphosate and its key metabolite aminomethylphosphonic acid (AMPA), which often appear to be present in agricultural soils although have very minimal non-target effects. The nominal concentration of concern for

---

[15] https://www.epa.govt.nz/hazardous-substances/rules-notices-and-how-to-comply/about-rules-and-controls-for-hazardous-substances/

glyphosate and AMPA was proposed to be 3 mg/kg, and following the principles outlined above, in order to provide a 'buffer' for protection, half this value could be used as an upper limit of risk-based background concentrations.

Table 23. Proposed risk-based background concentrations for additional contaminants of concern

Parameter	Criterion (mg/kg)	Basis
TPH C7–C9	110	Derived from the MfE's *Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (1999, revised as MfE 2011b). Table 4.15 (WasteMINZ 2023b)
TPH C10–C14	58	Derived from the MfE's *Guidelines for Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (1999, revised as MfE 2011b). Table 4.2 (WasteMINZ 2023b)
TPH C15–C34	150 (coarse soil[a]) 650 (fine soil[b])	Half Eco-SGV (Cavanagh & Harmsworth 2022)
PAH – BaP-eq	1	Empirical limit indicative of the presence of roading coal tar (WasteMINZ 2023a)
DDTs	0.5	Soil concentration above which DDTs in milk solids increase (Fonterra 2024)
Asbestos, fines, and fibrous asbestos	<0.001%	Quantification limit for respirable fibre risk; asbestos fibres may be present (BRANZ 2024)
PFOS and PFHxS	0.003	Human health investigation level for residential with garden/accessible soil (HEPA 2025)

[a] Coarse-grained soils are those that contain greater than 50% by mass of particles over 75 μm (mean diameter).

[b] Fine-grained soils are those that contain greater than 50% by mass of particles under 75 μm (mean diameter).

5.9 Additional considerations

5.9.1 Policy/planning considerations

The original impetus for this project was the updating of the Otago Land and Water Regional Plan (pLWRP), which is currently on hold. In response, we offer some thoughts for consideration in any further development of the Plan.

There have been previous calls for an evaluation of the use of background soil concentration information in existing policy and regulatory settings to determine whether the intended or optimal outcomes are being achieved (e.g. Is the use of background concentrations appropriate for clean fill waste acceptance criteria? Is clause 5(9) of the NES-CS achieving its intended purpose, and what is that purpose?) (Cavanagh, Harmsworth et al. 2023). As highlighted in section 5.6, the definitions of clean fill warrant further evaluation to determine whether they deliver the intended economic and environmental outcomes in terms of placement of materials that pose negligible human health or environmental risk.

We propose that these risk-based background concentrations could also be used as soil re-use criteria and thereby allow for unrestricted re-use of soils. Soils with higher concentrations should still be acceptable for re-use where it can be demonstrated that they do not elevate concentrations at the recipient site, and that the concentrations at the site are suitable for its use. We also suggest that criteria for beneficial re-use should go beyond contaminant criteria to include the key attributes of soil that influence beneficial re-use. Cavanagh, Harmsworth et al. (2023) have suggested that for use as topsoils, soil should have an organic matter content between 4% and 20%, with pH and nutrients on a fit-for-purpose basis, and that re-use criteria should extend to geotechnical criteria (particularly for subsoil materials) associated with the relevant beneficial use.

To provide assurance for councils that contaminated soils are not being placed in clean fills, or that soils are being re-used appropriately, there should be a greater requirement for tracking of the soil by both the 'donor' and recipient of the soil, with some verification of the quality of the soil required (note that WasteMINZ 2024b provides some guidance on this sampling and analysis).

Consideration should be given to identifying naturally elevated (As, Cr, Ni) or urban (Pb) zones to determine if there is greater value in these being 'informative' zones or 'harder' regulatory zones, to restrict movement of soils from these locations. For some contaminants, notably As, naturally elevated concentrations may pose a risk to human health, so it is useful to identify areas where this may occur and then assess the risk these concentrations may pose to human health. In particular, this assessment should include consideration of the bioavailability of As, which is expected to be generally lower for geogenic sources of As (e.g. Vandeuren et al. 2023; Bull 2017). From an ecological perspective, areas with naturally elevated concentrations can have unique ecosystems that have adapted to these elevated concentrations, and which may warrant protection for conservation purposes.

5.9.2 Comparison with background concentrations or re-use criteria

It should be noted that different sampling regimes and different statistical approaches are required to determine whether a site is above or below background concentrations (e.g. as per clause 5(9) in the NES-CS) vs characterising soil for 'disposal'. For the latter, the recently developed WasteMINZ guidelines for assessing surplus soils for disposal are relevant (WasteMINZ 2024b). CLMG#5 (MfE 2021) also provides guidance on site sampling and comparison of concentrations, with guideline values. Bull (2025) suggests that comparison of the upper quartile (75th percentile) of a test sample with the 95th percentile background concentrations provides a simple and robust approach. This author suggests a minimum of 10 samples is required for the test sample. Reports received by councils should be critically reviewed for their adequacy in undertaking the appropriate comparisons.

5.9.3 Determination of site-specific background concentrations

There are numerous documents that provide guidance on determining site-specific or local background concentrations (e.g. US EPA 2002; Diamond et al. 2009; ISO 2011; ITRC[16]; EPA Victoria 2021). However, it is useful to take a step back from the technical detail to clarify the purpose of undertaking site-specific determinations.

---

[16] https://sbr-1.itrcweb.org/

From the perspective of managing risk associated with soil contaminants, there seems little value in undertaking a site-specific determination of background concentrations *unless* these concentrations are anticipated to be *above* risk-based guidelines for the protection of human health or ecological receptors (including ground and surface water). Assessment in this case should be focused on how any associated risk from these naturally occurring concentrations might need to be managed, as it is unreasonable to require remediation goals to be below naturally occurring background concentrations. In these cases, sampling beyond the specific site under investigation would help to confirm the extent of natural elevation.

Where a site-specific determination of background concentration is considered appropriate, other factors, such as the size of the site and the ability to identify a sufficient number of locations that have not been affected by anthropogenic activity (to get sufficient samples to robustly determine background concentrations for the site in question), should also be considered. A minimum of 30 samples is recommended to characterise background concentrations of a given pedo-geological area (ISO 2011), although this depends on the area under consideration: it may be appropriate to analyse 30 samples for a regionally based characterisation, and a smaller number for a specific site investigation. In the latter case, 7 to 10 samples may be appropriate, as used by some US EPA jurisdictions (Diamond et al. 2009). Bull (2025) also suggests 10 as a minimum sample number for a site assessment.

6 Conclusions

This project has illustrated different approaches to developing nationally consistent estimates of background concentrations of selected naturally occurring trace elements across New Zealand, and which can be applied at regional scales. This included statistical modelling undertaken using three explanatory layers – a parent material layer, a soil order layer, and a land environment layer that allows for the inclusion of climatic variables – to develop predictions for background (rural ambient) concentrations across New Zealand.

Median concentrations determined for national and regional statistical modelling were similar to median values determined from the underlying values. For the upper percentile values, modelled results were generally lower than the underpinning data, particularly for Cr and Ni, and reflect the presence of soils with markedly naturally elevated concentrations. Statistical modelling provides an indication of the spatial variation in concentrations that is not provided by simple determination of percentiles of measured concentrations.

We developed a set of principles to help guide the selection of relevant background concentrations for Otago and Southland, as follows.

- Soil is a valuable resource, and opportunities to minimise removal and enable beneficial re-use should be encouraged.
- Risks associated with anthropogenic contamination should be negligible.
- Risks associated with naturally elevated concentrations should be identified and managed appropriately.

- When applied as criteria for clean fill, an adequate margin for error should be allowed so that exceeding a clean fill threshold by a minor margin will not inadvertently create contaminated land.
- In general, the unrestricted re-use of soil should be allowed.

A further factor used for determining the criteria was that they be readily implementable (i.e. are spatially simple). Consideration of these principles resulted in the selection of risk-based background concentrations largely based on 99th percentile concentrations of national or regional data sets, or values that were equidistant from the 95th percentile background concentration and the lower of the Eco-SGV or SCS (i.e. the most sensitive receptor).

More broadly, greater clarity is needed on the outcomes desired by the current use of background concentration information in the assessment and management of contaminated land, and as waste acceptance criteria. In particular, clause 5(9) of the NES-CS appears to place an undue emphasis on background concentrations, regardless of the risk associated with the concentration of soil contaminants. Similarly, the definitions of clean fill warrant further evaluation to determine whether these deliver the intended outcomes in terms of placement of materials that pose negligible human health or environmental risk

Background concentrations should only be relevant to consider where naturally occurring or ambient concentrations are anticipated to be *above* risk-based guidelines for the protection of human health, or for ambient concentrations only, ecological receptors. Similarly, site-specific background determination is only recommended for sites where naturally occurring concentrations are anticipated to be *above* risk-based guidelines. In these cases it is relevant to determine background concentrations, because it is not reasonable to require remediation to concentrations below naturally occurring, or arguably ambient, concentrations.

There is, nonetheless, a requirement that the risk associated with any elevated concentrations, regardless of whether they are natural or anthropogenic in origin, be assessed. However, the NES-CS (which only applies to a piece of land on which a HAIL activity is occurring, has occurred, or is more than likely to have occurred) and clause 5(9) specifically exclude the ability for this risk to be managed.

Model predictions are useful to identify areas where naturally elevated concentrations may occur. This is most relevant for As, Cr, and Ni. The 95th percentile modelled concentrations could be used to identify areas of likely elevation for which further investigations at a finer spatial scale are required to better delineate areas of naturally elevated concentrations that may pose a risk to human health, while also noting that unique ecosystems adapted to these elevated concentrations may also exist. Small-scale variations may also give rise to naturally elevated concentrations outside these areas.

7 Recommendations

Following are the key recommendations based on this report.

- Greater recognition should be given to soil as a valuable resource, and opportunities to minimise removal and enable beneficial re-use should be encouraged
- The proposed risk-based background concentrations should also be considered to be soil re-use criteria that enable unrestricted re-use of soils.
- The 95th percentile modelled concentrations should be used to identify areas in which arsenic, chromium, and nickel are likely to be naturally elevated, to assist in the management of soils and, where relevant, human health risk in these areas.
- Consideration should be given to using urban ambient concentrations of lead (excluding sites with concentrations above soil contaminant standards) and zinc (excluding sites with concentrations above the Eco-SGV) as background concentrations in urban areas.
- Greater tracking of the soil relocation – by both the 'donor' and the recipient of the soil – should be implemented to provide assurance to councils that soils are being re-used appropriately, and that contaminated soils are not being placed in clean fills.
- When use of these risk-based background concentrations is confirmed, 'user-friendly' guidance should be developed to provide clarity on application for contaminated land assessment and clean fill acceptance criteria
- Given the upcoming resource management reforms, opportunities should be sought to ensure that economic and environmental outcomes arising from the current use of 'background' concentrations in the NES-CS, and waste management and clean fill definitions, are clarified and evaluated to ascertain whether these outcomes are being realised. If not, changes should be advocated.

8 Acknowledgements

Erik Button, Joon van der Linde, Amber Smith, and Mark Crawford (Otago Regional Council), Leonie Grace (Environment Southland), Sarah Pearson and John Jones (Marlborough District Council), and Nic Jepson and Campbell Thomson (Dunedin City Council) are thanked for their input at workshops and in other discussions. James Ardo (BSI) is thanked for geospatial data support.

Jonathan Caldwell (Waikato Regional Council) and Kurt Barichievy (Hawke's Bay Regional Council) are thanked for providing information about the use of clean fill acceptance criteria and background concentrations in the Waikato Region and Hawke's Bay Region, respectively. Andrew Kalbarcyk (Auckland Council) is thanked for providing information on the basis of permitted activity criteria used by Auckland Council. Andre Eger and Dan Richards are thanked for reviewing the draft of this report.

9 References

Abraham E. 2020. Cadmium in New Zealand agricultural soils. New Zealand Journal of Agricultural Research. 63:202–219.

Ander EL, Cave MR, Johnson CC, Palumbo-Roe B 2011. Normal background concentrations of contaminants in the soils of England: available data and data exploration. British Geological Survey Commissioned Report, CR/11/145.

ARC (Auckland Regional Council) 2001. Background concentrations of inorganic elements in soils from the Auckland Region. Technical Publication No. 153. Auckland, Auckland Regional Council.

BRANZ (Building Research New Zealand) 2024. New Zealand Guidelines for assessing and managing asbestos in soil. Wellington, BRANX

Bull B 2025. Comparing contaminants with background – commentary from a statistical perspective. Litmus Datatech report, prepared for HAIL Environmental.

Bull D 2017. Arsenic bioavailability assessment at former pipfruit orchards on Mapua and Ranzau Soils, Tasman District. HAIL environmental report for Massey University and Tasman District Council. Envirolink Grant 1774-TSDC133.

Cavanagh J, McNeill S, Roudier P, Thompson-Morrison H, Martin A, Turnbull R 2023. Determining background soil concentrations of trace elements across New Zealand. Manaaki Whenua – Landcare Research Contract Report for Hawke’s Bay Regional Council. Envirolink Medium Advice Grant 2321-HBRC267.

Cavanagh J, Simcock R, Thompson-Morrison H 2023. Considerations for beneficial use of sediments from stormwater ponds across Auckland. Manaaki Whenua - Landcare Research Contract Report LC4384 for Auckland Council.

Cavanagh JE 2006. Development of soil guideline values protective of ecological receptors: Part 2. Landcare Research Contract Report LC0506/179, prepared for the Auckland Regional Council.

Cavanagh JE 2013a. Cleanfill criteria for the Marlborough District. Landcare Research Contract Report LC1579 for Marlborough District Council (MLDC-86). Envirolink Advice Grant: 1251 MLDC86.

Cavanagh JE 2013b. Determining background soil concentrations of contaminants for managing land. Landcare Research Contract Report LC1306 for Marlborough District Council (MLDC83). Envirolink Advice Grant: 1251-MLDC83.

Cavanagh JE 2015. Background concentrations of trace elements and options for managing soil quality in the Tasman and Nelson Districts. Landcare Research Contract Report LC-2286 for Tasman District Council.

Cavanagh JE 2021. Managing potentially contaminated soils in the Tasman District. Manaaki Whenua – Landcare Research Contract Report LC4016. Prepared for Tasman District Council. Envirolink Grant 2147-TSDC178

Cavanagh JE, Harmsworth G 2022. Exploring the implementation of ecological soil guideline values for soil contaminants. Manaaki Whenua – Landcare Research Contract Report LC4128. Envirolink Grant: 2214-MLDC162

Cavanagh JE, Harmsworth G 2023. An implementation framework for ecological soil guideline values. Manaaki Whenua – Landcare Research Contract Report LC4311. Envirolink Tools Grant C09X2206.

Cavanagh JE, Harmsworth G, Simcock R, Thompson-Morrison H 2023. Sustainable management of surplus soils: consultation draft. Manaaki Whenua – Landcare Research Contract Report LC4326. Envirolink Tools Grant C09X1402

Cavanagh JE, McNeil S, Arienti C, Rattenbury 2015. Background soil concentrations of selected trace elements and organic contaminants in New Zealand. Landcare Research Report 2440 for Envirolink Tools Grant C09X1402.

Cavanagh JE, Munir K 2016. Development of soil guideline values for the protection of ecological receptors (Eco-SGVs): technical document. Landcare Research Report 2605 for Envirolink Tools Grant C09X1402.

Cavanagh JE, Munir K 2019. Updated. Development of soil guideline values for the protection of ecological receptors (Eco-SGVs): technical document. Manaaki Whenua – Landcare Research Contract Report LC2605. Envirolink Tools Grant C09X1402.

Cavanagh JE, O'Halloran K 2006. Development of soil guideline values protective of ecological receptors. Landcare Research Contract Report LC0506/065, prepared for Auckland Regional Council.

Cavanagh JE, Whitehead B, Vickers S, Stevenson B 2020. Collating soil quality and trace element State of Environment monitoring data. Manaaki Whenua – Landcare Research Contract Report LC3803. Envirolink Advice Grant 2050-HBRC254.

Cave MR, Johnson CC, Ander EL, Palumbo-Roe B 2012. Methodology for the determination of normal background contaminant concentrations in English soils. Nottingham, UK, British Geological Survey (CR/12/003).

CCME (Canadian Council of Ministers of the Environment) 1999. Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health DDT (TOTAL) 1999. Available https://ccme.ca/en/res/ddt-total-canadian-soil-quality-guidelines-for-the-protection-of-environmental-and-human-health-en.pdf

DEFRA (Department for Environment, Food and Rural Affairs) 2012. Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance. April 2012. UK, HM Government. https://www.gov.uk/government/publications/contaminated-land-statutory-guidance (accessed July 2023).

Diamond D, Baskin D, Brown D, Lund L, Najita J, Javandel I 2009. Analysis of background distributions of metals in the soil at Lawrence Berkeley National Laboratory. Report prepared for U.S. Department of Energy under Contract DE-AC02005CH11231.

Diez M, Simón M, Martin F, Dorronsoro C, Garcia I, Van Gestel CAM 2009. Ambient trace element background concentrations in soils and their use in risk assessment. Science of the Total Environment 407: 4622–4632.

EPA Victoria (Environmental Protection Authority Victoria) 2021. Proposed methodology for deriving background level concentration when assessing potentially contaminated land. Melbourne, Victoria, EPA Victoria.

Fonterra Co-operative Group 2024. Managing DDE residues in milk. Fonterra Co-operative Group. DDE Factsheet 2023–2024. https://nzfarmsource.co.nz/content/dam/farmsource/docs/pdf/2023/dde-management-factsheet-2023-24.pdf

Gray CW, Cavanagh JE 2023. The state of knowledge of cadmium in New Zealand agricultural systems: 2021. New Zealand Journal of Agricultural Research 66(4): 285-335.

Hartig F 2022. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.4.6. https://CRAN.R-project.org/package=DHARMa

HEPA (Heads of EPA) 2025. PFAS National Environmental Management Plan 3.0. National Chemicals Working Group of the Heads of the EPA Australia and New Zealand.

Heron DW [custodian) 2014. Geological map of New Zealand 1:250,000. GNS Science geological map 1. Lower Hutt, New Zealand, GNS Science.

Hill RB, Sparling GP 2009. Soil quality monitoring. In: Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton, Land Monitoring Forum. Pp. 27–88.

ISO (International Standards Organisation) 2011. Soil quality – guidance on the determination of background values. ISO 19258:2011-09.

Jarva J, Tarvainen T, Reinikainen J, Eklund M 2010. TAPIR – Finnish national geochemical baseline database. Science of the Total Environment 408: 4385–4395.

Lado R, Hengl L, Reuter HI 2008. Heavy metals in European soils: a geostatistical analysis of the FOREGS Geochemical database. Geoderma 148: 189–199.

Lawley 2009. The Soil-Parent Material Database (SPM-v4): a user guide. Nottingham, UK, British Geological Survey (OR/08/034).

Leathwick J, Morgan F, Wilson G, Rutledge D, McLeod M, Johnston K 2002. Land Environments of New Zealand: a technical guide. Wellington, Ministry for the Environment.

Lilburne LR, Webb TH, Hewitt, AE, Lynn IH, de Pauw B 2012. S-map database manual. Lincoln, Landcare Research.

Manning T 2025. Setting guidelines well – do we have a problem? Oral presentation at the Joint Society for Environmental Toxicology and Chemistry and Australian College of Toxicology and Risk Assessment conference, Building a Lasting Legacy: Our Choice, Their Future. 25–28 August, Wellington, New Zealand.

Martin AP, Lim C, Kah M, Rattenbury MS, Rogers KM, Sharp EL, et al. 2023. Soil pollution driven by duration of urbanisation and dwelling quality in urban areas: an example from Auckland, New Zealand. Applied Geochemistry 148: 105518

Martin AP, Turnbull RE, Rattenbury MS, Baisden WT, Christie AB, Cohen DR, et al. 2015. Geochemical atlas of southern New Zealand. GNS Science Report 2015/26.

Martin AP, Turnbull RE, Rattenbury MS, Strong DT 2017. Otago-northern Southland Geochemical Surveys Analyses. GNS Science consultancy report 2017/124). Lower Hutt, NZ, GNS Science.

Martin AP, Turnbull RE, Roudier P, Cavanagh J, Rattenbury MS, Rogers KM, et al. 2023. Geochemical atlas of Aotearoa New Zealand. GNS Science report 2023/23. Lower Hutt, NZ, GNS Science.

Matschullat J, Ottenstein R, Reimann C 2000. Geochemical background – can we calculate it? Environmental Geology 39: 990–1000.

MfE (Ministry for the Environment) 2002. A guide to the management of cleanfills. Wellington, Ministry for the Environment

MfE (Ministry for the Environment) 2011a. Contaminated land management guidelines No. 2. Hierarchy and application in New Zealand of environmental guideline values (revised 2011). Wellington, Ministry for the Environment.

MfE (Ministry for the Environment 2011b Guidelines for assessing and managing petroleum hydrocarbon contaminated sites in New Zealand. Wellington, Ministry for the Environment.

MfE (Ministry for the Environment) 2011c. Methodology for deriving standards for contaminants in soil to protect human health. Wellington, Ministry for the Environment.

MfE (Ministry for the Environment) 2011d. Toxicological intake values for priority contaminants in soil. Wellington, Ministry for the Environment.

MfE (Ministry for the Environment) 2019. PFAS investigation, response and funding guidance. Wellington, Ministry for the Environment.

MfE (Ministry for the Environment) 2021. Contaminated land management guidelines No. 5. Site investigation and analysis of soils (revised 2021). Wellington, Ministry for the Environment.

Morgenstern R, Martin AP, Turnbull RE, Norton KP, Rattenbury MS, Rogers KM 2024. Urban geochemical atlas of Wellington, New Zealand. Lower Hutt, GNS Science.

Mortimer N, Rattenbury MS, King PR, Bland KJ, Barrell DJA, Bache F, et al. 2014. High-level stratigraphic scheme for New Zealand rocks. New Zealand Journal of Geology and Geophysics 57: 402–419.

Napp B, May F 2025. Position paper: resolving wastage in NZ's soil management approach. Wellington, Civil Contractors New Zealand. June 2025 Position paper - Resolving wastage in NZ's soil management approach_v3.pdf).

NEMS (National Environmental Monitoring Standards] 2022. Soil quality and trace element monitoring. https://www.nems.org.nz/documents/soil-quality-and-trace-element-monitoring

Otago Regional Council 2017. Memorandum: defining acceptable contaminant concentrations for cleanfill. Document ID: A1074601. Dunedin, Otago regional Council.

PCE (Parliamentary Commissioner for the Environment) 2024. Urban ground truths. Wellington, Parliamentary Commissioner for the Environment.

R Core Team 2023. R: a language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing. https://www.R-project.org/.

Rattenbury MS, Isaac MJ 2012. The QMAP 1:250 000 Geological Map of New Zealand project. New Zealand Journal of Geology and Geophysics 55: 393–405.

Reijonen I, Hartikainen H 2016. Oxidation mechanisms and chemical bioavailability of chromium in agricultural soil pH as the master variable. Applied Geochemistry 74: 84–93.

Reimann C, Filmoxer P, Garrett RG 2005. Background and threshold: critical comparison of methods of determination. Science of the Total Environment 346: 1–16.

Reimann C, Garrett RG 2005. Geochemical background: concept and reality. Science of the Total Environment 350: 12–27.

Rousset F, Ferdy J 2014. Testing environmental and genetic effects in the presence of spatial autocorrelation. Ecography 37(8): 781–790. https://dx.doi.org/10.1111/ecog.00566.

Sheppard SC, Grant CA, Sheppard MI, de Jong R, Long J 2009. Risk indicator for agricultural inputs of trace elements to Canadian soils. Journal of Environmental Quality 38: 919–932.

Thompson-Morrison H, Cavanagh J 2024. Analysis of pesticide residues in soils from the Greater Wellington region. Manaaki Whenua – Landcare Research Contract Report LC4516 for Greater Wellington Regional Council.

Tonkin & Taylor 2006. Background concentrations of selected trace elements in Canterbury soils. Environment Canterbury Report No. R07/1.

Tonkin & Taylor Ltd 2007. Background concentrations of selected trace elements in Canterbury soils. Addendum 1: Additional samples and Timaru specific background levels. Report R07/1/2 for Environment Canterbury.

Turnbull RE, Martin AP, Rattenbury MS 2017. Buller-East Nelson-Marlborough geochemical surveys analyses. GNS Science Consultancy Report 2017/43.

Turnbull RE, Martin AP, Rattenbury MS, Rogers KM, Strong DT, Morgenstern R 2017. Urban geochemical atlas of Dunedin City, New Zealand. GNS Science report 2017/31. Lower Hutt, NZ, GNS Science. doi:10.21420/G22P8N.

URS 2003. Determination of common pollutant background soil concentrations for the Wellington Region. Report prepared for Greater Wellington Regional Council.

US EPA (United States Environmental Protection Agency) 2002. Guidance for comparing background and chemical concentrations in soil for CERCLA sites. EPA 540-R-01-003, OSWER 9285.7-41. United States Environmental Protection Agency.

Vandeuren A, Pereira B, Kaba AJ, Titeux H, Delmelle P 2023. Environmental bioavailability of arsenic, nickel and chromium in soils impacted by high geogenic and anthropogenic background contents. Science of the Total Environment 902: 166073.

WasteMINZ 2023a. Guidelines for Assessing and Managing Coal Tar Contamination in Roading. Auckland, Waste Management Institute New Zealand Incorporated (WasteMINZ).

WasteMINZ 2023b. Technical guidelines for disposal to land (Land disposal technical guidelines). Auckland, Waste Management Institute New Zealand Incorporated (WasteMINZ).

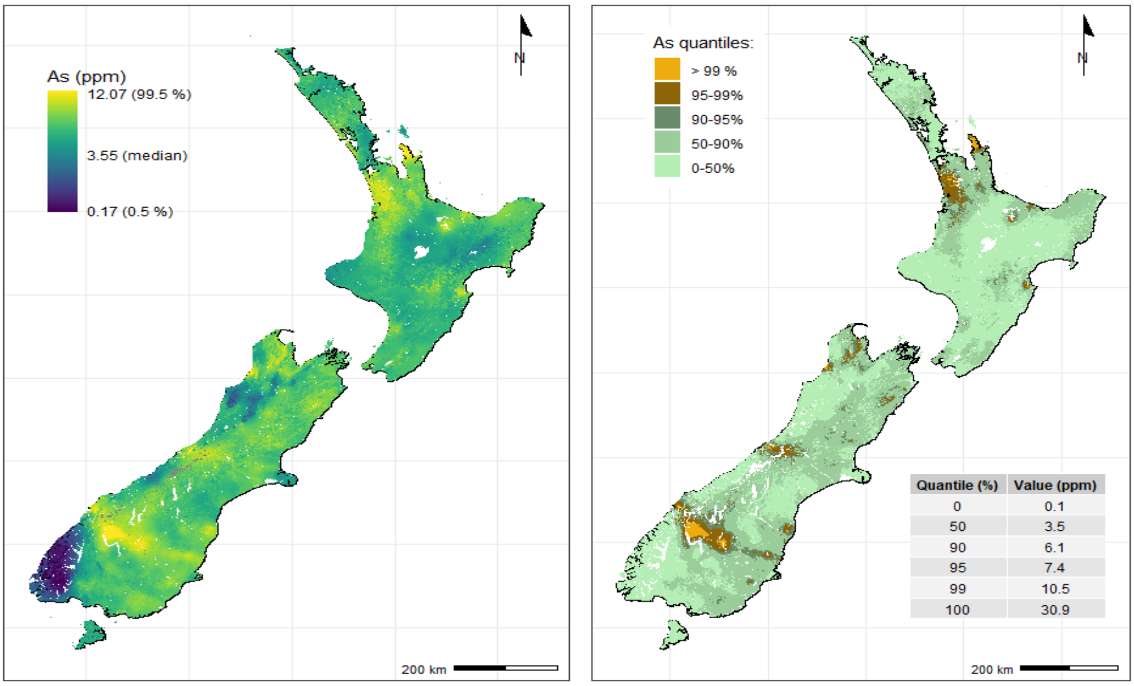
WasteMINZ 2024a. Reclaiming resources: optimising soil reuse in infrastructure and development. Auckland, Waste Management Institute New Zealand Incorporated (WasteMINZ).

WasteMINZ 2024b. Technical guidelines: characterising surplus soil for disposal. Auckland, Waste Management Institute New Zealand Incorporated (WasteMINZ).

Wiser SK, Buxton RP, Clarkson BR, Hoare RJB, Holdaway RJ, Richardson SJ, et al. 2013. New Zealand’s naturally uncommon ecosystems. In Dymond JR ed. Ecosystem services in New Zealand – conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand. Pp. 49–61.

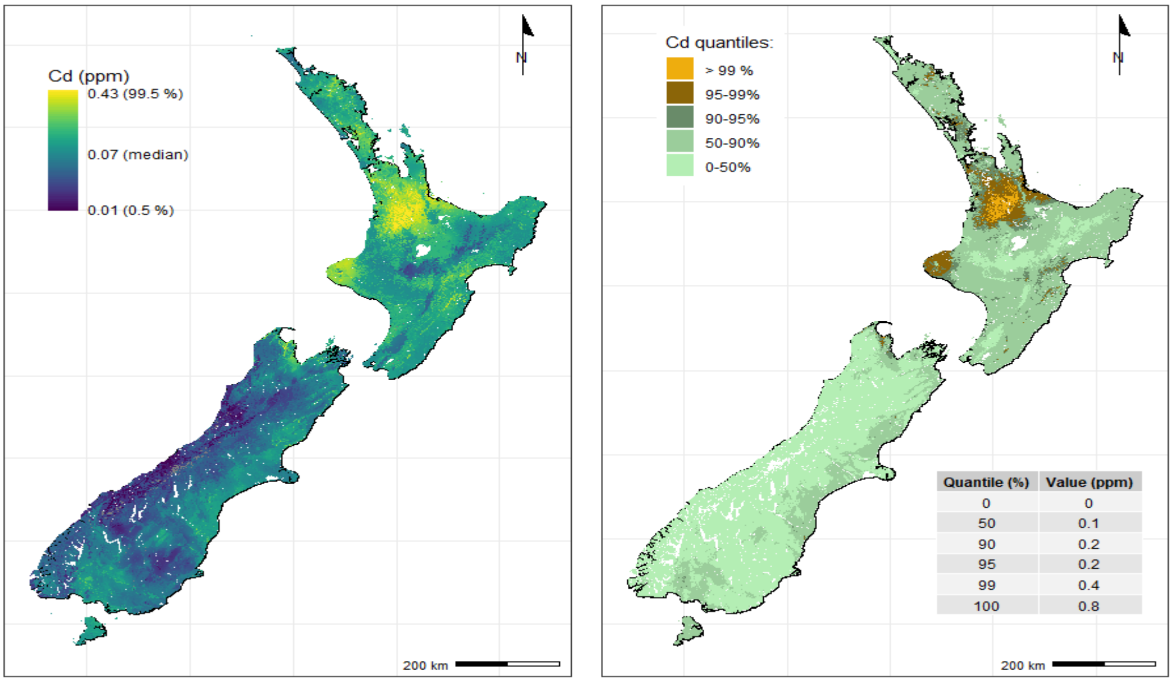
WRC (Waikato Regional Council) 2022. Waikato Regional Council standard operating policies for defining cleanfill acceptance criteria. Doc #10581789. Waikato Regional Council.

Appendix 1 – National maps



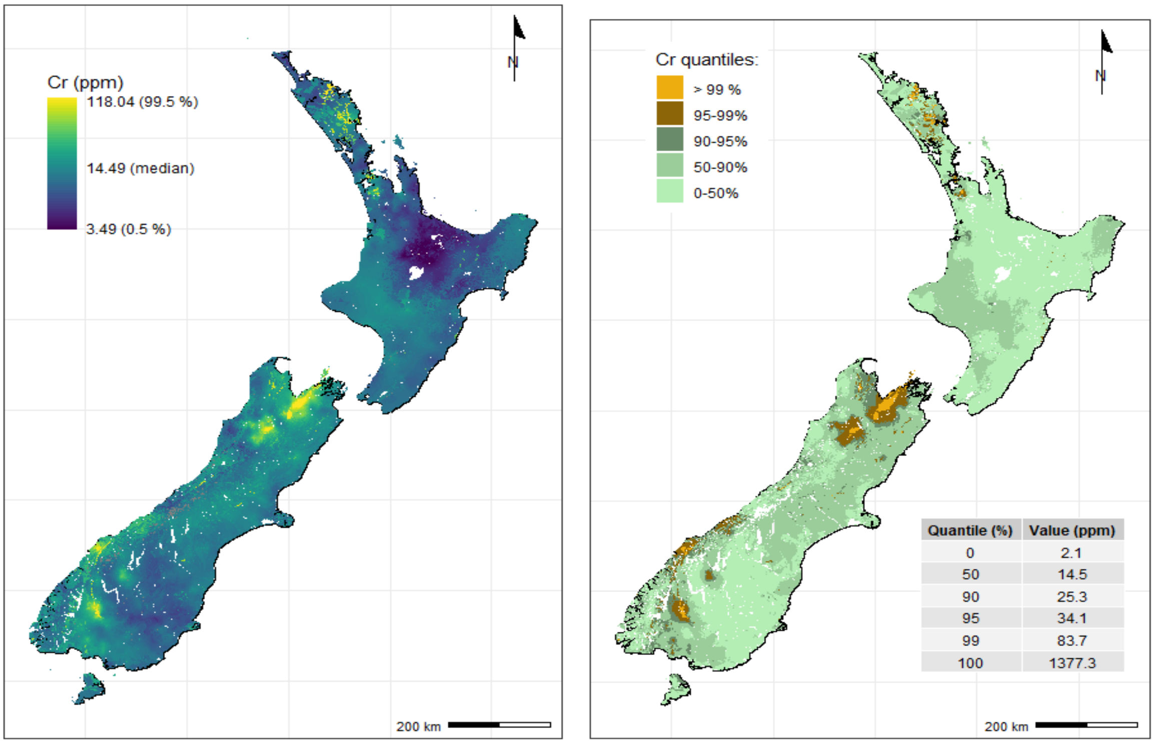
Quantile (%)	Value (ppm)
0	0.1
50	3.5
90	6.1
95	7.4
99	10.5
100	30.9

Figure A1.1. Estimate of arsenic concentrations (left) and contour plot (right) of arsenic quantile concentrations using the spaMM model.



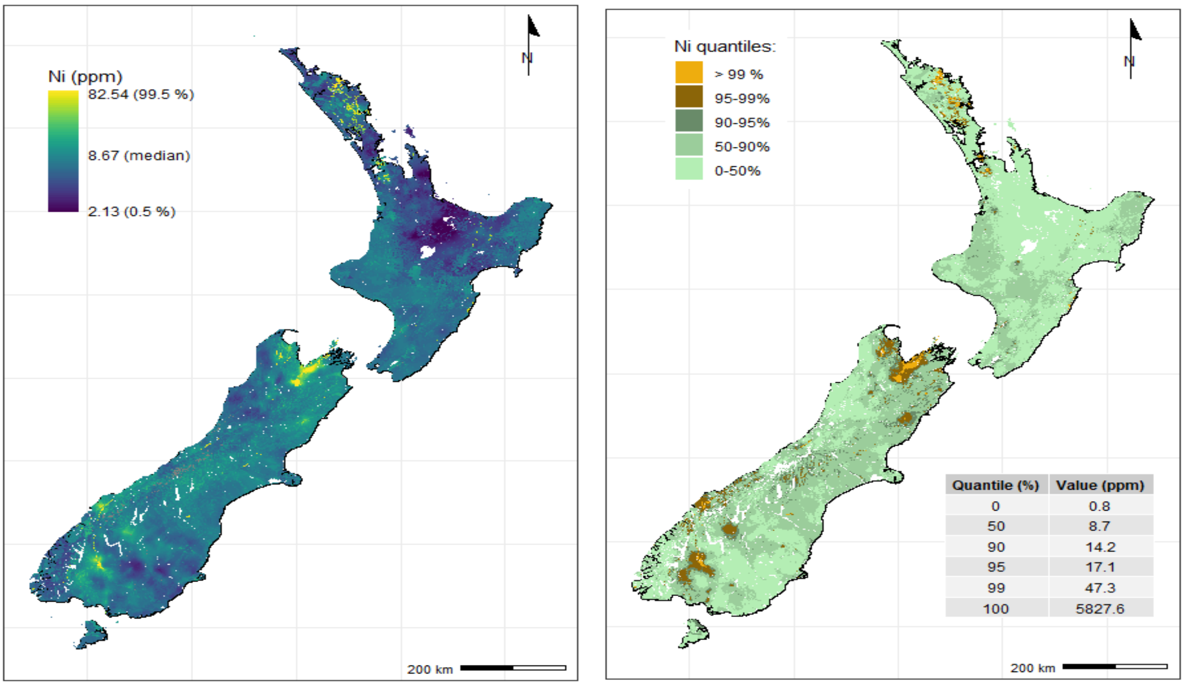
Quantile (%)	Value (ppm)
0	0
50	0.1
90	0.2
95	0.2
99	0.4
100	0.8

Figure A1.2. Estimate of cadmium concentrations (left) and contour plot (right) of cadmium quantile concentrations using the spaMM model.



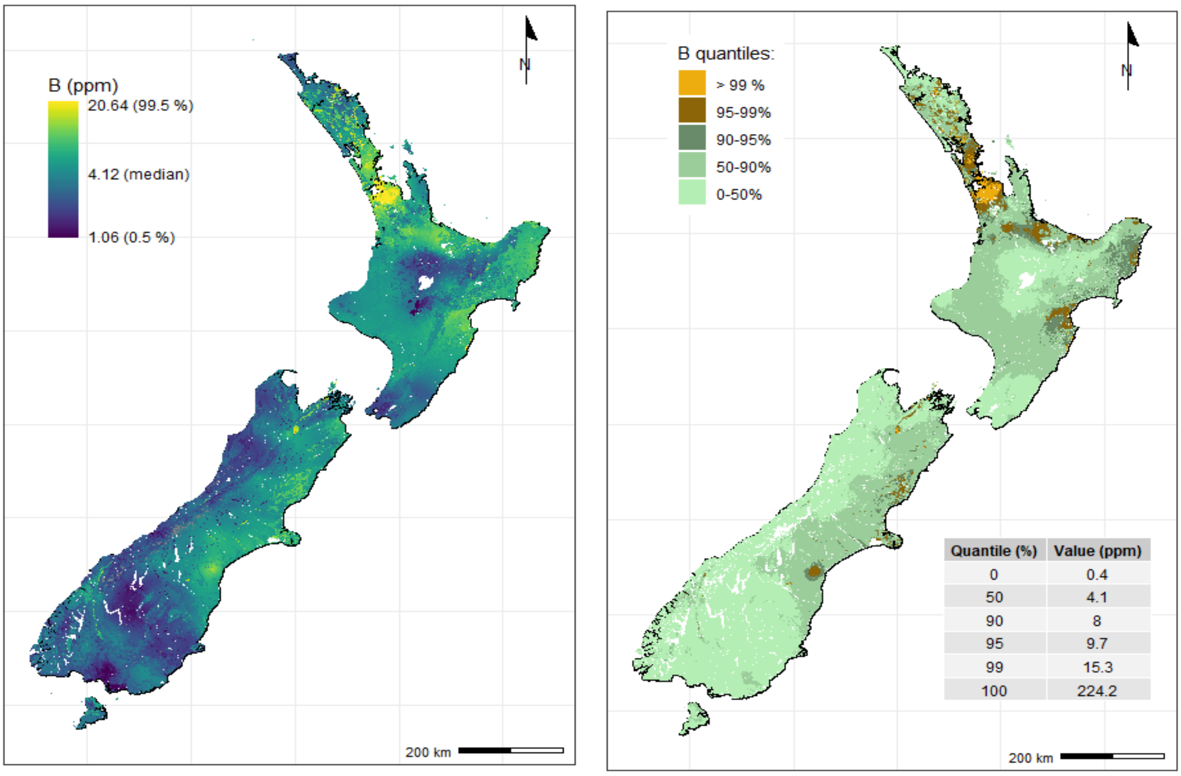
Quantile (%)	Value (ppm)
0	2.1
50	14.5
90	25.3
95	34.1
99	83.7
100	1377.3

Figure A1.3. Estimate of chromium concentrations (left) and contour plot (right) of chromium quantile concentrations using the spaMM model.



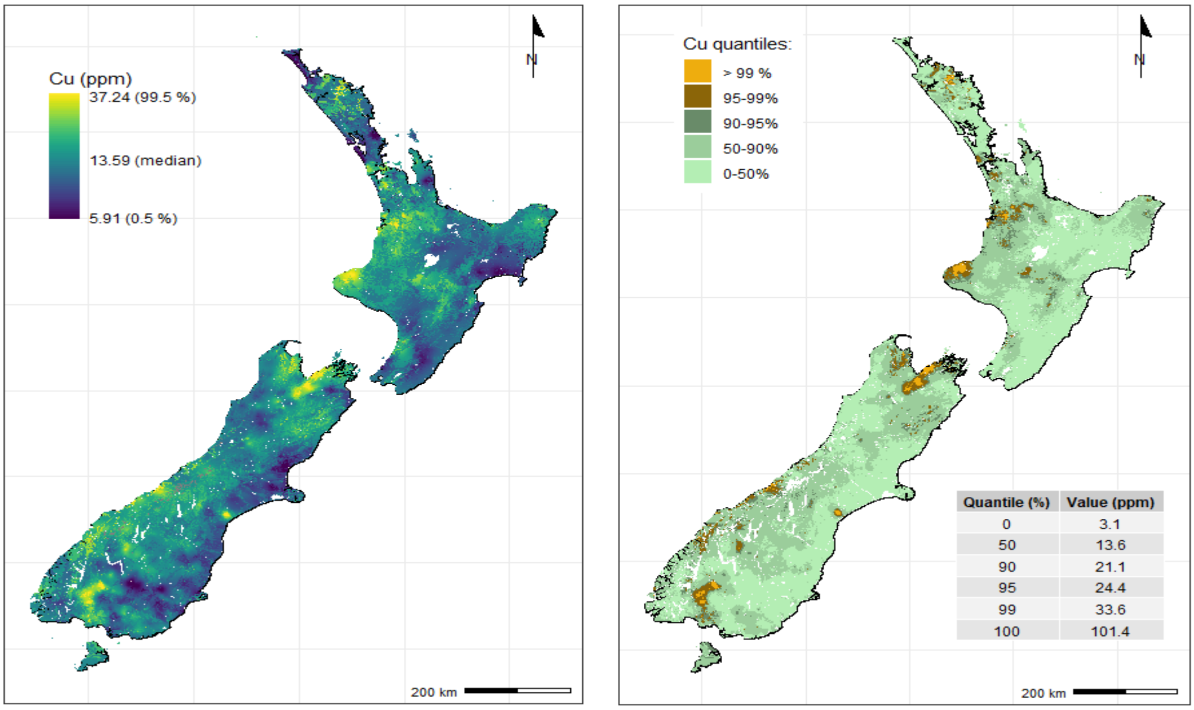
Quantile (%)	Value (ppm)
0	0.8
50	8.7
90	14.2
95	17.1
99	47.3
100	5827.6

Figure A1.4. Estimate of nickel concentrations (left) and contour plot (right) of nickel quantile concentrations using the spaMM model.



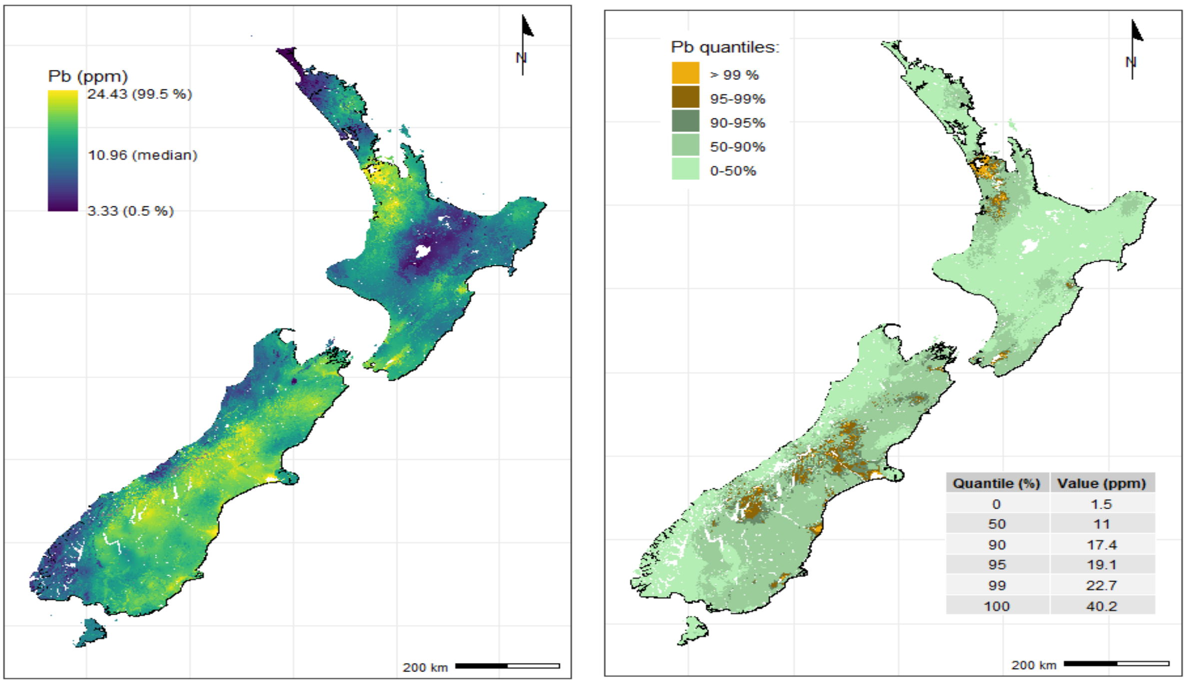
Quantile (%)	Value (ppm)
0	0.4
50	4.1
90	8
95	9.7
99	15.3
100	224.2

Figure A1.5. Estimate of boron concentrations (left) and contour plot (right) of boron quantile concentrations using the spaMM model.



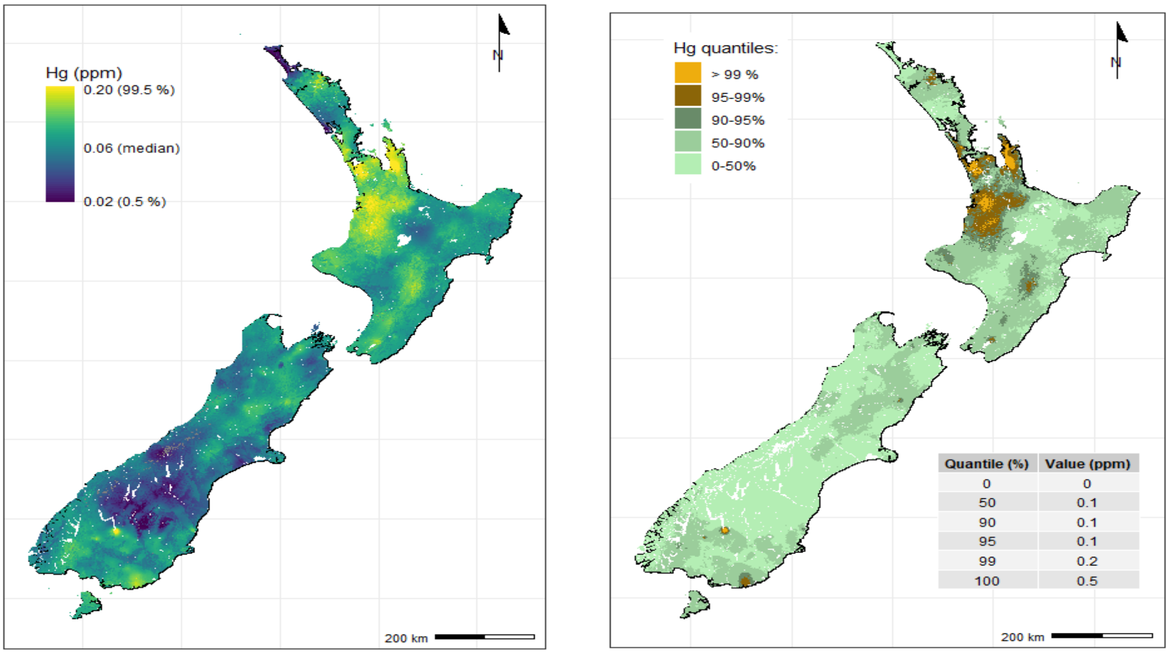
Quantile (%)	Value (ppm)
0	3.1
50	13.6
90	21.1
95	24.4
99	33.6
100	101.4

Figure A1.6. Estimate of copper concentrations (left) and contour plot (right) of copper quantile concentrations using the spaMM model.



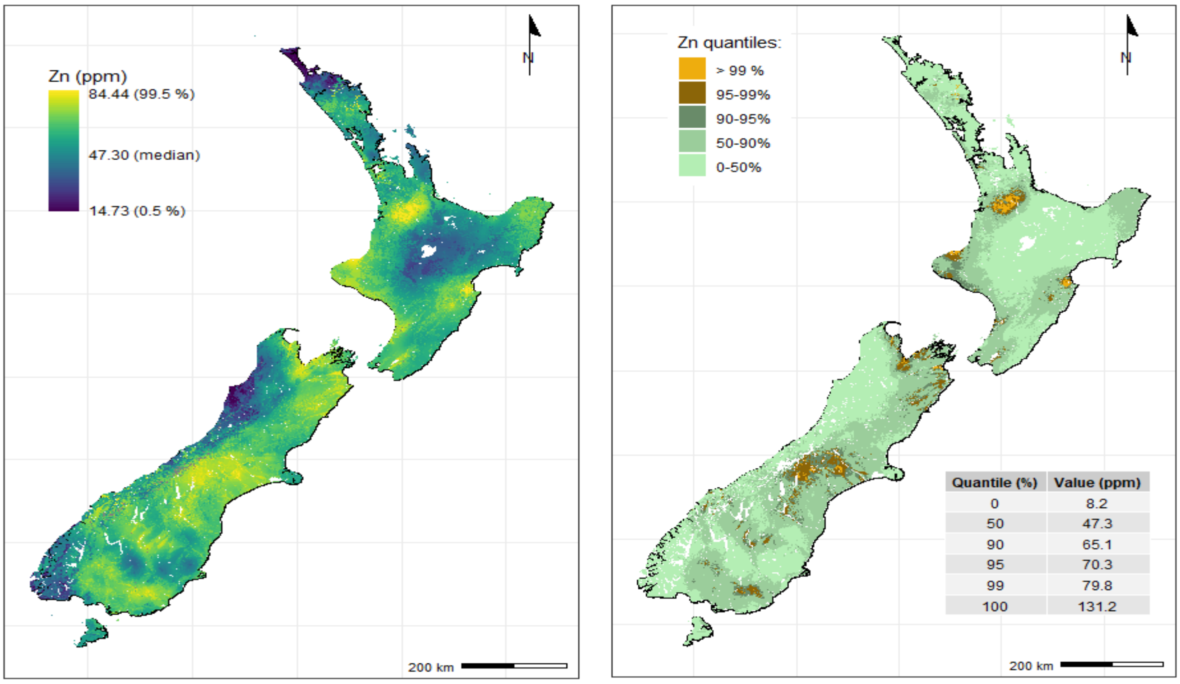
Quantile (%)	Value (ppm)
0	1.5
50	11
90	17.4
95	19.1
99	22.7
100	40.2

Figure A1.7. Estimate of lead concentrations (left) and contour plot (right) of lead quantile concentrations using the spaMM model.



Quantile (%)	Value (ppm)
0	0
50	0.1
90	0.1
95	0.1
99	0.2
100	0.5

Figure A1.8. Estimate of mercury concentrations (left) and contour plot (right) of mercury quantile concentrations using the spaMM model.



Quantile (%)	Value (ppm)
0	8.2
50	47.3
90	65.1
95	70.3
99	79.8
100	131.2

Figure A1.9. Estimate of zinc concentrations (left) and contour plot (right) of zinc quantile concentrations using the spaMM model.

Appendix 2 – Pedo-geological counts

Table A2.1. Summary of the percentage of sites with individual parent materials that have concentrations above the 95% percentile of the total data set, and the total number of sites in that category

Parent material	As	B	Cd	Cr	Cu	Hg	Ni	Pb	Zn	*n*
Clastic sediment	3	2	4	2	4	3	2	7	5	1,963
Felsic igneous	3	1	16	4	4	12	0	1	8	293
Limestone	9	5	9	0	0	0	0	0	0	22
Loess	1	0	1	0	1	1	0	3	3	307
Mafic igneous	2	15	7	9	19	26	22	22	22	176
NA	0	0	10	3	7	7	7	30	20	30
Peat	6	2	29	0	2	16	0	8	5	62
Schist	15	0	0	0	2	0	1	1	1	421
Ultramafic igneous	2	6	0	60	19	5	74	17	14	121

NA – not assigned, due to gaps in polygon layers.

Table A2.2. Summary of the percentage of sites in individual Chemical4 groups that have concentrations above the 95% percentile of the total data set, and the total number of sites in that category

Chemical4	As	B	Cd	Cr	Cu	Hg	Ni	Pb	Zn	*n*
Agglomerate	As	B	Cd	Cr	Cu	Hg	Ni	Pb	Zn	6
Alternating sandstone/siltstone	0	0	17	0	0	0	0	0	0	78
Amphibolite	6	6	1	0	5	9	5	29	14	4
Andesite	0	0	0	25	25	0	0	0	0	16
Argillite	13	13	0	0	6	31	0	6	13	27
Basalt	11	0	0	4	0	15	4	4	0	129
Breccia	2	9	9	9	18	33	14	28	16	46
Clay	0	0	11	22	22	0	20	0	2	8
Conglomerate	0	0	50	0	0	0	0	0	25	28
Dacite	4	7	4	0	0	0	0	0	0	11
Diorite	9	0	0	0	0	36	0	0	0	30
Fill	0	0	0	10	3	0	0	0	0	7
Gabbro	0	0	14	0	14	14	14	86	43	12
Granite	0	0	0	25	8	0	25	0	0	50
Gravel	0	0	0	16	2	2	0	0	0	1,047
Greenschist	3	0	2	2	3	1	3	5	5	3
Greywacke	67	0	0	0	0	0	0	0	0	249
Ignimbrite	2	2	1	1	2	2	1	6	5	112
Limestone	2	0	26	0	5	15	0	3	15	31
Marble	6	6	10	0	0	0	0	0	3	1
Melange	0	0	100	0	0	0	0	0	0	58
Metasediment	0	0	0	55	16	2	64	3	7	172

Chemical4	**As**	**B**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	***n***
Mud	4	0	0	1	1	0	0	1	2	78
Mudstone	5	5	18	0	3	12	0	14	8	87
NA	3	3	3	1	1	3	0	2	0	15
Peat	0	0	20	7	7	7	7	20	20	41
Peridotite	2	0	24	0	2	5	0	7	2	34
Pumice	0	0	0	94	9	0	97	3	0	4
Rhyolite	25	0	25	0	0	0	0	0	0	13
Sand	23	0	15	0	0	15	0	0	0	222
Sandstone	6	5	17	0	5	11	0	17	7	362
Schist	2	4	2	2	8	2	2	2	4	201
Scoria	25	0	0	0	2	1	1	1	1	20
Semischist	0	75	0	0	25	25	85	30	85	74
Silt	5	0	0	0	1	0	0	4	1	20
Siltstone	5	5	10	0	0	0	0	10	5	11
Till	0	0	0	0	0	0	0	0	9	43
Tuff	0	0	0	7	2	2	2	5	2	28

NA – not assigned, due to gaps in polygon layers.

Table A2.3. Summary of the percentage of sites in individual Chemical6 groups that have concentrations above the 95% percentile of the total data set, and the total number of sites in that category

Chemical6	As	B	Cd	Cr	Cu	Hg	Ni	Pb	Zn	*n*
Agglomerate Taranaki	0	0	20	0	0	0	0	0	0	5
Alternating sandstone/siltstone	6	6	1	0	5	9	5	29	14	78
Amphibolite	0	0	0	25	25	0	0	0	0	4
Andesite	15	15	0	0	8	38	0	8	8	13
Andesite Taranaki	0	0	0	0	0	0	0	0	100	1
Argillite	11	0	0	4	0	15	4	4	0	27
Basalt	0	4	0	17	24	2	20	11	11	46
Basalt Auckland	7	22	4	2	16	36	18	47	24	45
Basalt Canterbury	0	0	0	0	0	0	0	50	0	2
Basalt Northland	0	0	11	22	33	44	0	0	22	9
Basalt Waikato	0	0	33	0	7	78	4	33	11	27
Breccia	0	0	0	53	53	0	47	0	0	15
Breccia Taranaki	0	0	25	0	10	0	0	0	5	20
Breccia Tasman-Nelson	0	0	0	67	0	0	67	0	0	3
Clay Waikato	0	0	50	0	0	0	0	0	25	8
Conglomerate	7	13	7	0	0	0	0	0	0	15
Dacite	9	0	0	0	0	36	0	0	0	11
Diorite	0	0	0	10	3	0	0	0	0	30
Fill Auckland	0	0	14	0	14	14	14	86	43	7
Gabbro	0	0	0	25	8	0	25	0	0	12
Granite	0	0	0	16	2	2	0	0	0	50
Gravel Bay of Plenty	0	4	12	0	8	8	0	0	4	25

Chemical6	**As**	**B**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	***n***
Gravel Canterbury	2	0	0	0	1	1	0	5	3	186
Gravel Hawke's Bay	5	0	0	0	15	0	0	3	14	88
Gravel Manawatū-Whanganui	2	0	2	0	0	0	0	5	2	66
Gravel Marlborough	1	0	1	3	2	1	5	1	3	118
Gravel Otago	11	0	1	0	1	1	0	7	6	90
Gravel Southland	1	0	1	3	5	0	5	3	2	155
Gravel Taranaki	0	0	10	0	5	0	0	0	5	21
Gravel Tasman-Nelson	2	0	2	12	2	0	11	3	7	125
Gravel Waikato	0	0	38	0	0	19	0	5	24	21
Gravel Wellington	3	0	0	0	4	2	0	16	5	124
Gravel West Coast	9	5	0	0	0	5	0	5	0	22
Greenschist	67	0	0	0	0	0	0	0	0	3
Greywacke	2	2	1	1	2	2	1	6	5	249
Ignimbrite	0	0	8	0	0	23	0	0	0	13
Ignimbrite Bay of Plenty	0	0	7	0	0	7	0	0	0	14
Ignimbrite Waikato	2	0	33	0	7	16	0	4	20	83
Limestone	14	14	14	0	0	0	0	0	7	14
Limestone Hawke's Bay	0	0	9	0	0	0	0	0	0	11
Marble	0	0	100	0	0	0	0	0	0	1
Melange	0	0	0	55	16	2	64	3	7	58
Metasediment	4	0	0	1	1	0	0	1	2	172
Mud Auckland	3	10	8	0	3	8	0	18	10	39
Mud Waikato	9	0	31	0	3	17	0	11	6	35
Mudstone	3	4	3	1	1	3	0	3	0	67

Chemical6	**As**	**B**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	***n***
Mudstone Bay of Plenty	33	0	33	0	0	0	0	0	0	3
Mudstone Wellington	0	0	0	0	0	17	0	0	0	6
NA	0	0	20	7	7	7	7	20	20	15
Peat Auckland	0	0	50	0	0	0	0	0	0	2
Peat Otago	50	0	0	0	0	0	0	0	0	2
Peat Southland	0	0	0	0	14	0	0	0	0	7
Peat Taranaki	0	0	50	0	0	0	0	0	0	2
Peat Waikato	0	0	47	0	0	12	0	18	6	17
Peridotite	0	0	0	94	9	0	97	3	0	34
Pumice Bay of Plenty	33	0	33	0	0	0	0	0	0	3
Rhyolite	0	0	25	0	0	0	0	0	0	4
Rhyolite Bay of Plenty	50	0	17	0	0	17	0	0	0	6
Rhyolite Waikato	0	0	0	0	0	33	0	0	0	3
Sand Auckland	5	12	1	0	6	19	0	26	5	86
Sand Canterbury	0	0	0	0	17	0	0	33	17	6
Sand Marlborough	0	0	0	100	0	0	100	0	0	1
Sand Northland	7	0	0	0	0	0	0	3	0	29
Sand Taranaki	0	0	17	0	0	0	0	0	17	6
Sand Waikato	10	3	46	0	6	12	0	17	13	78
Sandstone	3	3	2	2	9	2	3	2	4	328
Sandstone Auckland	0	40	20	0	0	10	0	0	10	10
Schist	25	0	0	0	2	1	1	1	1	201
Scoria Auckland	0	75	0	0	25	25	85	30	85	20
Semischist	5	0	0	0	1	0	0	4	1	74

Chemical6	**As**	**B**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	***n***
Silt Canterbury	14	14	0	0	0	0	0	29	14	7
Silt Wellington	0	0	29	0	0	0	0	0	0	7
Siltstone	0	0	0	0	0	0	0	0	11	9
Till Otago	0	0	0	0	0	0	0	25	25	4
Till Tasman-Nelson	0	0	0	17	8	0	0	8	0	12
Till West Coast	0	0	0	13	0	13	13	0	0	8
Tuff	100	0	0	0	0	0	0	0	0	1
Tuff Auckland	7	26	0	0	11	19	44	67	48	27

NA – not assigned, due to gaps in polygon layers.

Appendix 3 – Modified ecological soil guideline values

As noted in section 5.5, we retain the default Eco-SGVs developed in Cavanagh & Harmsworth 2023 and shown in Tables 17&18 of the main text. However, we do modify some of the Eco-SGVs for the upper percentile estimates, given the reduced underestimation of these percentiles using the current model. Only the background concentration-adjusted Eco-SGVs are provided in this appendix. Further, for Cd, the recommended default Eco-SGVs are those based on providing protection for biomagnification (Cavanagh & Harmsworth 2023).

Table A3.1. A summary of relevant statistics for the range of predicted background (rural ambient) concentrations of selected trace elements[a]

Element	Median	90th	95th	99th[b]
As	**3.6**	6.1	7.4	10.5
B	**4.1**	8.0	**9.7**	**15.3**
Cd	**0.1**	0.2	0.23	0.37
Cr	**14.5**	25	**34**	**84**
Cu	**13.6**	21	**24**	**34**
Ni	8.7	14	17	47
Pb	**11.0**	17	19	23
Zn	**47.3**	**65**	**70**	**80**

[a] Bolded values are those to be used for developing Eco-SGVs, including for background adjustment of the 95% protection-level Eco-SGVs.

[b] It is recommended that the 95th percentile be used as a default value for these areas initially. Where it is recognised that there is significant local small-scale elevation in background concentrations, it may be appropriate to undertake site-specific determination of background concentrations.

Boron

The predicted background (rural ambient) concentrations for B are summarised in Table 2, and the spatial variation in concentrations across New Zealand are shown in Figure A1.5. Based on the range in rural ambient concentrations for B, background adjustment for Eco-SGVs based on total B concentrations is recommended in areas identified as being above the 95th percentile of modelled estimates. Added contaminant limits (ACLs) for B are based on both total and hot-water-soluble B (HWS-B, Table 17, although the contribution of background HWS-B is considered to be negligible (Cavanagh & Munir 2019), so Eco-SGVs based on HWS-B do not change. Revised background-adjusted 95% protection level Eco-SGVs are shown in Table A3.2. See Cavanagh & Harmsworth 2023 for more details on the application of Eco-SGVs.

Table A3.2. Background-adjusted 95% protection-level Eco-SGVs for boron based on the 95th and 99th percentile predicted background concentrations and the ACL for total boron[a]

Background concentration percentile	Background concentration (mg/kg)	ACL[b] $_{(EC30)}$ (mg/kg)	Eco-SGV[c] $_{(EC30}$
95th	10	9.7	20
99thd	15	9.7	25

[a] The contribution of background HWS-B is considered to be negligible, so Eco-SGVs associated with HWS-B do not vary with background concentration.

[b] See Cavanagh & Munir 2019

[c] Values have been rounded.

[d] It is recommended that the 99th percentile be used as a default value for these areas initially. Where there is recognised to be significant local small-scale elevation in background concentrations, it may be appropriate to undertake site-specific determination of background concentrations.

Chromium

The predicted background (rural ambient) concentrations for Cr are summarised in Table 2, and the spatial variation in concentrations across New Zealand shown in Figure A1.3. Based on the range in rural ambient concentrations for Cr, background adjustment for Eco-SGVs is recommended in areas identified as being above the 95th percentile of modelled estimates. Where there are recognised significant small-scale elevations in naturally occurring concentrations, it may be appropriate to undertake site-specific determination of background concentrations. Revised background-adjusted 95% protection-level Eco-SGVs are shown in Table A3.3. See Cavanagh & Harmsworth 2023 for more details on the application of Eco-SGVs.

Table A3.3. Summary of background-adjusted 95% protection Eco-SGVs based on the 95th and 99th percentile predicted background concentrations and the added contaminant limit (ACL) for chromium

Background concentration percentile	Background concentration (mg/kg)	ACL $_{(EC30)}$[a] (mg/kg)	Eco-SGV $_{(EC30)}$[b] (mg/kg)
95th	34	184	220
99th[c]	84	184	270

[a] See Cavanagh & Munir 2019.

[b] Values have been rounded.

[c] It is recommended that the 99th percentile be used as a default value for these areas initially. Where there is recognised to be significant local small-scale elevation in background concentrations, it may be appropriate to undertake site-specific determination of background concentrations.

Copper

The predicted background (rural ambient) concentrations for Cu are summarised in Table 2, and the spatial variation in concentrations across New Zealand are shown in Figure A1.6. Based on the range in rural ambient concentrations for Cu, background adjustment for Eco-SGVs is recommended in areas identified as being above the 95th percentile of modelled estimates. Where there are recognised significant small-scale elevations in naturally occurring concentrations, it may be appropriate to undertake site-specific determination of background concentrations.

There were sufficient toxicity data to derive added contaminant limits for three reference soils, with the values for the sensitive soils recommended as default values (Table 18; see Cavanagh & Munir 2019 for further details). Revised background-adjusted 95% protection-level Eco-SGVs are shown in Table A3.4 See Cavanagh & Harmsworth 2023 for more details on the application of Eco-SGVs.

Table A3.4. Summary of background-adjusted 95% protection Eco-SGVs for the three New Zealand reference soils, based on the estimated 95th and 99th percentile ambient concentrations

Percentile background concentration	Background concentration (mg/kg)	Eco-SGV $_{(EC30)}$ [a] typical soil	Eco-SGV $_{(EC30)}$ [a] sensitive soil[b]	Eco-SGV $_{(EC30)}$ [a] tolerant soil
95th%	24	125	**105**[b]	145
99th%	34	130	**115**[b]	155

[a] Values have been rounded.

[b] Suggested default Eco-SGV.

Zinc

The predicted background (rural ambient) concentrations for Zn are summarised in Table 2, and the spatial variation in concentrations across New Zealand are shown in Figure A1.9. Based on the range in rural ambient concentrations for Zn, background adjustment for Eco-SGVs is recommended in areas identified as being above the 95th percentile of modelled estimates. Where there are recognised significant small-scale elevations in naturally occurring concentrations, it may be appropriate to undertake site-specific determination of background concentrations.

There were sufficient toxicity data to derive added contaminant limits for three reference soils, with the values for the sensitive soils recommended as default values (Table 18; see Cavanagh & Munir 2019 for further details). Revised background-adjusted 95% protection-level Eco-SGVs are shown in Table A3.5. See Cavanagh & Harmsworth 2023 for more details on the application of the Eco-SGVs.

Table A3.5. Background-adjusted 95% protection Eco-SGVs for zinc for the three New Zealand reference soils, based on the estimated 90th, 95th and 99th percentile ambient concentrations

Percentile background concentration	Background concentration (mg/kg)	Zn Eco-SGV $_{(EC30)}$ [a] typical soil	Zn Eco-SGV $_{(EC30)}$ [a] sensitive soil[1]	Zn Eco-SGV $_{(EC30)}$ [a] tolerant soil
90th	65	215	**195**[b]	265
95th	70	220	**200**[b]	270
99th	80	230	**210**[b]	280

[a] Values have been rounded.

[b] Suggested default Eco-SGV.